GROWTH PERFORMANCE, FECUNDITY AND SEXUAL GROWTH DIMORPHISM OF *Oreochromis esculentus* AND TWO POPULATIONS OF *Oreochromis niloticus* UNDER CAGE CULTURE IN KISII COUNTY, KENYA

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OF

AGRICULTURE AND TECHNOLOGY

2023

Growth Performance, Fecundity and Sexual Growth Dimorphism of *Oreochromis esculentus* and Two Populations of *Oreochromis niloticus* Under Cage Culture in Kisii County, Kenya

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A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Science in Zoology (Conservation Biology) of Jomo Kenyatta University of Agriculture and Technology

2023

DECLARATION

This thesis is my original work and has not been presented for a degree in other university

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DEDICATION

This work is first and foremost dedicated to the Lord God Almighty whose spiritual guidance I sought and was forthcoming in my hours of great need. To my Parents, Andrew Muga, Janet Muga and Monica Muga for their guidance and support, even before embarking on this journey. To my Late Uncle Richard Muga, who kept prodding me to ensure that I complete the programme. To my wife Janet Kerubo for having been my pillar in encouraging me to soldier on. To my children Berkley, Leslie and Kimberly who have had to endure countless hours of missed quality time with their father. To baby Kingsley of whom I utilized my Paternity leave to complete my write up instead of rightfully being with him. To my siblings James, Martha, Deborah and Tito, for their words of motivation.

ACKNOWLEDGEMENT

I sincerely thank my able Supervisors; Prof. David Liti, Prof. Joseph Wakibia and Dr. Shadrack Muya who due to their tireless guidance took me through the entire period of my research, data collection, analysis, report writing and publication.

My gratitude to Prof. John Ochora, Dr. Peter Mwangi, Edwin Makworo, Elizabeth Nyanchiri, and the Jomo Kenyatta University of Agriculture and Technology (JKUAT) faculty members and staff, for the opportunity to be under their tutelage.

The National Commission for Science Technology and Innovation (NACOSTI) for the financial support that enabled me conduct the research work. I also acknowledge the research permit No: NCST/RCD/12B/013/7 that the commission issued me to conduct the research work.

My gratitude goes to the then Ministry of Fisheries Development for granting me study approval to undertake the Masters programme. The farm manager of the County Fish Multiplication and Training Centre (CFMTC), Kisii County; Mr. Gideon Gicheru and his team members comprising of Jeritah Mayaka, George Akunga, Meshack Mobisa, Jashon Ochola, Simon Otieno and Peter Mongare at the CFMTC. The Department of Agriculture, Livestock, Fisheries and Cooperative Development for allowing me to carry out the research at their facility.

Andrew, Mathias, Duncan and Julius who were instrumental in assisting me in the day to day data collection activity.

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ACRONYMS AND ABBREVIATIONS

ABDP	Aquaculture Business Development Programme
AU - IBAR	African Union – Inter – African Bureau for Animal Resources
CP	Crude protein
CFMTC	County Fish Multiplication and Training Centre
DO	Dissolved Oxygen
ERPARDP	Economic Recovery, Poverty Alleviation and Regional Development Programme
ESP	Economic Stimulus Package
F1	First filial
FAO	Food and Agriculture Organization of the United Nations
GIFT	Genetically Improved Farmed Tilapia
Grate	Growth rate
IFAD	International Fund for Agricultural Development
IUCN	International union for conservation of nature
JKUAT	Jomo Kenyatta University of Agriculture and Technology
KES	Kenya Shillings
MDGs	Millennium Development Goals
L_∞	Asymptotic length
NCST	National Council for Science and Technology
NACOSTI	National Commission for Science Technology and Innovation
NH_3	Unionized Ammonia
pH	Potential of Hydrogen
SE	Standard Error
SDGs	Sustainable Development Goals
SL	Standard Length
Temp	Temperature
TL	Total Length
UN – DESA	United Nations – Department of Economic and Social Affairs
W max	Maximum weight
W_∞	Asymptotic weight

ABSTRACT

The blue growth initiative can be a driver in helping to meet the increased demand for food. Tilapiine fish species, Singida tilapia, *Oreochromis esculentus*, a fish once prevalent in Lake Victoria and satellite lakes was relished by the local populace of the riparian Counties. Due to factors, such as predation by the Nile perch, *Lates niloticus* and competition by the introduced and closely related Nile tilapia, *Oreochromis niloticus*; its population has diminished drastically; hence necessitates for an intervention to ensure its sustainable existence. The main objective of this study was to evaluate the growth, sexual growth dimorphism and fecundity potential of *O. esculentus* and compare these traits with two populations of *Oreochromis niloticus* (from Kitaru dam and the County Fish Multiplication and Training Centre - CFMTC) in order to evaluate them for aquaculture. *O. esculentus* is a near threatened species, however little is known about its growth performance in captivity and potential for aquaculture in order to ensure its conservation. This study was conducted in twelve (12) 1 m^3 fish cages installed in a $362m^2$ production pond. The pond was located at the CFMTC, in Kisii town (S 00°40.308' E034°46.482'). The first filial (F1) generation of fingerlings of both *O. esculentus* and *O. niloticus* were sourced from brood stock from Gesebei and Kitaru dams in Nyamira County together with the Kisii CFMTC. Weight and length measurements of the fish from the two species were measured for a period of eight (8) months from March to November 2015. Samples of the fish were collected biweekly for weight and length measurements. Eggs / fry were retrieved from brooding females and relative fecundity was evaluated. Analysis of variance (ANOVA), regression analysis and Tukey test were conducted using the statistical package Statgraphics Centurion version 17.0. Results indicated that the asymptotic weight of *O. niloticus* from CFMTC (329.7±5.48 g) and that of *O. esculentus* (317.7±5.48 g) were significantly higher ($F_{2,2110}$=61.9, p<0.05) than that of *O. niloticus* from Kitaru (258.8±5.48 g). The *O. esculentus* had the highest asymptotic length of 30.5±0.29 cm, followed by *O. niloticus* (CFMTC) 28.5±0.29 cm and 26.5±0.29 cm for *O. niloticus* (Kitaru) ($F_{2, 2110}$=94.36, p<0.05). There was no significant difference in growth performance between the males and the females of *O. esculentus* in terms of asymptotic length ($F_{1,712}$=9.17, p>0.05) and weight ($F_{1,712}$=4.725, p>0.05). There was a significant difference ($F_{1,664}$=340.4, p<0.05) in asymptotic lengths (L_{∞}) and ($F_{1,664}$=342.1, p<0.05) weights (W_{∞}) between the males and the females of *O. niloticus* from CFMTC. Similar observations were also obtained for the males and females in *O. niloticus* from Kitaru ($F_{1,664}$=340.4, p<0.05). For the relative fecundity, there was no significant difference ($F_{2,269}$=0.652, p>0.05) among the slopes, of the three populations. The female and male of the *O. esculentus* from Gesebei dam had similar performance in both length and weight. This observation suggested that in a given environment, both sexes grow at the same rate and mature at the same size. The female and male of the two populations of *O. niloticus* (CFMTC and Kitaru dam) had distinct performance for both length and weight. This observation confirms the view that *O. niloticus* is the most prominent species for culture and that the males on average are superior to female in growth. There was no difference in the relative fecundity for all the treatments. The study showed that the *O. esculentus* and *O. niloticus* (CFMTC) had similar performance in terms of weight but not in length in which *O. esculentus* had greater length than the latter. However, both *O. esculentus* (Gesebei dam) and *O. niloticus* (CFMTC) had better performance than the *O. niloticus* population from

Kitaru dam. The males and females of *O. esculentus* had similar growth performance. All the test fish were able to breed in cages despite the fact they did not have access to a substrate where they could make nests. The study therefore showed *O. esculentus* is suitable for recruitment into aquaculture as the aspect of either sex performing on par qualifies it as a species for mixed sex culture or monosex of either sex. It is recommended that the recruitment of *O. esculentus* as an additional species for aquaculture be considered for inclusion in the draft National policies. It is also recommended that the monosex culture of either female or male *O. esculentus* be considered. Further investigation into the breeding of fish in cages is crucial to identify potential novel approaches to breeding and rearing species *Oreochromis* for aquaculture purposes.

CHAPTER ONE

INTRODUCTION

1.1 Background of the study

The blue growth initiative is a driver in helping meet the increased demand for seafood (Food and Agriculture Organization of the United Nations (FAO), 2022). Seafood is important due its nutritive value; the omega 3 fatty acids are renowned for lowering cholesterol and thus limiting high blood pressure and possibility of cardiovascular diseases (McManus & Newton, 2011). They have also been associated with beneficial cognitive development and reduced risk of cancer, rheumatoid arthritis, dementia and Alzheimer's disease (McManus & Newton, 2011). Currently, fisheries and aquaculture supports 58.5 million people employed in the fisheries sector (FAO, 2022). In the world today, supply of fish is set to reach 190 million metric tonnes by 2030 (FAO, 2022). This is an increase of 36 million tonnes as at 2011 (FAO, 2022). In Africa, the aquaculture sector has seen a high growth of about 10% between 2006 and 2018 (African Union – Inter – African Bureau for Aquatic Resources (AU – IBAR), 2019). The growth of aquaculture is the fastest globally and will probably fill the growing demand for fish in the continent (AU – IBAR, 2019). In Kenya, the blue economy is one of the sectors under the economic pillar of the sector plan for the blue economy under the Kenya Vision 2030 expected to contribute significantly to the Kenya's economic growth (Government of Kenya (G.O.K) Sector Plan for Blue Economy, 2018). The aquaculture sector's contribution to the Gross Domestic Product is approximately 0.8% supporting more than 4 million people along the value chain (AU – IBAR, 2019). Possibilities of a thriving aquaculture sub sector is indeed immense in the blue economy space with new species (not traditionally cultured) like the *Oreochromis esculentus* being promoted for culture as a food fish in addition to the traditionally cultured ones (Charo & Maithya, 2011).

Nearly 17,000 species of plants and animals are known to be threatened with extinction (Millennium Development Goals (MDGs) report, 2015). The loss of species will continue throughout this century, with increasing risk of dramatic shifts in ecosystems and erosion of benefits for society. Despite increased investment in conservation planning and action, the major drivers of biodiversity loss included high rates of consumption, habitat loss, invasive species, pollution and climate change (MDGs report, 2015). Biodiversity is important for human well-being with a wide range of ecosystem services on which life depends on (MDGs report, 2015). Billions of people, including many of the poorest, have always relied directly on diverse species of plants and animals for their livelihoods and often for their very survival (MDGs, 2010). There are 821 million people estimated to be chronically undernourished as of 2017, often as a direct consequence of environmental degradation, drought and biodiversity loss (Sustainable Development Goals (SDGs), 2016).

The world missed the 2010 target for biodiversity conservation, with potentially grave consequences (MDGs, 2010). The number of species facing extinction grew especially in developing Countries (MDGs, 2010). The Millennium development goals report also mentions that overexploitation of global fisheries stabilized, though steep challenges remained in ensuring sustainability (MDGs report, 2010). Fisheries policy and management will need to deal with matters of overcapacity in tandem with national and Sub national political as well as economic considerations (MDGs, 2015). To safeguard places that contributed significantly to global biodiversity, protected areas were established and identified as key biodiversity areas (MDGs report, 2015). In 2014, 15.2 per cent of the world's terrestrial and freshwater environments were covered by protected areas (SDGs – Department of Economic and Social Affairs (SDGs UN – DESA), 2015). The percentage of terrestrial key biodiversity areas covered by protected areas increased, from 16.5 per cent in 2000 to 19.3 percent in 2016 (SDGs, 2016). Over the same period, the share of freshwater key biodiversity areas that were protected increased from 13.8 per cent to 16.6 per cent, and the share of mountain key biodiversity areas under protection grew from 18.1 per cent to 20.1 per cent (SDGs UN – DESA 2015).

