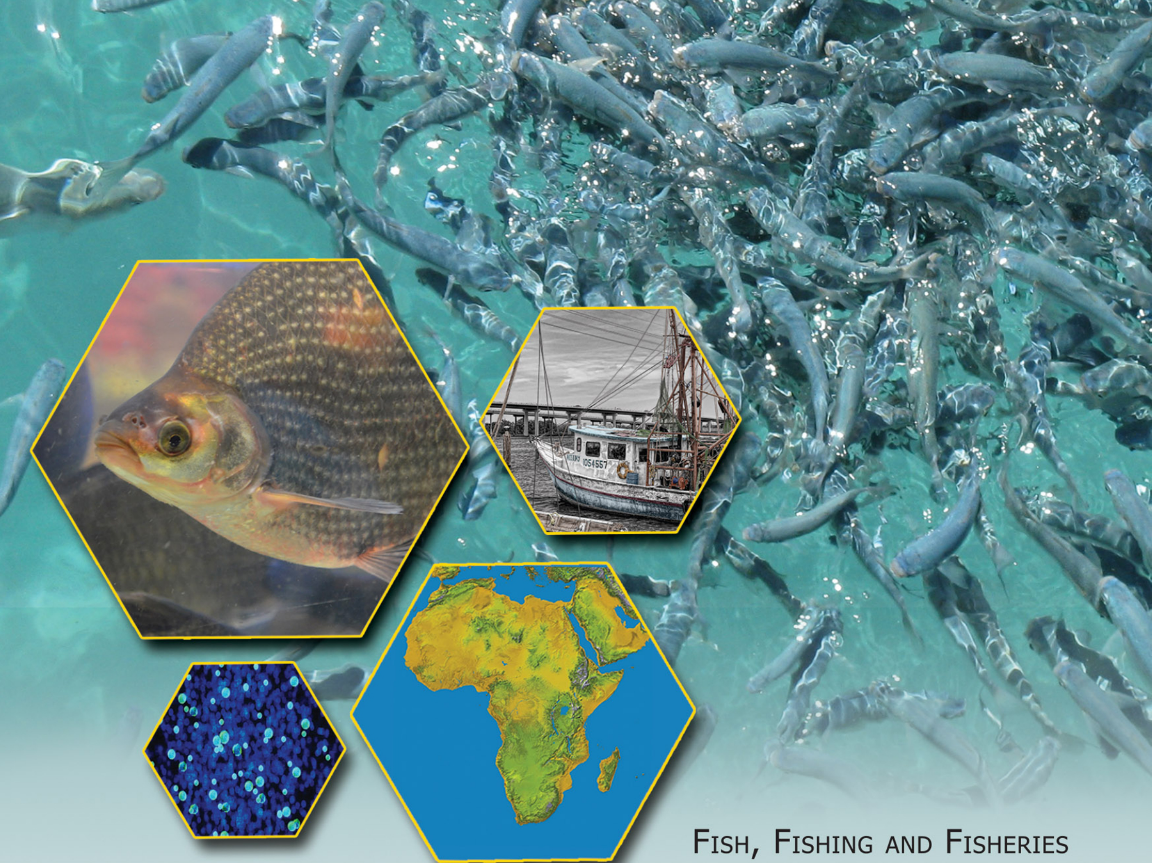

Fish, Fishing and Fisheries

Aquaculture

Management, Challenges and Developments

Joanne G. Buchanan
Editor

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FISH, FISHING AND FISHERIES

AQUACULTURE

MANAGEMENT, CHALLENGES AND DEVELOPMENTS

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FISH, FISHING AND FISHERIES

AQUACULTURE

MANAGEMENT, CHALLENGES AND DEVELOPMENTS

JOANNE G. BUCHANAN
EDITOR

New York

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PREFACE

This book provides current research on aquaculture. Chapter One reviews management, challenges and developments of aquaculture in Ghana, West Africa. Chapter Two covers the fundamental knowledge of phage infection in bacterial cell and extends it to phage therapy by using a model of Vibrio-phage, called VH-P, with its specific *Vibrio harveyi* host, VH 13-1. Chapter Three discusses taste-taint modelling in Recirculating Aquaculture Systems (RAS) farmed fish. Chapter Four investigates the causative effect of protein, lipid, feeding level and their interaction on growth, biological parameters and haematology of *Oreochromis niloticus*. Chapter Five provides a review on the mapping of the value chain for farmed fish and gender analysis along the aquaculture value chain in Kenya. Chapter Six answers why aquaculture trials have not been successful in Tanzania.

Chapter 1 - Food insecurity and malnutrition continue to pose a challenge in Ghana. New ways of increasing availability, affordability and consumption of protein and to improve alternative sources of livelihood are being exploited in Ghana that has the climate, water bodies and other resources suitable for aquaculture production. Aquaculture is currently practiced throughout the country, with over 60% of farms in the southern and central belts according to Ministry of Fisheries and Aquaculture Development (MoFAD) data. The fish farming sub-sector in Ghana conventionally uses land-based production systems since its start in the 1950s in the northern regions of Ghana. Dugouts, reservoirs and dams were primarily used as fish culture systems. Modern aquaculture techniques were introduced over the last four (4) decades. Ponds have been the turning point from enhancement stocking to raising fish in farm units. To date, ponds represent over 50% of the total aquaculture production units and contribute only about 6% to the total annual aquaculture production in Ghana. Nearly 90% of aquaculture production comes from cages, and reservoirs, dugouts and dams make up the reminder.

Although there has been a steady growth in farm establishment and government efforts to promote fish farming, the sector is producing below installed capacity. This is due to little development in removing or reducing constraining factors to reasonable levels. Poor quality and inadequate supply of fingerlings, inadequate technical know-how, inadequate extension services and training have been the major challenges affecting aquaculture production in Ghana. From the study, high cost of commercially available diets, lack of access to funds, poor market of farmed fish products and poor management of farms have been identified to be inhibiting the growth of the aquaculture industry. These challenges coupled with unfavourable weather conditions t and poor infrastructure lead to the increasing incidence of farm abandonment and the entire aquaculture development.

The study also revealed that, most fish farms in Ghana are poorly managed. This is due to the lack of technical know-how and unskilled labour at the different levels of production. This has contributed massively to the under development and negligible contribution of the sector to the overall fish production and economic development in the country. Poor management can be economically and environmentally injurious to the needs of aquaculture sustainability and development, hence, fish farmers must focus on how to equilibrate social and environmental needs.

Chapter 2 - The concept of phage therapy to control bacterial infection and contamination was conceived about a century ago. It has now been more important to understand this approach since drug resistant bacteria have become more common and development of new antibiotics has become more difficult. This article will cover the fundamental knowledge of phage infection in bacterial cell and extends it to phage therapy by using a model of Vibrio-phage, called VH-P, with its specific *Vibrio harveyi* host, VH 13-1. The VH 13-1 was isolated and collected from luminescent black tiger shrimp. To test the possibility of the use of permissive phage as a tool to treat the VH contamination in shrimp ponds, a VH-P which is a temperate phage was tested for its efficiency to kill the VH13-1. In the meantime VH16-1 which is not infected by VH-P was used as a control. The authors’ study was conducted with the MOI (multiple of infection) of 1-100. The success of the treatment is determined if no VH bacterial colony is observed in the culture medium after the phage treatment. The MOI of 20 resulted in the killing of all the VH13-1 while MOI 10 was inconsistent because two of the three experiments showed growth of bacterial colony and MOI of 1 resulted in significant survival of

VH13-1. These colonies were proved to become lysogenic infection of VH-P. The study shows that using temperate phage of VH-P to treat VH bacterium, it is necessary to treat with the sufficient amount of the VH-P phage at once. Insufficient amount of MOI will allow the VH to develop lysogenic infection and cause interference to super-infection of the same phage. Accordingly, the strategies to develop phage therapy as an alternative to using antibiotic treatment of bacterial contamination and infection will be discussed.

Chapter 3 - Farming of fish with Recirculating Aquaculture Systems (RAS) is becoming widespread due to diminishing wild-caught supplies. However, the accumulation of 'earthy' or 'muddy' off-flavours due to taint chemical as geosmin (GSM) or 2-methylisoborneol (MIB) in the fish-flesh of farmed species is a major concern. Inconsistent quality of farmed-fish has been identified as a major issue in buyer resistance. Predictive mathematical models, widely used in bio-chemical engineering, provide a basis for evaluating environmental toxicology and risk assessments in RAS farmed fish. The use of models to predict taste-taint chemicals in fish-flesh with growth is a new concept and can be used to help farmers and researchers in decision making and farm protocols. In this chapter the authors discuss taste-taint modelling in RAS farmed fish including: taste-taint problems in RAS farmed-fish; an overview of predictive models for chemical congeners in fish-flesh; models for predicting accumulation of GSM and MIB in fish-flesh; development and limitations of predictive models; factors to be considered in developing an adequate model for RAS fish, benefits of models to the supply chain, and; a critical review of an extensive recent experimental validation of one predictive model and risk analyses.

Chapter 4 – The authors investigated the causative effect of protein, lipid, feeding level and their interaction on growth, biological parameters and haematology of *Oreochromis niloticus*. Thus, *O. niloticus* (15.63 ± 0.40g mean weight ± SD) were reared at two different levels of protein (25% and 35%), two levels of lipid (8% and 12%) and three levels of feeding (100%, 70% and 50%) for 8 weeks. Higher weight gain % (WG%), feeding efficiency (FE) and specific growth rate (SGR) was observed in H35 suggesting that the main component in diet which influences growth is protein. Feed intake was inversely related to the dietary lipid level suggesting that high lipid levels could affect appetite of fish. There was no significant interactive effect of protein and lipid on WG (%), SGR, and feed intake (FI) indicative that *O. niloticus* can efficiently utilize carbohydrate better than lipid. High lipid level enhanced high viscerasomatic index (VSI) and intraperitoneal fat (IPF) indicating that fish fed with high lipid diets were unable to utilize the entire lipid for energy production and the excess fat was deposited in the viscera. The current study suggests that the recommended maximum level of crude protein, lipid and feeding level to maintain the welfare and maximum growth of *O. niloticus* is between 25 and 35%, 8% lipid level and feeding rate between 70 and 100% in a practical world.

Chapter 5 – The authors mapped the value chain of farmed fish and examined gender participation along the artisanal aquaculture value chain (AVC) in Nyanza region, Kenya as a case study for gender issues in aquaculture and fisheries. The study was carried out with aid of structured questionnaire that were administered through personal interviews. Results indicated that the Kenyan aquaculture value chain is relatively simple; including only three main stakeholder groups. These are seed producers, grow-out farmers and fish marketers and traders. At artisanal level, women dominate the production level in the aquaculture value chain suggesting that they could easily integrate aquaculture into the farming system of the farming families. However, since they are undertaken by women, they are often viewed as requiring little skill. This is a major gender issue in aquaculture and leads to women's work being undervalued and poorly rewarded. Contrary to women, majority of men owned farm land, limiting women access to credit due lack of collateral. Majority of women and men in Nyanza region dealt with fresh fish products as compared to processed fish, indicative of little transformation of aquaculture fish that does not travel far inland to rural villages. There are disparities in many aspects of fish farming between men and women, and thus training and credit should be made available to females along the aquaculture value chain so that they invest in cooling facility and or value addition to improve on profits.

Chapter 6 - Most aquaculture trials in Tanzania have made insignificant contributions to the community welfare because they did not learn from the mistakes of the past trials. To avoid repeating the past mistakes, a study was conducted to "review all aquaculture trials in Tanzania, objectively concluding why the past aquaculture trials have or have not been up scaled." Quantitative and qualitative designs were employed to collect data from Zanzibar. The study population comprised of milkfish, crab and sea cucumber farmers, as well as farmers who abandoned aquaculture. Instruments used for data collection included questionnaire, group discussion, researchers' observations and secondary information sources. The results showed that the aquaculture trials have not been up-scaled because of: low priority given to the aquaculture sector, targeting the poorer community, introduction process of projects that killed "self-help" sprit, the unmet objectives for undertaking aquaculture, the poor location of aquaculture farms, a lack of availability of quality fingerlings in the right quantities, inadequate feeds and fertilization, relative disadvantage of aquaculture in comparison to other competing activities and lack of ownership of the aquaculture farms. This review suggests the following: firstly, government support in creating an enabling environment in form of formulating appropriate policy, laws, regulations, guidelines, investments promotion and regulation of the aquaculture sector is vital. Finally, operating aquaculture as a business will enable it to address all the determinant factors for success identified by this study.

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Chapter 1

MANAGEMENT, CHALLENGES AND DEVELOPMENTS OF AQUACULTURE IN GHANA, WEST AFRICA

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ABSTRACT

Food insecurity and malnutrition continue to pose a challenge in Ghana. New ways of increasing availability, affordability and consumption of protein and to improve alternative sources of livelihood are being exploited in Ghana that has the climate, water bodies and other resources suitable for aquaculture production. Aquaculture is currently practiced throughout the country, with over 60% of farms in the southern and central belts according to Ministry of Fisheries and Aquaculture Development (MoFAD) data. The fish farming sub-sector in Ghana conventionally uses land-based production systems since its start in the

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1950s in the northern regions of Ghana. Dugouts, reservoirs and dams were primarily used as fish culture systems. Modern aquaculture techniques were introduced over the last four (4) decades. Ponds have been the turning point from enhancement stocking to raising fish in farm units. To date, ponds represent over 50% of the total aquaculture production units and contribute only about 6% to the total annual aquaculture production in Ghana. Nearly 90% of aquaculture production comes from cages, and reservoirs, dugouts and dams make up the reminder.

Although there has been a steady growth in farm establishment and government efforts to promote fish farming, the sector is producing below installed capacity. This is due to little development in removing or reducing constraining factors to reasonable levels. Poor quality and inadequate supply of fingerlings, inadequate technical know-how, inadequate extension services and training have been the major challenges affecting aquaculture production in Ghana. From the study, high cost of commercially available diets, lack of access to funds, poor market of farmed fish products and poor management of farms have been identified to be inhibiting the growth of the aquaculture industry. These challenges coupled with unfavourable weather conditions t and poor infrastructure lead to the increasing incidence of farm abandonment and the entire aquaculture development.

The study also revealed that, most fish farms in Ghana are poorly managed. This is due to the lack of technical know-how and unskilled labour at the different levels of production. This has contributed massively to the under development and negligible contribution of the sector to the overall fish production and economic development in the country. Poor management can be economically and environmentally injurious to the needs of aquaculture sustainability and development, hence, fish farmers must focus on how to equilibrate social and environmental needs.

Keywords: aquaculture, fish, Ghana, management, pond, production

INTRODUCTION

Fish is a preferred source of animal protein and consumed by the majority of Ghanaians ranging from the rural poor to the urban rich. It is estimated that 75% of the total domestic production of fish is consumed locally, contributing about 60% of the total animal protein requirement in the average Ghanaian diet. With a current population of about 27.4 million people, Ghana’s annual average per capita apparent fish consumption is estimated at 28 kg (GSA, 2014; MoFAD, 2015), which is higher than the world's average of 19.2 kg (FAO, 2014). The fisheries sector of the country therefore contributes substantially to the socio-economic development objectives through food security, livelihood support, Gross Domestic Product (GDP), poverty reduction, employment, foreign exchange earnings and resource sustainability.

However, the aquaculture sector has over the past two decades registered a slow growth of 6% per annum, falling short of its expected potential (MoFAD, 2013). The average annual fish production (marine, inland and aquaculture) in the last five years is 460,000 tonnes while the country's fish requirement has been currently estimated to be 1,000,000 tonnes, outstripping supply by over 50% (MoFAD, 2015). With the country's landings from capture fisheries being dwindled, fish demand will continue to increase. At present, the gap between demand and supply is bridged through fish imports valued at US$135 million annually (Failler et al., 2015). The Government of Ghana is determined to develop aquaculture and expand family fish farming across the entire country to reduce the importation of fish. Aquaculture has not only been an immediate option for Ghana alone, but is globally considered as a sustainable way of accelerating the recovery of the world fish stock through its fastest growth rate as animal producing sector while capture fisheries production remains stable (FAO, 2014). The country's rich water resources provide considerable opportunity for advancement of the different systems of freshwater and even marine aquaculture.

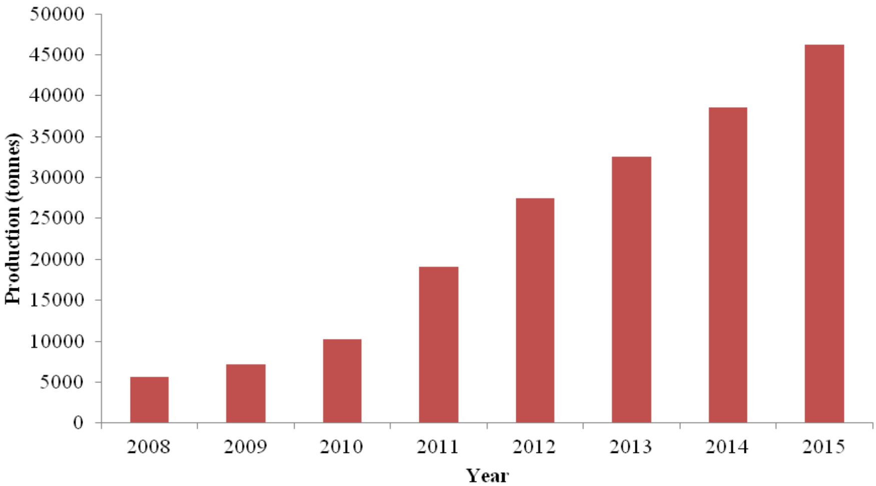
The aquaculture sector in Ghana is highly diverse and fragmented, ranging from smallholder ponds providing a few kilos of fish per year to commercial cage units. While local production from marine fisheries declined by 17% between 2000 and 2013 (MoFAD, 2014), aquaculture production increased from 38,547 tonnes in 2014 to 46,250 tonnes in 2015, an increase of 20%. This resulted in the reduction of fish imports from 145,910 tonnes in 2014 to 102,874.95 tonnes in 2014 (MoFAD, 2015). Despite this great contribution and potential of the aquaculture industry, most Ghanaians see it as a part-time, limited investment hobby due to the poor regard they have for aquaculture as an economic activity (Gitonga et al., 2004; Hiheglo, 2008). The relatively few farmers that culture fish because of its excellent economic growth opportunities are faced with a number of constraints. These challenges, according to Rurangwa et al. (2015) include insufficient availability of affordable fish feeds, seed quality and quantity. Inadequate involvement of private sector in the development of the aquaculture industry is also listed as one of the major problems as well as lack of financial resources for bringing about profitability of aquaculture operations, lack of appropriate skills or trained persons at the different levels of the aquaculture sector and lack of effective extension systems for knowledge transfer.

The most critical challenge is poor management of the farms due to lack of appropriate skills or trained persons at the different management levels of fish farming. The success or failure of any fish farm can be traced to effective management and farm governance. Most fish farms in Ghana are poorly managed thereby contributing massively to the under development and negligible contribution of the sector to the overall fish supply in the country. A lot of measures have been recommended for policy makers for a sustainable development of aquaculture including the provision of support to innovative and technological developments, ensuring a suitable regulatory framework that captures environmental costs within aquaculture processes, building capacity for monitoring and compliance and encouraging research on the supply and demand for fish and fish products.

BRIEF HISTORY OF AQUACULTURE IN GHANA

The Government of Ghana embarked on a programme to promote aquaculture and culture based fisheries in the upper (east and west) and northern regions of the country in 1950. These regions have long periods of drought and a single but unreliable rainy season which drastically affects the humans and the livestock population. In order to bring benefits in the form of fish for nutrition and cash to communities so as to reduce poverty in the North, the government embarked on a programme to have more dugouts and dams to provide a reliable source of water for humans, livestock, irrigation of cash crops and fish culture. Aquaculture started with the Department of Fisheries in the northern areas by stocking some of the water bodies with fingerlings and training some local people in fishing techniques. However, in spite of the mass initial entry, the initiative was flawed due to poor quality of fingerlings, poor selection of sites, and production without any business focus among others, led to the failure of the whole initiative.

In the early 1980’s, the government embarked on a massive campaign to persuade the public to establish pond fish culture (MacPherson and Agyenim-Boateng, 1991). The government’s main goal with promoting aquaculture was to develop culture-based fisheries in freshwater environments in order to take advantage of the huge potential that the country has for aquaculture which has been under-utilized for years. This campaign was productive and re-energized large number of people to build ponds in different parts of Ghana, especially in the southern part of the country (Hiheglo, 2008). But it was later discovered that a lot of the ponds were out of production and the few active ones were getting only a small proportion of economic returns on their investments. Moreover, about 23% of ponds constructed had been abandoned and those remaining in operation were not very productive (FAO, 1990). The main reason for the failure was because the government did not support its campaign with extension services to support the industry. Despite the earlier failures, effort is still being made to promote aquaculture development in the country. Studies conducted by Asmah (2008) reported a 16% mean annual growth rate in the number of aquaculture farms since the year 2000.



Source: Ministry of Fisheries and Aquaculture Development, 2015.

Figure 1. Estimated fish production from aquaculture in Ghana from 2008 to 2015.

CURRENT STATE OF GHANA’S AQUACULTURE

Aquaculture development effort in Ghana is focused on freshwater environment and one commercial project (Ghavie Shrimp Farm Ltd.) developed in the marine environment. The aquaculture sector comprises largely of small-scale subsistence farmers who practice extensive farming and very few commercial farms that contribute significantly to production. In recent years, production from aquaculture appears to be growing at a near exponential rate from 5,594 tonnes in 2008 to over 38,000 tonnes in 2015 (Figure 1).

SYSTEMS OF CULTURE

Fish culture in Ghana is mainly semi-intensive in earthen ponds, intensive culture in cages and other facilities such as reservoirs and dugouts (Figure 2). Pond culture includes single species culture and multiple species culture. Earthen ponds containing nutrient-rich water provide the needed plankton and organic debris, which tilapia and catfishes like to prey on. Ponds account for over 98% of the number of existing farms dominating the southern and middle belts of the country.

REGIONS	POND PRODUCTION			CAGE PRODUCTION			OTHERS (Dugouts, Reservoirs, Dams)
	No. of Ponds	Total Surface area(ha)	Production (mt)	No. of Cages	Vol. (m^3)	Production	Production (mt)
Greater Accra	275.00	75.00	158.05	350.00	43,750.00	1,531.25	-
Ashanti	1,205.00	150.63	384.68	39.00	4,875.00	20.00	-
Northern	90.00	2.85	1.23				450.90
Eastern	292.00	30.23	75.58	1,473.00	179,222.50	19,768.38	
Brong Ahafo	1,393.00	64.66	260.00	-	-	-	-
Western	644.00	82.80	207.00	3.00	225.00	7.88	-
Upper East	49.00	13.39	34.70	-	-	-	599.34
Upper West	17.00	0.80	0.00	10.00	1,000.00	1.97	380.30
Volta	247.007	98.32	282.72	416.00	50,900.00	2,919.02	-
Central	537.00	184.92	367.54	-	-	-	-
Total	**4,749.00**	**703.66**	**1,771.56**	**2,278.00**	**279,972.50**	**24,248.50**	**1,430.54**
Production 2012 - 27,450.56mt							

Source: Ministry of Fisheries and Aquaculture Development, 2012.

Figure 2. Aquaculture production systems in Ghana.

Cage culture is a relatively new culture method developed in recent years, which is usually used on the Volta Lake. Although the initial cost of cage culture is higher than other culture methods, cage culture has many advantages such as easy to stock and harvest, less feed loss, fast growth and high density in unit waters. The use of cages is currently growing geometrically in the commercial sector, however, without an in-depth management concerning water quality, waste and excess feed, the cage business could be disastrous. Overall, cage farms currently account for less than 2% of farms by number but much more by production. Most (88%) farmed fish production came from cage farming and the few commercial cage farmers consistently contributed to more than 88% of aquaculture production from 2011 to 2014 (MoFAD, 2014).

Pond production accounted for 8% of the total production of farmed fish while dugouts, dams and reservoirs contributed at 4% of the total aquaculture production. Concrete ponds and tanks are normally small and mostly used in hatcheries. Reservoirs and dugouts are mostly found in the northern belt of the country due to the relatively poor rainfall in northern Ghana and pen culture is commonly practiced in the Keta lagoon.

MAIN CULTURE SPECIES IN GHANA

Ghana's freshwater fish fauna includes 28 families, 73 genera and 157 species (Dankwa et al., 1999). Of these species, 121 have been recorded from Ghana's portion of the Volta river system, which drains more than two-thirds of the country (Safo, 2007). The most common species of fish farmed is the Volta Nile tilapia (*Oreochromis niloticus)* which represents 80% of aquaculture production (Asiedu et al., 2015; Kassam, 2014). Tilapia is also one of the most common aquaculture species in the world after carps (FAO, 2014). It has the advantages of fast growing, high tolerance to low dissolved oxygen, easy breeding, less occurrence of diseases and high yield.

The remaining 20% is comprised of catfish (*Clarias, Heterobranchus* or their hybrid). Initially, the catfish was scarce because it requires extraordinary hatchery techniques which Ghanaian farmers lacked. It is however possible to produce *Clarias* seed now using farmer friendly techniques in most farms (Safo, 2007). There are a few indigenous fish species namely the African bony-tongue, *Heterotis niloticus*, bagrid catfish, *Chrysichthys nigrodigitatus* and the African snake head, *Parachanna obscura*, which have aquaculture potential in Ghana (Dankwa et al., 1999) but have not received extensive research attention.

