GROWTH PERFORMANCE OF MIXED SEX NILE TILAPIA IN CAGE MONOCULTURE AND POLYCULTURE WITH AFRICAN CATFISH AND AFRICAN CARP

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A Thesis Submitted to the Graduate School in Partial Fulfillment of the Requirements for the award of a Master of Science Degree in Limnology of Egerton University

EGERTON UNIVERSITY

NOVEMBER, 2016

DECLARATION AND RECOMMENDATION

DECLARATION

This thesis is my original work and has not, wholly or in part, been submitted or presented for examination for award of a degree in any other University

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RECOMMENDATION

This thesis is the candidate's original work and has been prepared with our guidance and assistance and submitted with our approval as the University Supervisors

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DEDICATION

To my beloved wife Carolyne, children John Junior, Monica, Mary, Marga and my beloved mum Monica Senior and dad John.

Thank you for being there for me always.

ACKNOWLEDGEMENTS

Firstly, I would like to thank the Lord God Almighty for the grace of life, for financial provision, walking side by side with me always and for providing me with the strength to move on even in the face of adversity and despair. Secondly, I would also like to thank the Department of Biological Sciences, the Faculty of Science and the Graduate school of Egerton University for the support they gave during the production of this work. Thirdly, I would like to most sincerely thank my supervisors, Dr. Elick Otachi and Dr. Jonathan Munguti for the immense support and advice that they always gave. I would also like to thank the Government of Kenya for granting study leave. Thanks also go to Dr. Paul Orina of NARDTC-Sagana and the Kenya Marine and Fisheries Research Institute (KMFRI)-Sagana fraternity for the material support which they gave during my research work. Last but not least, I would also like to thank Dr. Julius Nzeve of Fisheries Department-Machakos and Mr. Ken Ochieng (Egerton University) for the assistance which they gave me during data analysis.

ABSTRACT

The excessive breeding of mixed sex Nile tilapia (*Oreochromis niloticus*) in ponds often lead to stunted growth. This study hypothesized that cage culture was a potential alternative in solving the problem. Furthermore, it was hypothesized that its growth performance does not significantly vary when polycultured in cages with the African catfish (*Clarias gariepinus* Burchell 1822*)* and African carp (*Labeo victorianus* Boulenger 1901). An experiment was set up in a completely randomized design (CRD) for four months to test these hypotheses. There were 4 treatments (T) each with three cages were as follows: in T1 (control), was a 100% monoculture treatment of mixed sex Nile tilapia; T2, had a 1:1 combination treatment of mixed sex Nile tilapia and the African catfish; T3 had another 1:1 combination treatment of mixed sex Nile tilapia and African carp and T4 had a 5:3:2 combination of all the three species; mixed sex Nile tilapia, African catfish and African carp, respectively. Representative fish samples of 30 per species per cage were taken during stocking and biweekly thereafter and measured for weight using a standard digital weighing scale (model Kern 572), total length using a standard measuring board while water quality parameters were measured using HANNA Multiprobe meter. Length-Weight (L-W) relationship were calculated using the equation $W= aL^b$ while condition factors using $K = 100W/ L^b$. Growth parameters were tested using One way ANOVA, $p<0.05$ and Tukey's Honest Post hoc test used to separate the means. The results revealed that there were no significant differences ($p>0.05$) in the growth rates, and final weight of juvenile mixed sex Nile tilapia when mono-cultured and poly-cultured. However, there were significant differences in the survival rates ($p<0.05$). The final weight (g) achieved were 32.59±8.75, 36.58±7.29, 34.16±7.73 and 32.02±9.00, respectively. The mean weight gain (g) for mixed sex Nile tilapia monocultured, polycultured with African carp, polycultured with African catfish and polycultured with the two in cages were 25.07±0.62, 29.86±3.04, 25.91±4.98 and 25.05±2.23, respectively. The survival rates were 72.5±7.2%, 61.7±2.5%, 42.3±4.5% and 48.7±5.5%, respectively. All the mixed sex Nile tilapia treatments showed isometric growth, with regression slope/weight at unit length (b) values ranging between 2.73 and 3.0. The condition factors for the treatments were all above 1 but there were significant differences between them (ANOVA, $p<0.05$). The water quality parameters monitored throughout the culture period had no significant variations that would adversely affect growth rate of fish. Mixed sex Nile tilapia cultured with the African carp showed a relatively higher potential for higher productivity with a relatively higher growth rate, isometric growth, high condition factor and relatively higher survival rates. African catfish treatments were generally characterized by high levels of predation.