In fisheries production, only ten species provide about 30% of marine catch while 10 species provides about 50% of aquaculture production worldwide; these are in order of volumes: Grass carp (*Ctenopharygodon idellus*), Silver carp (*Hypophthalmichthys molitrix*), Common carp (*Cyprinus carpio*), Nile tilapia (*Oreochromis niloticus*), Bighead carp (*Hypophthalmichthys nobilis*), *Carassius* spp., Catla (*Catla catla*), Atlantic salmon (*Salmo salar*), Roho labeo (*Labeo rohita*) and Pangasius catfishes (*Pangasius* spp.) (SDGs UN – DESA 2015). There exists a vital web of thousands of interconnected species, which support fisheries and aquaculture (FAO, 2018). The species contribute to the nutritional, economic, social, cultural and recreational wellbeing of humanity (FAO, 2018). The global total capture fisheries production in the year 2014 was 93.4 million metric tonnes (FAO, 2016). This was for both marine and inland water sources. Production from marine waters was 81.5 million metric tonnes in 2014, which indicated a slight increase from 2012 (FAO, 2016). The inland waters world catches contributed 11.9 million metric tonnes in 2014 (FAO, 2016). This is indicative of a positive trend of 37% in the past decade (FAO, 2016). The world's aquatic ecosystems are highly diverse structurally and functionally. Aquatic biodiversity is sustained in the wild across marine (oceans, seas, estuaries, brackish)and freshwater (lakes, reservoirs, rivers, rice paddies and other wetlands) environments, including under culture within managed production systems (FAO, 2018). Freshwater ecosystems, although they contain less than 1 percent of all water, hold approximately 40 percent of the world's fish species (FAO, 2018). Biodiversity is critical and its erosion will impair the potential for the aquatic ecosystems to adapt to new challenges such as population growth and climate change (FAO, 2018). In the past few decades, the role of biodiversity in supporting a number of critical ecosystem services has gained more and more attention (Beaumont *et al*., 2007). Most recently, a number of governments have made international commitments to conservation of marine biodiversity within the framework of the 2030 Agenda and the Convention on Biological Diversity (CBD) (FAO, 2018).

Bearing in mind the limited number of fish species used for aquaculture production, there was need to investigate the aquaculture potential of the near threatened *Oreochromis. esculentus* fish species that belong to the Cichlidae family (Natugonza & Musinguzi, 2022). The species, *Oreochromis. esculentus* is found in Lake Victoria and its satellite lakes in Kenya, Tanzania, and Uganda especially L. Nabugabo, L. Kyoga, L. Kwania and the Victoria Nile above the Murchison Falls, the Malawa River in Uganda and Lake Gangu west of Lake Victoria (Trewavas, 1983). Its natural habitats were swamps and freshwater lakes (Twongo *et al.*, 2006) while its population status in Lake Victoria varied (Trewavas, 1983). After 1954 when Red belly Tilapia (*Tilapia zillii*) was introduced into the Lake Victoria, *Oreochromis niloticus* and Blue spotted tilapia (*Oreochromis leucostictus*) also appeared there, probably introduced incidentally with the *T. zillii* (Lowe – McConnell, 1975). It was later noted that *O. niloticus*, which became very successful, had displaced *O. esculentus* (Wanjala & Marten, 1974).

According to Aloo (2003), the second half of the last century witnessed drastic ecological changes in the Lake Victoria ecosystem with most notable decline in populations of many endemic Cichlid fishes. Furthermore, the Lake lost nearly 200 Haplochromines and one tilapiine, the *O. esculentus* due to the ecological changes (Aloo, 2003). Other than the introduction of *O. niloticus*, the predatory Nile perch (*Lates niloticus*) that was also introduced into the L. Victoria resulted in the endemic populations becoming rare, declining by more than 80% in the last 20 years (Twongo *et al*., 2006). In addition to the threat by the introduced species, fishing practices of seining was the preferred harvest method that resulted in enhanced efficiency and capacity but led to over fishing (Steeves, 2011). The over fishing led to dwindled stocks with fishers resorting to use of fishing gear with smaller mesh sizes. Smaller and younger fish were being caught because of fewer adults in the population (Steeves, 2011).

Aquaculture in sub-tropical and tropical developing countries including Kenya is practiced at either extensive or semi – intensive levels (Liti *et al*., 2002). In addition, the suitability of tilapiines for culture revolves around its ability to tolerate a wide range of environmental conditions as well as utilization of food from the lowest trophic level to the detrital food chain (Liti *et al*., 2002). This is particularly so with respect to *O. niloticus* the most successfully cultured tilapiine closely related to *O. esculentus* (Liti *et al*., 2002). Hence, recruitment of the latter into aquaculture could be considered as a conservation strategy. The semi – intensive culture of tilapia is particularly ideal in developing countries because it provides a wide variety of options in management and capital investment (Liti *et al*., 2002). The management strategies in the lower level of intensification could be managed by the use of fertilizer to encourage natural productivity and improved levels of dissolved oxygen (Liti *et al*., 2002).

1.2 Statement of the problem

Oreochromis esculentus is a species that is relished more by the local populace of the riparian counties that border Lake Victoria comparative to other introduced Tilapine species due to its superior taste. In Uganda, *O. esculentus* remains popular with the surrounding community within the three lake systems of Nabugabo, Kooki and Kyoga. However, it is no longer abundant due to several factors including among others, predation and competitive exclusion by other exotic fishes notably *L. niloticus* and *O. niloticus* as well as increased fishing pressure. Bearing in mind the concerns of biodiversity loss cited in the MDGs and the SDGs report, there was a need to investigate the conservation potential of the near threatened *O. esculentus* through aquaculture. However, little is known about its growth performance, fecundity and sexual dimorphism in captivity and its potential for aquaculture.

1.3 Justification of the study

The *O. esculentus* (also known as Savoury cichlid) was delicacy fish of choice by the local populace with respect to its high palatability. It was an important food fish for the people of L. Victoria as a dietary protein input. It is a near threatened species of fish, which is currently placed in the red list status as per the International union for the conservation of nature and natural resources (IUCN, 2022). The red list status is a step away from the category of being vulnerable with a decreasing population trend; hence, concerted efforts have to be made to ensure the species sustained existence through aquaculture. There is need for conservation of the species through aquaculture. This was done by investigating its growth performance under aquaculture systems with compared performance to the traditional *O. niloticus*. If found to be promising, it would qualify as a possible candidate for culture hence ensuring food and nutrition security. Therefore, the need to determine its aquaculture potential.

1.4 Objectives

1.4.1 General objective

To evaluate the growth performance, fecundity potential and sexual growth dimorphism of Singida tilapia (*Oreochromis esculentus*) and two populations of Nile tilapia (*Oreochromis niloticus*) (CFMTC) and (Kitaru dam) under cage culture in Kisii County.

1.4.2 Specific objectives

1. To determine and compare growth performance of *Oreochromis esculentus* and two populations of *Oreochromis niloticus* (from the CFMTC and Kitaru dam) under cage culture.
2. To determine and compare sexual growth dimorphism of *O. esculentus* and two populations of *O. niloticus* (from CFMTC and Kitaru dam) in a semi intensive cage culture system.
3. To determine and compare the relative fecundity of *O. esculentus* and two populations of *O. niloticus* (from CFMTC and Kitaru dam) under cage culture.

1.5 Hypothesis

There is no difference in growth performance, fecundity and sexual growth dimorphism of *O. esculentus* and two populations of *O. niloticus* under semi intensive cage culture system in Kisii County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Introduction

The literature is presented to address previous knowledge underlying the study. As a conservation strategy through recruitment of *Oreochromis esculentus* as a possible species for culture, its growth performance in relation to the traditionally cultured species of *Oreochromis niloticus,* required to be studied. Not much in terms of culture of *O. esculentus* had been undertaken previously and hence the importance in undertaking the current study.

2.2 Description and feeding of *Oreochromis esculentus* and *Oreochromis niloticus*

The *O. esculentus* belongs to the Cichlidae family. A specimen of the species is shown below (see Plate 2.1).

Plate 2.1: ***Oreochromis esculentus*** **from Gesebei dam, Nyamira County**

The *O. esculentus* scientific classification is as follows; Kingdom – Animalia; Phylum – Chordata; Class – Actinopterygii; Order – Perciforms; Family – Cichlidae; Genus – *Oreochromis* and Species – *O. esculentus* (Graham, 1928).

According to Genner *et al*. (2018), a short description of the species was enumerated as follows; this was based on the holotype and 24 other specimens of 108 – 248 mm standard length (SL), from Lakes Victoria, Kyoga and Nabugabo and 5 juveniles of 51 – 63 mm SL from Lake Kwania. Body depth of the adults was between 40.5 – 45.4 mm, whereas juveniles were between 39.8 – 42.7 mm. Body depth refers to the maximum vertical distance between the dorsal and ventral margin of the fish body (Soranganba & Saxena, 2007). Length of head was 33.0 – 37.5 mm and over 34.0 mm in three quarters of specimen over 100 mm SL. The length of caudal peduncle was 12.0 – 15.8 mm. Diameter of eye is 19.0 – 24.8 mm at 109 – 185 mm SL and between 16.0 – 18.8 mm at 190 – 248 mm SL. The teeth were arranged in 3 series at 100 – 150 mm SL, between 4 – 5 series above 240 mm SL and between 2 – 3 series in juveniles. The Lower pharyngeal bone was longer than wide in adults with fine and crowded teeth. Scales on cheek were usually in 3 rows, occasionally 2 between dorsal and lateral line 4 – 5.5 or over 5 top of caudal peduncle, above lateral line 8 or 9. Dorsal spines/ dorsal soft rays formula was XVI – XVIII (10 – 12). For the anal spines / anal soft rays, the formula was III – IV (9 – 12). The vertebrae numbered between 30 and 31.

According to Trewavas (1983) and Genner *et al*. (2018), the caudal fin is truncated and often rounded due to wear and tear in adult fish. It was not densely scaled, but in large specimens, small scales sometimes extended to the rays nearly to the margin and were rather dense on the upper and lower rays. The genital papilla of the male was not prolonged, but could be bluntly bifid and had a number of short lobes of spongy texture (Trewavas, 1983). The general colour of the female and non-breeding male was olive brown to watery green, graded to cream or silvery white below (Trewavas, 1983; Genner *et al*., 2018). Soft vertical fins were usually with round white spots while the young possessed a clear ringed, conspicuous Tilapia mark, which sometimes could still be detected up to 170 mm SL, although not ringed (Trewavas, 1983). The breeding males' colours were predominantly black and red, with the black involving the whole ventral surface from mouth to anus, the pelvics and the anterior part of the anal fin as well as the dorsal fin (Trewavas, 1983; Genner *et al*., 2018). The white or greenish white spots on the dorsal and caudal fins could be intensified in the male (Trewavas, 1983; Genner *et al*., 2018). The sides of the head and body above the black area were crimson and elsewhere the scales were grey with pinkish – fawn edge (Trewavas, 1983; Genner *et al*., 2018). Welcome (1967) measured the length of the intestine in several fishes of *O. esculentus* and the introduced *O. niloticus*, *O. leucostictus* and *T. zillii* from 70 to 290 standard length. The intestine increased in length with the length of the fish (Welcome, 1967).

2.2.1 Feeding ecology of *Oreochromis esculentus*

The food of the *O. esculentus* in nature is overwhelmingly planktonic with blooms of the diatom *Aulacoseira* being associated with high yields of the species (Trewavas, 1983). The *O. esculentus* species is a plankton feeder that uses the mucus trap mechanism combined with its pharyngeal teeth (Trewavas, 1983). The *Aulacoseira* are diatoms that are unicellular although some species form colonies (Round *et al.*, 1990). According to Katunzi (2004), *O. esculentus* is essentially a phytoplankton feeder with *Aulacoseira*, *Botryococus* and *Porphyridium* found in large quantities in the stomach suggesting their relative importance in the diet of the *O. esculentus* (Katunzi, 2004). Higher plant materials like *Tetradon* spp., *Chlorella*, oocysts, rotifers and flagellates have also been found in small quantities in the stomachs of *O. esculentus* (Katunzi, 2004). *Chlorophycea* materials were also numerous. *Botryococus* appeared with very high frequency particularly at Lake Katwe. In Lake Victoria, *O. esculentus* fed on planktonic material particularly the diatoms (Lowe, 1956; Fryer, 1972; Witte *et al*., 1995). Stomachs of adult specimen comprised about 48.7% *Aulacoseira*. According to Payne (1971), *Aulacoseira* was noted as the most abundant item in the gut contents and comprised 48.75% of the total cells present in all fish stomachs. Silicon, that is vital for phytoplankton growth is thought to have been adversely affected due to increased inputs of phosphorus and resulting in the sedimentation of the former (Payne,1971). The growth of *Melosira* (*Aulacoseira*) which was the main food of *O. esculentus* largely depended on silicon. (Payne, 1971). This resulted in the dominance of cynobacteria (*microcystis* spp.) that are low in energy content and hence poor food source (Lampert, 1981; Harney, 1987). This decrease in *Aulacoseira* may have contributed to the disappearance of *O. esculentus* in Lake Victoria (Lampert, 1981; Harney, 1987).

2.2.2 Feeding ecology of *Oreochromis niloticus*

The *O. niloticus* is an important fish in the ecology of tropical waters and aquatic systems in Africa (Offem *et al*., 2007). It feeds mainly on algae and other plant materials in addition to detritus making it a link between lower and upper trophic levels in the aquatic food webs (Otieno *et al.,* 2014). A specimen of the *Oreochromis niloticus* species is shown in Plate 2.2.

Plate 2.2: *Oreochromis niloticus* (CFMTC) specimen during sampling and data recording.