Objective of the Chapter

The objective of this chapter is to identify the key management systems, the challenges of fish farmers in Ghana and highlight development opportunities in order to develop policy strategies and solutions targeting specific constraints in the aquaculture industry.

Content of the Chapter

Following the introduction section of the chapter is the methodology. This is followed by the analysis of the management systems, opportunties, challenges and development of aquaculture in Ghana. The chapter ends with conclusion section.

MATERIALS AND METHODS

Data Collection: Interviews

Qusetionnaires (Appendices 1 and 2) were administered to fish farmers. Qusetionnaires were to identify the management system, size of operation, marketing, challenges at the farm level.

Respondents were randomly selected and interviewed. Two main respondent groups were identified, Operational Farms (OF) and Abandoned Farms (AF). For the purpose of this study, operational farms are farms currently in production and abandoned farms are inactive farms. The Fisheries Commission (FC) was also contacted to attain their perspective on the challenges and prospects of fish farming. A series of dualistic questions were used, which included close and open ended types, to assess the challenges that limit production, opportunities and overall development of fish farming. Fifteen (15) individuals were interviewed from each of the main respondent groups with predesigned questionnaires. A total of 30 fish farmers were interviewed.

Data Collection: Document Analysis

Documents were obtained and analysed on fish production, imports, exports, demand and supply from official sources (Ministry of Fisheries and Aquaculture Development, Ministry of Trade and Industry, Food and Agriculture Organization, Ghana Statstical Services). A desktop study on the constraints, opportunities, management systems and sustainability of aquaculture in Ghana was also undertaken. Information from literature was used as guide to questionnaire design for the field study.

Data Collection: Key Informants and Experts

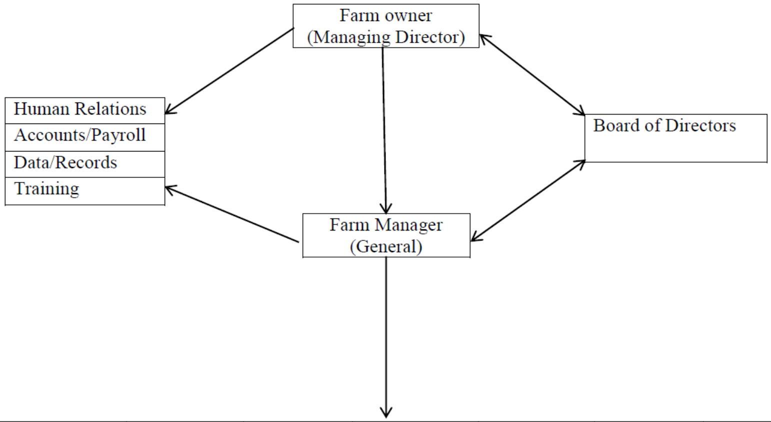
Key informants and experts were contacted to solicit their opinion on challenges, development and opportunities in the aquaculture industry of Ghna. Experts conducted include; deputy and assistant directors of fisheries, local aquaculture society executives, feed suppliers, leaders of market associations.

ANALYSIS OF THE MANAGEMENT SYSTEMS, CHALLENGES AND DEVELOPMENTS

Management Systems

The aquaculture business is not limited to the fish alone, but combines various production components such as land space, culture facilities, water, labour and capital for maximum and continuous returns. It requires effective management and carrying out routine activities to ensure the best returns from the farmers' efforts and capital investments. The success or failure of any aquaculture venture can be traced to effective management and farm governance. As the size and complexity of a fish farm increase, sound management becomes increasingly unavoidable.

Most medium and small scale farmers in Ghana employ operational farm managers, farm-hands (feeders/harvesters) and security guards to be the main managing body of their farms. But the few commercial farms in the country have detailed management structures in place that ensure that quality standards are not bargained in all the phases of production. Currently, because competition is getting keen due to the increase in the number of fish farms emerging and the brisk perishability of products, farmers who want to stay in business have developed essential managerial strategies and essential operational functions of the enterprise. Clear responsibilities and reporting, are therefore important and outlined for an effective operation of fish farm businesses. A typical management system for Tropo farms, the second largest cage farm in Africa, after Lake Harvest at Zimbabwe is shown in Figure 3.



Hatchery/Nursery	Feeding	Production	Fish Transport	Post-Harvest	Marketing	Security
Assistant Managers	Assistant Managers	Assistant Managers	Assistant Managers	Assistant Managers	Assistant Managers	Assistant Managers
Supervisors	Supervisors	Supervisors	Supervisors	Supervisors	Supervisors	Supervisors
Assistant Supervisors	Assistant Supervisors	Assistant Supervisors	Assistant Supervisors	Assistant Supervisors	Assistant Supervisors	Assistant Supervisors
Foremen	Foremen	Foremen	Foremen	Foremen	Foremen	Foremen
Labourers	Labourers	Labourers	Labourers	Labourers	Labourers	Labourers

Figure 3. System of management at Tropo Farms Ltd (*Source: Personal communication* Tropo Farms Ltd).

Challenges

Data on the key challenges were collected in two ways, challenges presented to farmers for ranking and those peculiar to farmers. Figures 4 and 5 present abandoned farmers (AF) and operational farmers (OF) rankings of the challenges developed from literature and presented to them for scoring on a 4-point scale. Overall mean rankings from abandoned and operational farmers' were 3.9 and 4.0 respectively**,** for high cost of feed. This was the highest mean rankings recorded, putting high cost of feed as a very important constraint. Lack of access to fund was the second with mean rankings 3.8 for AF and 3.6 for OF. Mean score for inadequate fingerlings supply was 2.7 and 2.8 for abandoned and operational farmers, respectively. To determine whether farm abandonment may be due to poor management, unsatisfactory management was presented to the AF group for ranking. Mean ranking for unsatisfactory management was 2.9. The lowest mean rankings observed were 2.3 for water quality management by OF and 2.6 for lack of extension and training by AF.

However, high cost of feed and lack of access to funds appeared as the critical ones.

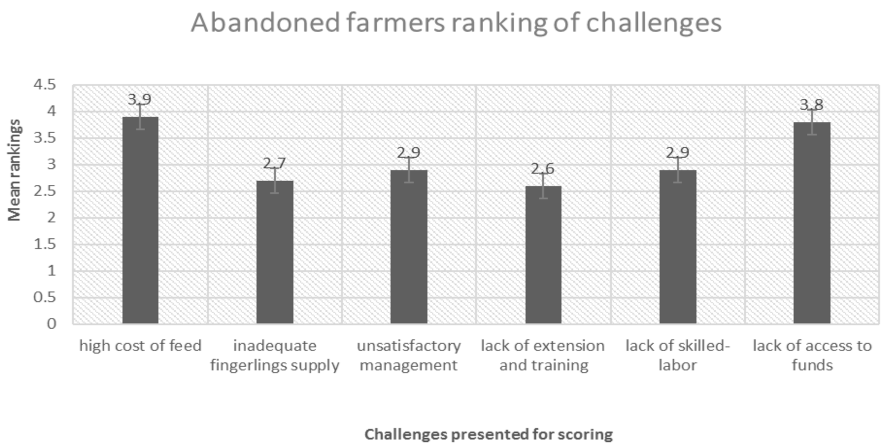


Figure 4. Challenges of abandoned farmers (AF).

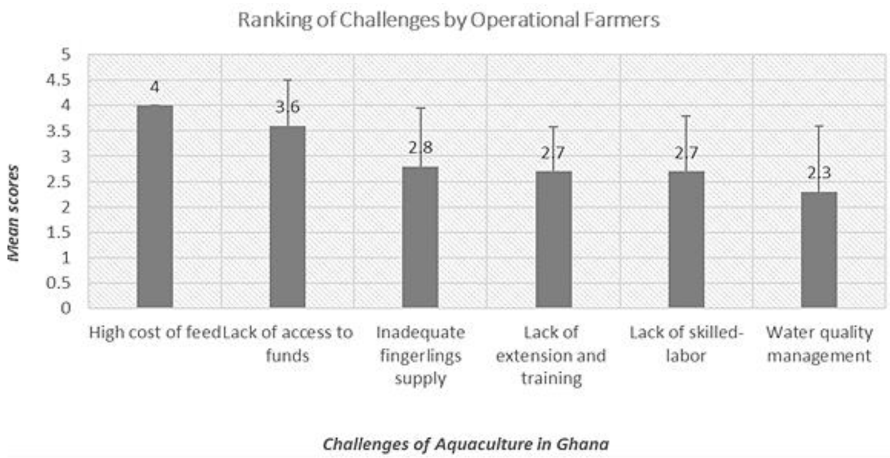


Figure 5. Challenges of operational farmers (OF).

Figures 6 and 7 present problems from farmers' perspective. According to the figures, poor market availability is a major challenge to aquaculture development. From the study, 27.9% of farmers abandoned farms due to poor market conditions, whilst 27.3% of operational farmers indicated that poor market limits their production capacity. In total, poor market, high cost of feed, inadequate fingerlings and inadequate funds constitute major reasons for farm abandonment. Figure 6 shows poor market accessibility, predation, high startup capital and high cost of nets as the main problems limiting the production capacity.

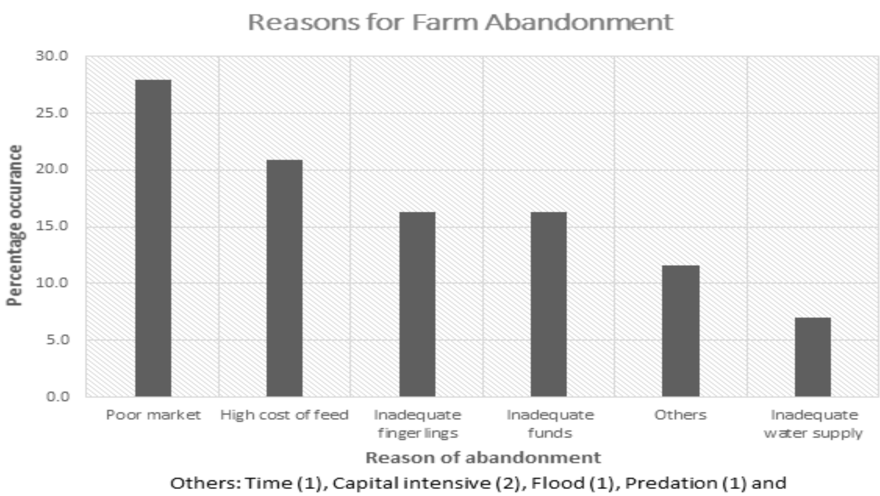


Figure 6. Reasons for farm abandonment.

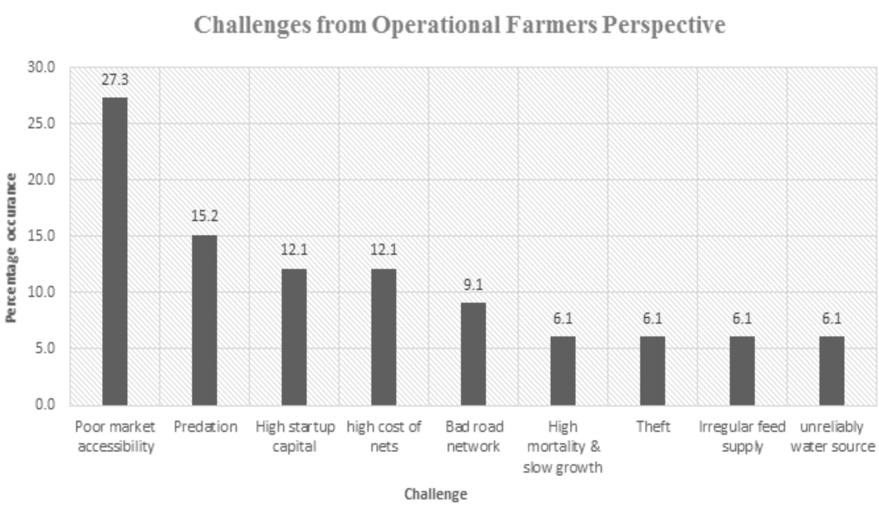


Figure 7. Challenges faced by operational farmers.

The aquaculture industry of Ghana looks promising. However, there are still a lot of constraints that need to be addressed in order to take this industry to its maximum potential. Infact, these challenges led to failure of aquaculture development in the 1980s. These challenges still remain a travesty in the development of the fish farm industry and meeting the nation's protein requirement of present and future generation. The major constraints include:

High cost of good-quality feed

Intensive fish culture where the fish are totally fed has become a usual culture method than extensive culture systems especially in cage farming where complete floating feeds are used in Ghana. Floating feeds are partly imported and produced in Ghana. The most common fish feed available in the local market include raanan, coppens and multi-feed. The crude protein (CP) content of the commercial feeds are; 55-58%, 40-48%, 30-38% and 27%. The most commonly used by fish farmers are 40% CP for juveniles and 30% CP for adults. Some farms also produce their own feed using locally materials such as maize, rice bran, groundnuts and cowpea. Local feedstuffs from plants source lack methionine and lysine required for optimum growth of fish. In intensive culture, the fish are totally fed by artificial compound feed. Feed cost has been the single largest operating expense of intensive fish culture, accounting for over 70% of the total operational costs. At present, the price of 15kg Rannan fish feed with 40% CP is GH₵60-65 (US$16-17) while 20kg with 30% CP is GH₵70-75 (US$18-20). The high cost is making it difficult for farmers to purchase enough feed, thereby leading to underfeeding of fish in most farms. Feed therefore plays a critical role in the aquaculture industry of Ghana. The lack of rich protein supplements has become a serious issue in feed industry. Fish nutritionist all over the world are constantly searching for the dietary protein sources in which fish will maximize growth and increase production within the shortest possible time and at lowest cost (Kaushik, 2000). The high cost of good quality feed must be tackled urgently to sustain the aquaculture industry of Ghana.

Lack of Access to Funds

Lack of access to funds had mean rankings 3.8 and 3.6, on a 4-point scale, for abandoned farmers and operational farmers, respectively. This puts, lack of access as the second most important problem limiting aquaculture production and led to abandonment of most fish farms in the study area. This is consistent with the findings of Anane-Taabeah et al. (2010) that investigated on the constraints and opportunities in cage aquaculture in Ghana and found out that, lack of access to funds major reason why farmers abandoned their cages. Aquaculture is generally capital intensive, characterized by high cost of feed, fingerlings, brood-stock and transportation. Lack of access to funds will therefore limit the amount of feed and fingerlings farmers can purchase and correlate to low aquaculture production. Rungwa et al. (2015) indicated that capital investment/financial base continue to be a major challenge particularly for the small and medium scale farms. A similar study by Hiheglo (2008) showed lack of access to funds is major to aquaculture development in Ghana.

Poor Market of Farmed Fish Products

Poor market continued to be a challenge to the expansion of Ghanaian fish farming enterprise. Poor market in this study include unstable prices, abuse by marketing intermediaries, inadequate advertisement, unreliable market and poor accessibility to market centres. When farmers were asked to state in order of significance challenges peculiar to them, 9 operational farmers representing 27.3% presented poor market as major constraint to increasing production. This was similar from abandoned farmers' perspective, 12 farmers representing 27.9% (see Figure 6 and 7). The results was inconsistent with the findings of Anane-Taabeah et al. (2010) and Asiedu et al. (2015) where lack of market emerged as a problem in the aquaculture industry.

Opportunities

Political Stability and Favourable Geography

Aquaculture in Ghana is still in the developing stage even though it started about 60 years ago. Ghana is endowed with good natural resources such as fertile land, water (rivers, lakes and the sea) and a large regional market that can support aquaculture production. Considering the Volta Lake alone, utilizing only 1% of the area of Lake corresponds to about 8500 hectares of water (Asmah, 2008). Therefore, due to the favorable geographic conditions, big opportunities lie in the expansion of the aquaculture enterprise. The culture of new freshwater species and even marine species for the domestic market can also be explored, especially considering that Ghanaians are also importing more marine fish. Currently, only the local Akosombo strain of Nile tilapia (Generations 1-10) can legally be cultivated in Ghana. Another opportunity for aquaculture development in the country is the farming of a more performing strain. Interest in better performing fish strains, namely the Genetically Improved Farmed Tilapia (GIFT) strain, is very high among most fish farmers and other stakeholders (Rurangwa et al., 2015). However, its introduction is not yet permitted because the environmental risk assessment has not been completed.

Skills and Capacity Building

In spite of the huge potential of aquaculture in the country, the current production is contributed by the few large scale commercial cage farmers. Meanwhile, there are a lot of small scale farmers that use the different systems of production. This proves that the technical and/or managerial expertise in most farms is underdeveloped. Currently, about five public and two private universities are invoved in aquaculture training. The private sector such as Ghana Aquaculture Society, Anioo Ansah Farms, Asufua Fisheries, are involved in aquaculture training. The success of fish culture does not only depend on the survival and growth rate of the fish strain but also on the skills of the labour and management of the farm. Therefore, another opportunity for aquaculture development is the establishment of more training or demonstration centers for capacity building and knowledge transfer to equip the small scale farmers with appropriate skills that are lacking at the different levels of production across the country. This can also help develop particularly pond farmers in the middle and central belts of the nation where several opportunities exist for constructing ponds. The culture of catfishes can also be expanded especially after the skill for artificially spawning becomes very well learnt.

Strong Governmental Support and Conducive Policies for Investors

The government of Ghana through the Ministry of Fisheries and Aquaculture Development has taken several steps to support and accelerate aquaculture development in Ghana. The measures are mainly training programmes in fish farming techniques. As of 2008 the Department of Fisheries had assisted in training more than three hundred people countrywide in aquaculture and over USD 500,000 was allocated to the newly trained farmers as start-up capital to promote production (Hiheglo, 2008). In 2012 a new Fisheries and Aquaculture policy, which embraces the development of aquaculture and provides detailed financial support to further promote investments into aquaculture was adopted. The government budgeted a total of US$ 84,313,900 to the support aquaculture development in Ghana. Among activities to be undertaken include; establishment of high priority aquaculture zones, establishment of national aquaculture business database, assisting more fish farmers to access funds more easily on competitive terms for investment in aquaculture business, strengthening the national capacity for ensuring the sustainable use of land and water resources in aquaculture-production (MoFAD, 2012).

The Government of Ghana is also committed to creating an enabling environment for the existing number of local and potential investors. For instance, new aquaculture enterprises are allowed a five-year tax free period. The government has also set up a special fast track court system in order to provide a quicker response to solving disputes and enforcing contracts which is a key factor in providing a healthy and efficient business environment. Studies conducted by Henriksen (2009) summarized that general conditions in Ghana are favourable and that investors find Ghana to be a sound location for business development.

Rapidly Growing Demand for Quality Fish

With the Ghanaian's social and economic conditions improving, the lifestyle of people is changing and preference is given to eating healthier food. Internal demand for farmed tilapia is high mainly due to the growing middle class with preference taste for tilapia and high malnutrition in the country (Asiedu et al., 2015). Fresh or alive fish being accepted by the average Ghanaian to be healthier than red meat and frozen or processed fish is considered as a real delicacy food. With Ghana's per capita fish consumption currently at 28kg (MoFAD 2015), it can be expected that, farmed fish demand and domestic market will increase as the national population and level of income of most Ghanaians also rise.

Rapidly Growing Excess Demand for Quality but Affordable Feed

According to Rurangwa et al. (2015), the average costs for tilapia farming in Ghana consists of 70% of feed cost. Currently, there is only one local aqua feed mill (Raanan Fish Feed West Africa Ltd.) producing feed at its maximum capacity, which implies that huge tonnes of feed are imported. Therefore, a great opportunity in the fish farm business in Ghana is the local manufacture of reliable volumes of quality feeds at a more stable price to replace the importation of foreign based protruded feeds, which is approximately 30% more expensive than locally produced feeds (Rurangwa et al., 2015). There is an avenue to introduce nationally owned feed mill, which would help reduce the production costs of intensive fish culture.

In-spite of the opportunities that the nation presents for the development of aquaculture, the business is a rather labour intensive and if labour costs get too high, the farmed fish will lose price advantage on the market. Also, as the intensive culture gets more popular in Ghana, matters on pollution of culture area need to be critically examined because if the water quality can't be controlled at a good level, there will be less space to meet the aquaculture standard and development in the future.

CONCLUSION

The aquaculture industry of Ghana looks promisimg as the climate, demand, water bodies and other resources are suitable for aquaculture production. Different management systems are employed at small-scale through medium to large scale levels. Management are adopted at all levels of production: hatchery, feeding, post-harvest and marketing.

The aquaculture industry is confronted with a number of challenges including l high cost of good quality feed, lack of access to funds, inadequate fingerlings, lack of training and extension services. The Government effort to make aquaculture alternative livelihood to capture fisheries, ensuring food security, increasing nutritional needs and other opportunities will be materialized if the bottlenecks are tackled urgently.

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APPENDICES

Appendix 1: Questionnaire on Aquaculture Challenges (*For the Operational Farmers (OF) Respondent Group)*

Interviewer	………………………
District	………………………
Community	………………………
Date	………………………
Interviewee	………………………
Gender	………………………
Farm Name	………………………
Contact	………………………

For the Operational Farmers (OF) respondent group: Challenges of Aquaculture

1. For how long have you been practicing fish farming? ....
2. What kind of production units do you have here?

☐ Ponds ☐ Cages

3. On average, what quantity of fingerlings is required to stock your farm? ....
4. Where is or are your source(s) of fingerlings? …………………………

5. Do you encounter some challenges that limit your production? *Yes/No*
6. Score the challenges below on the scale One to Five (1-5) in order of importance.
    a) High cost of imported feed …………..…
    b) Inadequate fingerlings supply …………..
    c) Water quality management ……..…......
    d) Lack of extension and training ………....
    e) Lack of skilled-labour ……..…………….
    f) Lack of access to funds

7. List other problems you are confronted, not mentioned in *four* (4) above:
    a) …………………………………………
    b) ……………………..............................
    c) …………………………………………
    d) ……………………………...................
    How do these problems affect your production? …..…………………

Prospects of Aquaculture in the Sunyni Municipal

8. What do you think could be done in order to solve/reduce the problems in questions *4 and 5* above, for the development of your farm and aquaculture in the Municipal?
    a) …………………………………………
    b) ……………………..............................
    c) …………………………………………
    d) …………………………………………

9. On the average, what quantity (Kg) of fish do you produce in a production cycle? …………..
10. Have your farm ever produce fish to meet the demand of your customer(s)? ..…….... *Yes/No*
11. Would you be able to market your products if you increase production? ………. *Yes/No*
12. If yes, would you be willing to expand your farm when problems are solved/reduced? ………. *Yes/No*
13. In general, do you think the aquaculture business is profit rewarding? ………. *Yes/No*
14. What is/are the source(s) of financing the business?

a) Personal Savings
b) Family and Friends
c) Government
d) Loan from Financial Institution(s)

If (c) *or* (d) specify which government program or the name of financial institution(s) below;

c)…………………………………………………………………….
d)…………………………………………………………………….

15. On the scale of 1-100 what is the chance of recommending aquaculture to someone?
    a) 1-20%
    b) 21-40%
    c) 41-60%
    d) 61-80%
    e) 81-100

Appendix 2: Questionnaire on Aquaculture Challenges (*For the Abandoned Farmers (AF) respondent group)*

16. How long have you practiced fish farming business? ....
17. For how long have you abandoned your farm now? …..………………...
18. What kind of production units were you using?

☐ Ponds ☐ Cages

19. Did you encounter some challenges that limit your production? .. *Yes/No*
20. Score the challenges below on the scale One to Five (1-5) in order of importance.
    g) High cost of imported feed …………..…
    h) Inadequate fingerlings supply …………..
    i) Water quality problems …..……..…........
    j) Lack of extension and training ………….
    k) Lack of skilled-labour ………………..…
    l) Lack of access to funds ………..................

21. List in order of significance, the reasons for the abandonment of your farm.
    e)……………………………………………
    f) ……………………...............................
    g) ………………………………………………
    h) …………………………………..................

In which way did the problems affect your farm operations and final abandonment of farm? ……………………………………………………………
....
....

22. What in your opinion, could be done to solve the problems and improve aquaculture in the municipal?
    a) ……………………………………………………………….…………
    b) ………………………………………………………………….………
    c) ……………………………………………………………….…………
    d) …………………………………………………………………………..

23. In general, is the aquaculture business profit rewarding from your experience? . *Yes/No*
24. On scale of 1-4, where 4 is certainty, what is your chance of practicing aquaculture again at reasonably reduced level of constraints? ....
25. In the course of your production, have you ever met the demand of your customers? *Yes/No*
26. What was/were your source(s) of finance for running the business?
    a) Personal Savings
    b) Family and Friends
    c) Government
    d) Financial Institution(s)

If (c) *or* (d) specify which government program or the name of financial institution(s) below;
(c)…………………………………………………………………………….
(d)……………………………………………………………………………

27. Despite your encounters, on the scale of 1-100 what is the chance of recommending aquaculture to someone?
    f) 1-20%
    g) 21-40%
    h) 41-60%
    i) 61-80%
    j) 81-100%

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Chapter 2

PHAGE THERAPY OF *VIBRIO HARVEYI*: A CONCEPT OF PROTECTION BACTERIAL CONTAMINATION IN AQUACULTURE INDUSTRY

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ABSTRACT

The concept of phage therapy to control bacterial infection and contamination was conceived about a century ago. It has now been more important to understand this approach since drug resistant bacteria have become more common and development of new antibiotics has become more difficult. This article will cover the fundamental knowledge of phage infection in bacterial cell and extends it to phage therapy by using a model of Vibrio-phage, called VH-P, with its specific *Vibrio harveyi* host, VH 13-1. The VH 13-1 was isolated and collected from luminescent black tiger shrimp. To test the possibility of the use of permissive phage as a tool to treat the VH contamination in shrimp ponds, a VH-P which is a temperate phage was tested for its efficiency to kill the VH13-1. In the meantime VH16-1 which is not infected by VH-P was used as a control. Our study was conducted with the MOI (multiple of infection) of 1-100. The success of the treatment is determined if no VH bacterial colony is observed in the culture medium after the phage treatment. The MOI of 20 resulted in the killing of all the VH13-1 while MOI 10 was inconsistent because two of the three experiments showed growth of bacterial colony and MOI of 1 resulted in significant survival of VH13-1. These colonies were proved to become lysogenic infection of VH-P. The study shows that using temperate phage of VH-P to treat VH bacterium, it is necessary to treat with the sufficient amount of the VH-P phage at once. Insufficient amount of MOI will allow the VH to develop lysogenic infection and cause interference to super-infection of the same phage. Accordingly, the strategies to develop phage therapy as an alternative to using antibiotic treatment of bacterial contamination and infection will be discussed.