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LIST OF ABBREVIATIONS AND ACRONYMS

CRD	Completely Randomized Design
DWG	Daily Weight Gain
ESP	Economic Stimulus Program
FAO	Food and Agriculture Organization
FFEP	Fish Farming Enterprise Productivity Program
HIV/Aids	Human Immuno Deficiency Virus-Acquired Immuno Deficiency Syndrome
KMFRI	Kenya Marine and Fisheries Research Institute
LIFDC	Low Income Food Deficit Countries
SDG	Sustainable Development Goals
MT	17 α-MethylTestosterone
MWG	Mean Weight Gain
NARDTC	National Aquaculture Research Development and Training Centre
PD/CRSP	Pond Dynamics Collaborative Research Support Program
PWG	Percentage Weight Gain
SGR	Specific Growth Rate
SR	Survival Rate

CHAPTER ONE

INTRODUCTION

1.1 Background information

Tilapiines have been an important component of subsistence fisheries for thousands of years supplying the much needed proteins to households (Gupta & Acosta, 2004). Of the 70 species of tilapiine cichlids, the Nile tilapia (*Oreochromis niloticus* L.) is the main cultured species. In the year 2011, tilapiines production was 3.5 million metric tons, compared to other cultured species such as the carps which contributed 24.2 million tons (71.9 %) to global aquaculture productivity (FAO, 2012). This relatively lower production of tilapiines compared to other species is majorly due to the predominant pond culture of mixed sex Nile tilapia that gives low yields as well as challenges with the uptake and penetration of monoculture of tilapia especially in Sub Saharan Africa (Ngugi *et al.*, 2007; Mucai *et al*., 2011). The Kenya government in 2009 funded an Economic Stimulus Program-Fish farming enterprise productivity program (FFEP) for fish farming which was to increase the fish production from 12000 metric tons/year in 2010, and was projected to hit 20000 metric tons in the next five years with Nile tilapia being the main cultured species (Nyonje *et al.*, 2011). However, the increase has been largely due to the expansion in the area under culture but not in the use of new production techniques that would increase production per unit area (Delgado *et al.,* 2003).

The production and further expansion of tilapia industry is constrained by factors such as the harvesting of too many stunted fish from overpopulated mixed sex ponds (De Graaf, 2004).

The implication of this is that at harvest 28-70% of the total biomass usually consists of low-value fingerlings. This has had a demoralizing effect on farmers, leading some of them to abandon tilapia fish farming altogether (Osofero *et al.,* 2014). Monosex culture of males has been proposed to try and overcome this problem (Lazard, 1996; Mair *et al*., 1997; Shelton, 2002). However, there are major constraints with the use of monosex culture in Kenya (Mucai *et al.,* 2011). Major challenges with obtaining all male fingerlings include the relatively large size (35 g and above) of fingerlings needed for successful hand sexing, the difficulty to maintain pure strains of parent stock and the unavailability or low production of "sex-reversal" feed (Osofero *et al*., 2014). Moreover, masculinization of tilapia fry by oral administration of 17α-methyl testosterone (MT) is also unfavorable. Leakage of MT from uneaten or un-metabolized food into the pond environment may also occur, further posing a risk of unintended exposure of hatchery workers, fish or other non-target aquatic organisms to the steroid or its metabolites (Osofero *et al.,* 2014). The presence of hormone residue in adult fish has also not been studied adequately, thus its effect on consumers is not well known, further restricting its use (Fuentes –Silva *et al*., 2012). These together with poor penetration and uptake of monosex culture has hampered Nile tilapia production.