There is a great preponderance of plant food that is blue green algae, diatoms and parts of microphytes (Otieno *et al.,* 2014). In certain periods, chironomid larvae formed large quantities though amounted to less than 50% of gut content (Trewavas, 1983; Otieno *et* *al.*, 2014). The fish fry are omnivorous and actively pursue copepods, hydraccarines, aquatic and terrestrial insects that fall into water (Lamboj, 2004). They also peck on detritus and aufwuchs (Moriarty, 1973; Lamboj, 2004). On attaining 6 cm total length they become more phytoplankton feeders using the mucus trap mechanism and pharyngeal jaws (Moriarty, 1973; Lamboj, 2004). *O. niloticus* has a diverse feeding habit that includes algae, zooplankton, fish parts, insects, plant materials and detritus with algae being the dominant food item consumed by the fish contributing up to 56% of the diet (Otieno *et al*., 2014). The fish showed an ontogenetic shift in their feeding habits with zooplankton being important in the diet of fish below 16 cm TL (Otieno *et al*., 2014). Feeding for *O. niloticus* was more intense at around midday and very low at night indicating that they depend on sight for foraging (Otieno *et al*., 2014).

2.3 Growth performance

The search for tilapia strains with superior performance is becoming more important by the day. This is due to the increasing demand for healthy food worldwide (Dos Santos *et al*., 2013). This demand has required the assessment of these fish cultured under different environments. Improved groups of Nile tilapia have been incorporated into the aquaculture industry (Dos Santos *et al*., 2013). These include the Genetically Improved Farmed Tilapia (GIFT) (Bentsen *et al*,. 1998). Growth of fish is related to a complex process affected by many abiotic factors including temperature and dissolved oxygen. (Dos Santos *et al*., 2013; Martínez *et al*., 2014). In captivity, determination of the optimal environment to realize the best growth performance is essential for the optimization and maximization of production (Ghouili *et al.,* 2018). Growth rate can be easily calculated fitting an exponential model, using the initial and final weight during a specific period considered necessary (Gamito, 1998). Growth performance is determined in terms of weight gain = (W_2-W_1; where W_2 is the final weight at harvest and W_1 is the initial weight at stocking) and through measuring the final length and weight and subjecting to them to analysis (Githukia *et al.*, 2015). Studies have shown that there is a large difference in relative culture performance of different populations and strains of tilapia across a range of environments (Mair, 2001). Fish and particularly in tilapia, strains are normally associated with the locality or origin and possess no distinctive traits, this can lead to confusion (Mair, 2001). In a study that was comprehensive, Eknath *et al*. (1993) compared the growth performance of eight strains of Nile tilapia. The strains include four from Africa (Egypt, Kenya, Ghana and Senegal) and four farm Asian strains from Israel, Singapore, Taiwan and Thailand. The African strains performed at par or better than the Asian strains (Eknath *et al*., 1993). The Egyptian strain performed the best while the Ghanaian was the lowest (Eknath *et al*., 1993).

2.4 Sexual growth dimorphism.

In quite a number of fish species, one sex grows faster or matures earlier than the other (Piferrer *et al*., 2012). Sex related growth differences which results in size dispersion is referred to as sexual growth dimorphism and therefore classification must be done in management regimes to avoid cannibalism or size hierarchies affecting social relations (Dou *et al*., 2004). Sexual growth dimorphism can favour males e.g. tilapias (*Oreochromis* spp.) (Beardmore *et al*., 2001) or more frequently females like the flatfish turbot (*Scophthalmus maximus*), European sea bass (*Dicentrarchus labrax*) and Salmonidae family (Salmon, trout, char, whitefish and graylings) (Imsland *et al*., 1997; Martínez *et al*., 2014).In aquaculture, growth rate is the main trait in terms of production (Lind *et al*., 2015). The differences noted in tilapiines due to sex, result in varied sizes of individuals due to faster growth associated with males in comparison to female (Lind *et al*., 2015). The present study intended to determine if sexual growth dimorphism with respect to the male and female of *O. esculentus* is pronounced in this species that is closely related to the traditionally cultured *O. niloticus.*

2.5 Growth plasticity

Plasticity is the ability of a given genotype to produce different phenotypes in response to different environments. It is part of the organisms' adaptability to environmental cues (Schnell & Seebacher, 2008). As with other species, there was evidence that the size at which breeding occurred with respect to *O. esculentus*, and probably also the rate of growth and maximum size are related to the size of the inhabited water body (Lowe, 1955a). According to Lowe (1955a), a pond population of *O. esculentus* in Korogwe had grown to 16 – 19 cm TL in under seven months. Garrod (1959) attempted to estimate the average growth rate of sections of Lake Victoria population of *O. esculentus*. His calculations were based on the presence in the scales of rings of irregular or broken circuli. Holden (1955) and Garrod and Newell (1958) showed that the presence in the scales of rings is related to the use of calcium reserves during the period of starvation accompanying sexual activity in the male and brooding in female.

The *Oreochromis esculentus* species reached a length of about 30 cm in nine years, and the growth rate was same at three of the four areas sampled (Garrod, 1960; Van Oijen, 1995). Throughout Lake Victoria, the species appeared to breed at an age of between two and three years and was full grown at about 10 years (Trewavas, 1983). Both Graham (1928) and Garrod (1959) noted that, especially in the Emin Pasha Gulf, large (up to 50 cm) individuals were found of unusual shape and heavy fin – spines (Graham, 1928). Both authors considered that these fishes had survived there because the fishery was less exploited there than elsewhere. In one of the *O. esculentus* specimen found at Emin Pasha Gulf, the number of rings on its scale was the highest (15) found and was considered to indicate an age of about ten years, thus not older than many 30 cm fishes (Garrod, 1960; Van Oijen, 1995). Garrod (1960) suggested that they were a late maturing group that had been able to maintain a higher growth – rate than the average.

2.6 Aquaculture perspectives for tilapias

Tilapia is one of the most important fish species cultured worldwide and males tend to grow larger than females (Lorenzen, 2000; Charo *et al.*, 2006). Due to this factor of better growth rate, methods of manipulating the sex of offspring to male for aquaculture have been adopted (Beardmore *et al.*, 2001). This has enhanced production and productivity and controlled the prolific reproduction of tilapia (Beardmore *et al.*, 2001). The attribute of faster growth rate of the male tilapia is what influences the uptake of monosex culture in holding units such as tanks and floating cages and also with the enhancement of stocking density in those and other holding units (Lind *et al*., 2015).However, it may be noted that certain reports indicate that mono sex production utilizing male only tilapia may not necessarily yield better results than a mixed sex culture (Kamaruzzaman *et al*., 2009). It may also be noted that the cost implications and resources needed for production of an all-male population may at a point in time be less lucrative than just going ahead with the production of a mixed sex population (Lind *et al.*, 2015). It may also be noted that certain niche markets such as the European Union, production as well as importation of aquaculture products that have undergone sex reversal with the use of hormones like the 17 α methyl testosterone are forbidden (Little *et al*., 2003). The intention of the present study was to ascertain whether *O. esculentus* could be one of those species that due to insignificance in sexual growth dimorphism does not warrant the mono sex production strategy in its production.

2.7 Conservation of endangered tilapiine species

Despite the Fisheries Act (Chapter 378: Laws of Kenya) having been in place and currently the Fisheries Management and Development Act of 2016, with various management measures for various fisheries, fish stocks are still dwindling more so in the over exploited Lake Victoria (Charo & Maithya, 2011). Lack of adequate enforcement coupled with lack of sense of ownership of the fisheries resource compounds the problem (Charo & Maithya, 2011). Various measures including co management with the resource users have been put in place through interventions like the Lake Victoria Environmental Management Programme (Charo & Maithya, 2011). However, the surest way of ensuring sustained supply of fish is through aquaculture production (Charo & Maithya, 2011).

According to (Charo & Maithya, 2011), conservation efforts include characterization of the refuge ecosystems of *O. esculentus* and Victoria tilapia (*Oreochromis variabilis*) (Charo & Maithya, 2011). It also involved the determination of their growth performance under culture conditions and assessing their suitability for aquaculture (Charo & Maithya, 2011). In addition, it included the recruitment of farmers to culture the species and testing the suitability of new dams and ponds under aquaculture (Charo & Maithya, 2011). Both species of *O. esculentus* and *O. variabilis* bred easily under culture conditions therefore production of fingerlings and their subsequent stocking in ponds, small water bodies and other larger water masses, including Lake Victoria, was a course of action likely to bring about restoration (Charo & Maithya, 2011). Rearing of indigenous threatened species should be considered as a way of minimizing the risks of total extinction of the species (Charo & Maithya, 2011). Liti *et al*. (2002) attest that testing of pond management strategies that are locally and regionally practicable, are required to identify those most cost effective; such testing may require a number of sequential experiments using different feeds and fertilizers. This could be considered for the critically endangered Singida tilapia as well.

2.8 Relative fecundity of fish

Relative fecundity is the number of eggs found in the ovaries of a specimen with respect to its body weight of which the unit of measure is specific, in either kilogrammes or grammes (Baegal, 1978; Adebisi, 1990). Fecundity is an important aspect in the recruitment and management of stock in fish production, whether it is in the natural water bodies or in aquaculture. (Qadri *et al.*, 2015). The biological importance of fecundity as a concise productivity capacity of female brood stock and its data in relationship to weight, length, size and age as morphological characteristics, provides a reliable index of density dependent factors affecting population size (Qadri *et al.,* 2015). One of the density dependent factors that affect population size is the competition for limited food resources amongst members of a population (Qadri *et al.,* 2015). This causes a population's per capita growth rate to change by either plateauing or falling with increase in population density (Qadri *et al.,* 2015). Increase in stocking density significantly reduced fecundity (eggs/ female) in *Oreochromis mossambicus* (Shubha & Reddy, 2011).

2.9 Breeding in *O. esculentus*

Either female or male sex of *O. esculentus* grew at the same rate and matured at the same size (Lowe, 1955a; 1956; Garrod, 1959). According to Cridland (1961), in over a period of twenty – three months, the average growth of males of ten aquarium bred pairs was faster than that of females. As with other species, the size of the initial breeding is determined by the environment they occurred, i.e. in aquaria, in the open lake and in ponds (Cridland, 1961). Garrod (1959) reports that in aquaria this may occur at 10 cm and at an age of five months. In a pond at Korogwe, Tanzania, to which *O. esculentus* was introduced, Lowe (1955a) found that both sexes had bred when they were less than seven months old and had reached a length of 16 – 19 cm TL. In Lake Victoria, the minimum breeding size was 20 – 21 cm; in some localities 19 cm (Lowe, 1955a).

Nests for *O. esculentus* were not definitely identified in Lake Victoria's turbid waters (Trewavas, 1983). At Korogwe pond, the nests were circular, basin shaped pits about 30 cm in diameter, corresponding to the small size of the breeders (Lowe, 1955a). Spawning sites were identified in Lake Victoria as the places where ripe males congregated and predominated in numbers over the females (Lowe, 1955a). Sex ratios tend to favour males than female. According to Nagayi and Ogutu–Ohwayo (2005) who sampled satellite Lakes in Uganda, the total counts of female per male were made as ratios of male: female (m:f). This was repeated for all lakes and was established that the overall sex ration of *O. esculentus* was 1,297 male and 1,079 females of those studied hence a ration of m: f = 1: 0.96 (Nagayi & Ogutu–Ohwayo, 2005).

The ovaries of females show that a female may have a succession of three or more broods in a spawning period, and it was surmised that this would be followed by a period of rest (Trewavas, 1983). Males remained sexually active for a long period. Cridland (1961) recorded seven broods from one pair in twenty – one months. Ripe ovarian eggs were pear shaped, with a long diameter of about 4.5 mm (Lowe, 1955b). Lowe (1955b) found some evidence that fewer eggs were produced in the last brood series than the first and also the maximum number increased with the size of the female, ranging from 324 in a fish of 17 cm TL to 1,672 in one of 36 cm (Lowe, 1955b). Female brooding eggs in the mouth were sometimes caught with ripe males, but more often moved off to the shelter of weed beds or swampy places (Lowe, 1956). The young became independent at a length of about 15 mm (Trewavas, 1983).

2.10 Farming systems of fish in aquaculture subsector

Aquaculture, compared to other crop and animal farming, is much more diverse and varied. There are many different species that are cultured, each with different ecological requirements (Mbugua, 2009). They have different water quality, feeding and breeding requirements. Aquaculture like any other culture production is done at different management and therefore intensification methods (Mbugua, 2009). Aquaculture production systems therefore have been developed to meet both the economic needs of the producer and the requirements of the species to be cultured (Mbugua, 2009).

The three main production systems in Kenya are extensive, semi intensive and intensive (Mbugua, 2009). In the extensive systems, little or no input is used in the production (Mbugua, 2009). Fish are stocked in holding units and left to fend on their own. Low stocking densities of less than two fingerlings per square metre and thus low yields of approximately 1,500 kg per hectare characterize the system (Mbugua, 2009). The main species cultured under this system include tilapiines (e.g. *O. niloticus*), catfish (*Clarias gariepinus*) and common carp (*Cyprinus carpio*) (Mbugua, 2009). A majority of small-scale subsistence farmers in Kenya fall under this category. Production in this system falls between 500 and 1,500 Kilogramme/ Hectare/ year (Mbugua, 2009).