Keywords: bacterial infection and contamination, drug resistant bacteria, phage therapy

INTRODUCTION

Vibrio harveyi (VH) was reported to involve the luminescent disease in shrimp aquaculture (Ruangpan et al., 1999; Manefield et al., 2000; Phuoc, 2008) and many other aquaculture animals (Haldar et al., 2010; Ruwandeepika et al., 2012; Zhou et al., 2012). Like other bacterium, V. harveyi can be infected by specific bacteriophage. Some of the bacteriophages were reported to be the partners of the bacterium infection to cause shrimp death due to the luminescent symptom, as called phage conversion (Ruangpan et al., 1999) by a, so called, lysogenic infection. On the other hand, there are other bacteriophage of the VH that kill the bacterium, know as lytic phage infection (Crothers-Stomps et al., 2010; Raghu et al., 2014).

Before the discovery of antibiotic, phage therapy had been studied to be a strategy to fight against bacterial infection (Kropinski, 2006; Dublanchet and Fruciano, 2008). After the discovery of antibiotic, however, the idea of phage therapy was overlooked in the western world. On the other hand, it has still been studied in Eastern Europe (Kropinski, 2006). Now, the concept of phage therapy has been investigated widely for advantage in the food industry (Huff et al., 2005; Atterbury et al., 2007; Bielke et al., 2007), animal farms (Wall et al., 2010; Silva et al., 2014), environment (Abdulla et al., 2007; Beheshti Maal et al., 2015) and medical treatment (Kumari et al., 2009; Sundar et a.l, 2009; Santos et al., 2010; Mattila et al., 2015). However, the effectiveness of phage therapy is not certain according to different groups of investigators.

Since bacterial infection is the one of the greatest concerns in shrimp aquaculture industry. This forces many farmers to use excessive amounts of antibiotic with the hope to prevent the bacterial epidemic. Using astronomical amounts of antibiotic in shrimp farms cause various problems: e.g., the extravagant expense, environmental concern, lower shrimp quality with the excessive dose of antibiotics which become unacceptable in high standard market. Also, this action increases the potential of antibiotic resistant pathogens to consumers (Durans and Marshall, 2005). The study of phage therapy is an interesting concept to pursue in the shrimp industry, especially with regard to the green environmental concept.

INFECTION PATHWAY OF BACTERIOPHAGE

There are two main kinds of phages which are virulent and temperate phage. Virulent phage infects the bacterial cell by the mechanism of lytic infection only and it is also called as lytic phage. Lytic infection is synonymous to acute infection which causes the bacterial cell death immediately once it infects (Dimmock et al., 2001; Cairns et al., 2009). On the other hand, temperate phage can infect bacterial cells not only by lytic infection but also lysogenic infection. Lysogenic infection closely resembles chronic or persistent infection as in high animals and human (Dimmock et al., 2001). Most of the temperate phages cause lysogenic infection by integrating their genomes into the bacterial chromosomes and exist as a parasite but does not kill the bacterial hosts. Thus, in the lysogenic infection, the phage and bacteria live together accommodatingly (Dimmock et al., 2001, Pasharawipas et al., 2005). However, during division in the early stages of temperate phage infection, the generated bacterial cells can become either lytic or lysogenic infection. (Dimmock et al., 2001). There is no clear explanation of this phenomenon why the temperate phage behaves to switch from lytic to lysogenic infection. However, we know that the expression of two sets of genomes in temperate phage substitutes between lytic and lysogenic infection (Stahl, 1998). While the first group of genes, such as *Cro* gene, influences the lytic infection, the other set of genome, for example *CI* gene, plays a role to express lysogenic infection (Stahl, 1998; Dimmock et al., 2001, Oppenheim et al., 2005). The influential factor to activate the *CI* and *Cro* genes to alternate their roles is not well understood. However, ultraviolet and organic substances such as mitomycin-C are reported to induce the lysogenic infection of the temperate phage to a lytic infection (d'Ari, 1985).

However, there is another kind of temperate phage in which its genome locates in the bacterial cell like a plasmid, without chromosomal integration as the ordinary temperate phages do. This means the phage genome does not insert its genome into the bacterial chromosome but localizes extra-chromosomally or plasmid-like in the bacterial cell (Kawakami and Landman, 1968; Khemayan et al., 2006; Pasharawipas et al., 2008). The previous study of Khemayan et al. (2006) called the lysogen with an extra-chromosomal phage genome as true lysogen (TL). The researchers also showed that the sub-cultural colony of TL by an isolation technique can produce another kind of lysogen which is called pseudolysogen (PL). The PL is proven to generate from TL but does not contain any phage genome in its cytoplasm (Khemayan et al., 2006). It is hypothesized that PL is derived from the TL by the unequivalent division of the lysogenic chromosome. Since the speeds of genomic duplication of the phage genome and the bacterial chromosome do not replicate simultaneously during the binary fission of the TL, the process erroneously produce PL, besides the TL (Pashrawipas et al., 2008).

Usually, TL can prevent itself from super-infection of the same kind of phage (Dimmock et al., 2001). This is a well-known phenomenon although the clear explanation for its mechanism is not well accepted. Surprisingly, the PL can also prevent itself from super-infection as the TL does although the phage genome does not really exist in the bacterial cell (Pashrawipas et al., 2008). Besides the toleration of phage to super-infection as found in lysogenic bacteria, it is also found in viral infected eukaryotic cells. The mechanism for this has been proposed with a few different hypotheses. For example, it was explained by the appearance of defective phages (Cambell, 1960), the role of cytokines (Sidahmed et al., 2007), gene mutation (Skurnik and Strauch, 2006) and disappearance of viral receptor molecules (Skurnik and Strauch 2006, Pasharawipas et al., 2008).

Apparently, the toleration of lysogen, either true lysogen or pseudolysogen, to re-infection by the same phage is one of problems for the phage therapy. Thus, to make the concept of phage therapy promising, it is more appropriate to use virulent phage for the phage therapy to avoid lysogenic infection. However, our previous study demonstrated that using temperate phage to treat bacterium is possible with the key consideration of bacterium-phage ratio, so called MOI (multiplicity of infection).

PHAGE TREATMENT OF *VIBRIO HARVEYI* WITH TEMPRATE PHAGE

In our previous study (Pasharawipas et al., 2011), using temperate phage to treat *Vibrio harveyi* (VH) has been reported. VH13-1 is a luminescent VH which was isolated from luminescent shrimp in Songkhla province, Thailand. In the meantime, VH-P phage was found to be a specific temperate phage of the VH13-1 from the shrimp pond in Chantaburi province. In this case, VH-P had been tested for the possibility to treat the VH13-1 in *in vitro* study. The three repeated experiments have been tested for the phage treatment of VH-P against VH13-1 as shown in Figure 1. We found that to kill the VH13-1 completely, the least MOI of the VH-P phage has to be 20 while the control VY16-1 was not affected. The optimal time to completely kill all the VH can be within 45 minutes. This is determined by the result that there is no VH colony growth in TCBS after incubation for 24 hours in 28ºC. In case of the insufficient amount of VH-P treatment, at the MOI of 10, a few colonies were still observed in two of the three experiments while the MOI of 1, there are a lot more of VH13-1 survived. The bacterium colonies from both MOI of 10 and 1 were proved to be lysogenized by VH-P genome as tested by PCR technique and become resistance to the VH-P phage super-infection.

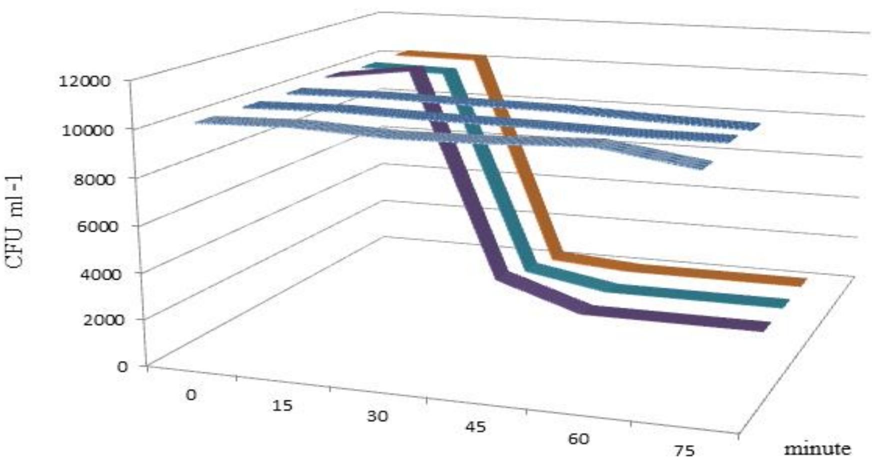

Figure 1. The VH-P phage treatment against VH 13-1 with the MOI 20. The solid lines represent VH13-1, the pattern filled lines represent VH 16-1.

STRATEGIES OF PHAGE THERAPY

Logically, it is more promising to use virulent phage to treat bacterial infection, especially in human and animals (Soothill,1992; Kumari et al., 2009; Wang et al., 2006), and contamination in food products (Leverentz et al., 2001; Wall et al., 2010). This is because any progeny of the virulent phages can be reproduced and attack the other regenerated bacterium again without the prevention of super-infection by the bacterium. On the other hand, the temperate phage can naturally cause the target bacterium to tolerate the same phage infection to produce either lysogen or pseudolysogen.

There are reports that there are more temperate phages than virulent phages in our body. Oppositely, there are more virulent phages than temperate phages in natural environment (Chibani-Chennoufi, 2004a). However, we studied the phage of *Vibrio harveyi* (VH), which is the pathogenic bacterium of black tiger shrimp. Although over 20 strains of temperate VH phages have been isolated, we have never been able to isolate a virulent phage against VH from any shrimp pond. As mentioned above, it is still possible to use temperate phage to treat bacterium contamination in shrimp pond if the sufficient MOI of the temperate phage was applied to kill the bacterium at once. Insufficient MOI of temperate phages can induce the bacterium to develop lysogenic bacterium which can tolerate the same phage super-infection. So, the same temperate phage cannot be used to eliminate the VH bacterium any longer (Pasharawipas et al., 2011).

Accordingly, using temperate phage as an anti-bacterium tool can be disadvantageous compared to the use of virulent phage. The application of temperate phage is not proven to be appropriate for the study or treatment within the body especially in human since the phage genome might convert the normal flora to a pathogenic bacterium (Dublanchet and Fruciano, 2008). This phenomenon is called phage conversion which is a mechanism to convert non–pathogenic to a pathogenic bacterium by the phage genome as reported in *Vibrio cholerae* (Campos et al., 2010; Hansan et al., 2010), *Staphylococcus aureus* (Endo et al., 2003) *Salmonella enterica* (Brown et al., 1999), and others (Dobrindt and Reidl, 2000). However, many believe that phage conversion is unlikely to occur since the phage requires a specific bacterium host to infect. It is not very promising that phage can infect normal flora unless the phage for some bacterial species is used such as the phage to treat pathogenic *E. coli*. It is known that in using phage to treat pathogenic *E. coli*, we should be aware. *E. coli* is a normal flora in our gastrointestinal tract. On the other hand, using the phage to treat the infectious agents such *Vibrio* species should not cause phage conversion since *Vibrio* species is not a normal flora in human body. Thus, we should consider studying the safety of the temperate phage to treat bacterium infection case by case if we are going to apply temperate phage *in vivo* treatment. In addition, it is a better alternative to have two or more kinds of temperate phage which are permissive to infect the same strain of bacteria. How to use multi-phage treatment of any problem-causing bacterium is a major question. Whether using all the phages simultaneously or at different time does better, requires further investigation. The ideal is to prevent any lysogens which become resistance to those phages.

Concerning the safety of phage therapy, the main concern is the phenomenon of phage conversion. This can occur in case of using temperate phage for the treatment but not the case for virulent phage. However, the phage conversion should be concern only in the case that the infectious agent is the same specie as the normal florae as a example of *E. coli* as mentioned above. In the meantime, it is unlikely that bacteriophage can be pathogenic directly to animal and human because phage is a bacterial infectious agent not eukaryotic cell. However, to know all well, we do need to keep learning further.

PROPOSAL TO DEVELOP PHAGE TREATMENT

As mentioned concerning the problems in using natural temperate phage for treatment, the concept to eliminate or knock out any particular gene(s) that create the lysogenic infection pathway can be the strategy to overcome these problems. Theoretically, genomic modification technique may be possible to convert a temperate phage to a virulent phage in the research laboratory (Wolf and Woodside, 2005). The process can be done by sequencing the particular phage genome to localize the involved lysogenic genes and subsequently alter or delete them to prevent lysogenic infection in bacterial cell. This can be a way to covert the temperate phage to be virulent phage for treatment of bacterial infection and contamination.

However, the major concern in using phage as a tool to fight against bacterium is the specificity of phage infection in the bacterium cell. Research shows that the phage infection in bacterium is a phenomenon of strain specific, not specie specific (Nagy, 1974; Rakhuba et al., 2010; Chibani-Chennoufi, 2004b). This means if there is more than one strain of pathogenic bacterium, we need to obtain all the strains of phage that can infect the pathogenic bacteria. In this case, it is necessary to collect all phage species in order to treat the particular bacterial infection. It is estimated that each species of bacterium may be infected by at least 10 phage species (Chibani-Chennoufi, 2004a). Thus, we need to search all the phages, as a cocktail, for particular specie of bacterial pathogen (Santos et al., 2010). This is like searching for a needle in a hay stake. However, there is a report of the polyvalent phages which can infect broad host range of bacteria (Kilic et al., 2001; Lu et al., 2003). In addition, there is a phage that can orientate its receptor-interacting gene to synthesize a new molecule for attachment to a different bacterial cell (Scholl et al., 2001). These information, polyvalent phage and interacting molecule orientation, can lead to the possibility that we can develop a common molecule or ligand for phage infection to attack a broad range of bacteria. Thus, one might propose a study in developing only one kind of phage to treat more strains or species of bacteria and eliminate the need for various kinds of phages as a cocktail. To make this successful, we, at least, need to thoroughly understand the interaction of bacterial cell and phage. This can be very diverse for each pair of bacteria and phage.

CONCLUSION

One of the advantages of phage treatment is its specificity to pathogenic bacteria so it cannot cause any harm to normal florae bacteria. However, the specificity of phage interaction to bacterial cell is also disadvantageous for phage therapy since it limits the use of phage for treatment to a limited range of bacterial species. It is more reasonable to use virulent phage more than temperate phage for bacterial therapy. However, virulent phage is a scarcity for many bacteria. In this case, the available temperate phages might be an alternative choice. However, the sufficient amounts of temperate phage must be administered with special care to prevent the lysogenic infection. Alternatively, molecular technology can be applied to alter temperate phage to act as a virulent phage to prevent lysogenic infection. Also, the technology might produce a phage to attack a broader range strains or even more species of bacteria. In the future, with our progressive difficulty of using antibiotics, phage therapy could be an alternative to our fight against bacterial infection and contamination. In the main of fact, using antibiotics extravagantly by farmers has been known to be one of the major problems to cause antibiotic resistance of bacteria. Base on this consideration, it will be better to decontaminate bacterium with bacteriophage than antibiotic. Although at present time, there are many obstacles limiting the use of phage therapy for the treatment of bacterial contamination in various environments including in aquaculture industry, further research offers an alternative to antibiotic therapy in the future.

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Chapter 3

MODELLING OF TASTE-TAINT IN FISH FARMED IN RECIRCULATING AQUACULTURE SYSTEMS (RAS)

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ABSTRACT

Farming of fish with Recirculating Aquaculture Systems (RAS) is becoming widespread due to diminishing wild-caught supplies. However, the accumulation of 'earthy' or 'muddy' off-flavours due to taint chemical as geosmin (GSM) or 2-methylisoborneol (MIB) in the fish-flesh of farmed species is a major concern. Inconsistent quality of farmed-fish has been identified as a major issue in buyer resistance. Predictive mathematical models, widely used in bio-chemical engineering, provide a basis for evaluating environmental toxicology and risk assessments in RAS farmed fish. The use of models to predict taste-taint chemicals in fish-flesh with growth is a new concept and can be used to help farmers and researchers in decision making and farm protocols. In this chapter we discuss taste-taint modelling in RAS farmed fish including: taste-taint problems in RAS farmed-fish; an overview of predictive models for chemical congeners in fish-flesh; models for predicting accumulation of GSM and MIB in fish-flesh; development and limitations of predictive models; factors to be considered in developing an adequate model for RAS fish, benefits of models to the supply chain, and; a critical review of an extensive recent experimental validation of one predictive model and risk analyses.

Keywords: geosmin (GSM), 2-methylisoborneol (MIB), Recirculating Aquaculture Systems (RAS), predictive models, taste-taint

INTRODUCTION

Fish farmed in Recirculating Aquaculture Systems (RAS) is a globally important alternative to capture of wild-fish, particularly as wild-caught seafood population levels plateau or decline. RAS is increasingly important in filling the demand gap and is becoming popular due to a higher production per unit area, less water and land usage, a year-round production and better control of the fish-rearing environment than other conventional fish farming methods such as ponds and sea-cages (Ebeling and Timmons, 2012). Aquaculture such as RAS is expected to grow and develop as the global demand for farmed species grows.

A problem however is the potential for accumulation in the RAS growth water, and consequently in the fish-flesh, of unwanted taste-taint as 'off-flavours' and unpleasant odours. It has become a major concern in RAS industry. Of particular interest are the taint-taste chemcials geosmin (GSM) and 2-methylisoborneol (MIB).

The dynamics of the RAS growth water and taint environment are complex, with the quantity of GSM/MIB in the growth water and fish-flesh varying with micro-organism, system location, water nutrient(s), and fish species and size (Howgate, 2004; Percival et al., 2008). A substantial number of benthic cyanobacteria and actinomycetes species in aquaculture systems are reported to produce taste-tainting chemicals (Izaguirre and Taylor, 2004). Notably, cyanobacteria are thought to be the main micro-organism responsible in conventional outdoor ponds, whereas actinomycetes are assumed to be the associated micro-organism in RAS (Tucker, 2000; Howgate, 2004; Guttman and van Rijn, 2008). In addition, there are several species of fungi and amoeba that are also capable of producing these chemicals (Juttner and Watson, 2007; Zaitlin and Watson, 2006); although their contribution is not well understood. In general, both species are assumed to be present in RAS.

Fish can take up GSM and MIB chemicals from tainted waters and accumulate these in their flesh. The uptake of taste-taint chemicals by fish can occur through several routes including, gills, skin and alimentary canal.

However, gills are considered to be the predominant path of uptake because of the reported relatively low octanol-water partition coefficient (K_{OW}) of both these two chemicals (Howgate, 2004).

A substantial amount of research has been undertaken to characterize the problem and/or to find an effective control mechanism. Taste-taint in fish-flesh due to GSM and/or MIB in RAS has been reported to include, but is not limited to, barramundi (*Lates calcarifer*) (Hathurusingha and Davey, 2014), Murray cod (*Maccullochella peelii peelii*) (Palmeri et al., 2008), rainbow trout (*Oncorhynchus mykiss*) (Robertson et al., 2006), arctic charr (*Salvelinus alpinus*) (Houle et al., 2011), largemouth bass (*Micropterus salmoides*), and; white sturgeon (*Acipenser transmontanus*) (Schrader et al., 2005). This problem is not unique however to vertebrate fish but also to other fish species, such as shrimp and clams (Howgate, 2004).

Even though this problem directly impacts on the marketability of the fish there are no reported associated health affects to the fish well-being or to human consumers (Bai et al., 2013). A number of approaches to remove (or inactivate) these chemicals have been investigated but effective practices to control taste-taint in farmed fish apparently have not gained acceptance (Howgate, 2004; Schrader et al., 2010).

Purging of RAS fish post-growth in clean water and prior to marketing is widely practised to leach taste-taint chemicals (Tucker and van der Ploeg, 1999). Tucker (2000) showed that the time taken for purging is dependent on factors such as the environmental conditions of the grow-out ponds, the nature of the taste-taint chemicals and farming methods employed, and; the type of fish farmed. The drawbacks with the double handling of fish required, intensive labour, time taken for purging, higher water demand and separate tanks for purging have led to the search for an attractive alternative. Widrig et al. (1996) argued that an economically feasible means is yet to be found to purge taint causing chemicals.

Elimination of taste-taint chemicals from growth water can be useful in manipulating taint development in fish. Hathurusingha and Davey have recently investigated the use of low concentration of hydrogen peroxide as a benign biocide to control GSM and MIB in RAS growth water using a special apparatus that can read-and-dose hydrogen peroxide concentration in growth water in real-time (Hathurusingha and Davey, 2016 a). They have reported promising results in pilot-scale studies and concluded that induced micro-mixing is likely to be required to deliver better results in commercial-scales studies (Hathurusingha, 2015).

Quantitative mathematical models, widely used in the chemical engineering and process foods industries, offer the potential for insight, management, and ultimately control of taste- taint in RAS farmed fish. Modelling of taste-taint chemicals in fish with time is a fairly new concept in aquaculture management but is gaining wider acceptance due to the associated lower cost than with direct experimentation.

However, it is important to develop an adequate model to take account of the dynamic and complex nature of RAS. Here we report a comprehensive, critical review of taste-taint modelling in RAS fish that includes: an overview of predictive models for chemical congeners in fish-flesh; models for predicting accumulation of GSM and MIB in fish-flesh; development and limitations of predictive models; factors to be considered in developing an adequate model for RAS fish; benefits of models to the supply chain, a critical review of an extensive recent experimental validation of one predictive model, and; risk analyses of predictive models.

An Overview of Predictive Models for Chemical Congeners in Fish-Flesh

Predictive models, widely used in chemical engineering, provide a basis for evaluating environmental toxicology and risk assessments in farmed fish.

They are increasingly being used by regulators, scientists, and toxicologists for decision making (Arnot and Gobas, 2004). This include evaluating the possible environmental hazards from new and existing chemicals through trophic levels (Arnot and Gobas, 2003), quantifying maximum daily loading of congeners of interest (Gobas et al., 1998), assessing potential impacts on biota due to various pollution sources, determining the effectiveness of control measures (Gobas and Z'Graggen, 1995; Morrison et al., 1998), providing site-specific information about chemical concentrations (Arnot and Gobas, 2004), and; quantifying the toxicological fate of chemicals in the environment (Wen et al., 1999).

However, difficulties are to determine sufficient and adequate data, particularly because of the complexity of the natural environment, and the intensive labour and costs needed (Peters, 1991).

In model development an understanding is required of the biological, physio-chemical and structural factors of the biota that can influence the kinetics of chemical accumulation. The rate of chemical accumulation is dependent on the uptake and elimination efficiencies of the chemicals concern. A low elimination rate is known to be the governing factor for higher bio-accumulation (Neely et al., 1974).

A number of models have evolved. Notably, there are some that predict the level of chemical concentrations in fish, but few have been published (S. Poole, *Department of Agriculture Fisheries and Forestry*, Australia (DAFF), *pers. comm*.). A simple model can be based on the chemical equilibrium partitioning between two phases. Generally, a living organism is treated as one-compartment by applying a mass balance. In this case, it is assumed that chemicals are immediately distributed in the fish-flesh once ingested. In more complex models such as the Pharmacokinetic models (PBPK), the organism is considered as a combination of individual organs or tissues (Wen et al., 1999). In these types of models, chemicals are thought to be distributed among various organisms within the fish with different kinetic rates (Howgate, 2004).

All possible exposure routes of the taste-taint chemicals as well as eliminating routes have to be taken into account when developing models. There are three (3) uptake routes: food, respiration and dermal diffusion, and six (6) meaningful elimination paths: respiration, dermal diffusion, egestion, metabolic conversion, reproductive losses and growth dilution.

It is important to understand the appropriate processes.

MODELS FOR PREDICTING GSM AND MIB IN FISH-FLESH

Howgate (2004) derived simplified kinetic equations for the uptake and elimination of GSM and MIB based on a bio-concentration factor.

What was modelled were the uptake kinetics under constant and varying concentration of GSM in water and, the depuration kinetics in terms of constant concentration with time (day). Howgate (2004) reported a greater accumulation under-steady concentration than that under-increasing concentration, starting from an initial zero concentration. He concluded that taste-taint concentration in fish-flesh is related to the concentration in water of the GSM and MIB chemicals. For depuration kinetics, he developed an exponential model for reduction in GSM and MIB over time, with half-lives of 2.3 day for GSM and 1.3 day for MIB.

However, this work cannot be seen as a ‘true’ model because important elements such as the growth of the fish and taste-taint dilution due to fish growth and metabolic elimination, have not been considered with regard to accumulation of GSM and MIB.