Cage culture of mixed sex Nile tilapia has been proposed as an environmentally friendly measure to this problem (McGinty, 1991; McGinty & Rakocy, 1996). It has also been argued that tilapia aquaculture must adopt sustainable practices (such as polyculture) for increased production and sustainability (Wang & Lu, 2015). However, the interaction effect of other fish on the feeding and growth rates of tilapia (mixed sex Nile tilapia commonly cultured in this region) in poly-culture systems, especially cage poly-culture, is little understood particularly in Kenya as there is little data on cage culture let alone cage polyculture (Blow & Leonard, 2007; Munguti *et al*., 2014).

The main objective of this study was to assess growth performance of mixed sex Nile tilapia in cages as an environmentally friendly approach to its production by innovatively utilizing feeding habits and niches through polyculture with other teleost fish such as the African catfish and the African carp. In addition, the growth performance of mixed sex Nile tilapia when polycultured in cages with African carp, a newly introduced species of fish into aquaculture in Kenya, is not known.

1.2 Statement of the problem

Mixed sex Nile tilapia ponds are frequently characterized by excessive breeding. At harvest, 28-70% of the total biomass consists of low-value stunted fingerlings and low output due to the high recruitment. This discourages farmers, with some abandoning tilapia fish farming altogether in Kenya. It is argued that in cages, the breeding cycle of tilapia is disrupted. Therefore, there is a need to assess the growth performance and productivity potential of mixed sex Nile tilapia cages for a solution to the problem of stuntedness. In ponds with tilapia only, the supplementary feeds (the floating pellets) are eaten by the upward feeding fish but the uneaten feed goes to waste as it sinks and decomposes leading to water quality deterioration. The deteriorated water quality causes stress to the cultured fish species resulting in poor growth, greater incidences of disease, increased mortality and low production. Polyculture with other warm water culture species such as African catfish and African carp that occupy other niches in the pond need to be assessed on the efficiency of feed utilization, growth performance and water quality. Besides, some of the proposed species for poly-culture like African carp has been newly introduced into aquaculture and its interaction with Nile tilapia and the effect of such interaction on growth in cages is not known. Furthermore, cage culture data for Nile tilapia and in polyculture with other teleost/finned fish are also scarce in this region and especially Kenya.

1.3 Objectives

1.3.1 General objective

To assess growth performance of mixed sex Nile tilapia in cage monoculture and polyculture with African catfish and African carp.

1.3.2 Specific objectives

1. To monitor water quality and its effects on growth of fish in cage monoculture of mixed sex Nile tilapia and in polyculture with African carp and African catfish during the study period.

2. To determine and compare growth rates of mixed sex of Nile tilapia, African catfish and African carp in various species combination treatments in cages throughout the culture period of four months.
3. To determine and compare length-weight relationships and fish condition factors for the three species of fish in their different species combination treatments for the period of study.

1.4 Hypotheses

1. Water quality changes do not significantly affect the growth rates of the caged mixed sex Nile tilapia, African carp and African catfish
2. There are no significant differences in the growth rates of mixed sex of Nile tilapia, African carp and African catfish reared under the different species combination treatments in cages.
3. The length-weight relationships and fish condition factors of mixed sex Nile tilapia, African carp and African catfish in their different species combination treatments are not significantly different.