The semi - intensive form the bulk of aquaculture practiced in Kenya (Mbugua, 2009). The holding units use natural productivity of the water to sustain the species under culture (Mbugua, 2009). To enhance productivity, the ponds are fertilized using organic and/ or inorganic fertilizer at varying proportions to enhance natural production (Mbugua, 2009). Use of exogeneous aqua feed is undertaken to supplement pond productivity (Mbugua, 2009). Polyculture or monoculture of the commonly cultured species is practiced and commercial production of these systems ranges between 1-3 Kilogrammes / m^3/ year (approximately 10 – 30 tonnes / Ha/ year) depending on management levels individual farmers employ (Mbugua 2009). The main species cultured under the semi intensive system are *O. niloticus*, *C. gariepinus* and *C. carpio* (Mbugua, 2009).

The table 2.1 below shows some stocking density of some management regimes practiced in aquaculture.

Table 2.1: Management regimes and stocking densities.

Management you intend to practice	Expected capacity	Number of fish to stock per square meter pond surface			
	(kg per 100m^2)	150 g	200g	300g	400g
1. Composting, grasses and small amounts of manure.	15 kg	1	0.75	0.5	0.38
2. Chemical fertilizers at maximum recommended rate.	25 kg	1.7	1.25	0.83	0.6
3. Manure and feed such as bran.	40 kg	2.7	2	1.3	1
4. Our best management practice: bran at ½ recommended rate plus chemical fertilizer at full recommended rate.	70 kg total 60 of tilapia; 10 of *Claria*s spp	4.7	3.5	2.3	1.75
5. Pelleted feed at ¾ ration plus fertilizer to bring total N and P to full recommended rate.	Estimated at 120 kg	8	6	4	3

In the intensive culture system, water flows in and out continuously (Mbugua, 2009). This allows for higher stocking density and the need for good quality water. Less land is required to produce similar quantities of fish as compared to extensive and semi intensive systems (Mbugua, 2009). The system employs raceways, tanks and floating cages as holding units. Complete formulated feeds are utilized and aeration of the holding unit is done (Mbugua, 2009). This system is used for high value fish and in Kenya there are very few and majorly produce Rainbow trout (*Onchorhyncus mykiss*) (Mbugua, 2009). Production from this system produces between 10 - 50 kilogrammes /m^2/ year (Mbugua, 2009). In Kenya, compared to production of 1,000 metric tonnes per annum in 2006, Aquaculture production rose to 18,656 metric tonnes in 2015, this yield was for all production systems countrywide (GOK, Ministry of Agriculture, Livestock and Fisheries, State Department of Fisheries Statistical bulletin, 2016). This was because of the Government led Economic stimulus programme (ESP) implemented in the 2009 – 2013 period (GOK, Ministry of Agriculture, Livestock and Fisheries, State Department of Fisheries Statistical bulletin, 2016). Other methods of intensification include the utilization of net cages in addition to ponds (Dias *et al.,* 2012). The culture of fish in cages uses a considerable amount of feed for aquatic organism production in relatively small areas/ volumes, stocked at high densities (Dias *et al*., 2012). These have impacts on the environment due to the metabolites and feed remnants into the surrounding waters (Dias *et al*., 2012). Utilization of net cages in aquaculture can increase global production of fish. Generation of basic information with respect to this production system is necessary (Dias *et al*., 2012).Culturing tilapiine species in cages at high density seems to be feasible with high survival rates of up to 99.5% (Osofero *et al*., 2009). They also attested of the inverse relationship between stocking density and survival rate of the cultured species (Osofero *et al*., 2009).What can be referred to as the initial true cages for fish production were probably developed in South East Asia towards the end of the 19^{th} Century (Masser, 2012). In the 1950s, synthetic materials were in vogue, cages were built using these, and as a result, the modern cage culture ensued (Masser, 2012). The advantages of cage culture include; many types of natural water bodies e.g. lakes, reservoirs, shallow dams, ponds, rivers and streams which may be problematic to harvest can be utilized; low initial investment; simplified harvesting; sampling and observation of the biomass is easy and allows other use like extensive fish farming and sport fishing (Masser, 2012). Quite a number of finfish species are suitable for culture in cages. Those of which research has taken place and have been reared successfully include tilapia in the southeastern region of the United States of America (Masser, 2012). *O. niloticus* Florida red tilapia and Aurea red tilapia are some of the tilapiines that have been reared in cages (Masser, 2012). In aquaculture, the method of cage culture seems promising as a method and has gained in roads worldwide due to advantages over the conventional fish farming practices in the form of use of ponds, raceways and tanks as holding units (Uddin *et al*., 2016). Cage culture system has advantages and disadvantages. The advantages include its installation in an existing body of water, meaning a relatively low initial investment, flexibility in management, effective use of Aqua feed, little manpower requirement, better control of fish population, ease of movement to a different locality, treatment of diseases, less investment due to the existing water body, fish handling is simple and less chances of predation (Soltan, 2016). The disadvantages include feed must be nutritionally complete and kept fresh, diseases are a common problem in cage culture systems (Soltan, 2016). The crowding in cages promotes stress and allows disease to spread rapidly, poor water quality, like low dissolved oxygen may affect fish leading to sudden losses, public water bodies may have competing interest to that of cage farming resulting in conflicts and caged fish are unable to get natural food of their choice (Soltan, 2016). In the year 2018, 963 metric tonnes of fish with a value of Kes 279,838,000 were harvested from cages (G.O.K, Ministry of Agriculture, Livestock and Fisheries, State Department of Fisheries Statistical Bulletin, 2020). This was up from the 2017 were 228 metric tonnes worth Kes 75,696,000 was realized. 75% of harvest from the cages was *O. niloticus.*

2.11 Government interventions in aquaculture

The Government through the fish farming programme sponsored by the ESP and its successor the Economic Recovery Poverty Alleviation and Regional Development Programme (ERPARDP) realized the establishment of 2,275 fishponds for beneficiaries in the Kenya (Government of Kenya (GOK), Kisii Central and Gucha District Annual reports 2010, 2011 and 2012). These reports indicated the high potential for aquaculture. In addition, GOK requested International Fund for Agricultural Development (IFAD) for support in designing and funding a project that supports smallholder aquaculture fish production (ABDP, 2017). In response, IFAD fielded two design missions (in March-April and June 2017) to review the issues with GOK, the rural communities and other public and private sector stakeholders, and to generate an appropriate package of capacity-building and investment measures to accelerate and consolidate the expansion of aquaculture production and trade within the country by realizing the productive potential of smallholders (ABDP, 2017). The ABDP envisaged a national scope but targeted Counties with high concentrations of aquaculture activity, high production, existing sectoral infrastructure (processing, marketing and research), adequate water resources and marketing potential. The Programme targeted Kisii in addition to 14 other Counties (ABDP, 2017).In conclusion, the outcome of growth performance of *O. esculentus* in relation to *O. niloticus* determines whether the former can be recruited as an aquaculture species and hence address the conservation aspect of this near threatened species currently placed in the red list for the IUCN (IUCN, 2022). Sexual growth dimorphism will be an indicator as to which management regime suits the species in relation to *O. niloticus* of which the monosex culture of males is common practice (Githukia *et al*., 2015). The importance of fecundity data is its utilization to determine the brood stock requirements, acquisition, estimation of survival, as well as planning for hatchery/ nursery management for the population and stock (Lasker, 1985; Qadri *et al*., 2015).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study site

The present study was carried out in fishponds at the State Department for Fisheries in their fish farm (S 00^{o}40.308’ E034^{o}46.482’) at Kisii County, Western Kenya (Figure 3.1). Kisii County is part of the catchment that drains towards Lake Victoria where *Oreochromis esculentus* is endemic.

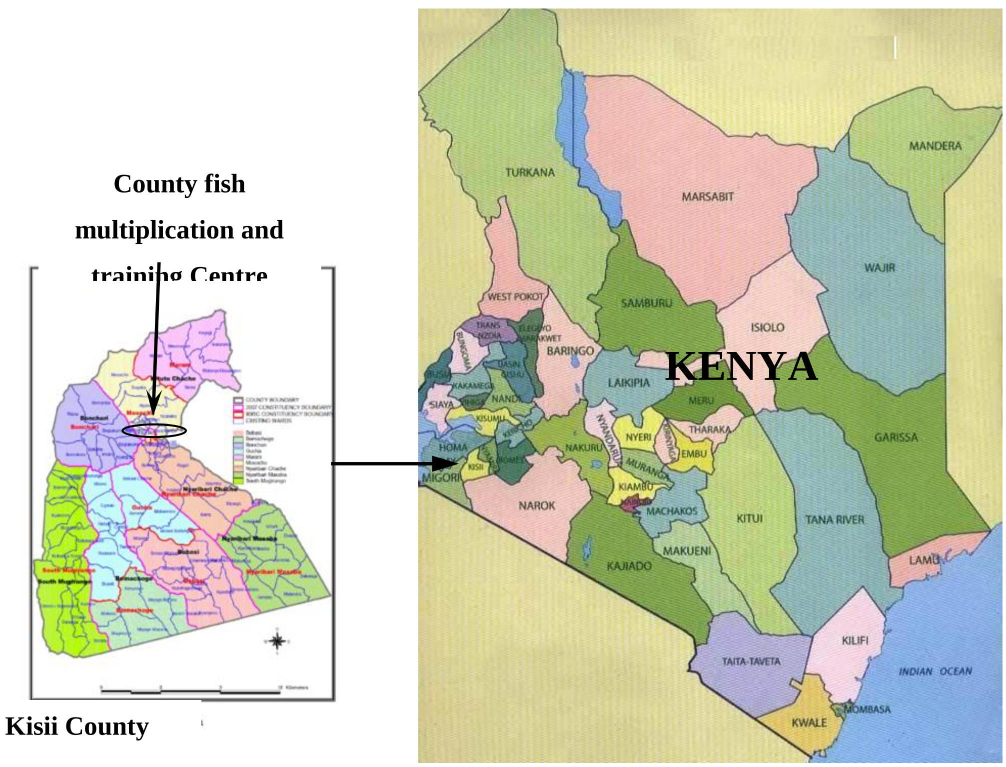

Figure 3.1: Map of study area courtesy of the County Integrated Development Plan (CIDP, 2018).

The Kisii County lies within the highlands west of the rift valley, 305.1 kilometres from Nairobi. Its elevations range from 1,250 m to 2,200 m above mean sea level. The County has a highland equatorial climate resulting in a bimodal rainfall pattern with an average annual rainfall of 1,500 mm. The County is endowed with numerous springs, streams and rivers therefore water as a resource is abundant. The minimum temperatures range from 15^o – 20^oC and maximum of 21^o and 30^oC. The County has high potential for agriculture development including aquaculture. The site was selected due to its accessibility and the agro geographical zone falling within the catchment of Lake Victoria where the fish species occur.

Source of fingerlings

Fingerlings of both *Oreochromis esculentus* and *Oreochromis niloticus* from the First Filial (F1) generation of brood stock were sourced from Gesebei and Kitaru dams in Borabu Sub County of Nyamira County while *O. niloticus* fingerlings were sourced from the brood stock at the County Fish Multiplication and Training Centre (CFMTC), Kisii County.

3.2 Experimental design for the study

A completely randomized block design was used for the present study. The experimental units were made of 12 cages of 1 m^3 installed in a large concrete pond measuring 362 m^2. One species of *O. esculentus* and two populations of *O. niloticus* were stocked in 12 cages of one cubic metre each. Three (3) treatments were used: the *O. esculentus* from Gesebei dam (Gesebei), the *O. niloticus* from County Fish Multiplication and Training Centre (CFMTC) and the *O. niloticus* from Kitaru dam (Kitaru).The fingerlings were stocked in groups of four cages (replicates) each for the *O. esculentus, O. niloticus* (CFMTC) and *O. niloticus* (Kitaru). The stocking density was 30 fingerlings per cage. The fish were fed isonitrogeneous and isocalorific diets with 28% dietary protein level. Fish were fed at 3% live body weight. Each ration was split in to two equal parts and fed twice a day at 10.00 and 16.00hrs, Plate 3.1 shows how the feed were administered to the fish.