The model simply explains how the uptake and elimination kinetics impact on accumulation of the taste-taint chemicals. Further, theoretical predictions were not validated with any empirical or independent data.

Martin et al. (1990) studied the distribution and elimination of MIB using a two-compartment model. In their research, a known concentration of MIB was injected into channel cat fish, and its concentration then measured in the plasma and selected organs at various time intervals. The decrease of MIB concentration in plasma was found to be consistent with the projected results of the two-compartment model. They showed that the distribution of MIB in different tissues depended on lipid concentrations. Similar findings with regard to this kinetic two-compartment model have been reported by Schlenk et al. (1999).

One of the major problems encountered in the literature for reporting of predictive models is the lack of data for kinetics of GSM and MIB. However, there are some reported kinetic studies for similar chemical contaminants (Howgate, 2004). Therefore, it is thought these data can be used as a guide to develop an adequate model for both GSM and MIB.

Inadequacies of Existing Models

With any model, the model predictions need to agree with observed data (Wen et al., 1999). It is important nevertheless to emphasise that there can be uncertainties in any model.

A number of bio-magnification (BCF = bio-concentration or BAF = bio-accumulation) models have been derived (Clark et al., 1990; Neely et al., 1974), but these do not adequately predict the chemical concentration in fish-flesh.

Possible reasons for this include: the lack of kinetic data, biological variability, too few factors considered, errors in experimental and field samplings, and; variation in applied methodologies (Sijm et al., 1992).

Although a life-cycle bio-magnification model is more descriptive and comprehensive, a major drawback is the processes have produced inconsistent results leading to inaccurate predictions (Sijm et al., 1992). That BCF models need to be integrated with bio-magnification and bio-transformation processes have been ignored in present models.

More research with BCF models needs to be done with existing data to evaluate the reliability of these processes (Weisbrod et al., 2007). Other shortcomings of BCF models are the taste-taint chemicals of interest need to be non-ionic and not metabolised. In addtion,in the fugacity models, the bio-transformation parameter was ignored. This means the output tends to over-predict, leading to some errors (Weisbrod et al., 2007).

Food-web models have been synthesized to predict chemicals concentrations in aquatic organism based on BCF, BAF or BSAF (Bio-sediment accumulation) (Arnot and Gobas, 2004; Hendriks et al., 2001; Morrison et al., 1997; Sharpe and Mackay, 2000). They are increasingly used for chemical management programs (Weisbrod et al., 2007). However, the limitations include restricted suitability for chemicals such as Persistent Organic Pollutants (POPs) which have greater K_{OW}, and slow metabolic potential and dietary intake (Weisbrod et al., 2007). The reliability of the food-web models is yet to be confirmed for all chemical classes, including ionizing substances because of the lack of field data. There has to be specific data, such as sediment water column disequilibria of the chemicals, dissolved and particulate organic carbon concentration in water from the food-web, for model operation (Weisbrod et al., 2007).

However, the weaknesses of this type of model are contaminant concentrations can vary widely among individual organism in the environment; and, site-specific data cause some discrepancies. For an example, the use of population mean for highly variable elements can result in unreliable predictions. It is generally accepted that food-web models are difficult to use as these require site-specific ecosystem conditions and input data for specific food-webs (Weisbrod et al., 2007).

Physiologically-based pharmacokinetic models have some disadvantages: they are (reportedly) highly complex due to the number of equations being used, require a large number of data for model validation, and; have data-acquisition problems (Balant and Gex-fabry, 1990).

Therefore, it requires a great deal of knowledge to identify the specific compartment kinetically (Wen et al., 1999). Understandably, two-compartment and physiologically-based pharmacological models appear to be more suitable models to describe the uptake and elimination of taste-taint chemicals than bio-concentration or bio-magnification models. However the mathematically derived physiological models have more parameters than single compartment models.

This lack of reliable data to model the uptake and elimination kinetics of taste-taint chemicals has led to a disregard of the physiologically-based pharmacological models, and instead use of the simpler one-compartment models. In addition, the unavailability of more descriptive data sets has overlooked the opportunity of comparing the predictive capabilities of other models (Howgate, 2004).

A significant concern is that bio-magnification models are based on steady-state assumptions. It has been reported that steady-state is not readily reached in RAS and therefore bio-magnification factors are difficult to measure. Moreover Sijm et al. (1992) reported that steady-state conditions do not necessarily imply ‘equilibrium’. For example, experiments carried out with guppies (*Poecilia reticulata*) and rainbow trout showed that chemical accumulation continues if fish stop growing (Sijm et al., 1992). A similar experiment conducted with growing- and non-growing fish under field and laboratory conditions showed that the use of steady-state assumption is not valid (Sijm et al., 1992).

Moreover, it has been reported that steady-state conditions and kinetics of uptake/depuration are unrelated variables (independent); for example, fish growth impacts on the steady-state conditions whereas gender influences the kinetics of elimination (Sijm et al., 1992).

Finding reliable empirical data for model validation is demanding and also an expensive challenge to measure the biological variables. For example, uptake and elimination rate constants for large-scale are difficult to calculate accurately from laboratory-scale and also to replicate in the natural environment. In the kinetic models, net changes of chemicals across the fish body and environment are assumed to be negligible, or zero, under steady-state conditions. In reality, it is difficult to measure or establish when steady-state is attained (Hawker and Connell, 1988). Additionally it is questionable whether steady-state assumptions can be reasonably made for practical RAS systems.

It is apparent there is no empirical evidence that the net chemical exchange rate is zero between the RAS water and fish-flesh phases. Therefore an adequate model to predict GSM and MIB in RAS farmed fish needs to be developed considering these inadequacies.

FACTORS TO BE CONSIDERED IN DEVELOPING AN ADEQUATE MODEL FOR RAS FISH

Although RAS is a complex system, biological and physical variables can be determined and a consumer acceptable threshold concentration can be established experimentally from harvested fish-flesh.

It is acknowledged that manipulation of changing variables i.e., fingerling livestock, and nutrients in RAS, can affect taste-taint chemical concentration in growth-water and, in turn, in the fish-flesh. Therefore, a user friendly and potentially economic model needs to be developed for simulating possible outcomes in fish with RAS water temperature and harvest time.

There is some urgency to synthesize and test a model that can be applied to simulate taste-taint chemical uptake, accumulation and elimination over time. Because a threshold concentration of taste-taint as GSM (0.74 µg kg^{-1}) and MIB (0.7 µg kg^{-1}) (Jones et al., 2013; Robertson et al., 2005) in fish-flesh for consumer rejection has been established, processes that can be mathematically modelled are therefore open to optimisation. This is attractive as an inexpensive and efficient way of RAS farming, and reduces the need for manually solving potential problems of the biological RAS system. All uptake and elimination kinetics associated with taste-taint chemicals accumulation in fish-flesh however need to be taken into account, especially as to how they are impacted by the physical environment of the RAS i.e., water temperature, and dissolved oxygen concentration.

Importantly, any proposed model needs to be simple and easy to use. Once established and validated, it could be used for day-to-day farming operations as a management tool and potential optimisation(s).

BENEFITS OF THE MODEL TO THE SUPPLY CHAIN

Analyses of GSM and MIB chemical taste-taint in fish-flesh is expensive and time consuming, and few research institutes have the necessary facilities (G. Vandenberg, *Faculté des sciences de l'agriculture et de l'alimentation, Université Laval, pers. comm.*). It is therefore impractical for daily monitoring by farmers and fish processors.

Due to these practical limitations, less expensive sensory assessment have been widely adopted in determining whether fish are tainted beyond a threshold concentration for market consumption (Grimm et al., 2004; Percival et al., 2008). However, this is based on human perception and requires experts to perform the task accurately. It is therefore subjective.

Farmers however are generally unable to afford either the analytical or sensory method due to associated costs. It is also questionable whether sensory experts are representative of the general population (Howgate, 2004). Moreover, it is suggested successive testing of MIB influences the taste adaptation in experts - and can lead to reduction of perceived sensitivity to taste-tainting chemicals (Brett and Johnsen, 1996; Johnsen and Brett, 1996).

There is therefore a need to develop a simple, yet effective taste-taint predictive model to assist farmer's confidence in harvesting fish that have taint less than the consumer rejection threshold, without recourse to extensive and expensive analytical analyses. A timely harvest, with the help of the model simulation, can possibly eliminate the current purging-step and would avoid double-handling of fish, reduce labour and increase profits to the farmers by sending fish to the market without any mass loss.

It is clear one of the key parameters impacting taste-taint in fish-flesh is the concentration of GSM and MIB in the RAS growth water. If a model can be synthesized it can be applied to determine the limiting concentrations of GSM and/or MIB in growth water before reaching the consumer rejection threshold of the fish-flesh at the time of fish harvest.

Resulting insights could be used to develop an effective protocol to minimise GSM and MIB in RAS growth water. Clearly, a range of farming practices could be investigated in this way with a minimum cost, and possible optimisation.

Judicious use of the validated model could assist famers to develop growth protocols resulting in fish at harvest that have taste-taint chemicals concentration lower than the consumer threshold without recourse to extensive analytical analyses.

A Critical Review of an Extensive Recent Experimental Validation of One Predictive Model

A new quantitative process model to predict concentration of taste-taint, as either GSM or MIB, to aid RAS management has been developed by Hathurusingha and Davey (2014).

Their model is based on conservation of mass and energy principles (Foust et al., 1980) and thermodynamic processes established in (bio)chemical engineering (Bailey and Ollis, 1986), and a whole-of-process perspective. The aim was to produce a quantitative guide for RAS farming practice that could be applied to minimize taint in fish-flesh and promote market growth and obviate drawbacks with existing models, including (longer term) extensive experimental evaluation. In their model the taste-taint concentration in fish was the difference of two exponential terms of simultaneous taint uptake and taint elimination with growth time.

An advantage of their model is that it is 'generalised' in form and can be conveniently simulated in standard spread-sheeting tools for use by a range of users of different sophistication. This appears to be the first model that might be used to minimize taint in RAS farmed fish.

The model was illustrated with independent data for farmed barramundi (*Lates calcarifer*), an important RAS fish in Australia and globally, for both constant and varying concentration of GSM and MIB in the RAS growth water. However, there has not been extensive data published on taint accumulation as either GSM or MIB with RAS systems. They have however obtained limited data for taint as GSM from growth ponds from the *Department of Agriculture Fisheries and Forestry*, Australia (DAFF) (S. Poole, *pers. comm*.) for this study.

The model was used to simulate taint accumulation up to the consumer rejection threshold (~ 0.7 μg kg^{-1}) and also to simulate the impact of varying growth water temperature on taste-taint accumulation in the harvested fish-flesh. More generally however, if a fish is to grow for a longer (indefinite) period, then an 'S-curve' for growth has been proposed to make the model more universal and to generalize it for a range of other RAS fish species (Hathurusingha and Davey, 2014; Davey and Hathurusingha, 2014; Hathurusingha and Davey, 2013)

The applicability of the generalized form of the model for prediction for other aquaculture species, in particular rainbow trout *(Oncorhynchus mykiss*), was assessed with independent published data by Davey and Hathurusingha (2014). Reported predictions showed moderate-to-good agreement for both fish species and it was concluded the model is therefore adequate for these two species.

They concluded the model was free of programming and computational errors. Significantly, the quantitative nature of the model suggested it could be applied through application to automatic growth controls.

For model validation, an extensive two-year study with commercial RAS farmed barramundi (*Lates calcarifer*) in which fingerlings (~ 0.01 kg) were grown to harvest (~ 0.85 kg) at 245 days was carried out. Importantly, the concentration of both taint chemicals in the RAS growth water was controlled using continuous dosing of hydrogen peroxide (2.5 mg L^{-1}) as a benign biocide. A dedicated dosing apparatus was used for this purpose (Hathurusingha and Davey, 2016 b; Hathurusingha, 2015).

They reported, generally very good agreement between observed and predicted taint concentration in the range 0 to 2, μg kg^{-1}, and especially below the important consumer rejection threshold (< ~ 0.7 μg kg^{-1}). Despite a very good correspondence between model prediction and the extensive experimentally determined data, the model in its present form was shown to over-predict taste-taint chemical accumulation in fish-flesh. Particularly, this general over-prediction of chemical was about a half of the N = 706 simulations in the range 0 to 12, μg kg^{-1}. Predictions were reported to be conservative therefore i.e., on the 'safe' side. The possible reasons for this include dissimilar (exponential) growth constants for smaller and larger fish, and the oscillatory RAS environment. However, it proposed to include in a revised model two growth constants, one for smaller (juvenile) fish and one for the fish as they approach harvest. Significant additional validation studies would be required however in this case. They reported that this theoretical development was currently being planned (Hathurusingha and Davey, 2016 b).

Findings highlighted (Hathurusingha, 2015) that the work could be meaningfully applied to RAS systems to develop protocols to limit taste-taint in harvested fish. Significantly, the results are the first for RAS farmed-fish covering an entire production cycle from fingerlings to harvest and will therefore be of immediate benefit and interest to RAS farmers, selling agents and researchers.

This validated model of Hathurusingh and Davey (2014) provided insights into taste-taint modelling in RAS and demonstrated new ways to predict taint accurately in fish-growth.

It is worth noting that modelling is ongoing process - and it is expected will continue in time to supplant older ones with new.

RISK ANALYSES OF PREDICTIVE MODELS

A major drawback of current predictive models is they are based on 'average' or 'mean' deterministic values for input. There will however be naturally occurring, chance fluctuations in biological input parameters that could impact outcomes. It is uncertain how these can impact on predictions.

To be able to quantify the impact of naturally occurring random fluctuations in key parameters in otherwise well-operated systems, Davey and co-workers developed a new probabilistic quantitative methodology of risk analyses known as '*Fr 13*'. Their hypothesis is that these random fluctuations can unexpectedly and suddenly accumulate and combine in one direction and leverage significant (surprise) change in product or plant (Davey et al., 2015). They used probability distributions for the input parameters to mimic naturally occurring fluctuations in parameters. The output therefore was also a distribution of scenarios, with the probability of each occurring (e.g., Davey et al., 2015; Abdul-Halim and Davey, 2015; Davey, 2015; 2011; Davey et al., 2013).

Hathurusingha and Davey (2016 c) recently applied this risk methodology to the model of Hathurusingha and Davey (2014) to demonstrate quantitatively the impact of naturally occurring fluctuations in RAS water (growth environment) on taste-taint accumulation in fish-flesh. A significant new insight was that taste-taint chemical as GSM and MIB in RAS farming of barramundi can be significantly impacted by naturally occurring, small fluctuations in key process parameters. The accumulation of taste-taint as a result of these fluctuations could unexpectedly lead to the consumer threshold being exceeded i.e., taste taint failure - with consequent economic losses to farmers.

The approach was based on the taint chemicals entering the fish-flesh via the gills and dilution through metabolism and growth, together with a chemical taint risk factor (p) such that for all $p > 0$ the taint chemical was above a desired threshold concentration (which includes a practical tolerance of 10 %) respectively, 0.814 and 0.77, µg kg^{-1} for GSM and MIB. Monte Carlo (with Latin Hypercube) sampling of chemical in the growth water, water temperature and growth time were used to simulate practical RAS farmed barramundi for up to 260 days growth.

It was concluded that some 10.10 % of all harvests over the long term could result in fish with taste-taint as GSM above the threshold concentration due to natural fluctuations in the RAS environment. For MIB this failure rate was 10.56 %. The vulnerability to taste-taint failure was shown to be impacted highly significantly by the time to harvest, and to a lesser extent by concentration and fluctuation of the taint chemicals in the RAS water. They showed further the time to harvest could be readily monitored and practically controlled by farmers to limit taste-taint accumulation as GSM and MIB. A time to harvest of > 240 day would result in rapidly increasing vulnerability to taint accumulation. Findings appeared to be of immediate benefit to RAS farmers and to risk researchers in foods processing.

Pointedly, this insight could not be obtained from traditional single value assessment (SVA) computations or with traditional risk and hazard assessments. This is because this random element is not explicit in these. It is notable that the results of this *Fr 13* risk assessment are new and, importantly, quantitative.

Because any particular growth scenario could be individually identified and isolated, clues could be gleaned from 'second-tier' simulations (e.g., Davey et al., 2015) to assess the impact of changes that could be made to the physical system to improve reliability in RAS practice and mitigate taint failures.

The *Fr 13* risk assessment also appeared to be generalizable and applicable to a range of RAS farmed species, including rainbow trout (*Oncorhynchus mykiss*) and arctic charr (*Salvelinus alpinus*). Because there appears no limit to the number of distributions that could be used to mimic the behavior of the natural environment (Davey 2015; Davey et al., 2015) iterative improvements might be made to the simulations. Longer term application would be a necessary element to permit the establishment of computer auto-control in RAS farming of fish.

CONCLUSION

Established predictive models for taste-taint chemical in fish-flesh have been based on steady-state assumptions. However, it was thought debatable as to whether a steady-state assumption could be upheld i.e., there was no evidence that the net chemicals exchange is zero across the fish body and RAS water phase.

An original, new and quantitative model that predicts the time dependent concentration of taste-taint chemicals as GSM and MIB in harvested fish-flesh was therefore developed by Hathurusingha and Davey (2014). This model is based on conservation of mass and energy, and thermodynamic principles established in (bio)chemical engineering with chemical uptake into and elimination routes from the fish considered. The risk methodology of Davey and co-workers highlighted that vulnerability to taste-taint failure as GSM and MIB in RAS is principally controlled by the time to fish harvest, and to a lesser extent by concentration and fluctuation of these taint chemicals in the RAS water. This work is of practical benefit because growth time can be readily controlled by farmers.

Model simulations for two RAS species, barramundi (*Lates calcarifer*) and rainbow trout (*Onchorhynchus mykiss*) with independent data showed good agreement with experimental observations. A major benefit of this new model is that simulations can be used to investigate a range of growth protocols in RAS farming to minimize taint in fish-flesh. An advantage is it can readily be simulated in standard spread-sheeting tools by users with a range of sophistication.

Model predictions when compared with experimental observations obtained from a detailed two-year study in commercial-scale RAS showed good agreement over the range of low taste-taint concentration (0 to 2, µg kg^{-1}), especially below the consumer rejection threshold (~ 0.7 µg kg^{-1}). Possible reasons for some over-predictions are attributed to rapid fluctuation of taste-taint concentration in RAS water with growth time and different (exponential) growth constants shown by larger and smaller fish, and errors in obtaining representative samples from fish-flesh. These validation studies highlighted that the model can be meaningfully applied to RAS systems with lower variations and/or lower taste-taint chemical concentrations in RAS growth water. This model can be considered as most up-to-date.

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Chapter 4

EFFECTS OF PROTEIN, LIPID, FEEDING LEVELS AND THEIR INTERACTION ON GROWTH, BIOLOGICAL PARAMETERS AND HAEMATOLOGY OF MONOSEX NILE TILAPIA (*OREOCHROMIS NILOTICUS* L.)

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ABSTRACT

We investigated the causative effect of protein, lipid, feeding level and their interaction on growth, biological parameters and haematology of *Oreochromis niloticus*. Thus, *O. niloticus* (15.63 ± 0.40g mean weight ± SD) were reared at two different levels of protein (25% and 35%), two levels of lipid (8% and 12%) and three levels of feeding (100%, 70% and 50%) for 8 weeks. Higher weight gain % (WG%),

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feeding efficiency (FE) and specific growth rate (SGR) was observed in H35 suggesting that the main component in diet which influences growth is protein. Feed intake was inversely related to the dietary lipid level suggesting that high lipid levels could affect appetite of fish. There was no significant interactive effect of protein and lipid on WG (%), SGR, and feed intake (FI) indicative that *O. niloticus* can efficiently utilize carbohydrate better than lipid. High lipid level enhanced high viscerasomatic index (VSI) and intraperitoneal fat (IPF) indicating that fish fed with high lipid diets were unable to utilize the entire lipid for energy production and the excess fat was deposited in the viscera. The current study suggests that the recommended maximum level of crude protein, lipid and feeding level to maintain the welfare and maximum growth of *O. niloticus* is between 25 and 35%, 8% lipid level and feeding rate between 70 and 100% in a practical world.

Keywords: *Oreochromis niloticus*, protein, lipid, feeding rate, growth performance

INTRODUCTION

Fish feed accounts for over 50% of the total cost of fish production and is a major constraint to fish farming in resource poor regions (Craig and Helfrich, 2002; Ali et al., 2009). Protein usually is the most expensive nutrient yet it is also the most important factor affecting growth performance of fish (Lovell, 1989; Tacon, 1993; Fotedar, 2004). Majority of fish feeds contain fish or shrimp meal as the main source of dietary animal protein. Major source of fishmeal being the ever diminishing capture fishery, the sustainability of the aquaculture sector is questioned (Naylor et al., 2000). The sustainability of the aquaculture industry cannot be achieved unless progressive reduction of wild fish inputs into fish feed is addressed (Naylor et al., 2000; Liti et al., 2005; Munguti et al., 2009). Presently, substituting fishmeal with plant protein sources in fish diets is becoming a common practice in order to minimize feed costs (El-Saidy and Gaber, 2004; Hernandez et al., 2010; Olivera et al., 2011; Richie and William, 2011). The results show great variation in the degree of success for partial or complete substitution depending on the ingredient of the test feeds as well as species of fish under culture. Even though fish are known to be good convertors of dietary protein, considering the rapid growth of aquaculture and the sky-rocketing of the feed cost, there is necessity for improvement of dietary protein utilization.

Research shows that dietary protein is poorly utilized when there is inadequate non-protein energy in the diet because good amount of protein is metabolized to generate energy which can lead to excessive ammonia excretion into the environment consequently affecting water quality (Phillips, 1972; Shyong et al., 1998). Dietary lipids can spare dietary protein from use as energy and limit ammonia production through a process called protein sparing action (Cho and Kaushik, 1990; Gaylord and Gatlin, 2000) and improving feed efficiency and growth (Hillestad and Johnsen, 1994; Einen and Roem, 1997). Providing adequate energy through dietary lipids can minimise the use of more costly protein as an energy source (De Silva et al., 1991; Jayaram and Beamish, 1992; Bazaz and Keshavanath 1993; Van der Meer et al., 1997; Jantrarotai et al., 1998; Company et al., 1999; McGoogan and Gatlin III, 2000). Thus dietary non-protein sources such as lipids and carbohydrates have the potential of reducing the amount of dietary protein in fish diets hence minimizing the use of more costly protein as an energy source (De Silva et al., 1991; Jayaram and Beamish, 1992; Bazaz and Keshavanath 1993; Van der Meer et al., 1997; Jantrarotai et al., 1998; Company et al., 1999; McGoogan and Gatlin III, 2000).

Although dietary lipids are important in the diets, the inclusion level could be influenced by the crude protein level. In many cases, the efficiency of high crude lipid level in the diet is noticed when crude protein level is low compared to high crude protein level. This practice is successful in salmonid culture where lipid inclusion level can be as high as 300g/kg or more in the diet thus reducing the dietary protein level significantly (Helland and Grisdale-Helland, 1998; Rasmussen et al., 2000; Torstensen et al., 2001).

In addition, since feeding regime affects nutrient requirements, knowledge of optimum feeding regime is considered a prerequisite to the determination of nutrient requirements (Tacon and Cowey, 1985; Talbot, 1985). Feeding regimes (e.g., ration size, frequency, duration of a meal etc.) are also reported to influence fish growth, feed conversion and body composition (Reinitz, 1983; Li and Lovell, 1992; Munsiri and Lovell, 1993; Arzel et al., 1998; McGoogan and Gatlin III, 2000). Efficient use of feed is important in achieving profitable aquaculture. In fish an inverse relationship between optimal dietary protein level (as a percentage of the diet) and feeding regime (ration size) has been suggested (Ogino, 1980; Tacon and Cowey, 1985).

There is very little known about the protein-sparing action by dietary lipids in warm-water species (Page and Andrews, 1973), unlike in cold-water species (Lee and Putnam, 1973; Takeda et al., 1975; Reintz et al., 1978; Beamish and Medland, 1986; Tabacheck, 1986; Davies, 1989). In view of the increasing demand for fish meal and the predicted reduction in the fish-meal supply in the world (Wijkstrom and New, 1989) it will be useful to determine and utilize the protein-sparing capabilities of lipids in warm-water fishes. Hence the aim of the present study was to investigate dietary protein, lipid and feeding regime interaction and its influence on growth, protein utilization, biological parameters and hematology of male *Oreochromis niloticus.*

MATERIALS AND METHODS

The study was conducted in Kegati aquaculture research station (Figure 1) from September-December 2012. Kegati station is located at 0042' 50.44S and 0344 47' 59.4 E' and at an altitude of 1974m in Kisii County.

Four different experimental diets were formulated containing the same digestible energy. Two of the diets contained 35% crude protein while the other two contained 25% crude protein. The crude protein was provided by fish meal. The proximate composition of experimental diets is shown in Table 1.