1.5 Justification

Fish and fishery products represent valuable sources of protein and essential micronutrients for balanced nutrition and good health not only locally but also globally. The Sustainable Development Goals (SDGs) one, two, three and eight aim at eradicating poverty, eradicating extreme hunger, good health and wellbeing, decent work and economic growth respectively. SDG number fourteen also emphasises on sustainable use and management of life below water. Simple and affordable ways of food production (especially expensive proteins) at the household level are critical in achieving these goals. The methods/techniques of food production should however also ensure environmental sustainability through responsible consumption and production. Agriculture is a major pillar targeted as a major employer in the vision 2030. The aquaculture sub-sector has vast potential that is unexploited, for example in cage culture, not only for food production but also as an employer of youth and prospective fish farmers. Aquaculture provides livelihoods and income for people engaged in the primary sector of fish production. The government funded Economic Stimulus Program (ESP) has not only increased fish farming countrywide from 1% to 7% by 2010, but has also led to increased commercial thinking among Kenyan fish farmers. Nile tilapia farming constitutes over 75% of the farmed fish in the country. With the constraints experienced with monosex culture of this fish, if simpler, more commercially viable ways of culturing the mixed sex are not generated, then the momentum generated through ESP in the development of the sector could be lost. Farmers could be discouraged and give up since the high recruitment of the mixed sex of the fish gives low returns to the farmers. Besides, the share of employment in capture fisheries is stagnating or decreasing while aquaculture has the potential of providing increased opportunities. This research work will generate data and knowledge on cage culture for improving not only tilapia production but for general aquaculture productivity as well.

CHAPTER TWO

LITERATURE REVIEW

2.1 Classification of Nile tilapia

Nile tilapia (*Oreochromis niloticus*) is a freshwater fish species in the cichlids family (family Cichlidae) of order Perciformes. The species can be differentiated from the other tilapiine species by possessing 29 to 31 dorsal fin rays, 16 to 18 dorsal spines and black bars on the tail fin (Figure 1).