Plate 3.1: A worker feeding the fish in the cages at the County Fish Multiplication and Training Centre (CFMTC), Kisii County

3.3 Sampling Design

The sampling design took into consideration the sampling unit, source list, size of the sample, parameters of interest, budgetary constraints as well as sampling procedure (Kothari, 2004). The study consisted of fish drawn from two species, *O. esculentus* and *O. niloticus*. The size of the sample was determined by the stocking density for a semi intensive cage culture system that requires a minimum of three fingerlings per cubic metre and minimum of three replicates. Hence, the number of items selected constituted juveniles of fish to be cultured through an eight month production cycle were restricted to 360 individuals in total. This was optimal stocking density for a semi intensive cage culture system that is a minimum of three fingerlings per cubic metre. The experiment was conducted between March and November 2015. The following parameters of interest were growth in terms of length and weight of the test species, in addition to the number of eggs per individual weight of female. Water quality testing in relation to the environmental factors that have a bearing of performance for the growth of fish were also measured. Budgetary constraints and limited holding units at the CFMTC also informed the decision for sample size taken for the trials.

In order to realize the objectives in the present study, activities undertaken towards meeting them are seen in Figure. 3.2 to help visualize its layout. This is as per an input, process and output concept akin to project implementation (Sace & Fitzsimmons, 2013).

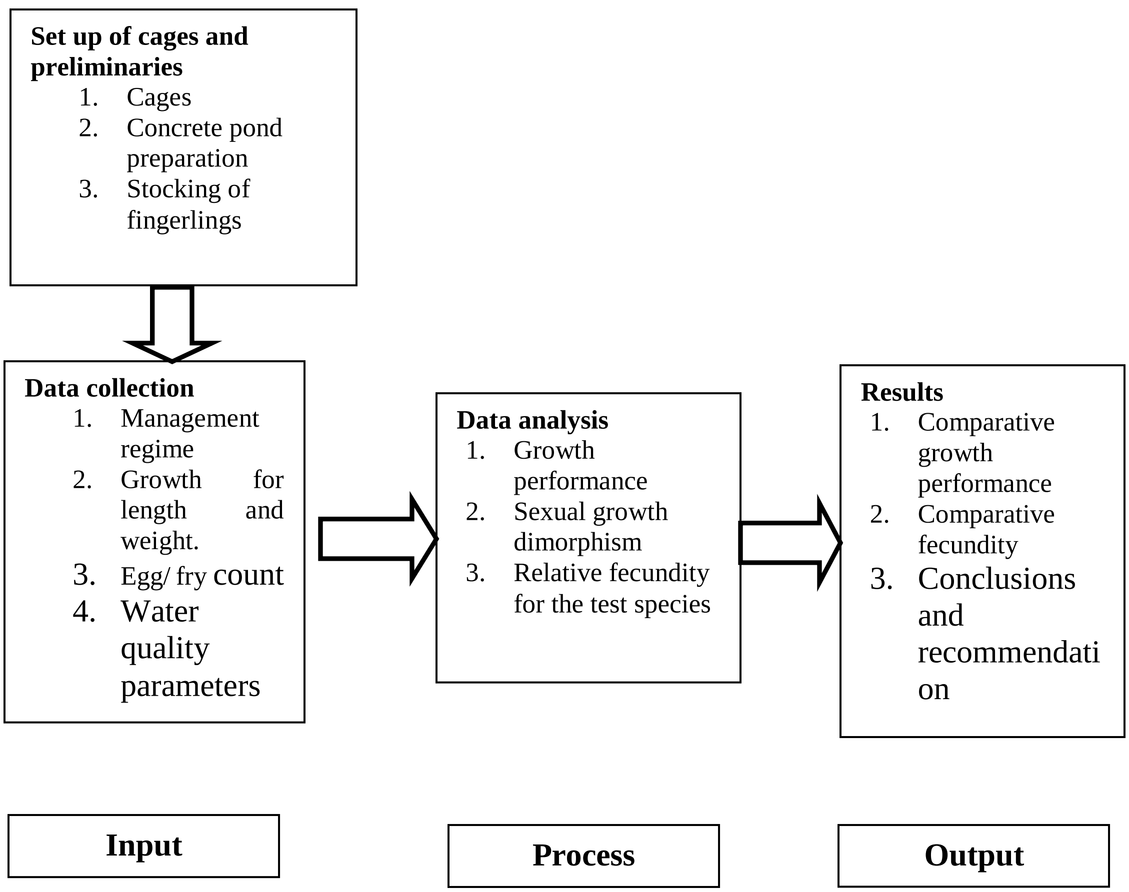

Figure 3.2: Summarized conceptual framework adapted from (Sace & Fitzsimmons, 2013)

In this case, the input to the production system to get the results are the cages for rearing the fish, the concrete pond that was used to install the cages, the fingerlings at the onset and feed utilized for their growth, fall under the management regime. The data collection for the length, weight, fecundity and water quality parameters also fall under the input for the trail. The growth performance, sexual growth dimorphism and relative fecundity data analysis using statistical packages forms the process. The end result for comparative growth performance, comparative fecundity, conclusions and recommendations are the output of the study.

3.4 Data Collection procedures for the experiment

3.4.1 Length and weight determination of fish samples

Sampling was undertaken biweekly for length and weight determination for the entire population of 360 fish contained in the cages. The study was conducted for eight months for both species from March to November 2015, where weight was measured using an electronic weighing scale (Scout Pro SPU 601, with a range of 0.1 – 600 grammes) whereas the length was measured using a graduated measuring board (Plate 3.2).

Plate 3.2: Measuring board (on the left) and electronic weighing scale (on the right) with a fish specimen on it

3.4.2 Relative fecundity of the fish samples

Relative fecundity for both *O. esculentus* (Gesebei) and *O. niloticus* (CFMTC and Kitaru) was calculated from the count of the total number eggs per gram of female (Bagenal, 1978). This was during the period of the biweekly sampling. The number of eggs/ fry were recorded alongside the specimen's total length and weight.

3.4.3 Sexual growth dimorphism of the fish sample

Determination of the sexual growth dimorphism for both *O. esculentus* and *O. niloticus*, commenced during the month of August 2015, when the definite differentiation between male and female anatomy of both species could be determined without any reservations. During the biweekly sampling, sex, length and weight were recorded from each of the replicates for both *O. esculentus* and *O. niloticus*.

3.4.4 Environmental parameter

The following water quality parameters were determined: dissolved oxygen (DO), water temperature, pH, and the total ammonia nitrogen. The dissolved oxygen was taken using a dissolved Hanna type oxygen meter (Plate. 3.3).

Plate 3.3: Hanna DO meter used to record dissolved oxygen readings

Water temperature (in degrees centigrade) was taken using the thermometer reading on the DO meter. Potential Hydrogen (pH) was recorded using a Hanna type pH meter (Plate. 3.4).

Plate 3.4: Hanna type pH meter

The total ammonia nitrogen was measured in situ using an ammonia testing kit (Model HI 28049, Hach, USA) (see Plate 3.5). The DO and temperature were recorded three times a day, in the morning at 8 am, at noon and evening at 5 pm. The pH was measured at 8 am and 6 pm. The total ammonia nitrogen was measured in situ in the evening at 6 pm. The water quality parameter measurements were taken at four points within the pond and the average of the readings was recorded.

Plate 3.5: Ammonia testing kit (Model HI 28049, Hach, USA).

These parameters (except for unionized ammonia which commenced in August 2015) were measured daily from the onset of the study in March 2015. All the parameters were then inputted in an excel computer package from the initial hand written record of a field notebook.

3.5 Data analysis

Growth performance

To evaluate the growth performance of the different fish species, the Von Bertalanffy growth model was used to estimate the growth parameters asymptotic length (L_∞), asymptotic weight (W_∞), and growth coefficient (K). The following formula was used (Pauly *et al.*, 1993):

$$L_t = L_\infty (1 - e^{-K(t-t_o)})$$

where:

L_t = length at time t

L_∞ =asymptotic length or the maximum length the fish can grow indefinitely

K =growth coefficient

t_o = a scaling factor

The analytical procedure followed protocols described by Pauly *et al*. (1993), but modified to use differential represented by a linear regression equation:

$$LnWt = Lna + L_\infty * 1/Lt$$

where:

n as applied in $dl/dt = K (L_\infty - \bar{L})$

$(L_2 - L_1) / (t_2 - t_1) = a + b (L_1 + L_2) / 2$ (Gulland & Holt, 1959)

Analysis of variance (ANOVA) was used to determine whether there were significant differences in growth parameters (length and weight) among the three treatments.

Sexual growth dimorphism

To investigate sexual growth dimorphism in the fish populations, ANOVA was used to identify whether there were significant differences in asymptotic length and weight between male and female fish across the various populations. Regression analysis was used to understand the relationships between fish size and weight.

Fecundity assessment

To assess fecundity, which involves measuring the reproductive capacity of the fish, ANOVA was used to evaluate if there were significant differences in fecundity among different treatments. Regression analysis was used to explore the relationships between fish size and fecundity. Analysis of variance (ANOVA), regression analysis and Tukey test were conducted using the statistical package Statgraphics Centurion version 17.0 (version XVII, Statpoint Technologies, Inc. Warrenton, Virginia).

A research permit to undertake the research was sort for from the National Council for Science and technology as required by law for one undertaking research in Kenya vide a formal application and upon payment of the requisite fee of KES 1,000/=. A research clearance permit number NCST/ RCD/ 12B/ 013/ 7 was issued on the 31stof January 2013 that allowed the researcher to conduct the work in Kisii Central District of Nyanza Province, currently Kisii County in the new dispensation. This was subject to the conditions attached on the permit itself and is contained herein the Appendix I.

CHAPTER FOUR

RESULTS

4.1 Environmental parameters

Water quality parameters were taken for the entire culture period of the study in THE large concrete pond (362 m^2) and the average for dissolved oxygen (DO), pH, temperature (^oC) and unionized ammonia (NH_3) are summarized in Table 4.1.

Table 4.1: The Average Water Quality Parameters (Dissolved Oxygen PH, Temperature and Total Ammonia Nitrogen in the Large Concrete Pond Over the Culture Period (Means ± Se, N=4)

Parameter	**Means ± SE**
Dissolved Oxygen (mgL^{-1})	11.99±0.53
pH	8.67±0.18
Temperature (^oC)	24.84±0.18
Total ammonia nitrogen (mgL^{-1})	0.10±0.0

Where SE Is Standard Error of the Mean

4.2 Growth performance of *O. esculentus* and two populations of *O. niloticus*

The maximum average asymptotic length (L_∞) for the fish species were significantly different ($F_{2,\,2110}$=94.36, p<0.05), with the highest mean length of 30.5±0.29 cm obtained from *O. esculentus* (Gesebei) and lowest for *O. niloticus* (Kitaru) at 26.5±0.29 cm (Table 4.2). The mean asymptotic length of *O. niloticus* (CFMTC) was 28.5±0.29 cm. The maximum asymptotic weights (W_∞) for *O. niloticus* (CFMTC) 329.7±5.48 g and *O. esculentus* (Gesebei) 317.7±5.48 g were significantly higher ($F_{2,\,2110}$=61.9, p<0.05) than that of *O. niloticus* (Kitaru; 258±5.48 g). There was no significant difference in growth coefficient K in 365 days (Kyrs) and growth rate ($F_{2,41}$=2.495, p>0.05) among the treatments (Table. 4.2).

Table 4.2: The Average Asymptotic Length L_∞ (cm), Asymptotic Weight W_∞ (G), Growth Coefficient K (years), growth rate (g/day) and survival rate of *O. esculentus* and *O. niloticus* under cage culture (mean ±SE, n =4)

Species/ populations	L_∞ (cm)	W_∞ (g)	Kyrs	Grate
O. esculentus (Gesebei)	30.5±0.29[c*]	317.7±5.48[b]	1.0±0.03[a]	1.5±0.03[a]
O. niloticus (CFMTC)	28.5±0.29[b]	329.7±5.48[b]	1.0±0.03[a]	1.2±0.03[a]
O. niloticus (Kitaru)	26.5±0.29[a]	258.8±5.48[a]	1.3±0.03[a]	1.2±0.03[a]

*The values in the same column having different superscript letters are significantly different ($p<0.05$).

4.3 Sexual growth dimorphism of *O. esculentus* and two populations of *O. niloticus*

The results for sexual growth dimorphism of lengths and weights for males are presented in Figures 4.1 and 4.2, respectively. The asymptotic length (L_∞) (Figure 4.1) and asymptotic weight (W_∞) (Figure 4.2) of the male *O. niloticus* (CFMTC) at 47.66±2cm; 1,505±134gm were significantly higher ($F_{2, 1133}$=802.7, $p<0.05$) than the *O. esculentus* (Gesebei) and *O. niloticus* (Kitaru) males at (42.46±2cm; 884.54±134 gm and 42.04±1cm; 984.37±81gm respectively).