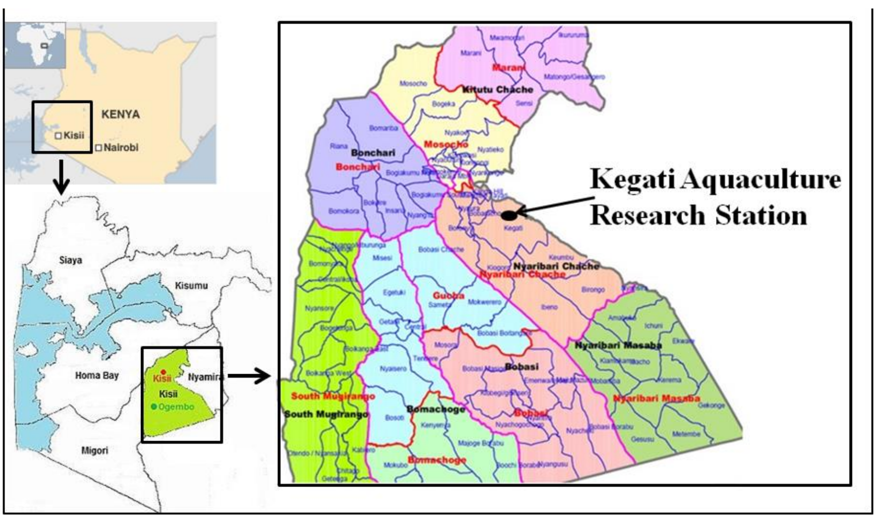


Figure 1. Map of Kegati Aquaculture Research Station (shown by a dot and an arrow), Kisii, Kenya where the experiment was conducted.

Table 1. Formulations and proximate composition of experimental diets (% dry matter)

Ingredient (%)	CP35CL12	CP35CL8	CP25CL12	CP25CL8
Fishmeal	21.10	21.10	14.10	14.10
Cassava	25.20	41.10	44.70	56.80
Oil mixture	10.30	4.30	10.80	4.80
Cellulose	9.80	0.00	6.10	0.00
Basal mixture	5.70	5.70	5.70	5.70
Proximate composition				
(%)	34.95	34.86	24.91	25.14
Crude protein	12.56	8.44	11.98	8.61
Crude lipid	12.75	8.73	8.79	8.56
Moisture	8.30	8.28	6.30	6.23
Ash	355.6	352.7	353.3	350.8
Energy (kcal/100g diet)[3]				

[1] Lipid source: corn oil.

[2]Basal mixtures: Calcium phosphate 0.50%; Choline chloride 0.70%; Vitamin mixture 1.50%; Mineral mixture 3%.

[3]Energy was calculated according to Anderson et al. (1991) cassava and fishmeal; Boscolo et al. (2002) for oil.

Corn oil was added to each diet to provide the lipid content of the diet. Each crude protein level had two different lipid levels (12% and 8%). The four different diets were as follows: CP35CL12, CP35CL8, CP25CL12, CP25CL8.

The diets were prepared by mixing the ingredients in a mixer. When the ingredients were thoroughly mixed, oil and water were added to obtain moist dough which was then made into pellets through a meat mincer, with a 3 mm size. The feed was oven dried at 70^0C for gelatinization of starch for 2 hours and then at 40^0C overnight to ensure proper drying. The feed was kept in a refrigerator at 4^0C and the required amount periodically taken for feeding.

O. niloticus fingerlings (15.63 ± 0.40g) were obtained from Kegati hatchery. They were acclimatized in the holding tanks for two weeks then stocked for the experiment. At the start of the experiment, individual weight and length of all the fish used in the experiment were taken. The acclimatized fish were randomly distributed in the 33 *hapas* at a stocking density of 300 fish per *hapa*. The sizes of the *hapas* were 8 m^3. Water quality was monitored in the morning and evening, just before feeding. Fish were sampled monthly for growth rate.

Based on the diet administration, each diet was divided into 3 different treatments (100, 70, 50%) except diet CP25CL8 which was divided into only two treatments (100 and 70%). All the treatments were in 3 replicates and satiation feeding was considered at 100%. The experimented lasted for 4 months.

At the end of the experiment, all the fish were counted, weighed and length taken for determination of weight gain, specific growth rate, feed efficiency, protein efficiency ratio, feed intake, protein intake and survival.

Blood samples were collected from 3 fish in each *hapa* 24 h after last feeding at 3rd and 4th month. Fish were anaesthized using tricaine methane sulphonate (MS-222). Blood samples were then collected from the caudal vein of the fish using heparinized syringes when the fish were completely sedated. Blood samples were centrifuged at 8000 rmp for 5 minutes using Mikro 120, Hettick Zentrifugen, Germany immediately after collection. Blood plasma was separated and stored at 4^0C in a refrigerator.

Triglyceride, cholesterol and total protein were analysed after but for glucose, it was analysed within 18 h after blood collection. Triglyceride, cholesterol and glucose were analysed by triglyceride, cholesterol and glucose kits, respectively with the help of manufacturer's instructions (Human Gesellschaft fur Biochemica und Diagnostica mbH, Germany). Total protein was analysed with total protein reagent (Tonyar Biotech Inc., Taiwan) with Lympho Chek Assayed Control standard solution (BioRad Laboratories, USA). The blood parameters (triglyceride, cholesterol, glucose and total protein) were measured by spectrophotometer (Clinical Analyzer model 1011).

For the last blood sampling, at the end of the experiment, the fish were sacrificed and dissected to weigh the viscera, liver and intraperitoneal fat in order to determine hepatosomatic index (HIS), Viscerasomatic index (VSI) and intraperitoneal fat index (IPF). The lengths of the intestines were also measured to determine intestinal length ratio.

Proximate composition of the feeds were determined using the standard methods of Association of Official Analytical Chemist (AOAC, 1995). Crude protein was determined by use of micro-kjedahl method, crude fat was extracted by soxhlet method, ash by incineration of samples in muffle furnace at 550^0C for 6 h and moisture was calculated from the weight difference after oven drying the samples at 105^0C for 24 h.

The following formulae were used for calculations:

- Percentage weight gain (WG %) = 100 x (final mean weight-initial mean weight)/initial mean weight.

- Specific growth rate (SGR) = 100 (in final mean weight- in initial mean weight)/days
- Feed efficiency (FE %) = 100 x (wet weight gain of fish)/dry weight of fish consumed
- Protein efficiency ratio (PER) = weight gain x 100/protein intake
- Protein intake (PI) = crude protein level/100 x feed intake
- Viscerasomatic index (VSI) = 100 x (viscera weight)/(body weight)
- Hepatosomatic index (HIS) = 100 x (liver weight)/(body weight)
- Intraperitoneal fat (IPF) = 100 x (intraperitoneal fat weight)/(body weight)
- Intestineal length ration (ILR) = intestine length/body length

The data was analysed using STATISTICA computer package (Statsoft Inc., 2010, version 8.0). Before statistical analysis, normality of the data was determined using Shapiro-Wilk test, while homogeneity of variance was ascertained using Levene's test. The results were presented as mean ± standard error after subjecting the data to three way ANOVA followed by one-way ANOVA using Dancan multiple range test. The difference was considered significant at $p < 0.05$, $p < 0.01$ and $p < 0.001$ based on the threshold of each interaction.

RESULTS

The main effects of crude protein, crude lipid and feeding rate on growth parameters at the end of 4 months are shown in Table 2. At the end of 16 weeks study period, neither mortality nor external clinical symptoms occurred in any treatment during the period of this study. Higher WG%, FE and SGR was observed in H35 treatment and it was significantly different ($p < 0.01$) from H25 treatment. However, higher FI was noted in H25 treatment but it was not significantly different ($p > 0.05$) from H35 treatment. Higher WG%, SGR and FI was observed in L8 treatment and it was significantly different ($p < 0.001$) from L12 treatments. Notably, FE (%) was higher in L8 treatment but it was not significantly different ($p > 0.05$) from L12 treatment. With regard to the feeding rate, significantly higher ($p < 0.01$) WG%, SGR and FI was recorded in H100 and it was significantly different ($p< 0.05$) from M70 and L50 treatments. However, higher FE was recorded in L50 and it was significantly different ($p < 0.01$) from H100 but not significantly different

($p > 0.05$) from M70. There were no significant interactive effects of protein and lipid on WG (%), SGR, and FI. However, there was a strong significant interaction of protein and feeding rate on WG (%), SGR and FE. Notably, there were strong interactive effects of protein, Lipid and feeding rate on FE.

Table 2. The effects of crude protein, crude lipid, feeding rate and their interaction on growth parameters at the end of 16 weeks

Parameter	WG (%)	SGR	FE (%)	FI (g)
CP (P) (%) L 25	442.0 ± 19.4 [b]	2.99 ± 0.07 [b]	75.2 ± 3 [b]	88.16 ± 5.55
H 35	514.8 ± 20.1 [a]	3.22 ± 0.07 [a]	99.0 ± 3 [a]	80.15 ± 4.52
CL (L) (%)				
L 8	539.5 ± 19.7 [a]	3.30 ± 0.05 [a]	95.2 ± 0.4	94.75 ± 4.93 [a]
H 12	430.2 ± 18.7 [b]	2.96 ± 0.06 [b]	87.0 ± 4	74.66 ± 3.87 [b]
FR (F) (%)				
L 70	388.1 ± 15.0 [c]	2.82 ± 0.05 [c]	86.2 ± 3 [a]	59.02 ± 1.68 [c]
M 50	479.7 ± 23.0 [b]	3.12 ± 0.07 [b]	99.0 ± 5 [a]	82.12 ± 2.51 [b]
H 100	548.9 ± 22.6 [a]	3.33 ± 0.06 [a]	79.4 ± 4 [b]	104.04 ± 3.36 [a]
Interaction				
P x L	ns	ns	*	ns
P x F	**	**	**	ns
L x F	ns	ns	**	*
P x L x F	ns	*	**	ns

Values are means ± SE; values within the same column without a common superscript are significantly different ($p < 0.05$).

WG % = percentage weight gain; SGR = specific growth rate; FE = feed efficiency; FI = feed intake. Significant level of differences: ns, $p > 0.05$; *, $p \leq 0.05$; **, $p \leq 0.01$.

The main effects of crude protein, crude lipid and feeding rate on blood parameters at the end of 4 moths are shown in Table 3. Plasma TG, CHOL, TP and GLU concentrations tended to decrease significantly ($p < 0.001$) with increasing dietary protein level. Dietary crude lipid level had no significant ($p > 0.05$) effects on plasma TG, CHOL, GLU and TP. Feeding rate was found also not to have significant ($p > 0.05$) influences on plasma TG, CHOL and TP. For plasma GLU, the highest value was observed in high feeding rate even though it was not significantly different ($p > 0.05$) from medium feeding rate. The lowest GLU value was observed in low feeding rate but it was also not significantly different ($p > 0.05$) from medium feeding rate. There was a strong interactive effect of PXL, PXF and LXF on blood plasma TG. Notably, there was a strong interactive effect of PXL, PXF on plasma GLU.

Table 3. The effects of crude protein, crude lipid, feeding rate and their interaction on blood parameters at the end of 4 months, blood sampled 24 h after feeding

Parameter	TG (mg/dl)	CHOL (mg/dl)	GLU (mg/dl)	TP (g/dl)
CP (P) (%) L 25	533.7 ± 46.6 [a]	415.1 ± 12.2 [a]	75.5 ± 1.6 [a]	3.20 ± 0.14 [a]
H 35	151.1 ± 10.5 [b]	239.1 ± 9.4 [b]	66.8 ± 2.2 [b]	2.35 ± 0.06 [b]
CL (L) (%)				
L 8	275.8 ± 37.0	315.8 ± 20.8	68.8 ± 2.8	2.54 ± 0.10
H 12	366.0 ± 66.0	321.9 ± 26.8	72.3 ± 1.7	2.90 ± 0.16
FR (F) (%)				
L 50	222.3 ± 56.5	273.8 ± 33.4	65.8 ± 3.7 [b]	2.43 ± 0.16
M 70	315.7 ± 46.6	329.2 ± 27.8	69.1 ± 2.2 [ab]	2.76 ± 0.16
H 100	411.3 ± 86.4	343.0 ± 27.9	76.0 ± 1.7 [a]	2.95 ± 0.19
Interaction				
P x L	**	*	**	ns
P x F	**	ns	**	ns
L x F	**	ns	ns	ns
P x L x F	*	ns	ns	ns

Values are means ± SE; values within the same column without a common superscript are significantly different ($p < 0.05$).

TG = plasma triglyceride; CHOL = plasma cholesterol; GLU = plasma glucose; TP = plasma total protein.

The ranking of the treatments based on the growth performance at the end of 4 months is shown in Figure 2. Growth response was significantly ($P < 0.05$) affected by the inclusion level of dietary protein and lipid. The highest growth was observed in treatment CP35CL8-100% and the lowest was noticed in treatment CP25CL12-50% which was not significantly different ($p > 0.05$) from CP35CL12-50% and CP25CL12-70%.

The ranking of treatments based on the blood parameters at the end of 4 months is shown in Figure 3. Treatments with low crude protein and high or low crude lipid gained higher plasma TG whereas those with high crude protein and high or low lipid got lower plasma TG. Similar trend was observed for blood plasma CHOL. For blood plasma GLU, without treatments CP25CL6-100% and CP35CL6-50%, there were no significant differences ($p > 0.05$) among all the treatments. Blood plasma TP without treatments CP35CL12-50%and CP35CL6-50% did not have any significant difference ($p > 0.05$) among all the treatments.

The correlation between growth and blood parameters is shown in Table 4. A negative correlation was observed between WG% and blood parameters such as TG, CHOL and GLU while a positive correlation between it and ATP. Apart from TG, all the correlation between WG% and blood parameters was significant and the highest was observed between it and CHOL. The trend of correlation between FBW and blood parameters was similar to the correlation that existed between WG% and blood parameters. A negative correlation occurred between SGR and plasma TG and TP and the correlation was significant between it and TP but not TG. A positive correlation occurred between SGR and plasma CHOL and GLU and they were all significant. A positive correlation occurred between FI and plasma TG and TP while a negative correlation occurred between it and plasma CHOL and GLU. The highest correlation was observed between FI and TP than CHOL.

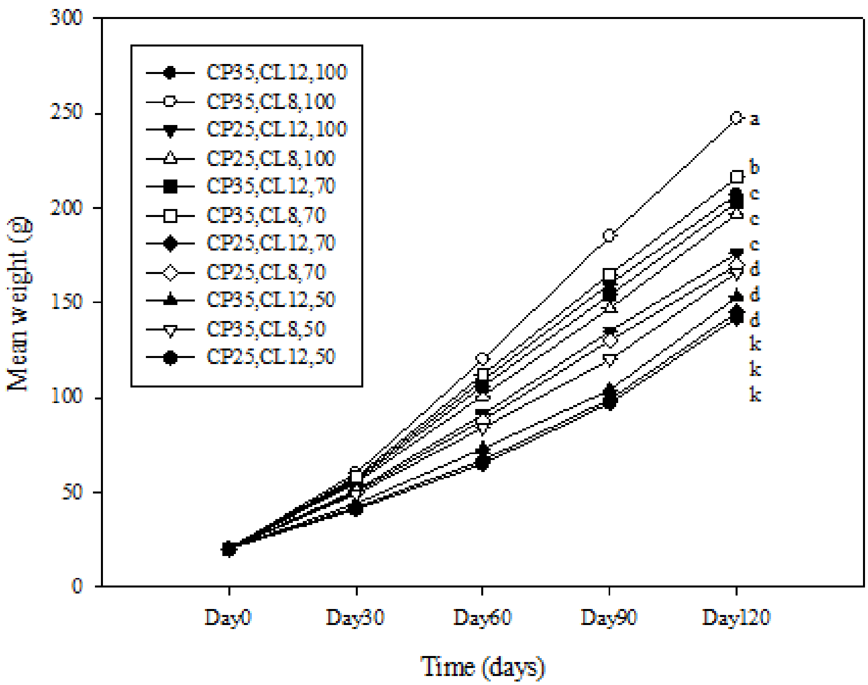
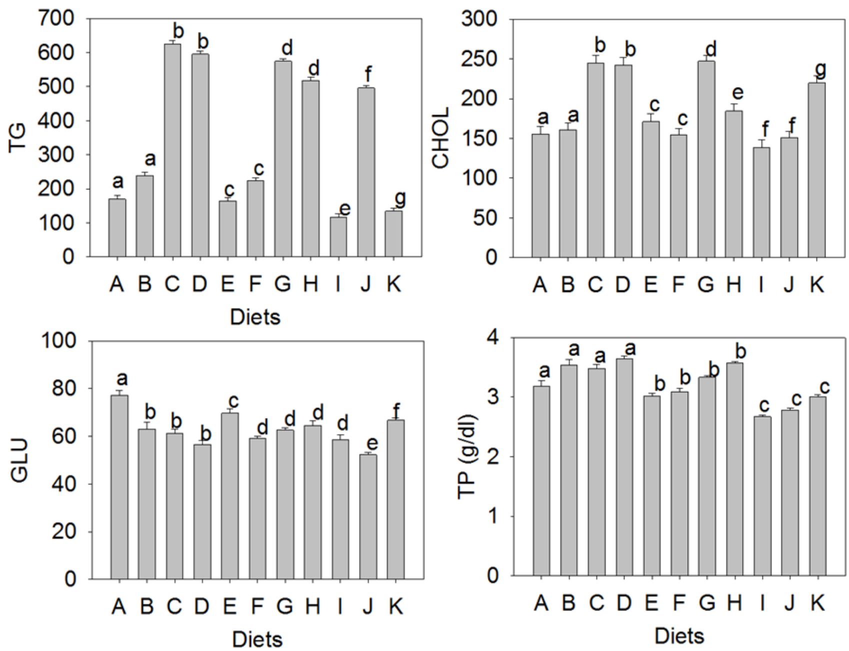


Figure 2. Mean body weight (±SEM) of fish reared under different levels of protein, lipid and feeding levels.



Bars are mean ± SE of three replications; bars without a common superscript are significantly different ($p < 0.05$).

Figure 3. Blood plasma concentrations of triglycerides, cholesterol, glucose, and plasma total protein in *O. niloticus* reared under different levels of protein, lipid and feeding levels. A = CP35CL8,100; B = CP35CL8,70; C = CP35CL12,100; D = CP35CL12,70; E = CP25CL8,100; F = CP25CL12,100; G=CP25CL8,70; H = CP35CL8,50; I = CP35CL12,50; J = CP25CL12,70; K = CP25CL12,50.

The main effects of crude protein, crude lipid and feeding rate on biological parameters at the end of 4 months are shown in Table 5. Lower crude protein level enhanced significantly higher ($p < 0.0001$) values for HSI and IPF whereas high crude protein level enhanced significantly lower values. Crude protein level had no significant ($p > 0.05$) influence on VSI and ILR. High crude lipid level gained significantly ($p < 0.05$) higher VSI, HSI and IPF while low crude lipid got significantly ($p > 0.05$) lower values. Crude lipid level had no significant ($p > 0.05$) effects ILR. High feeding rate had significantly ($p < 0.05$) higher values of VSI and IPF while medium and low feeding rates had significantly ($p > 0.05$) lower values. High feeding rate enhanced significantly ($p < 0.05$) higher value of HSI but it was not significantly ($p > 0.05$) different from the medium feeding. On the other hand, low feeding rate enhanced significantly ($p < 0.05$) lower value but it was also not significantly ($p > 0.05$) different from medium feeding. Feeding rate had no significant ($p > 0.05$) influences on ILR. There were no significant interactive effects of PxL, PxF, LxF and PxLxF on any of the biological parameters tested.

Table 4. Correlation between growth parameters and blood parameters

Parameter		TG (mg dl^{-1})	CHOL (mg)	GLU (mg dl^{-1})	TP (g dl^{-1})
WG (%)	R	-0.13001	-0.57451	-0.24679	0.35610
	P	0.2981	<.0001	0.0458	0.0033
FBW (g)	r	-0.16772	-0.59866	-0.24385	0.33700
	p	0.1783	<.0001	0.0485	0.0057
SGR	r	-0.19729	0.41332	0.36253	-0.33830
	p	0.1123	0.0006	0.0028	0.0055
FI(g)	r	0.27172	-0.31180	-0.18023	0.59198
	p	0.0273	0.0108	0.1476	<.0001

WG % = percentage weight gain, FBW = final body weight, SGR = specific growth rate, FI = fide intake

TG = triglyceride, CHOL = cholesterol, GLU = glucose, TP = total protein, r = coefficient of correlation, p = probability.

The ranking of the treatments based on biological parameters at the end of 4 months is shown in Figure 4. Intestinal length ratio (ILR) was not affected significantly ($p > 0.05$) by the independent variables and no significant ($p > 0.05$) differences were exhibited among all the treatments. The highest hepatosomatic index (HSI) value (3.50) was observed in treatment CP25CL12-100% while the lowest value (1.80) was observed in treatment CP35CL6-50%. Considering the values of viscerasomatic index (VSI), there were no significant ($p > 0.05$) differences among all the treatments without treatments CP35CL6-70% and CP35CL6-50%. The values of intraperitoneal fat (IPF) ranged from 1.35 observed in treatment CP35CL6-70% to 3.48 observed in CP25CL12-100%. Also, condition factor (CF) without treatments CP35CL12-50% and CP25CL12-50%, did not have significant ($p > 0.05$) differences among the treatments.

Table 5. The effects of crude protein, crude lipid, feeding rate and their interaction on biological parameters at the end of 4 months

Parameter	HSI	VSI	IPF	ILR
CP (P) (%) L 25	3.08 ± 0.09 [a]	10.82 ± 0.24	2.53 ± 0.18 [a]	5.27 ± 0.13
H 35	2.19 ± 0.09 [b]	10.26 ± 0.39	2.00 ± 0.18 [b]	5.31 ± 0.11
CL (L) (%)				
L 8	2.42 ± 0.13[a]	9.98 ± 0.39 [b]	1.92 ± 0.15 [b]	5.43 ± 0.08
H 12	3.74 ± 0.14[b]	10.96 ± 0.27 [a]	2.51 ± 0.19 [a]	5.18 ± 0.13
FR (F) (%)				
L 50	2.34 ± 0.22 [b]	9.66 ± 0.49 [b]	1.61 ± 0.14 [b]	5.35 ± 0.19
M 70	2.50 ± 0.16 [ab]	10.13 ± 0.31 [b]	2.07 ± 0.17 [b]	5.28 ± 0.14
H 100	2.89 ± 0.13 [a]	11.55 ± 0.28 [a]	2.89 ± 0.19 [a]	5.27 ± 0.12
Interaction				
P x L	ns	ns	ns	ns
P x F	ns	ns	ns	ns
L x F	ns	ns	ns	ns
P x L x F	ns	ns	ns	ns

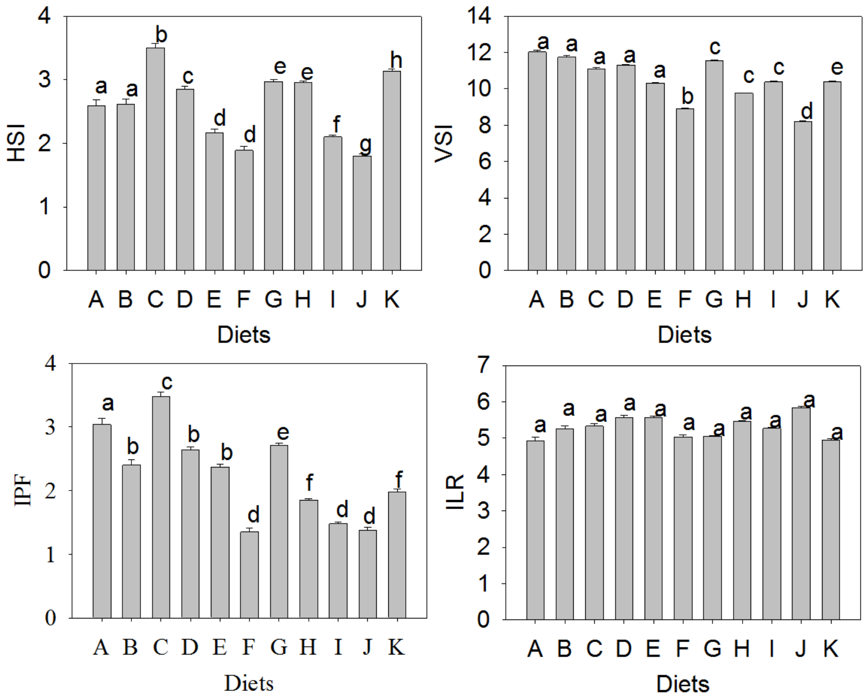
Values are means ± SE; values within the same column without a common superscript are significantly different ($p < 0.05$); ns = not significant.

HIS = hepatosomatic index; VSI = viscerosomatic index; IPF = intraperitoneal fat; ILR = intestinal length ratio.

DISCUSSIONS

With regards to the dietary crude protein level, fish fed with high dietary protein gained significantly higher WG % and SGR while those fed with low dietary protein got low WG % and SGR. This could be because protein intake was high at high dietary protein level and the main component in diet which influences growth is protein. However, the present results are different from the results of El-Saidy and Gaber (2005) who found no significant increase on growth performance at high dietary protein level (30%) compared to the low one (25%). It could be due to the size of the fish they used as it is known that the protein requirement of fish reduces as they grow (Wilson, 1989).

Basically, from the results, it was observed that higher values of WG % and SGR were observed in high feeding rate. Similar results were obtained in common carp (El-Saidy and Gaber, 2005; Adelghany and Ahmad, 2002; El-Sayed, 2002).



Bars are mean ± SD of three replications; values within the same column without a common superscript are significantly different ($p < 0.05$).

Figure 4. *hepatosomatic index*, *viscerosomatic index*, *intraperitoneal fat* and *intestinal length ratio* in *Oreochromis niloticus* fed various diets. A = CP35CL8,100; B= CP35CL8,70; C = CP35CL12,100; D = CP35CL12,70; E = CP25CL8,100; F = CP25CL12,100; G = CP25CL8,70; H = CP35CL8,50; I = CP35CL12,50; J = CP25CL12,70; K = CP25CL12,50.

From the results, it was clearly shown that feed intake was inversely related to the dietary lipid level. When fish are fed on high lipid diets, the excess lipid which they are unable to utilize as energy is stored as fat and this fat accumulation when high can reduce feed intake which consequently affect growth negatively due to lack of nutrients (Daniels and Robinson, 1986; Babalola and Adebayo, 2007). The low growth rate observed in fish fed with high lipid diets in the present study could be due to the high deposition of fat in their viscera cavity which affected their protein intake and consequently reduced the growth (Marais and Kissil, 1979; Ogata and Murai, 1991; Jobling and Miglavs, 1993; Shearer et al., 1997; Wealtherup et al., 1997; Silverstein et al., 1999). While it seems that most fishes utilize dietary lipid well (Cowey and Sargent, 1979), at high dietary levels, lipids may reduce fish growth, adversely affect body composition (Erfanullah and Jafri, 1998; Hanley, 1991; El-Sayed and Garling, 1988; Garling and Wilson, 1977), as well as create problems associated with pelleting and development of rancidity in stored feed (Jauncey, 1982). Fattiness is often undesirable in fish cultured for food and increasing the dietary protein level may be a strategy for producing a leaner product. There were no interactive effects of protein and lipid on WG and SGR. This could indicate that the effect of different levels of protein is independent of the level of lipid in the diet of *O. niloticus*. The protein sparing effect of high lipid, the main factor of the research has been reported in many fish species such as in hybrid tilapia (*O. niloticus* x *O. aureus)* (Gaylord and Gatlin, 2000; Jauncey, 2000; Teshima et al., 1985; El-Sayed and Garling, 1988) but high dietary lipid level (12%) did not show any further improvement on growth parameters of low or high dietary protein diet compared to low lipid diet (8%) at the same feeding level in the present study. Similar results have been reported in seabass (Catacutan and Coloso, 1995). Thus the protein sparing action of lipid reported by many researchers was not observed in this study. This could indicate that *O. niloticus* is unable to secrete sufficient bile/lipase to meet digestive demands at the highest lipid level. As all the diets have similar energy level, it is probably that *O. niloticus* can efficiently utilize carbohydrate better than lipid because FI decreased at high lipid level with the same dietary protein level.

From the results, it was quite obvious that low dietary protein enhanced higher triglyceride and cholesterol compared to high dietary protein level. This is because percentage feed intake per body weight was generally high at low dietary protein and the extra energy generated by high feed intake which cannot be utilized by fish was stored as fat which in turn after metabolism increased the plasma TG and CHOL levels. Similar observations have been reported for carp (Shimeno et al., 1995) and tilapia (Shimeno et al., 1993). When fish are fed on low dietary protein diets, their blood plasma TG and CHOL levels go up. High dietary protein was reported to cause low plasma TG in African catfish (*Clarias gariepinus*) (Matter et al., 2004) which is in agreement with our findings. Also, similar to our results were the findings of Cheng et al. (2006) in grouper and also (Chen et al., 2009) in juvenile tilapia (*O. niloticus)* where low TG and CHOL were observed from fish fed on high dietary protein.

Crude lipid level has no significant influences on plasma TG and CHOL at the end of the experiment which is conflicting with the results of Cheng et al. (2006) in grouper. The reason could be the difference in species. May be *O.niloticus* can utilize dietary lipid more efficiently than grouper. Meanwhile, feeding rate also has no significant effects on plasma TG and CHOL either at the end of the experiment but there was a trend which showed that TG and CHOL increase with increasing feeding rates.

From the results, low GLU level observed at high dietary protein level could be caused by low starch content. This is consistent with the results in other fish species such as Arctic charr (*Salvelinus alpines*) (Cameron et al., 2002) and young Japanese flounder (*Paralichthys olivaceus*) (Lee et al., 2002) where low plasma GLU levels were observed at high dietary protein levels. However, the present results differ from the findings of Chen et al. (2009) who reported significant increase of plasma glucose content at high dietary protein level in juvenile red tilapia (*O. niloticus*).

Low dietary crude protein level enhanced high plasma TP and the contrary happened to the high crude protein. This is contrary to the findings of Cheng et al. (2006) in grouper (*Epinephelus coioides*) who found no significant difference of plasma TP between high dietary protein and the low one. It could again be due to the difference in species. But Jauncey (1982) also reported that protein retention is known to be high at low level of protein inputs.

Crude lipid level has no significant effects on plasma TP at the end of the experiment. This is different from the results of Aderolu and Akinremi (2009) where fish fed with high dietary lipid diets gained significantly higher plasma TP and vice versa. There was a clear cut difference between high and medium feeding levels compared to low feeding level with regards to the influence of feeding rate on plasma TP at the end of the experiment. This could be due to the amount of feed they ate.

The highest correlation between WG % and blood parameters was observed between it and CHOL (57%). There was a negative correlation which means that the higher the WG %, the lower the CHOL in plasma. The same trend was observed between FBW and blood parameters. A positive correlation occurred between SGR and CHOL which implies that as SGR value increases, CHOL level also increases. The correlation between FI and TP showed that as FI increases, plasma total protein also increases.

Low crude protein enhanced significantly higher HSI and IPF than high crude protein. This implies that HSI and IPF tend to be inversely related to the dietary protein level and directly related to dietary carbohydrate (cassava) content in the diet in this study. This kind of relationship was revealed in many studies (Papaparakeva-Papoutsoglou and Alexis, 1986; Daniels and Robinson, 1986; Hidalgo and Alliot, 1988; Brown et al., 1992; Yang et al. 2002; Peres and Oliva-Teles, 1999) where the increase of HSI was due to high digestible carbohydrate. From the results, it was observed that high lipid level enhanced high VSI and IPF while the contrary occurred for the low lipid. It may be that the fish fed with high lipid diets were unable to utilize all the lipid for energy production and the excess fat was deposited in the viscera (Gallagher,1999). Fattiness is often undesirable in fish cultured for food and increasing the dietary protein level may be a strategy for producing a leaner product.

Hepatosomatic indices (HSI) were insignificantly higher in fish fed the lower protein diets and there was a trends of gradually increased HSI with increasing dietary lipid and energy, probably due to higher liver lipid and liver glycogen accumulation as a result of lower dietary protein to energy ratios (Brown et al., 1992; Nematipour et al., 1992; Jantrarotai et al., 1996, 1998; McGoogan and Gatlin III, 1999). Generally, it appears that reducing feeding level from 100 to 50% significantly reduced HSI, VSI and IPF. This could be due to the difference in feed intake as those under satiation feeding have been accumulating fat especially towards the end of the experiment while those under low feeding might not have enough nutrients for their needs let alone accumulation of fat.

CONCLUSION AND RECOMMENDATIONS

In this research, the best growth performances were observed in fish fed with high protein with low lipid diet compared to others at the same feeding level while the lowest growth performances were observed in those fed with low protein and high lipid diet compared to other treatments at the same feeding rate. At the same dietary protein and feeding level, fish growth performances were better at low lipid than high lipid. From the results it is likely that percent weight gain increases as the dietary crude protein and feeding levels increase but decreases as the lipid level increases. Feed efficiency was better at high crude protein and low feeding rate but not significantly influenced by the dietary lipid level.

The use of low dietary protein level enhanced high plasma triglyceride, cholesterol, and total protein. Low dietary protein level also enhanced high HIS and IPF while high dietary lipid and feeding levels enhanced high deposition of fat and viscerosomatic index in this experiment. Based on our results, the study advocates for crude protein level between 25 and 35%, 8% lipid level and feeding rate between 70 and 100% in a practical world. Further research with *O. niloticus* should investigate fundamental aspects of the physiology and biochemistry of dietary protein and energy utilisation. Well known biochemical pathways provide the theoretical basis for this.

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Chapter 5

MAPPING THE VALUE CHAIN FOR FARMED FISH AND GENDER ANALYSIS ALONG THE AQUACULTURE VALUE CHAIN IN KENYA

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ABSTRACT

We mapped the value chain of farmed fish and examined gender participation along the artisanal aquaculture value chain (AVC) in Nyanza region, Kenya as a case study for gender issues in aquaculture and fisheries. The study was carried out with aid of structured questionnaire that were administered through personal interviews. Results indicated that the Kenyan aquaculture value chain is relatively simple; including only three main stakeholder groups. These are seed producers, grow-out farmers and fish marketers and traders. At artisanal level, women dominate the production level in the aquaculture value chain

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suggesting that they could easily integrate aquaculture into the farming system of the farming families. However, since they are undertaken by women, they are often viewed as requiring little skill. This is a major gender issue in aquaculture and leads to women's work being undervalued and poorly rewarded. Contrary to women, majority of men owned farm land, limiting women access to credit due lack of collateral. Majority of women and men in Nyanza region dealt with fresh fish products as compared to processed fish, indicative of little transformation of aquaculture fish that does not travel far inland to rural villages. There are disparities in many aspects of fish farming between men and women, and thus training and credit should be made available to females along the aquaculture value chain so that they invest in cooling facility and or value addition to improve on profits.

Keywords: aquaculture value chain (AVC), Nyanza region, gender analysis, Artisanal fisheries

1. INTRODUCTION

Kenyan aquaculture sector has witnessed rapid expansion over the past five years as a result of Fish Farming Enterprise Productivity Program (FFEPP) under the Economic Stimulus Program (ESP). As a result of FFEPP, farmed fish production increased from 4,220 MT in 2007 to 20,487 MT in 2012, representing a percentage contribution from 2.5% to 15% to the national fish production. This production was from 68,734 ponds, 161 tanks measuring 23,085 m^2 and 124 reservoirs with an area of 744,000 m^2 throughout the country (GoK, 2012).

Aquaculture expansion in Kenya has been accompanied by a gradual shift from extensive to semi-intensive culture systems. This approach has in turn created a national short-term demand of about 28 million certified tilapia and catfish fingerlings and over 14,000 metric tonnes of formulated fish feeds. The multiplier effect resulting from farmers digging their own ponds is expected to increase the demand for fingerlings to over 100 million and the demand for fish feeds to 100,000 MT in the medium term (Charo-Karisa and Gichuri, 2010). This has resulted in the number of hatchery operators increasing from only 5 state –owned hatcheries to over 100 hatcheries in 2012 (GoK, 2012). The investment of private sector in fish seed industry has sharply increased over the past few years. However, the value chain of the sector has not yet been mapped and the key players have not been clearly identified. Therefore, the value chain performance of the Kenyan aquaculture industry is not well understood.

Value chain analysis has been proved to be a useful means to assess gender performance in different systems (El-Sayed et al., 2015; Macfadyen et al., 2012; Robin et al., 2009; USAID, 2011; Mamun-Ur-Rashid et al., 2013; Nasr-Allah et al., 2014; Veliu et al., 2009). In Kenya, like in many developing nations, women’s labour contribution is often greater than men’s although there is almost a complete absence of macro-level aquaculture-related gender disaggregated data (hereafter referred to as, MAGDA). This is symptomatic of the general lack of attention to gender dimensions in aquaculture despite the important role women play in the sector (Williams et al. 2012). Lack of MAGDA in Kenya has led to women being left out in matters of policy and development.

Previous studies indicated that both men and women play different roles in fisheries with women dominating the post-harvest sector and men dominating the production sector (Lwenya and Abila., 2001). However, changing roles in fisheries have been observed where men have seized the opportunity to enter into fish trade, which was once a female domain. Studies conducted by Medard et al. (2002) in Tanzania indicated that in most cases men are the owners of the ponds while women manage the ponds. In developing countries such as Kenya, customary beliefs, norms and laws, and/or unfavorable regulatory structures of the state, reduce women’s access to fisheries resources and assets (FAO 2006; Porter 2006). In patrilineal communities, men are the owners of assets such as land hence women are disadvantaged, confining them to the lower end of the supply chain. Notably, education has also been a stumbling block for the development of fisher women around Lake Victoria region. Ikiara (1999) indicated that most fishers are poorly educated but the issue mostly affects the female and this limits their roles and opportunity in the sector. Despite all the constraints, many studies have indicated that women perform many unpaid tasks at pre and post-harvesting which goes unacknowledged or undercounted as employment (Williams et al., 2005; FAO, 2006, Choo et al., 2008). It has been reported that women roles and extent of participation in aquaculture value chain (AVC, hereafter) seem even higher than in fisheries in Southeast Asia (Williams et al., 2005; FAO, 2006). However, there has been no documented information on gender participation along the AVC in Kenya. Understanding gender means understanding opportunities, constraints and the impacts of change as they affect both men and women. Therefore, the aim of the current study is to map the value chain for farmed fish in Kenya, describe the main actors and stakeholders and determine gender roles within the chain, as a case study for further global inference.

Figure 1. Location of study area in Nyanza region, Kenya (shaded in red colour) bordering Lake Victoria.

2. MATERIALS AND METHODS

The study was carried out in Nyanza region, Kenya, comprising Kisumu, Bondo, Nyando, Rachuonyo, Homa-Bay, Suba, Kisii central and Migori Counties (Figure 1) between March-July 2012. The samples were selected purposively to focus entirely on the value chain arising from pond farm production as it accounts for around 85% of the total aquaculture production in Kenya. Individual interviews and focus group discussions with hatchery operators, grow out fish farmers and traders/retailers were used to collect quantitative and qualitative information. The focus group discussions provided a basis for the analysis of qualitative data (Humphrey, 2005). A total of 524 respondents (139 males and 385 females) were interviewed. Data collected from the field was entered and analyzed statistically using the Statistical Package for the Social Sciences (IBM - SPSS Inc., version 20.0). Descriptive analysis was done by use of means, standard deviation, percentages and frequency distribution of responses. Inferential statistics was done using Chi-square (χ^2) test of goodness of fit. All data analyzed were considered significant at 0.05 level of significance.

3. RESULTS

Aquaculture Value Chain

The survey indicated that the value chain for farmed fish in Kenya is comprised of three main stakeholders (Hatchery operators, Grow-out fish farmers, traders/retailers) before fish reaches the consumer, as presented in Figure 2 below. There is insignificant value addition of farmed fish and virtually no export of farmed fish. Notably, there are no distinct value chains for different species in Nyanza region.

Stakeholder Characteristic by Gender

Table 1 summarizes the socio-demographic characteristics of respondents in the AVC in the study area. The survey noted that there was a slightly higher proportion of female respondents (62%; n = 524) in the study area as compared to males (38%; n = 524). Age distribution ranged from 18-60 years, with most of the female respondents (75%; n = 524) aged between 30-39 years. Of the female respondents interviewed, 79% were married, 9% were single, while 12% were widowed. In comparison, nearly the same proportion of male respondents (i.e., 80%), were married while 16% were widowed. Both men and women tended to be poorly-educated, with a high proportion being primary school drop outs, especially amongst women. A relatively high proportion (89%; n = 524) of households was headed by men and those headed by females were widows.

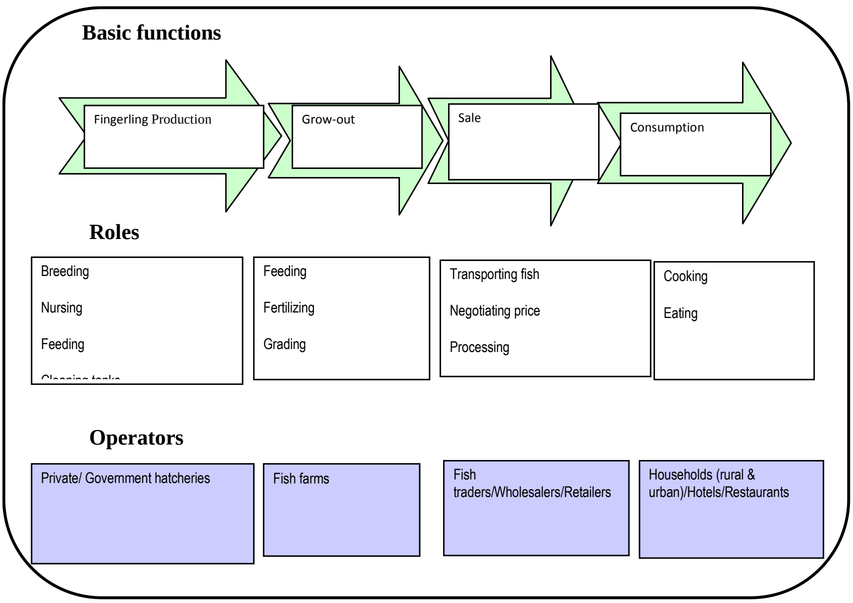

Figure 2. Generic value chain (AVC) for aquaculture products in Nyanza region, Kenya.

Gender Roles in Aquaculture

The survey indicated that the females dominated production (80% of hatchery operators) and grow-out (77% of grow out farmers). At the hatchery, majority of the females (80%) were mainly involved in breeding, nursing and feeding of fry while majority of males (92%) were involved in cleaning of tanks and counting of eggs. At the grow-out stage, majority of females (89%) were involved in fertilizing ponds and feeding of fish while majority of males (98%) were involved in harvesting and grading of fish. In AVC, after all the activities of the day, a woman spends 19% of her time sleeping while a man spends 32% of his time sleeping (Figure 3 and 4). Notably, house chores are predominantly the responsibility of the female in Nyanza region.

Table 1. Socio-economic profile of aquaculture value chain, AVC (% of respondents) in Nyanza region, Kenya

Variable	Response	Frequency (n = 524)		Percent	
		Male	Female	Male	Female
Age(Years)	18 to 24	1	2	33	67
	25 to 29	3	8	27	73
	30 to 39	28	82	25	75
	40 to 49	30	38	44	56
	50 to 59	22	8	73	27
	>60	1	1	50	50
Education level	No schooling	5	22	19	81
	Incomplete primary	24	26	48	52
	Complete primary	41	46	47	53
	Incomplete secondary	17	5	77	23
	Complete secondary	11	3	79	21
	Post-Secondary	22	2	92	8
Household heads		199	25	89	11

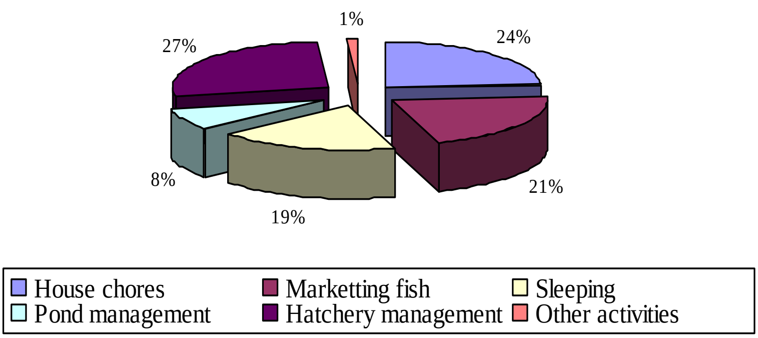

Figure 3. Time allocation for a woman in aquaculture in Nyanza region, Kenya.

Management/Ownership of Resources

Majority of men owned farm land both at Hatchery (90%), grow-out (97%), and marketing (98%) level (Figure 5) while women and children manage the ponds. Majority of the women (92%) had access to but not ownership of land/ponds. There was statistically significant association between gender and ownership of land/pond ($\chi 2$ = 1.872; df =6; p = 0.003) in Nyanza region.

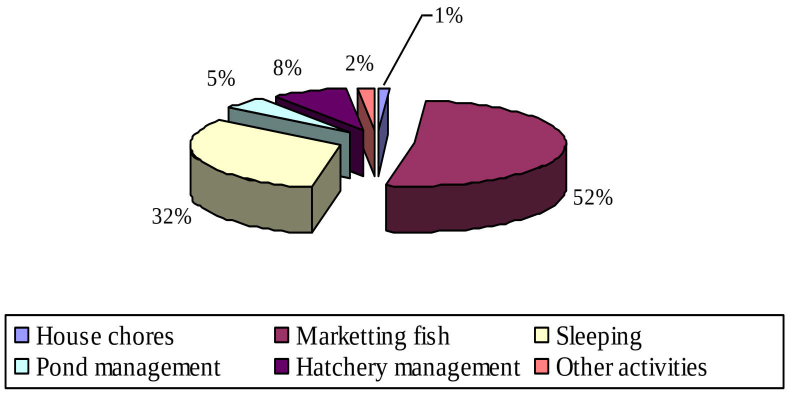

Figure 4. Time allocation for a man in aquaculture in Nyanza region, Kenya.

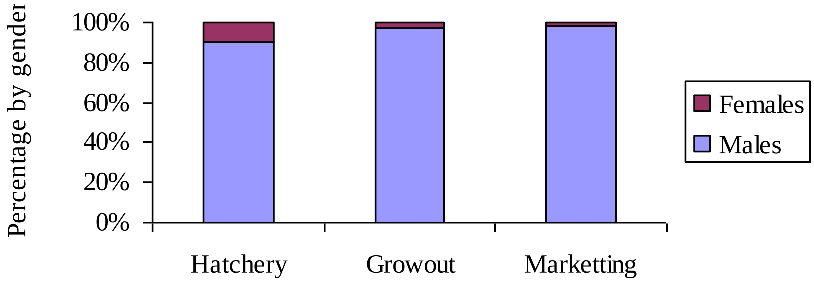

Figure 5. Ownership of resource by gender along the aquaculture value chain in Nyanza region.

Access to Credit

The survey indicated that women had limited access to credit both at hatchery (17%), grow out (21%), and marketing (19%) levels. A higher proportion of the female respondents (92%) indicated lack of collateral as the main hindrance for obtaining credit.

Technology/Training

Training for men and women in aquaculture related matters also varies considerably in Nyanza region. For instance, for the year 2012, the Kenya Marine and Fisheries Research Institute (KMFRI) enrolled more men (78%) than women (22%) in the monosex tilapia seed production training held at Sagana, Kenya. Males dominated trainings both at hatchery (77%), grow-out (68%), and marketing (64%) levels (Figure 6).

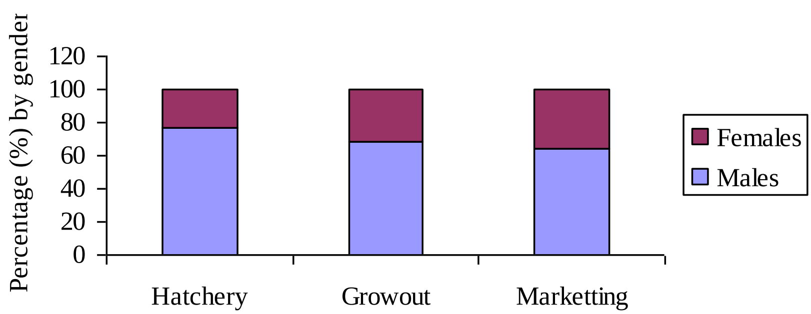

Figure 6. Training by gender along the aquaculture value chain in Nyanza region, Kenya.

Fish Species Cultured/Traded

Females dominated the culture of catfish (61%; 56%) and *ningu* (65%; 63%) both at hatchery and grow out, respectively while males dominated the culture of tilapia at the hatchery (58%) and grow out stages (55%). A higher proportion of men (82%) are engaged in tilapia trading compared to women. In contrast, a greater percentage of women traded in catfish and *ningu* than men (Figure 7). However, there was no significant association between gender and species traded ($\chi2 = 2.883$; df =8; $p = 0.913$).

A greater percentage of female (97%) and male (99%) respondents dealt in fresh fish products as compared to processed products in Nyanza region (Figures 8 and 9). Proportionately more men (91%) interviewed sold fresh fish than women, while proportionately more women (34%) deal in processed fish than men. The fish species reported to be of the highest economic importance for both men (54%) and women (46%) traders were Nile tilapia. Fish trading was informal with the producers selling directly to local villagers or to local hotels and restaurants.

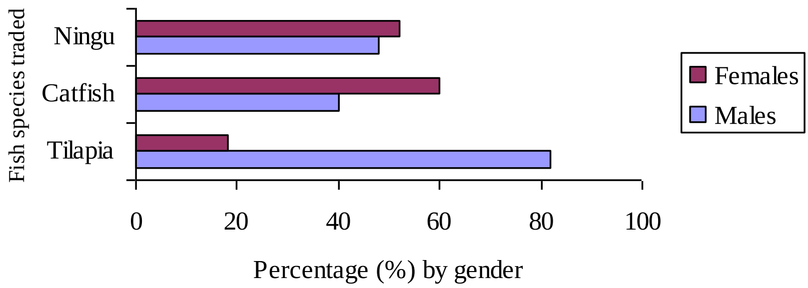

Figure 7. Principal fish species traded by trader's gender in Nyanza region, Kenya.

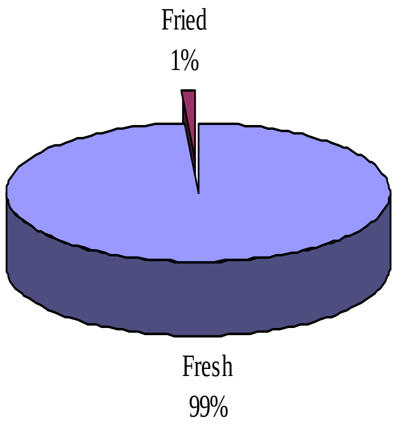

Figure 8. Fish product forms traded by men in Nyanza region, Kenya.

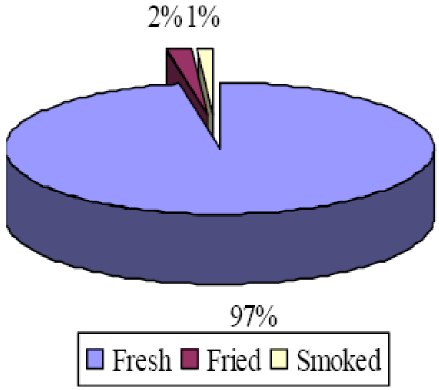

Figure 9. Fish product forms traded by females in Nyanza region, Kenya.