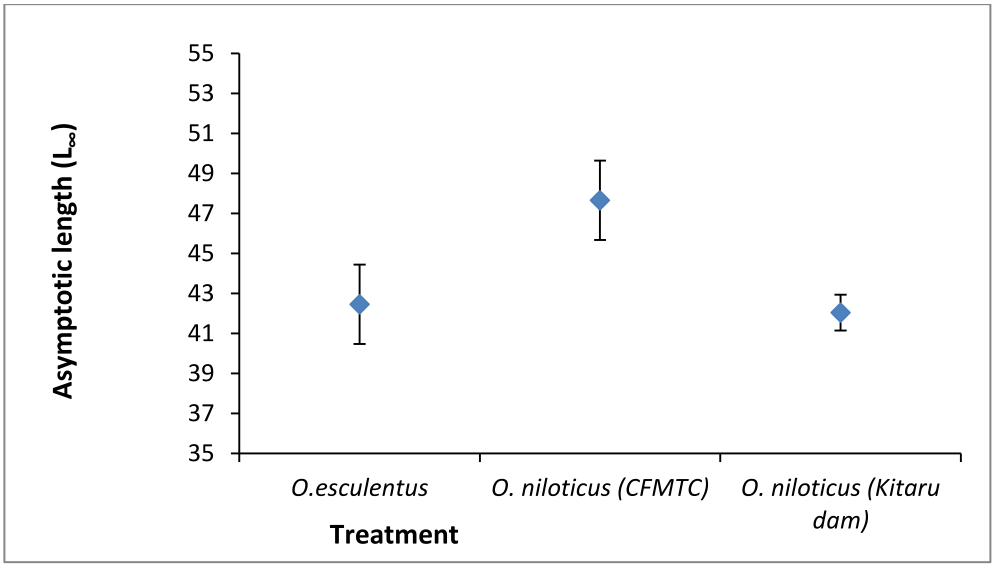

Figure 4.1: Average asymptotic lengths (cm) for males among treatments under cage culture (mean±95% confidence intervals (CI), n=4)

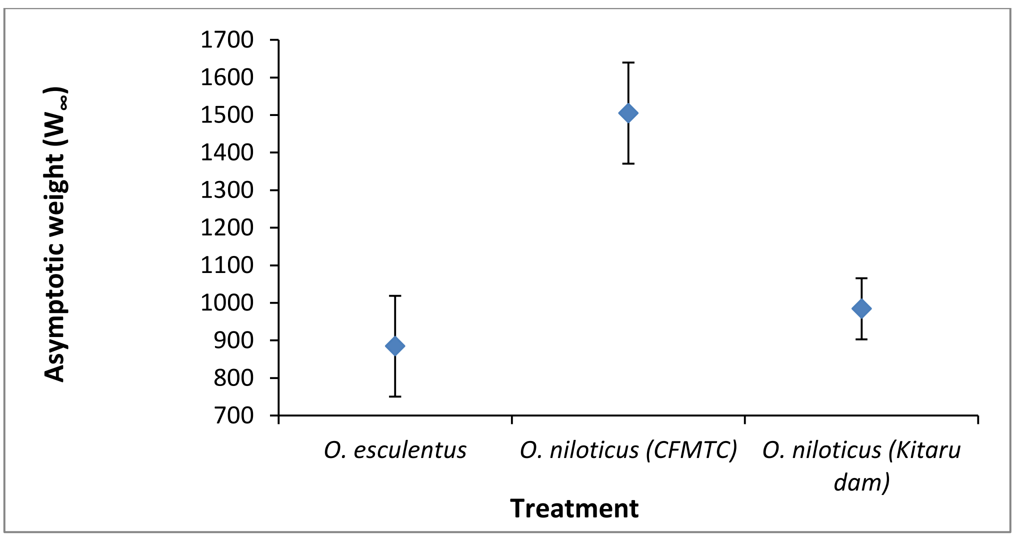

Figure 4.2: Average asymptotic weights (g) for males among treatments under cage culture (mean ± 95% CI, n=4.)

The sexual growth dimorphism of lengths and weights for females are presented in Figures 4.3 and 4.4, respectively. The *O. niloticus* (CFMTC) and *O. esculentus* (Gesebei) females recorded higher mean asymptotic lengths (41.54±2cm and 41.26±1cm) than the *O. niloticus* (Kitaru) females ($F_{2,946}$=161.6, $p<0.05$) (Figure 4.3). The mean asymptotic weights of the treatments were significantly different ($F_{2, 946}$=291.5, $p<0.05$) (Figure 4.4), with female *O. niloticus* (CFMTC) having the highest value (1000±110cm), female *O. niloticus* (Kitaru) the lowest (600±56cm), while female *O. esculentus* (Gesebei) was intermediate (800± 59cm).

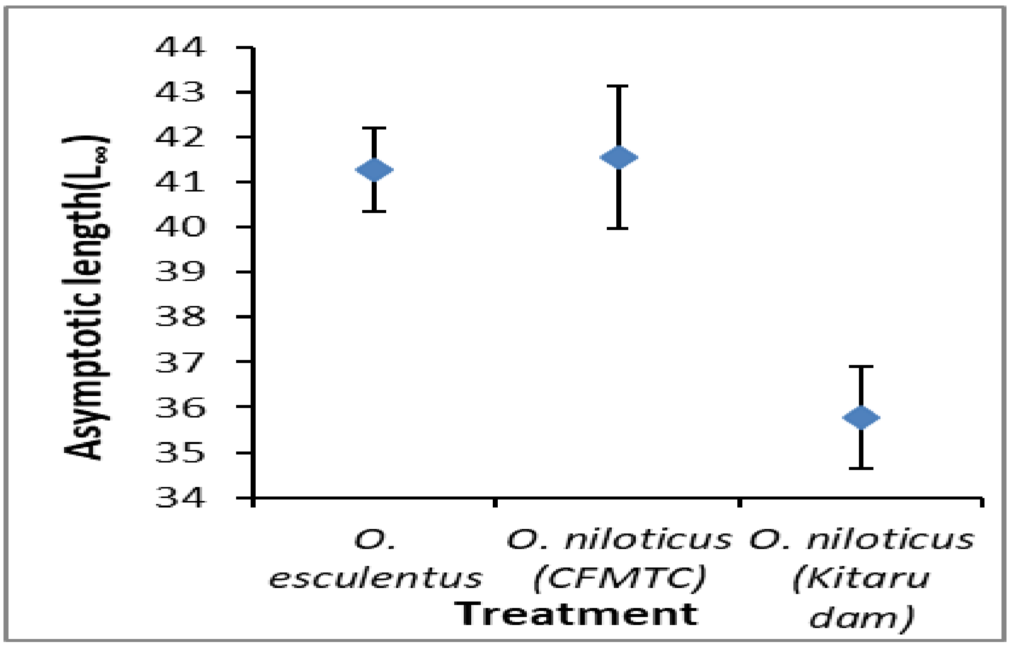

Figure 4.3: Average asymptotic lengths (cm) for females among treatments under cage culture (mean ± 95% CI, n=4)

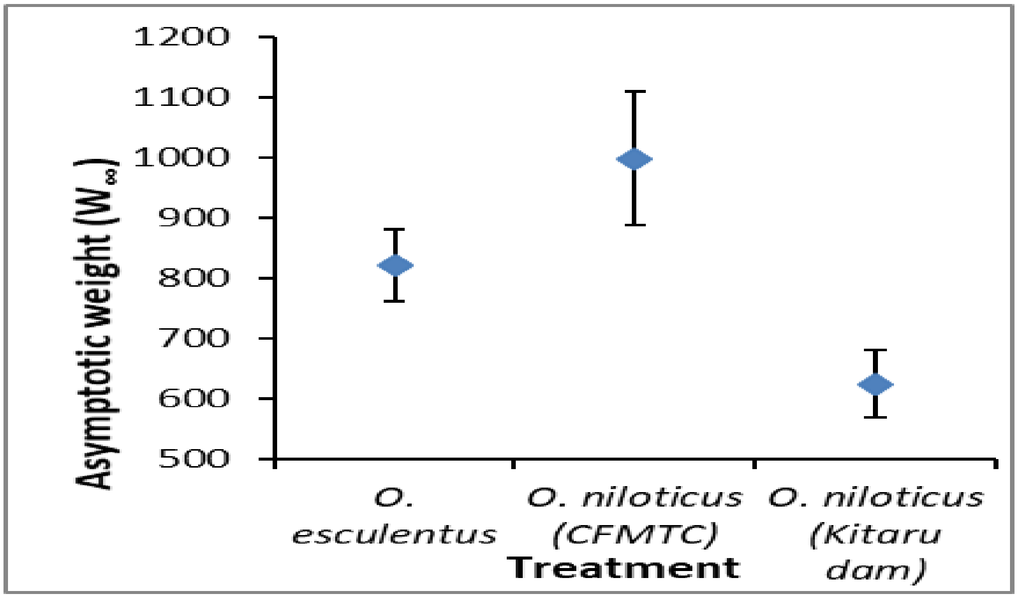

Figure 4.4: Average asymptotic weights (g) for females among treatments under cage culture (mean ± 95% CI, n=4)

There was no significant difference ($F_{1,712}$=9.17, p>0.05) in average asymptotic length at 42.46±2cm; 41.26±1cm and ($F_{1,712}$=4.725, p>0.05) in the average asymptotic weight at 884.52±139gm; 821.94±63gm between the males and the females of *O. esculentus* (Gesebei) (see Figures 4.5 and 4.6).

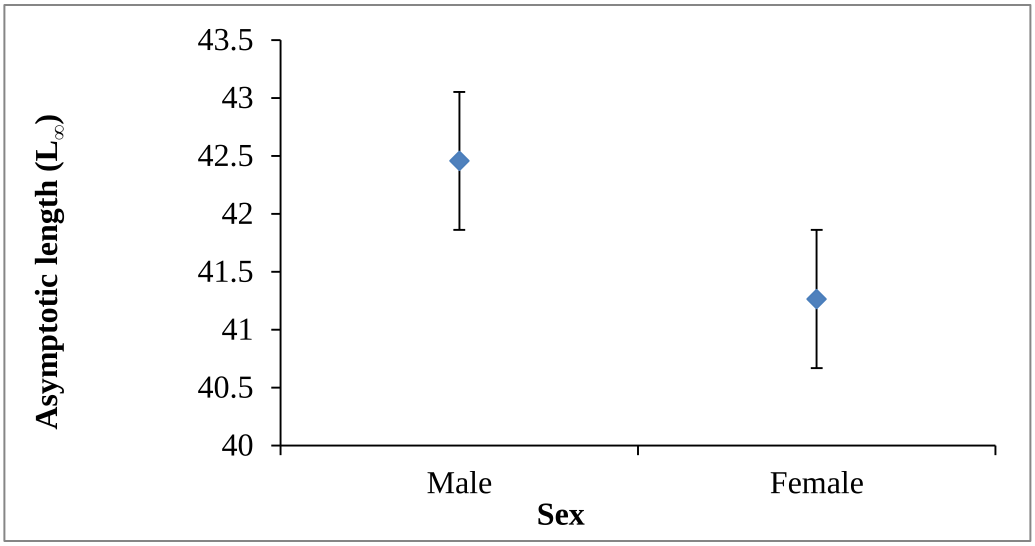

Figure 4.5: Average asymptotic length (cm) for males and female of *O. esculentus* (Gesebei) under cage culture (mean ±95% CI, n=4).

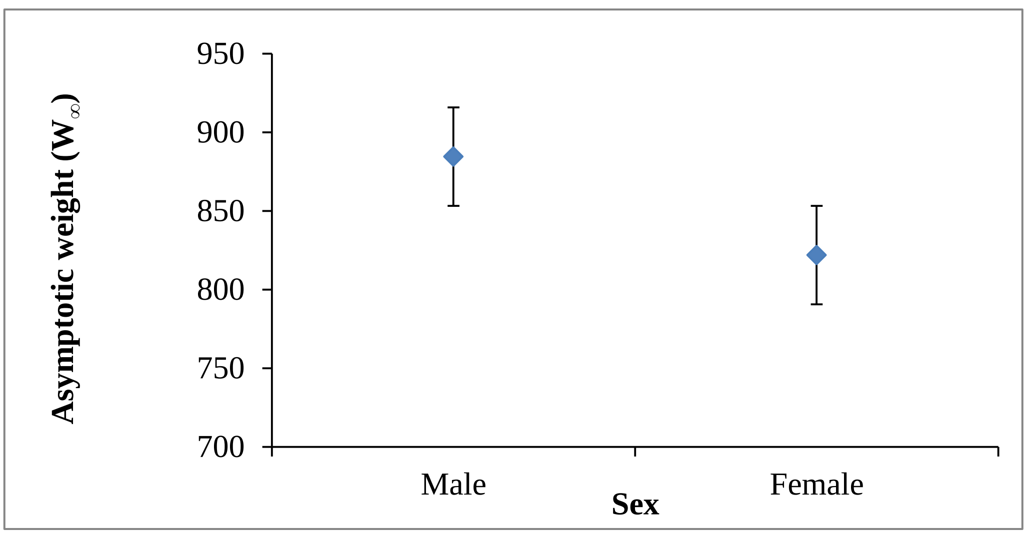

Figure 4.6: Average asymptotic weight (g) for males and females of *O. esculentus* (Gesebei) under cage culture (mean ±95% CI, n=4)

There was a significant difference ($F_{1,664}$=340.4, $p<0.05$) in average asymptotic lengths at 47.66±1cm; 41.54±1cm and average asymptotic weights ($F_{1,664}$=342.1, $p<0.05$) at 1,505.09±73g ; 997.88±102g between the males and the females of *O. niloticus* (CFMTC), with the males recording higher values than females as shown in Figures 4.7 and 4.8.