Involvement of Women in Research

There are more men than women in the aquaculture research division in Nyanza region, Kenya. However, of the women who are employed, only 2% have held senior managerial posts (Figure 10).

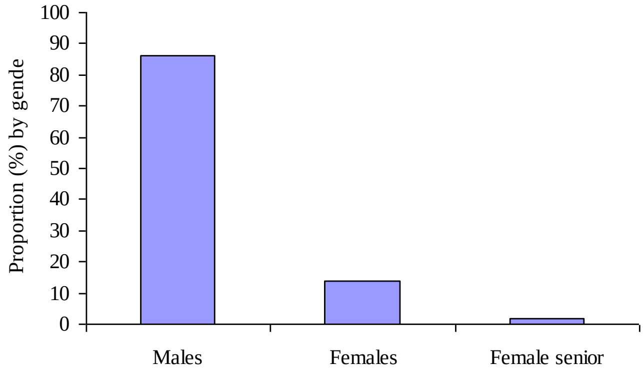

Figure 10. Involvement of women in aquaculture research by the year 2012.

Table 2. Problems experienced by respondents along the AVC in Nyanza region, Kenya

Chain	Challenges	% of respondents	
		Male	Female
Hatchery	Access to capital	17	83
	Quality/cost of feed	52	48
	Water quality	62	38
	Cost of labour	46	54
	Labour skills	12	88
	Land ownership	10	90
	Availability of electricity	50	50
Production	Feed cost/quality	48	52
	Seed quality	42	58
	Water quality	62	38
	Predators	48	52
	Theft	48	52
	Fish health	43	57
Marketing	Consumer perceptions about farmed fish	49	51
	Price fluctuations	12	88
	Road networks	49	51
	Lack of value addition	47	53
	Lack of export	50	50

The Main Problems Experienced in Aquaculture by Gender

Both males and females experienced various problems in AVC. Feed cost and seed quality are the major problems for both males and females both at the hatchery and production levels. Notably, consumer perceptions about farmed fish are an issue that affects both genders during marketing (Table 2). Notably, lack of value addition is also an issue that affects marketing of farmed fish. The perishable nature of fish necessitates prompt sales at whatever cost. However, there were no significant association between gender and problems experienced in aquaculture ($\chi 2$ = 1.672; df =8; p = 0.763) in Nyanza region.

4. DISCUSSION

Unlike capture fisheries, the survey indicated lack/very minimal post-harvest traders in AVC suggesting that at present, capture and aquaculture value chains are separate and probably do not meet at any point (World Bank, 2012). Lack of post-harvest traders could also indicate that the volumes produced from aquaculture are too small to justify as established upon post-harvest chain of intermediaries (Norad, 2014). Notably, it could suggest that unlike capture fisheries, aquaculture value chains are short hence the very short period from harvest to final consumption by consumer hence low rates of post-harvest losses. The general lack of chill/frozen storage equipment/ facilities means that all fish need to be sold quickly by the pond side, and prices are reduced by sellers to ensure that product is sold, even at a low price, rather than not being sold at all.

There were a slightly high proportion of females (62%) in this study, probably an indication that in artisanal aquaculture in developing countries; women represent the majority of rural poor population (Wangila, et al., 2007). The results of the current findings concurs with other authors who have indicated that women engagement in AVC ranges from 42-80% (Williams et al., 2005; FAO, 2006) with percentages much higher in certain regions (Krishna, 2012). Moreover, over 50% of both males and females are below the age of 45 years likely due to more economic participation by youths in AVC. The gender disparities in educational level suggest constraints to access to education for women in Kenya. This could also be a contributing factor to their marginalization in decision making (Ndanga et al., 2013).

In aquaculture in Nyanza region, females dominate fish production and the few men involved in production rely on the full participation of women and the family (Rutaisire et al., 2010). Unlike in capture value chain where women are mostly involved in post-harvest activities, conversely in AVC, a higher number of women (83%) are involved in production level, suggesting that women are the key players in aquaculture sector in Kenya. The results of the current study contradicts the findings of Ikiara (1999) who found out that women dominate the fish marketing system of Lake Victoria while men dominate its production. The difference could be due to the nature of the two value chains as AVC is shorter as compared to capture value chain (herein, CVC) which is well established. It could also be because women's aquaculture tasks, is often based near the home, and this is especially convenient as they fit closely with their existing roles in supporting the household. However, since they are undertaken by women, they are often viewed as requiring little skill (Williams et al., 2005; FAO, 2006, Choo et al., 2008). This is a major gender issue in aquaculture and leads to women's work being undervalued and poorly rewarded.

House chores are predominantly the work of females in Nyanza region. Despite the fact that children are the sole responsibility of women, and given their dual role in domestic chores and reproduction, more women actively participated in aquaculture activity along the value chain. This is because given the cost of feeding, clothing and sending children to school, the necessity for an income is considerable (Medard et al., 2002).

Majority of land/pond is owned by men in Nyanza region. Most fish pond owners in Africa are men because they have better access to resources (Harrison, 1995). Evidence of land ownership is regarded as a problem for women wishing to engage on their own in aquaculture. In patrileneal communities, men have always owned productive assets such as land, while women may have access rights to, but not control over family resources. Another factor that may contribute to this difference in farm ownership is women's limited access to capital, which is essential for engaging in aquaculture due to the need for expensive imported inputs such as feed, fish farming chemicals, and improved technology. Ownership of land is significant as a means of increasing the income and food production in households and provides some security (Lwenya et al., 2009).

Women's access to credit, important in varying degrees in all systems, is also limited, because credit from formal systems often demands land as collateral. Aquaculture farming is a capital-intensive activity compared to other forms of agricultural and livestock production, involving both a large investment outlay, particularly for the more sophisticated methods, and high operating costs for energy, and feed. These conditions tend to inflate the unit cost of aquaculture farming and reduce competitiveness. The constraints are felt more deeply by women as they do not own property that they can use as collateral to obtain credit from the banks (Lwenya and Abila 2001; Ndanga et al., 2013).

The survey indicated that males dominated trainings across the AVC, probably suggesting that the key constraint experienced by women is the access to information hence they lack confidence to culture fish successfully (Frocklin et al., 2013; Harper et al., 2013). In African countries, the target of various training programs is men in the family to receive the information (Norad, 2014). Unfortunately, according the female respondents, men who attend the trainings do not freely share that information with other members in the family. Despite low training and education, women actively participated in production and grow-out levels in Nyanza region. The results of the current survey contradicts findings of Ikiara (1999) who indicated that education is a key-influencing factor determining women roles in the society and lack of training limited their participation to the peripheral parts of the value chain, such as fish processing and trading that do not require much knowledge. This could possibly suggest that the women had gained experience in fish culture by learning and doing as opposed to class room trainings.

Females dominated the nursing of catfish and *ningu* at the hatchery level. Catfish and *ningu* do not reproduce under captivity hence the need for artificial propagation. Egg and fry nursing requires close follow-up and attention. The process also involves patience, which respondents claimed females had and males did not. Looking after a fish pond/hatchery is perceived by women as an extension of their responsibility and it is convenient for them since the ponds are located in the same place as their farm activities (FAO, 2014). Women could easily integrate aquaculture into the farming system of the farming families. However, there are changing roles in the fisheries where men have seized opportunity to enter into fish trade, which was once a female domain. Thus we find men dominating the tilapia trade, which is more profitable, pushing women to the less profitable fish species of catfish and other indigenous fish species like *ningu*. The fish species reported to be of the highest economic importance for both men (46%) and women (54%) traders were Nile tilapia, which could be explained by high aquaculture fish abundances due to the impetus of Fish Farming Enterprise Productivity Program (Musa et al., 2012). Consumer preference for Nile tilapia over other species has also been reported around the Nyanza region (Musa et al., 2014).

Majority of women and men in Nyanza region dealt with fresh fish products as compared to processed fish; an indication that there is little transformation of aquaculture fish through frying and smoking. This could also indicate that aquaculture fish does not travel far inland to rural villages (Norad, 2014). Fish trading remained informal with producers selling directly to local villagers due to the small quantities produced, indicating no distribution network has been established to reach consumers. Proportionately more women than men dealt in processed fish products. Processing of fish often require a lot of patience, factors that tends to favour women more than men (Lwenya et al., 2009). The difference in ways of processing is partly because of taste and preference among the consumers. Previous survey by Musa et al. (2014) indicated a high demand of fresh followed by fried fish around Nyanza region.

The main problems experienced by both genders in Nyanza region are cost and quality of feeds. Most Kenyan fish farmers have mentioned cost of fish feed and feed management as their major challenges (Shitote et al., 2001). Many authors concur that growth of the aquaculture is positively correlated to the progressive use of quality feeds, which meet the nutritional requirements of the cultured fish (FAO 2010). Both genders indicated poor quality seed as a major challenge along the AVC. The results of the survey could serve as an indicator that feed and seed quality are the most serious bottlenecks in the AVC in many developing nations such as Kenya. Consumer’s perception affects marketability of farmed fish in Kenya which concurs with other previous findings (Darko 2011, Musa et al., 2014). Consumer’s perception that wild caught fish is tastier than cultured fish is still a stumbling block for acceptability of cultured fish in many regions (Drake et al., 2006; Dasgupta et al., 2010; Musa et al., 2014).

CONCLUSION AND RECOMMENDATIONS

This study has shown that women play an important role in AVC. Majority of men owned farm land/ponds while women had access to but not ownership of land, limiting their access to credit due to lack of collateral. Post-harvest trade and sale of farmed fish is currently a “black hole” that remains to be filled and organized as production increases to ensure the fish produced meets both the protein needs of local poor households and demand for fish further afield.

Women dominated production and grow-out stage along the AVC. Despite their importance and contribution to this artisanal industry, women have received little attention from the government in terms of capacity building. Training and credit should be made available to females along the aquaculture value chain so that they invest in cooling facility and or value addition to improve on profits. The existing collateral base credit facility should be revisited so as to accept startup projects based on the strengths of the project document incorporating mechanism for credit extension through holding the project itself as collateral. For optimum fish production in Kenya, the feed industry must be improved to provide quality and affordable feeds to fish farmers.

Furthermore, improvement of Knowledge, Information services and Management (KIM) along the AVC for small-scale farmers (both men and women) is important for sustainability. It is crucial that this should be complemented with efforts in raising public awareness on the importance of fish farming to the overall health and well-being of the country.

CONFLICT OF INTERESTS

The authors state that there is no financial relation with the mentioned enterprise therein which might lead to conflict of interests among themselves or between them and the institutions therein. In addition, the authors are purely trained researchers with the information herein only meant for research purposes and therefore they account for their output based on research and information dissemination. In addition, there is no conflict of interests among all the authors, financier, and the organization herein that could inappropriately influence, or be perceived to influence, their work. Notably, the work herein has not been previously published or submitted to another journal, but only to this journal.

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Chapter 6

WHY AQUACULTURE TRIALS HAVE NOT BEEN SUCCESSFUL IN TANZANIA?

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ABSTRACT

Most aquaculture trials in Tanzania have made insignificant contributions to the community welfare because they did not learn from the mistakes of the past trials. To avoid repeating the past mistakes, a study was conducted to "review all aquaculture trials in Tanzania, objectively concluding why the past aquaculture trials have or have not been up scaled." Quantitative and qualitative designs were employed to collect data from Zanzibar. The study population comprised of milkfish, crab and sea cucumber farmers, as well as farmers who abandoned aquaculture. Instruments used for data collection included questionnaire, group discussion, researchers' observations and secondary information sources. The results showed that the aquaculture trials have not been up-scaled because of: low priority given to the aquaculture sector, targeting the poorer community, introduction process of projects that killed "self-help" sprit, the unmet objectives for undertaking aquaculture, the poor location of aquaculture farms, a lack of availability of quality fingerlings

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in the right quantities, inadequate feeds and fertilization, relative disadvantage of aquaculture in comparison to other competing activities and lack of ownership of the aquaculture farms. This review suggests the following: firstly, government support in creating an enabling environment in form of formulating appropriate policy, laws, regulations, guidelines, investments promotion and regulation of the aquaculture sector is vital. Finally, operating aquaculture as a business will enable it to address all the determinant factors for success identified by this study.

Keywords: aquaculture trials, fingerlings, self-help sprit, dependency syndrome, poor farmers

INTRODUCTION

Aquaculture Potential in Tanzania

Tanzania has high potential for both freshwater and marine aquaculture development (URT, 2009; URT, 2012). Firstly, the country has an area of 62.0 million hectares covered by water, Exclusive Economic Zone (EEZ) area covers 223,000 km^2, coastline covers 1,450 km long and fresh water covers 54,040 km^2 (Lake Victoria, Lake Tanganyika and Lake Nyasa) and minor water bodies include - dams, reservours and rivers (ibid.). Secondly, the country has favorable temperatures in the range of 22-30 ^oC, which ensure good growth of most aquatic organisms. Thirdly, it is endowed with suitable sites and topography for aquaculture - an important indicator of good site selection for construction of milkfish and fresh water fish ponds. Fourthly, it has suitable soils of high clay content (fine texture), which is suitable for pond construction as it retains water. Fifthly, there is high demand for aquaculture products in the local and international market, which makes fish prices to remain high or steadily increasing (URT, 2009; Wetengere et al., 1998). Sixthly, the availability of agricultural by-products which may be used as inputs and/or used to produce industrial feeds. In addition, FAO (1987) asserts that aquaculture potential is created by a combination of the producer's desire to be an aquaculturist and the consumer's wish for aquatic products. This is in line with Bueno (2011) who categorized the potential for aquaculture development into biological, technincal, economic, social and environmental. Summing up aquaculture potential in Tanzania, the Tanzania Fisheries Research Institute (TAFIRI) estimated that the country exploited less than 1% of its aquaculture potential (SUA, 2002). Since then the aquaculture production (other than seaweed) has only risen from 630 tonnes in 2002 to 3472 tonnes in 2013 (FAO Statistics) so that the potential is still largely untapped.

Despite such potential and the past government efforts to assist the farmers, aquaculture has not registered remarkable growth as productivity has continued to be very low (URT, 2009). Lack of skilled manpower, inadequate and lack of quality seeds and feeds supply, employment of outdated technology and inadequate extension services have contributed substantially to the slow development of aquaculture in the country (ibid.).

History of Aquaculture in Tanzania

Aquaculture in mainland Tanzania is believed to have started in 1927 in the form of sport fishing, with fish stocked into rivers around Mount Kilimanjaro and the Mbeya region (Balarin, 1985). Pond fish culture started in the early 1950s with the establishment of experimental ponds in Korogwe and Malya, located in Tanga and Mwanza regions respectively. The government provided fingerlings, technical and financial assistance to the farmers. By 1960s Tanzania had some 10,000 ponds with a surface of 1,000 ha. However, due to poor technology and management, government's failure to produce and supply quantity and quality fingerlings and unsustainable extension approach, many of the ponds were abandoned. After independence in 1961, the government established regional centers to breed fingerlings and promote extension in most suitable sites. To support the above efforts and realizing the importance of fisheries sector, the Department of Fisheries (DFs) was formed in 1964 with fisheries offices located in all regions, districts, to the village level. During the first and second Five-year National Development Plans (1964-74)' however, priority was given to the development of fisheries over aquaculture (Balarin, 1985). Moreover, due to lack of funds, manpower and political will, the regional centers failed to produce and distribute fingerlings to the scattered farmers. More important, since the aim of aquaculture trials were to improve the welfare of the poor community, the government had to provide assistance in cash and/or kind for free. However, this system could not be sustained and most of the projects failed.

In the 70s and 80s Tanzania witnessed numerous aquaculture development projects which were donor supported. The same approach of project promotion, provision of support for free and targetting the poor community as before was adopted. The aquaculture production remained low (Table 1).

Donor supported programs regretably did not build upon the local '*community's self-help spirit*'[1], the projects were not sustainable, and as soon as the donor support ceased, the projects were abandoned.

In 2008, the Government of Tanzania declared its interest to ending decades of neglecting aquaculture. It reaffirmed this commitment and its desire to improving aquaculture contribution to economic growth by establishing a full-fledged Directorate of Aquaculture (DA). The new DA has added impetus to the development of the sector by adopting a National Aquaculture Development Strategy (NADS) in 2009 that provides new set of objectives, approaches and methods of a framework for the development of aquaculture. This strategy is aimed at involving the farmers right from the planning stage to the implementation in aquaculture development (URT, 2009). The main issue in the NADS is that aquaculture should operate and stand as a business (ibid.). Similarly, the Revolutionary Government of Zanzibar has given a high priority to aquaculture development so that the sector becomes a significant contributor to social and economic development (Bueno, 2011). The Government has plans to increase the production of seaweed, cultured finfish, crustacean and mollusc species to complement the declining position from capture fisheries. The associated strategies focus upon diversification of mariculture away from seaweed and the improvement of seaweed farming and marketing. So far little has been done in practice to achieve the objectives of both strategies, and it appears that fiscal incentives do not form part of the instruments which the government proposes to use to try to achieve these targets.

Fresh Water Aquaculture Production

Fresh water aquaculture in Tanzania is dominated by Nile tilapia (*Oreochromis niloticus*) and to a lesser extent the African catfish (*Clarias gariepinus*). In some areas the two species were integrated. Much of fish pond

[1] The term "self-help sprit" refers to "the willingness of the local people to actively participate in public activities such as construction of schools, dams, roads and other community physical assets". It is a situation where the local people willingly participate in doing public activities on their own with minimal external support. In so doing, the local people own these activities or assets and therefore take care of them. However, when the outsiders come and do these activities for the local people (particularly those activities that the local people were able to do themselves), they ruin this valuable spirit. After ruining this spirit, the outsiders then make the local people to depend upon them (the outsiders), thus creating a deadly disease called "dependency syndrome"!

culture is concentrated in the Southern part of the country, notably, Mbeya, Iringa and Ruvuma regions and in the Northern parts in the regions of Kilimanjaro and Arusha. Currently (2015), there were 19,930 earthen ponds with the Nile tilapia (*Oreochromis niloticus)* and catfish. Fresh water aquaculture has increased from 4 tonnes in 2004 to 2,980 metric tonnes in 2013[2] (Table 1). The largest increase of production took place following the implementation of the NADS of 2009. Despite such achievement, freshwater aquaculture is still largely a subsistence activity practiced by small-scale farmers with low social, cultural and economic status and limited access to technology, markets and credits (Chenyambuga et al., 2012). Usually, this consists of small fish ponds of an average size of 10 m x 15 m with a depth range from 1 m to 1.5 integrated with crops or animal husbandry (ibid). Closer analysis shows that these farmers lack the proper principles of integrated aquaculture and agriculture. There are also 10 raceways of 25 m x 25 m in a rainbow trout (*Oncorhynchus mykiss*) farm in Arusha region. The production of rainbow trout has remained small fluctuating from 4 - 8 tonnes annually (Table 1).

Table 1. Fresh water production by specie in Tanzania mainland (tonnes/yr)

Year/ Species	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Fresh water fish	630	2	4	4	4	4	5	75	200	221	2913	2980	-
Rainbow trout	-	-	7	6	6	6	7	7	8	0	3	4	-

Source: FAO (2013).

Most small-scale fish farmers reported lack of funds, stunted growth of stocked fish, inadequate knowledge on fish farming and unavailability of concentrate feeds as the major constraints to fish farming (Chenyambuga et al. 2012). Other constraints included irregular water supply, predation, unavailability of fingerlings, floods, theft, and lack of transport.

[2] These data, however, differ from those obtained from the Ministry of Livestock and Fisheries Development (MLFD), which shows that the production of fresh water increased from 640 tonnes in 2004 to 2,989 tonnes in 2013. To be noted that FAO data is obtained from the country so, this discrepancy need to be clarified.

Marine Aquaculture Production

Marine aquaculture (Mariculture) in Tanzania is generally an extensive practice involving collection of fingerlings (or seaweed cuttings) from the wild for rearing and feeding in enclosures (or string racks in the case of seaweed). Seaweed farming in Tanzania started with Professor Mshigeni of the University of Dar es Salaam in 1976. Commercial farming started by export companies in 1989 with experimental farms on the East Coast of Zanzibar. Crab fattening, shrimp and shellfish farming experiments were conducted in 1990s and early 2000s. Finfish farming was started in mid 1990s through integrated mariculture pond systems experiment conducted by the Institute of Marine Sciences (IMS) at Makoba Bay, Zanzibar. During the 2000s, donor funded projects on seaweed, crab fattening and milkfish farming showed some success. These projects expanded and to some extent contributed to household food and income security (Table 2a and 2b). Recently, the farming of sea cucumber has taken pace in Zanzibar and potential exists as there is high demand in the international market. However, the main challenge facing the activity is unavailability of wild fingerlings.

Table 2a. Mariculture production by species in Tanzania mainland (tonnes/year)

Year/ Species	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Sea weed	2000	2000	3000	3000	2200	4000	5000	5520	6885	6601	6510	6689	-
Milk fish	-	-	2	2	2	2	2	10	8	137	221	203	-
Shrimp	-	-	-	-	59	32	302	108	231	290	270	285	-
Crabs**	-	-	-	-	-	0.1	0.3	1.5	5.1	7.0	1.0	-	-

Source: FAO (2013).

** Data obtained from the Ministry of Livestock and Fisheries Development (2015).

In 2007, there were an estimated 100 milkfish ponds (Msuya and Mmochi, 2007) and in 2008 this had increased to 150 ponds (WIOMSA, 2011). Current production of milkfish stands at 203 tonnes (2013) in Tanzania and 10 tonnes (2013) in Zanzibar (Table 2a and 2b). However, milkfish farming has not taken off on a commercial scale because not much attention has been paid to economics and marketing considerations, poor transportation infrastructure, poor site selection and pond construction, most ponds have been constructed by research institutions rather than the farmers, fingerlings have not been available and not much attention has been placed on sorting of fingerlings

(Requintina et al., 2008). Shrimp farming has been operating in Mafia Island and its production has increased from 59 tonnes in 2006 to 285 tonnes in 2013 (Table 2a and 2b).

Table 2b. Mariculture production by specie in Pemba and Unguja (in tonnes/year)

Year/ Species	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Sea weed **	111830	94640	71860	73620	76760	84850	107925	102682	125157	130400	150876	110438	-
Milk fish	-	-	-	-	-	-	-	-	-	-	10	10	-

Source: FAO (2013).
** Include production for both *Eucheuma denticulatum* and *Kappaphycus alvarezii* species.

The cultivation of seaweed has increased steadily from a production of 71,860 metric tonnes (wet weight) in 2004 to approximately 110,438 metric tonnes by 2013 (Table 2a and 2b). Most of the seaweed is produced in Zanzibar (110,438 tonnes in 2013) whereas mainland Tanzania produces about 6,689 tonnes only[3]. Currently, the entire seaweed crop is baled and transported abroad for processing at a very high cost of transport while seaweed commodities are re-imported back to Tanzania for consumption. For seaweed farming to be more profitable, at least some significant part of the seaweed crop has to be processed and consumed in Tanzania. The Zanzibar Seaweed Cluster Initiative working with local entrepreneurs (mostly women) are trying to do this through making seaweed soap, shampoo and oil as well as food items such as cakes and juices. The most successful farmers of pearl oysters are producing an average of 20 pearls per month earning at least 13 US$ per raw pearl or 260 US$ per month. The production of crabs in 2012 was estimated at one tonne annually (Table 2a).

Despite the existing potential for aquaculture development and the government committment to ending decades of neglecting the sector, aquaculture has continued to operate as a subsistance activity practiced by poor small-scale farmers and much of its development is dependent on donor funding. Consequently, the aquaculture industry has had insignificant contribution to the welfare of the local community and the nation as a whole.

[3] These figures (standardized wet weight for global comparisons) differ greatly from those obtained from the MLFD (dried weight for marketing) which shows that for the past ten years sea weed production ranged between 200 to 600 tonnes in mainland Tanzania and between 6,000 to 13,301 tonnes in Zanzibar.

One of the main reasons for failure of most aquaculture is that new trials were established without learning from the mistakes of the past trials. To avoid repeating the mistakes of the past attempts, it was decided to conduct a critical review as to why the past and the on-going aquaculture trials have or have not been up scaled. The findings of this study will be used as an input when establishing of new aquaculture trials. This study is meant to fill that gap.

OBJECTIVE AND METHODOLOGY OF THE STUDY

Objective of the Study: The main objective of the study was to conduct a "critical review and assessment of all aquaculture trials in Tanzania, objectively concluding why the past aquaculture trials have or have not been up scaled."

Study Area: A survey was conducted during a field mission between 30th March and 3rd April, 2015 along the coastal areas of Zanzibar. The studied area covered six villages in Unguja and Pemba. The choice of this area was purposive, because there is a good number farmers operating milkfish farming, crab fattening and sea cucumber farming.

Survey Design: Qualitative and quantitative designs were used for data collection during this survey in order to describe the existing perception, attitude, behaviour or values of individuals within the village communities. The survey interviewed individual farmers and/or groups of individuals with experience in aquaculture and organizations like the Zanzibar Chamber of Commerce and buyers of marine products.

Sample size and study population: Of the total respondents, six farmed sea cucumber, four farmed milkfish and five dealt with crab fattening. The two respondents that had been involved with crab fattening had abandoned farming and the rest were still farming. Having respondents that included those that had abandoned aquaculture was important in order to get reasons for abandonment as well as for continuing with the aquaculture activities.