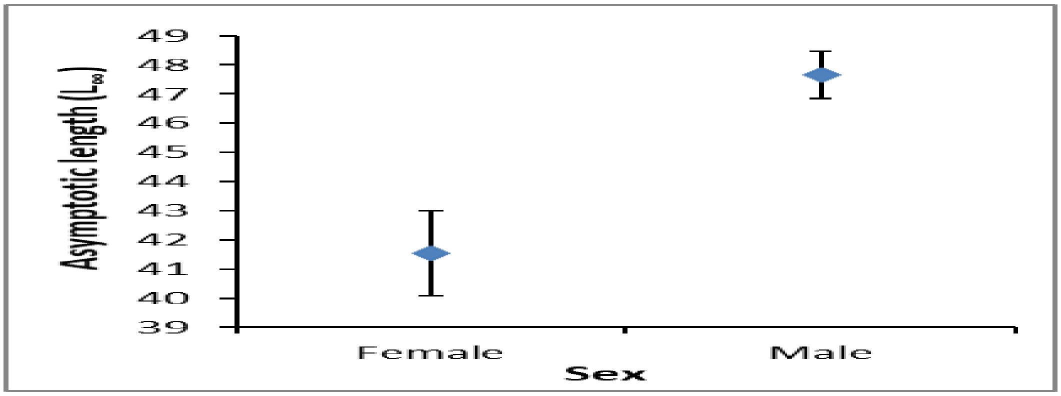

Figure 4.7: Average asymptotic length (cm) for males and females of *O. niloticus* (CFMTC) under cage culture (mean ±95% CI, n=4).

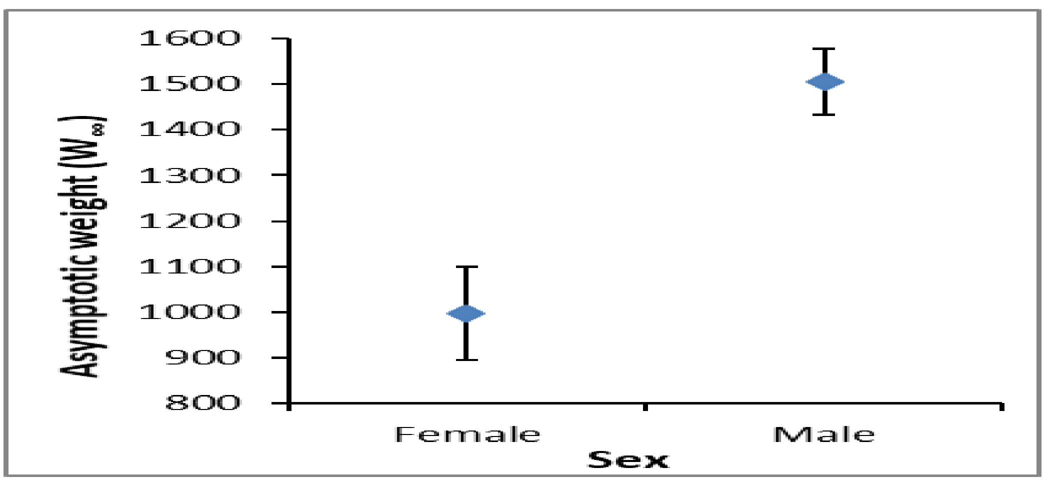

Figure 4.8: Average asymptotic weight (g) for males and females of *O. niloticus* (CFMTC) under cage culture (mean ±95% CI, n=4)

Similar observations were also obtained for the males and females *O. niloticus* (Kitaru) having significant difference in the average asymptotic weight and length, ($F_{1,664}$=340.4, $p<0.05$). The average weight and length of 984.37±64gm; 624.62±59gm and 42.04±1cm; 35.79±1cm, are as depicted in figures that follow (Figures 4.9 and 4.10).

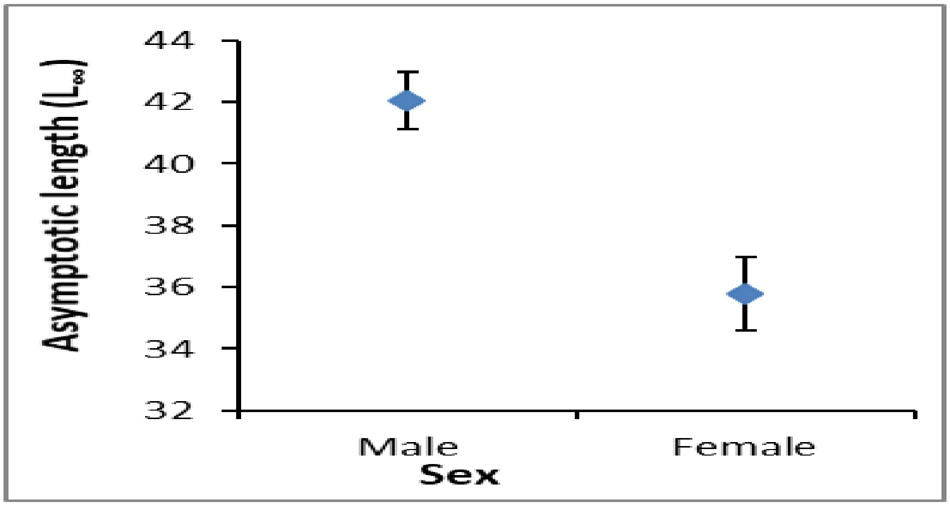

Figure 4.9: Average asymptotic length (cm) for males and females of *O. niloticus* (Kitaru dam) under cage culture (mean ±95% CI, n=4)

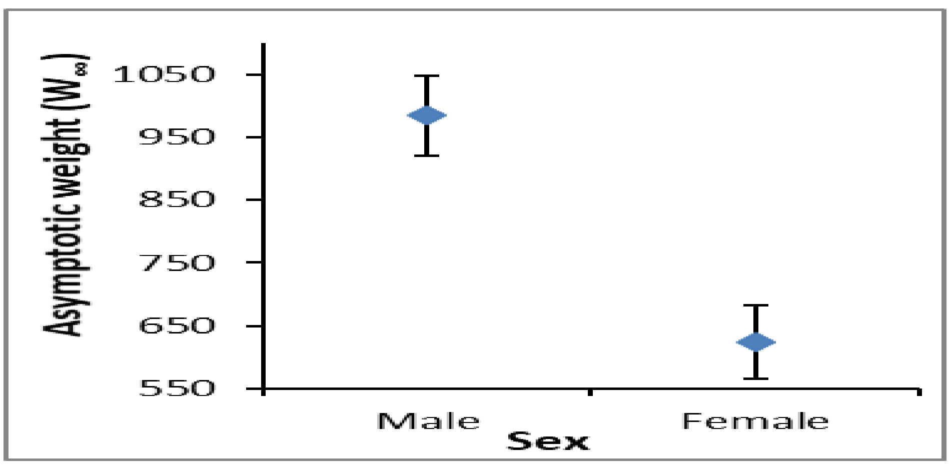

Figure 4.10: Average asymptotic weight (g) for males and females of *O. niloticus* (Kitaru dam) under cage culture (mean ±95% CI, n=4)

4.4 Fecundity of *Oreochromis esculentus* and *Oreochromis niloticus*

Figure 4.11 shows the means for relative fecundity among the three treatments: *O. niloticus* (CFMTC), *O. niloticus* (Kitaru) and *O. esculentus* (Gesebei). There was no significant difference in relative fecundity among the treatments ($F_{2,269}$=0.652, p>0.05). In all instances, except in one of the cages, the fish caught with egg/ fry were observed in the month of April, 45 days from the onset of stocking. The cage was one of the replicates for *O. niloticus* (CFMTC) of which fry were retrieved in May and may indicate a delayed maturation for that group. The highest number of eggs counted was from a 19 g individual *O. esculentus* was 575.

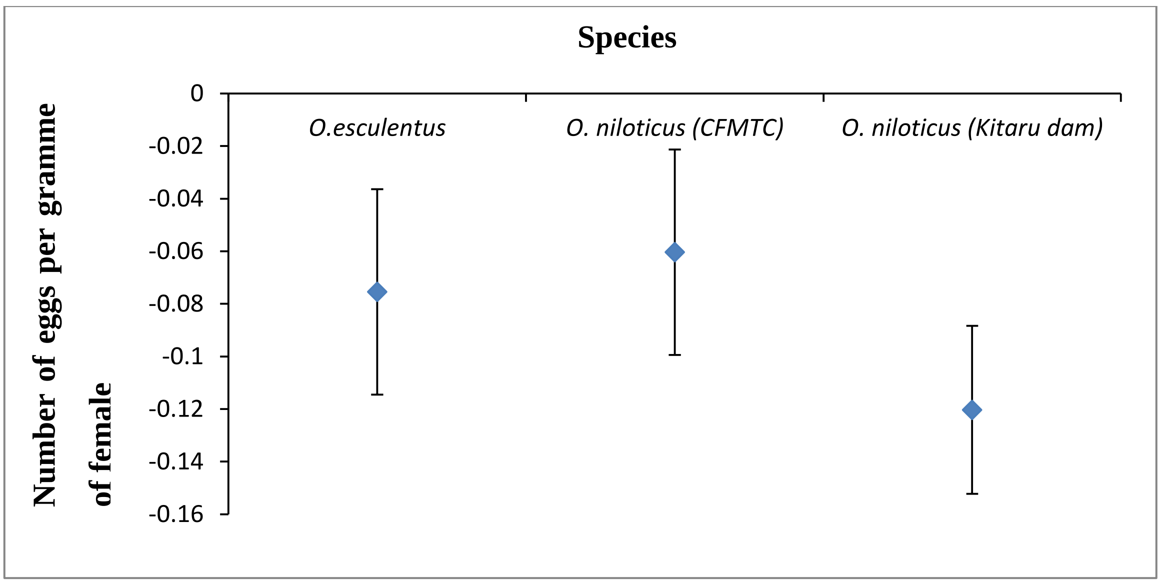

Figure 4.11: Average fecundity among species / treatments under cage culture (mean ± SE, n=4).

CHAPTER FIVE

DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Discussion

Growth performance of *Oreochromis esculentus* and *Oreochromis niloticus*

The results of the present study confirmed the superiority of *Oreochromis niloticus* over *Oreochromis esculentus* with respect to the growth performance in weight (Yakubu *et al.* 2012; Munguti *et al*., 2014; Githukia *et al*., 2015). In tropical pond waters and under semi-intensive culture management, *O. niloticus* can grow up to 150 – 250 g in four to six months, 500 to 800 g in 10 to 12 months, and 2 – 3 kg in 2 years (Kohinoor *et al*., 2003). It is also noteworthy that the success of *O. niloticus* in aquaculture is due to its high potential for growth and reproduction in a wide range of environmental conditions (Liti *et al*., 2005). The findings of better performance in weight for *O. niloticus* relative to the *O. esculentus* concurs with other findings (Shelton, 2002). This better performance of the *O. niloticus* may be attributed to its long history of selective breeding, as the parent stock were brooders from the CFMTC. The growth of some species of fish have been markedly improved by selection programs that have given them some level of improvement in selected traits including growth and reproduction, which are considered to be the main indices of performance (Dos Santos *et al*., 2013). Therefore, such breeding practices could have been the contributing factor in the better performance of *O. niloticus*. Selective breeding is known to offer continued genetic gain, and these can be permanent, and can be transmitted from one generation to the next hence a factor to be considered with respect to the *O. niloticus* from the CFMTC (Ponzoni *et al*., 2007). The *O. esculentus* fingerlings however, were first filial (FI) generation of a brood stock sourced from Gesebei dam, whereas those of *O. niloticus* (Kitaru dam) were F1 generation of brooders sourced from Kitaru dam. The dams, which contained the *O. niloticus* and *O. esculentus* were constructed in the colonial time and subsequently stocked for recreation purposes. It is possible that inbreeding occurred with passing on of poor performance traits to the *O.*

esculentus and the *O. niloticus* hence resulted in breeding depression. The widespread introgression of genes from other less desirable feral tilapia species is a point in mind (Macaranas *et al.*, 1986). The performance in weight of *O. esculentus* from Gesebei dam was lower than *O. niloticus* from CFMTC. In the present study, *O. esculentus* (Gesebei dam) had a lower weight, but performed better in length comparative to the *O. niloticus* (CFMTC) and the *O. niloticus* (Kitaru dam). Trewavas (1983) made a similar observation, in which the author attributed the longer length to the longer caudal peduncle of the *O. esculentus* relative to that of the *O. niloticus*. The longer length of *O. esculentus* does not translate to significant increase in flesh and weight, attributes that are important in aquaculture (Liti *et al*., 2005). Despite lower performance of *O. esculentus* in terms of weight compared to *O. niloticus*, the former is famed for its superiority in palatability and highly valued by local fishermen, who refer to it as "ngege". *O. esculentus* is referred to as singida tilapia in the literature (Twongo *et al.*, 2006) and could have an advantage if marketed as a high value fish, putting it in league with species like the turbot in Europe and the Salmon where the approach have been seen and targets niche markets (Felip *et al*., 2006). The *O. niloticus* from Kitaru dam performed the least in weight compared to the other treatments. It is possible that the parent stock that predominate the population of Kitaru dam may have crossbred by other species within the water body. The poor growth performance traits may have passed on to their progeny. The survival rate for the two species indicates good conditions within the environment and the management regime.

Sexual growth dimorphism in *O. esculentus* and *O. niloticus*

In the comparison of growth performance of males among treatments, the performance of male *O. niloticus* from CFMTC was better than in the other treatments whereas the *O. esculentus* and *O. niloticus* (Kitaru dam) had similar growth in both length and weight.

The female and male of the *O. esculentus* from Gesebei dam had similar performance in terms of both length and weight. This observation is supported by the findings that in a given environment both sexes grow at the same rate and mature at the same size (Garrod, 1959). Such an outcome would advocate for either a mono sex culture regime of either male or female. A mixed sex culture of the species could also be considered.

The female and male of the *O. niloticus* had distinct performance in terms of both length and weight with the males performing better than the females. This observation confirms the view that in *O. niloticus*, the males on average are superior to female in growth (Lorenzen, 2000). The males were reported to be 20 – 30% heavier in weight compared to females (Kohinoor *et al*., 2003). The results of these authors correspond with the outcome of the present study and validates the view that *O. niloticus* is best suited for all male monosex culture. In many species including *O. niloticus,* the culture of monosex is very common (Lorenzen, 2000). Production of monosex populations is related to sexual growth dimorphism, with either males or females growing faster depending on a particular species (Martínez *et al*., 2014). Examples of preference for female monosex culture include turbot, Salmonids and the European Sea brass (Felip *et al*., 2006) while in tilapiines, male monosex culture takes precedence (Martínez *et al*., 2014). This is because in *Oreochromis* spp., one of the most important aquaculture species, males are on average larger than females (Lorenzen, 2000).

The female and male of *O. niloticus* from Kitaru dam also had distinct difference in growth performance between males and females the males performing better than the females in both length and weight. This observation is in agreement with that of Lind *et al*. (2015) who demonstrated that the magnitude of sexual size dimorphism could vary substantially within and among tilapiines. Tilapiines being non-mass spawning species and that through male to male combat gain reproductive advantage, selective pressure favours males that are larger in size (Parker, 1992). Males can be larger than females, but seldom twice as large in size (Parker, 1992).

Relative fecundity in *O. esculentus* and *O. niloticus*

One of the intriguing observations in this study was the presence of fry in the buccal cavity, which was an indicator that fertilization of the eggs took place. It was noted that despite the fish being held in cages with netting mesh size of 2.54 cm, the brooding females were still able to spawn and collect their eggs in to the buccal cavities. Available literature indicates that the *Oreochromis* genus lay their eggs in a depression mainly dug by the male and subsequently fertilized externally (Trewavas, 1983). The fact that there was no possibility of digging depressions in the cages raises the question about the value of the excavation of the basins. The observation also suggests that there are several possible strategies adopted in the breeding of mouth brooders. The perception that by using cages can reduce the breeding of *O. niloticus* seems misleading, as the females could still be able to collect the eggs in to their buccal cavities for incubation.

In the present study, relative fecundity decreased with increase in female weight. This is in agreement with other reports where relative fecundity has also been reported to decrease with the increase in female size (Siraj *et al*., 1983). Throughout the period of the biweekly sampling counting of the eggs / fry was done and weight of the female taken. The number of eggs produced by a female at a time varies with the strain, age and weight as well as the environmental factors prevailing at the time (Kohinoor *et al*., 2003).

The water quality parameters were within the acceptable limits conducive for optimal performance of the fish. The optimal range for DO for tilapia culture is not less than 3 mgL^{-1} , for pH the optimal range of 6.5 – 9 and temperature range from 20 – 36^{o}C being conducive (Makori *et al*., 2017); total ammonia nitrogen with an optimal range of up to 0.19 mgL^{-1} (Githukia *et al*., 2015). The similar environmental conditions were subject to all the treatments equally and hence could not influence the results in an adverse manner.

5.2 Conclusions

1. The *Oreochromis niloticus* (CFMTC) and *Oreochromis esculentus* had significantly better growth performance with respect to asymptotic weight than the Kitaru populations. The study showed that the *O. esculentus* is a possible candidate for recruitment in aquaculture though it has a lower weight for a given length compared to *O. niloticus*. The slenderness of *O. esculentus* is reflected in its greater

length compared to *O. niloticus* and is a possible indicator of low fat in the fish and thus lower cholesterol. This is an implication of high nutritional quality of the carcass of *O. esculentus*. These indicators qualify *O. esculentus* as suitable candidate for aquaculture.

2. The aspect of either sex of *O. esculentus* performing on par qualifies it as a species for mixed sex culture or monosex of either sexes. This would then be a cost effective as there will be no need of investment in the expensive exercise of sex reversal for either all male or all female seed. In addition, a mixed sex population could also be a production strategy for this species in aquaculture. The female and male of the *O. niloticus* had distinct performance in terms of both length and weight. The male of both populations of *O. niloticus* significantly outperformed the females. Monosex (all male) populations for uniform higher yields should be maintained. However, populations of female are required for breeding purposes.
3. The two test species had no significant differences in their relative fecundity. The recruitment of *O. esculentus* and the two populations of *O. niloticus* of ova and fry indicates that as candidates in aquaculture, they both qualify. Fecundity is an important perquisite that ensures sustainable aquaculture through the availability of seed for supply to fish farmers for production. Both *O. niloticus* populations and the *O. esculentus* showed that under cage culture, they were able to reproduce without hindrance.

5.3 Recommendations

1. For growth performance between the two species, *O. esculentus*' slight deficiency in weight compared to *O. niloticus* does not imply non qualification as a species for aquaculture. The presumed superiority in palatability, macro and micro nutrient composition needs to be ascertained.
2. As for the sexual growth dimorphism, the exclusive rearing of monosex population of either male or female *O. esculentus* to further reinforce the conclusion that both gender perform on par may qualify it as a species for mixed sex culture regime. The possibility of female population of *O. esculentus* out performing male with

respect to sexual growth dimorphism needs to be investigated further. The availability of fry also indicated another strategy for breeding adaptability of genus *Oreochromis*. This needs to be investigated further to ascertain the phenomenon. Other than contributing to additional base for culture will indeed ensure the conservation of *O. esculentus*, there is need to recruit the near threatened species for aquaculture in addition to the traditionally reared ones like *O. niloticus* as a conservation strategy. At the same time, it will address food and nutrition security in the region and the Country as a whole. Currently the National Aquaculture Policy and the National Aquaculture strategy and development plan are under review. The strategic issue contained therein on increasing the number of cultured species might well be advised to consider *O. esculentus* as one such species.

3. The observation that fertilized eggs and fry were retrieved from the buccal cavity of females in the absence of depressions dug by the males for the females to lay their eggs in before fertilization needs further study. Due to the nettings of the cages, the males could not dig the nests, this invites for re-examination of the breeding strategies of *Oreochromis* species.

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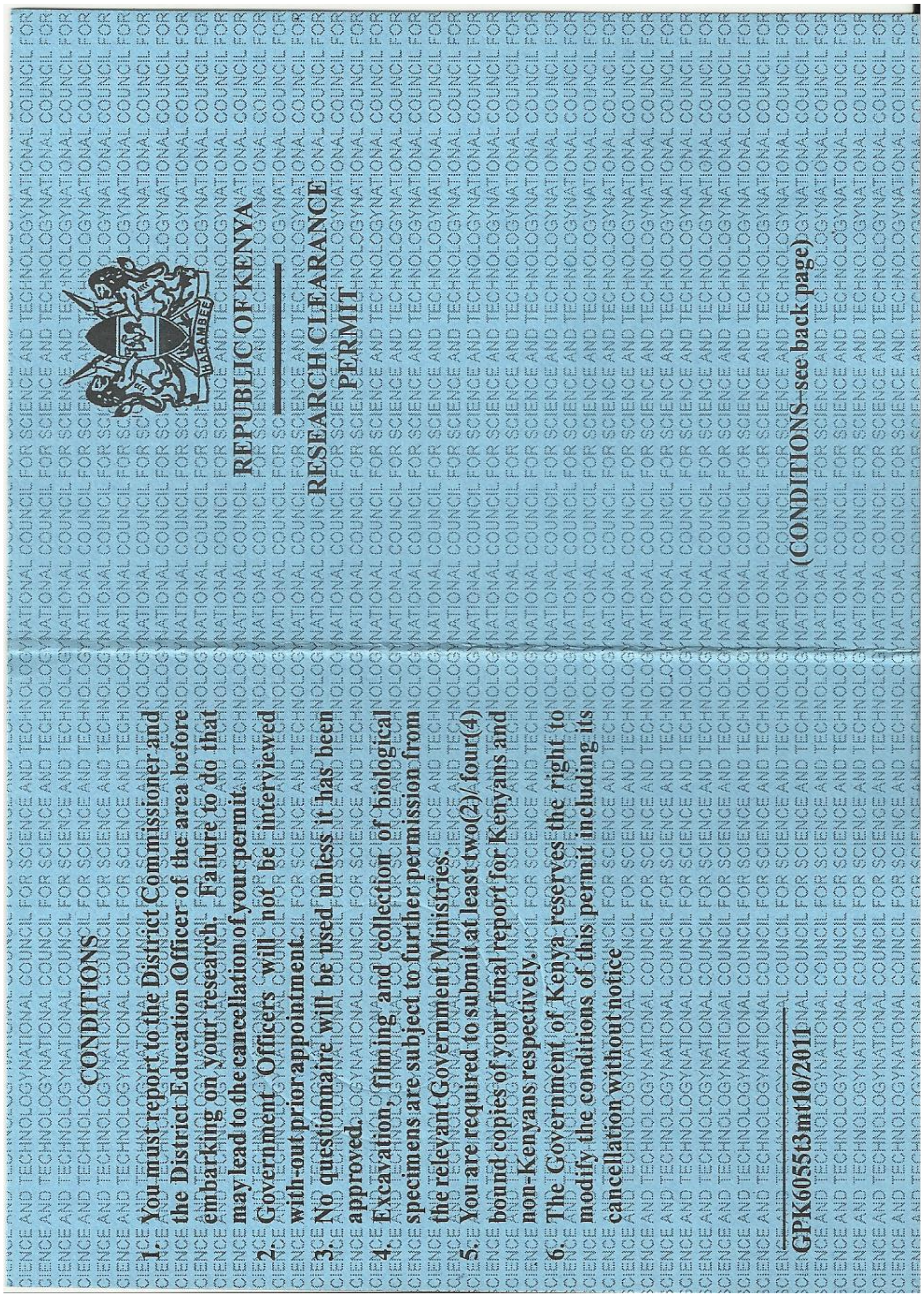
APPENDICES

Appendix I: Research Permit



CONDITIONS

1. You must report to the District Commissioner and the District Education Officer of the area before embarking on your research. Failure to do that may lead to the cancellation of your permit.
2. Government Officers will not be interviewed with-out prior appointment.
3. No questionnaire will be used unless it has been approved.
4. Excavation, filming and collection of biological specimens are subject to further permission from the relevant Government Ministries.
5. You are required to submit at least two(2)/four(4) bound copies of your final report for Kenyans and non-Kenyans respectively.
6. The Government of Kenya reserves the right to modify the conditions of this permit including its cancellation without notice

GPK6055t3mt10/2011

REPUBLIC OF KENYA

RESEARCH CLEARANCE PERMIT

(CONDITIONS—see back page)

PAGE 2

THIS IS TO CERTIFY THAT:
Prof./Dr./Mr./Mrs./Miss/Institution
Edwin Robin Muga
of (Address) Jomo Kenyatta University of Agriculture and Technology
P.O.Box 62000-00200, Nairobi.
has been permitted to conduct research in

	Location
Kisii Central	**District**
Nyanza	**Province**

on the topic: Growth performance of Singidia Tilapia (Oreochromis esculentus) on differen Feeding Regimes under aquaculture systems in Western Kenya.

for a period ending: 30th April, 2013.

PAGE 3

Research Permit No. ***NCST/RCD/12B/013/7***
Date of issue ***31st January, 2013***
Fee received ***KSH. 1,000***

....
Applicant's Signature

....
Secretary
National Council for Science &Technology