Sources of Information: Quantitative and qualitative information for this review was obtained from the following sources: responses to checklist questions concerning aquaculture adoption and practice; field observation during the mission; responses to a questionnaires administered by the mission team and various published and unpublished (gray) literature.

THE CONTRIBUTION OF AQUACULTURE ON THE COMMUNITY WELFARE

Aquaculture production has high potential to contribute to the welfare of the people and the development of Tanzania as whole and Zanzibar in particular. However, due to a number of challenges which the sector has been facing, it's contribution has been insignificant. Nevertheless it is important to identify those areas where aquaculture can play an increasing and significant contribution if it is properly developed.

Provide Source of Animal Food: Aquaculture provides animal protein which is in short supply in many rural areas. Aquatic organisms are high in protein, minerals and vitamins and are generally low in fat, higher in polyunsaturates that can help to reduce cholesterol in blood and have a higher carcass dress-out percentage than land animals (Hague, 1992). Similarly, aquatic products can be consumed more often and at any time of the year as it is easier to catch a few cultured organisms for consumption than to slaughter other domesticated animals. However, due to low production not much consumption of animal protein came from aquaculture production. Wetengere and Madalla (2011) indicated that on average the consumption of farmed milkfish and crab was only once or twice a year. This is in line with this study's survey results from Zanzibar which revealed that aquatic products were consumed irregularly. In comparison, wild capture fish was consumed year round and on regular basis (ibid.).

Provide Income: Similarly, aquaculture provides products for sale to contribute to people's income. An advantage of aquatic products as a cash crop over other cash crops is a continuous flow of income (non-season) as a result of planned harvest. Harvest of crops like green maize, fresh tomatoes or vegetables cannot be postponed to capture higher profits in certain periods of the year. It can also be an important source of foreign exchange for a country. However, due to low production, aquaculture contributes less than 10% of small scale total income in Tanzania. A study by Wetengere and Madalla (2011) in Rufiji, Mafia and Kilwa (RUMAKI) districts revealed that aquaculture contributed only 0.4% of the total household income (compared to 20% of total earning from wild capture fisheries, 58% from businesses and 19% from agriculture). Furthermore, wild capture fisheries earned 50 times more than what milkfish and crab farming together were earning. In addition, on average, farmers earned income from milkfish and crab farming only once per year compared to 10 months income earning from wild capture fisheries and 11 months earning from businesses (ibid).

Employment: Aquaculture has to some extent created employment in rural communities where economic opportunities are limited. Farmers earned income from aquaculture through pond and cage construction and repair; harvest of aquaculture produce and selling of seeds captured from the wild or own ponds and earning from doing business of aquatic produce.

Other Impacts of Aquaculture: Mariculture contributed to environmental degradation of land through cutting of trees or destruction of the mangrove ecosystem to establish milkfish ponds, crab fattening and shrimp farming areas. Similarly, fresh water aquaculture can lead to deteriorating quality of public water as a result of the wastes discharged.

The Review and Assessment of Aquaculture Projects

From a survey conducted in Zanzibar and a review of previous aquaculture initiatives as described in the methodology, this section identifies the major factors which have determined the success and failure of the past and the on-going aquaculture trials.

Low Priority Given to Aquaculture by the Government

The history of the development of aquaculture in Tanzania shows that until more recently, the government had neglected aquaculture paying more attention to capture fisheries. This attitude contributed a lot to the present underdeveloped state of aquaculture leading to the dependence of the development of the sector on externally funded technical cooperation projects. Despite recording varying degrees of success, project achievements have mostly been short lived simply because the methods they relied on did not sufficiently build upon an existing government extension system and '*farmer's self-help spirit*.'

Low priority accorded to the sector was reflected in the following ways: Firstly, in terms of lack of political will which led to allocate meager funds to the aquaculture sector. Consequently, it adversely affected the development of extension workers and extension services. Poor motivation of the extension workers had crippled the aquaculture extension services, leading to inadequate knowledge among farmers. This has in turn led to poor pond construction, poor quality seed production, poor pond management, and irregular and incomplete harvest. Low yields resulting from such practices discouraged farmers, rendering aquaculture a low priority or a secondary activity.

Secondly, was the lack of manpower to manage the sector. Learning from the past, the Department of Fisheries (DoF) was responsible for development of aquaculture in Tanzania and prior to 1990 it used to be represented by Fisheries Officers (FOs) in all regions and districts, down to the village level. This was the structure through which aquaculture extension was channeled. However, after 1993, lack of funds necessitated retrenchment of fisheries officers at division and village levels. Additionally, in 2000, the Regional Fisheries Offices (RFOs) were dissolved, leaving only District Fisheries Offices (DFOs) at district level. A common phenomenon, however, was that in all district councils there was very low priority to aquaculture development, their main concern being revenue collection. In view of the above, not much development of aquaculture can be expected through such institutional channels. Fortunately, changes would be made under the current structures. Another problem related to control and management. Following decentralization of 1972, the DFO was answerable to the Ministry of Local Government and Cooperatives and not to the Ministry of Livestock and Fisheries Development. This meant that the DFOs were not under the direct control of the Directorate of Aquaculture (DA). The result was that management programs proposed by the DA were not fully implemented and decisions taken are not necessarily in the best interest of fisheries development (Balarin, 1985). The Ministry of Livestock Development and Fisheries (MLDF), seeing the shortfalls in the development of aquaculture industry in later years embarked on a strategy to operate aquaculture as a commercial enterprise (URT, 2009). This implies that since then it is recognised that private institutions in collaboration with the government will emerge to supply the necessary inputs in order to boost the development of aquaculture.

Thirdly, was the inability of the institutions to support aquaculture development. The main support service expected from the institution includes research and extension, seed and feed production and supply, disease control and credit facilities. If these are not properly provided, the long-term viability of aquaculture will be affected. While acknowledging the potential for success of aquaculture in Tanzania, Balarin (1985) pointed out that poor institutional framework, among others, was then the main reason for lack of success. After development of the NADS of 2009, the situation has improved but there is still much more to be done. For instance, one may question why despite the existence of training and research centres and institutions, aquaculture is still faced by so many challenges today! To what effective use are these institutions placed and what are their impacts?

Government committment and will to support aquaculture is key to development and sustainability of aquaculture. Commenting on the achievements of aquaculture in China, FAO (2000) noted that the engine for economically resilient and sustainable aquaculture is the government's will and resolve to *establish sound policies* to support and develop the sector. The Thematic Evaluation of Aquaculture found that successful projects were those supported by strong government commitment (FAO, 1987). It is in view of the above that recently the government of Tanzania have committed to create an enabling environment to promote aquaculture development in the following ways: manpower recruitment and development, policy formulation, provision of laws, regulations, guidelines, investments promotion and regulation of the aquaculture sector (URT, 2009; Bueno, 2011).

Targeting of the Beneficiaries of the Aquaculture Trials

Most of the aquaculture projects targeted the poor individual or households in an effort to improve rural food security through aquaculture. Past emphasis on the important role of aquaculture to homestead food security aspect alone favoured those who would want to produce their own food. Similarly, emphasis of aquaculture as a means for poverty reduction can also create a negative impression that aquaculture is only good for the poor. The temptation to focus on the poorest may be compelling, but was unfortunately often unsuccessful because they did not have the resources (financial, time, willingness and mental resources) required to establish and sustain aquaculture. Small-scale rural aquaculture is an activity that relies almost entirely on on-farm resources, or at most within the village. Very rarely were the inputs purchased. Thus, if aquaculture is to develop beyond subsistence level, more emphasis should be given to those who have access to resources and have the opportunity to facilitate the sustainable development of aquaculture. In other words, since the technological know-how required for economically successful aquaculture is demanding (FAO, 2000), promotion of commercial aquaculture is inevitable. Commercial aquaculture puts more emphasis on economic incentives which, unlike in small-scale farming, are strong enough to convince farmers to invest and tend to their ponds/farms regularly (Ridler and Hishamunda, 2001). In that regard, commercial aquaculture requires some cash and therefore access to bank credit is essential. A recommended way to attract lending in the industry is to demonstrate its profitability. That means, the contribution of aquaculture is best achieved if aquaculture is taken as a business from the beginning of the promotional programme.

Experience from elsewhere in the world supports the view that aquaculture becomes sustainable when it is pursued for profit and is commercially oriented from the outset. Sustainable small scale aquaculture is enabled by relatively larger commercial investments that create demand for quality seed, formulated feeds and markets (Ridler and Hishamunda, 2001). It should be understood that commercial aquaculture is not an alternative to rural aquaculture but rather a complement (ibid.). Commercial aquaculture has been a helping hand to small-scale aquaculture in many ways. It aids rural aquaculture by diffusing knowledge to small-scale rural aqua-farmers or acting as models for rural aqua-farmers to emulate (ibid.). Similarly, income earned from commercial aquaculture and research findings can support small-scale aquaculture. That said, it should therefore be stressed that the top agenda in development of aquaculture in Tanzania today is that of attracting commercial farmers, who are capable of producing a surplus that can be saved and re-invested (Sevillaje, 2000). Failure to emphasise the commercial rewards of aquaculture enterprise often discourages potential SME producers. Aquaculture should be seen as a business like any other farm enterprise and should be promoted as such. Policies to subsidise and maintaining low prices or even handing out juveniles for free discourage enterprise and establishes a situation as if it would be impossible to farm without giveaway.

The Introduction Process of Aquaculture Trials

The manner that the projects were introduced had significant impact on their sustainability. Often the promotion of aquaculture by government or donor projects was accompanied with promises of assistance in cash and/or kind. While such assistance to individuals or group members seemed useful at the time in order to initiate aquaculture activities, it also had undesirable long term impacts. Such assistance enabled group members to pay for pond construction costs as well as purchasing feeds, fingerlings and other inputs such as pumps, gum boots, pipes, hand hoe, shovels etc. Nevertheless, some assistance like paying farmers to do activities that farmers could do themselves

(Wetengere and Madalla, 2011), paying farmers allowances to attend training and paying for food when farmers were doing some project activities was not needed. However important the provision of these inputs for free was, it was not sustainable. Such assistance could not be asked for crops like maize, beans, rice and cassava simply because their cultivation was a "*live or die*" matter to the farmers. By doing things that farmers could do themselves, projects ruined the sense of local community ownership and created a 'dependence syndrome' jeopardising sustainability of the project. Most farmers did not see the project as their own property but of the promoter (i.e., the projects/government). This happened when the projects substituted rather than complemented farmers efforts. In many instances, direct funding by the projects was the main motivation for group members to participate rather than enthusiasm for benefits accruing from successful aquaculture. This largely explains why most donor projects were unsustainable. It should be emphasized here that although external assistance may be necessary to improve farmers' resources (cash), organization knowledge and technical skills, care should be taken not to erode the farmers' *spirit of self-help*.

For a project to become sustainable, the introduction process should be to build upon the 'farmer's self-help spirit.' The best way to sustain projects is to ensure that the farmers are fully involved in all stages of the project. This leads to ownership of the project design, results in active participation in the implementation and management by the local people, and helps to ensure that local priorities are addressed. The project/government initiative has to ensure that it complements rather than substitutes farmers' efforts. Finally, the project/government initiative should not provide inputs for free as it has been shown that it is unsustainable.

The Reasons for Undertaking Aquaculture Trials

Literature shows that farmers adopted aquaculture technology in order to obtain fish for home consumption as well as for sale to improve their income (FAO, 1996; Edwards et al., 1997; Wetengere et al., 1998 and Wetengere, 2010). Wetengere and Madalla (2011) indicate that most farmers along the coastal areas adopted aquaculture in order to generate income, and this was also the situation seen in Zanzibar in April 2015. Several studies have shown that only few farmers achieved their primary reason for undertaking aquaculture that is to generate considerable income and eat fish frequently and at a time when other relishes were in short supply. This was due to reasons such as low production which was attributed to poor growth of aquaculture produce, human theft, inadequate fingerlings and feeds, lack of aquaculture knowledge, low price of fish/crab, fish ponds/cages washed away by high tide and problems associated with group owned fish pond/cages. The farmers' failure to meet their objectives explained to a large extent why aquaculture had been operated as a *leisure affair* and why farmers kept asking for assistance in cash and/or kind from the project/government. This is also somewhat the situation seen during the mission in Zanzibar.

Supporting the above, some farmers during the field survey were of the opinion that cash generation was more pressing and important in the study area. This implies that if aquaculture is to be adopted and sustained, it has to generate significant and regular income. To be able to do so, aquaculture has to operate as a business, which will require intensification. Successful intensification can result from an increase in quantity and quality of fingerlings, proper grow-out management, and good marketing.

Location of the Aquaculture Ponds/Cages

Site selection is one of the most important first stages in aquaculture development (Mmochi, 2011). A good site particularly for milkfish pond mariculture needs to have good supply of water, be protected from flooding, waves and strong winds and with clay or clay loam soil for construction of the dikes. Sites for crab fattening and sea cucumber farming also need to be selected with care. Wrong site selection can cause problems including theft, animal predation, unavailability of water supply, flooding, water seepage and breakage of the dikes by strong waves and winds. The site needs to be accessible and well-guarded. Most milkfish ponds suffered from water shortage as spring tide, the main source of water, occurs only twice a month (Wetengere and Madalla, 2011). The situation was exacerbated by poorly selected sites where even the spring tide was insufficient to fill in the pond. A shortage of water resulted in perilously low pond water levels exposing fish to predatory birds, high water temperatures and increased water salinity (ibid.). Water quality deteriorated further due to overcrowding of fish in the refuge trench. This led to poor growth, mortality and poor yields (ibid.).

Most of milkfish ponds, crab fattening cages and sea cucumber farms were located as far as 5 km away from homesteads (Wetengere and Madalla, 2011). Such distance caused difficulties in routine management activities and increased exposure to theft, vandalism and predation. In some areas ponds/cages were too close to human activities (like fish landing sites) making them prone to trespassing and issues such as defecation and waste dumping in the pond (ibid.). Accessibility to most sites in Rufiji, Mafia and Kilwa (RUMAKI) was extremely difficult due to deep mud, piercing mangrove prop roots and mosquitoes (ibid.). These necessitated proper protective gear to ensure a conducive working environment.

Quantity and Quality of Fingerlings

A major challenge facing aquaculture development in Tanzania today is that of the availability of a regular supply of quality fingerlings (Wetengere, 2009a). It is a chronic problem with several important dimensions: quantity, quality, cost of producing fingerlings and means of distributing fingerlings to the farmers (FAO, 2000). The main source of fingerlings for most marine species is collection from the wild (Wetengere and Madalla, 2011; Mmochi, 2011; Bueno, 2011). Fingerlings are collected by farmers, fishermen or local collectors. The dependence on wild collection constrains the development and sustainability of aquaculture: Firstly, it is difficult to collect the amount for the correct stocking rate of the pond/cage especially for bigger ponds/cages. Most ponds/cages seen during the field work in Zanzibar were understocked or not stocked at all. This is possibly also because farmers were unable to pay for a large number of fingerlings at a time. Secondly, occurrence of wild fingerlings is seasonal and location specific. There are generally two peak seasons for fingerlings coinciding with long and short rainy seasons. In Zanzibar, studies indicate peak abundance from February to May and October to November (Dubi et al., 2004) with significant periods when fingerlings are not readily available. This compels the farmers to a culture period coinciding with the abundant supply of fingerlings. Lunar cycles also influence the occurrence of fingerlings in the coastal waters. For instance, milkfish spawn in the wild during the first and last quarter moon, so fry are abundant in coastal waters during full and new moons. Fingerling catches increase when the wind direction is towards the shore. They are normally caught in sandy shores, estuaries and mangrove areas. Thirdly, the fingerlings are not all of the same size which impacts on growth and harvest. Moreover, a number of other fingerlings species are also caught some of which are carnivorous and predate on milkfish resulting in large losses (Mmochi, 2011). Finally, collection from the wild does not guarantee the quality of the fingerlings.

Importantly, questions arise about the long-term sustainability of wild caught fingerlings and the effect on biodiversity and recruitment if the aquaculture industry expands. The field work in Zanzibar revealed that most sites which previously had plenty of these organisms have started experiencing shortages of wild fingerlings, thus the pressure and desirability of setting up a hatchery. A good example is the acute shortage of sea cucumber fingerlings now along the Pemba coastal area compared to the 80s. To address the above shortcomings, there is a need to set up a system which will ensure that the production and distribution of fingerlings to farmers is carried out as a business. Wetengere et al. (2008) indicated that one farmer in Mahenge District in Morogoro region was able to do a lot of fish farming extension simply because he earned more income from selling of fingerlings than selling food fish and other farming products (ibid.). Later, however, as more ponds were stocked and demand for fingerlings decreased, so did his extension efforts. This shows how a lack of consistent demand for fingerlings has hindered the development of private fingerling producers and distributors in many areas (ibid.). This should serve as a lesson for fingerling production and distribution system which is intended to operate on commercial basis.

Feeding and Fertilization

Feeding is an important and critical issue for the higher trophic animals that need a high-energy, high-protein diet such as marine finfish, mud crab as well as shrimp. Milkfish were fed maize bran, rice bran, rice polishing, cassava meal and copra meal. The daily ration recommended was 10% of body weight at a feeding frequency of 2-3 times a day throughout the culture cycle (Wetengere and Madalla, 2011). Mud crabs were fed gastropods, trash fish and fish offal at a daily ration of 10% of body weight and a feeding frequency of twice a day. Fertilization was only an issue for milkfish ponds (ibid.). However, due to distance of the pond from the homesteads and unavailability of fertilizers, most ponds were fertilised only once per culture cycle. The fertiliser used was animal manure (cattle, chicken and goat) which was put in 20kg sacks and placed in the pond (ibid.). Management in most aquaculture projects in Tanzania was very poor due to ponds/cages located far from the homestead and unavailability of inputs (ibid.). Ponds/cages in some areas were located as far as 5 km away from homesteads and the environment was not conducive to proper management.

The application of feeds and fertilizers is a key factor in the success of aquaculture business. Availability of good quality feed is required to hasten the growth of the organisms. However, if most farmers were unable to feed the recommended amount of locally available feeds, it is unlikely that they will afford to buy good quality industrial feeds. So, targetting farmers who are able to buy feeds and operate aquaculture as a business should be given due emphasis. It should also be noted that the quicker aquaculture produce grows and the bigger the size, the more preferred in the market and the more profitable the product. Fertilization of fresh water fish ponds has a similar impact on the growth and size of aquaculture products.

Relative Advantages of Aquaculture technologies versus Other Competing Technologies

Aquaculture can contribute significantly to household food and income security. However, there are other activities which compete with aquaculture to meet those objectives. Household resources are allocated across various activities based on their contribution to household food and income security. For instance, milkfish, crab and sea cucumber farming competes with livestock production and capture fisheries to meet animal protein intake. It also competes with crop production, livestock production, capture fisheries and off-farm activities to generate cash income. The decision whether to adopt, continue or intensify aquaculture activities will depend on the relative advantage of aquaculture against other competing production activities. The key characteristics determining the choice of production activity include: profitability, marketability, operation costs, immediacy of reward, complexity and status. Of the six characteristics profitability, marketability, immediacy of reward and risk are the most important in the development of aquaculture.

Wetengere and Madalla (2011) showed that aquaculture was ranked low in all attributes. Fish from capture fisheries which aquaculture was intended to reduce fishing pressure was ranked high in all attributes. It was not surprising to see why aquaculture was performing poorly. This is similar to the field findings undertaken by this review where aquaculture also did not perform well in those attributes. Most participants depended on allowances and money provided by the projects rather than benefits accruing from aquaculture.

Profitability: A main reason for undertaking aquaculture should be to generate income. The underlying assumption in resource allocation is that aquaculture will attract resources only if it is more profitable than the competing activities. But aquaculture was the least profitable activity in many areas (Wetengere, 2010b; Wetengere and Madalla, 2011). Profitable activities produced products which were not easily perishable, were easy to transport, and were sold in distant urban markets. For example Wetengere (2010b) found that beans' was the most profitable crop in Morogoro and Dar es Salaam regions because it met the above conditions. The low profitability of aquaculture was attributed to low yield as most ponds were too small, were located far from homestead, were poorly managed, fertilisers and feeds were unavailable or too costly, poor quality fingerlings were used at low stocking density due to an insuffficent supply of fingerlings, irregular harvest, unreliable markets, animal predation, theft, and loss of aquaculture produce due to high tides.

Marketability: Money earned from fish farming is significantly determined by the market situation. Brummett (2000) showed that the ability to transport fresh product to urban centres where they can be sold for higher price determines the amount of money an aquaculturist makes. In Zanzibar farmers that sold their produce in Dar es Salaam earned more than those who marketed in their village. Farmers indicated that the marketability of fish and crab was determined by their size and most farmed fish and crab was small in size and fetched low prices. There is also huge international demand for crab and sea-cucumber which could be harnessed. A crucial attribute in both local and export markets is competitiveness. This means competing in cost, quality, reliability of supply and sometimes volume with the same products of other countries. It also means being competitive against substitutes.

Risk: Aquaculture was ranked as a most risky activity (Wetengere, 2010b; Wetengere, 2010c; Wetengere and Madalla, 2011). In Morogoro and Dar es Salaam regions and RUMAKI districts high risk in aquaculture was attributed to animal predation, human theft, high probability of ponds being washed by high tides, death of fish due deterioration of water quality, fingerlings transport, poor harvesting methods and rotting due to poor preparation and preservation methods (Wetengere, 2009; Wetengere and Madalla, 2011). Production of most agriculture crops were less risky compared to production of aquaculture products.

Immediacy of reward: Aquaculture was ranked last in terms of rewarding immediately or soon after starting the activity. Fishers indicated that the harvest of most aquaculture products was usually once a year compared to fisheries products which were harvested every day. Business and wild capture fisheries were the activities which rewarded faster followed by coconut farming (Wetengere, 2010b; Wetengere, 2010c; Wetengere and Madalla, 2011).

The above findings imply that the technological characteristics of aquaculture determining profitability, immediacy of reward, marketability and risk need to be improved.

GROUP OWNED AQUACULTURE PONDS/CAGES

Aquaculture can be carried out by an individual farmer, a family or a group of farmers (Balarin, 1985; Wetengere, 2008; Wetengere, 2011). Operating aquaculture activities in group was a result of advice from some projects (Balarin, 1985; Michielsens, 1998) or from farmers' own initiatives. Farmers may decide to operate aquaculture in groups for the following reasons: firstly, as a way to mobilize labour or funds particularly in doing labourious or time consuming or money demanding activities like pond or cage construction. Secondly, lack of suitable land for fish farming may force interested farmers to join other farmers with suitable land (Wetengere, 2008, 2011). Thirdly, the risk involved for each individual member in a group-owned pond/cage is minimal (Michielsen, 1998). Similarly, advocated for groups in aquaculture for the following reasons: firstly, more farmers could be reached during extension activities. Secondly, an aquaculture group could act as a demonstration entity in order to reach individual farmers. Thirdly, some development agencies and government institutions often promised to provide loan to farmers only when they operated in groups.

This review found that aquaculture groups experienced a number of problems. Firstly, there was poor attendance and sluggishness among members which often resulted in prolonged pond or cage construction (Michielsens, 1998; Wetengere, 2000; Wetengere, 2011). Secondly, some organizational problems such as quarrels, misunderstanding, difficult of agreeing what to do and conflicting interests were noted particularly when groups were too big (Wetengere, 2011). Thirdly, there was often a lack of commitment or willingness for some farmers to invest their time and inputs in the group activity. Fourthly, low returns from group-owned ponds/cages/farms discouraged members to participate actively. Fifth, most farmers joined groups expecting cash or material gain and once this was not realized they kept on complaining or dropped from the group or put less effort. Finally, it was difficult to compensate members who quit the group after or before harvest.

Based on the above it was advised that extension approaches targeting voluntary groups of farmers should make it clear that group tactics are good for demonstration and marketing in form of association and cooperatives. Group enterprise approaches should be used as means for lowering product costs such as through marketing conditions rather than as means of production. Available information suggested that group work rather than group owned ponds/pens/farms would be more preferred and easy to manage (Wetengere, 2011). In agriculture for instance, farmers were mobilized to do certain activities like tilling land together but ownership of the farm belonged to an individual farmer. The same approach could be applied in milkfish farming and crab fattening where farmers as a group can undertake specific, preferably one-time, activities like pond/pen construction, milkfish/crab harvesting, pond repair and joint marketing of the aquaculture products to reduce transport and transaction costs. It was noted that during this field study, some farmers associated group-owned ponds with *ujamaa* (socialism), a policy which failed in Tanzania and was abandoned in the early 1980s. During this survey, farmers were asked to suggest what was to be done to improve production of milkfish and crab. An advice given by most farmers was to reduce the size of group members and/or to operate as a family or a company.

Conclusion and Recommendations

The objective of this study was to critically review and assess aquaculture trials in Tanzania, objectively concluding why the past and the on-going aquaculture trials have or have not been up scaled. The review shows that the aquaculture trials have largely not been up-scaled because of: low priority given to the aquaculture sector, targeted at the poor section of the community, introduction of projects that encouraged dependency, the unmet objectives for undertaking aquaculture, the poor location of aquaculture farms, a lack of availability of quality fingerlings in the right quantities, inadequate feeds and fertilization, relative disadvantage of aquaculture in comparison to other competing activities and lack of ownership of the aquaculture projects. This review suggests the following: Firstly, government support in creating an enabling environment in form of formulating appropriate policy, laws, regulations, guidelines, investments promotion and regulation of the aquaculture sector is vital. Finally, operating aquaculture as a business will enable it to address all the determinant factors for success of aquaculture trials identified by this study.

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