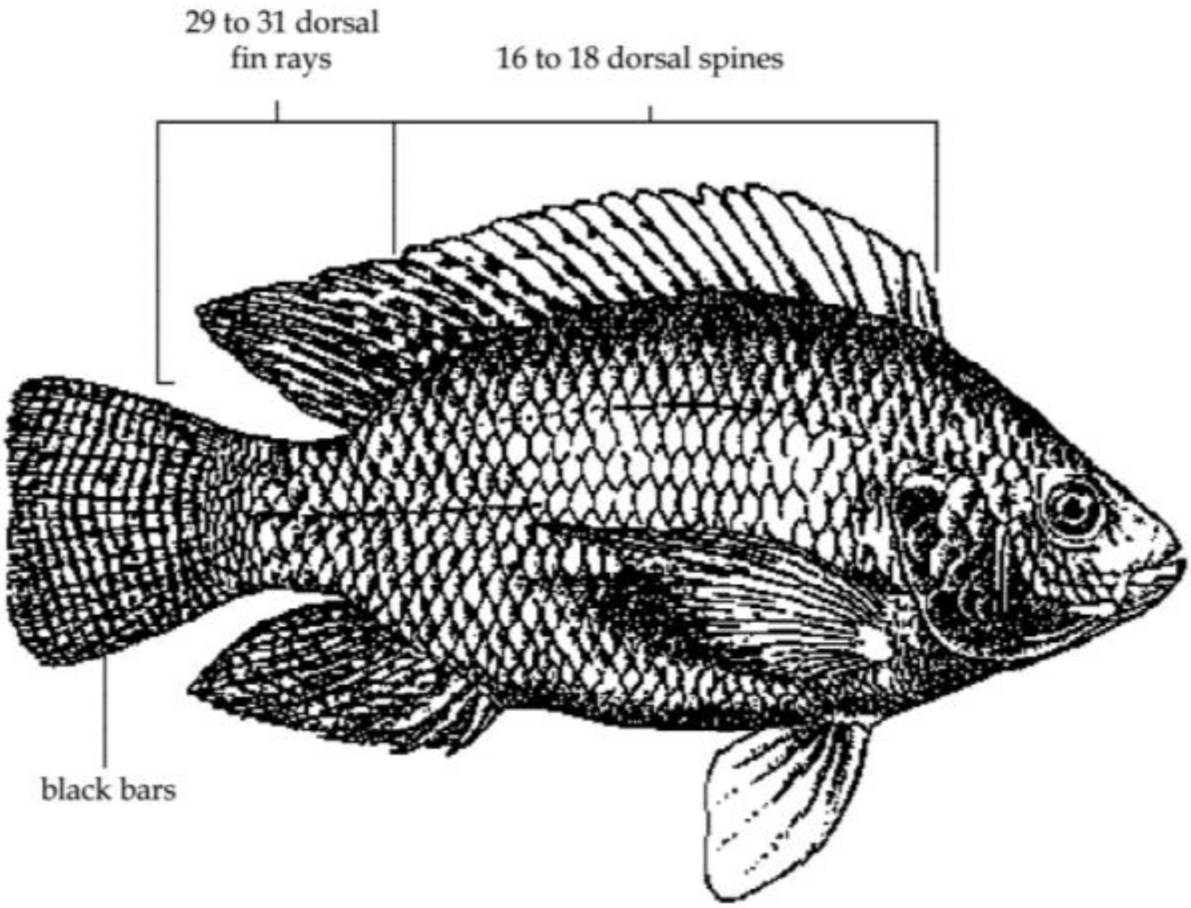


Figure 1 Distinguishing morphological characteristics of Nile tilapia (Adopted from Offem & Omoniyi, 2007).

2.2 Feeding habits of Nile tilapia

Nile tilapia is a generalist feeder and can feed on algae and detritus as well as zooplankton and insects (Njiru *et al*., 2004; Semyalo *et al*., 2011). This general feeding makes it a link between lower and upper trophic levels in the aquatic food webs. This helps the species to survive well in non-native environments since it can feed at different trophic levels (Peterson *et al*., 2006). For this reason it is cultured in many parts of the world in warm water. Other favorable traits such as year-round spawning, parental brood care, capability of filter feeding by capturing food particles in the water column and a highly flexible growth rate gives it the ability to adapt well to different environmental conditions even in ponds, tanks or raceways (Moreira, 2002).

2.3 Reproduction in Nile tilapia

Nile tilapia is a gravel spawner with the eggs brooded by the female fish in the mouth for one to two weeks until the yolk sac is absorbed. In the natural environment, the male prepares the nest/pits on the ground and then leads the female to the nesting area. It then butts against the female genital area to induce egg laying. The female then lays the eggs and after fertilization by the male, she collects the eggs into her mouth to incubate them until hatching (Lovshin, 2013). This behavior influences the growth condition of the female fish which does not feed actively during this period, leading to slower growth rate compared to males (Njiru *et al*., 2008). Besides, the fish is a prolific breeder laying over 2000 eggs per brood. This leads to high recruitment in the ponds, raceways or tanks stocked with mixed sex of the fish and if not controlled then 28-70% of the harvest is made up of low value fingerlings and stunted mature fish due to competition (Osofero *et al.*, 2014).

In culture/ hatcheries, several methods are used for the production of tilapia frys and fingerlings for propagation. One of the simplest and most commonly used method in Kenya and other parts of the world is the open pond method. In this method, a properly constructed and well fertilized pond serves both for breeding and rearing fry. Brooders are stocked into the ponds and allowed to spawn naturally. The brood fish are stocked at the rate of 100 to 200 kg/ha at a sex ratio of 1:3 or 1:4 (males to females). A female brood fish of 90-300 g produces as much as 500 eggs per spawning. Harvesting of the frys is done every 17-19 days (FAO, 2016). The other method that is used for tilapia fry and fingerling production in fish farms/hatcheries for commercial production of frys and fingerlings is the 'hapa' method. A hapa is a cage like, rectangular or square net impoundment placed in a pond for holding for holding frys and fingerlings, it is made of fine/ small mesh size material. Stock brooders weighing about 100 to 200 g at a ratio of about 1:5 to 1:7 males to females are put in hapas at a density of 4 - 5 brooders / m^2. The fry are removed using a scoop net after every two weeks and taken into holding tanks, other hapas, or a rearing pond. Production in hapas range from 150 fry/m^2/month to over 880 fry/ m^2/month (FAO, 2016; Sipe, 2004). The third method which is much more advanced technologically has been used in Thailand to generate large numbers of monosex fingerlings at a time. The technology is basically to produce all-male fry by maintaining a large number of broodfish in hapas, collecting eggs, incubating them artificially in clean and controlled system (in fiber glass containers) and feeding them, the feed may be treated with 17 α methyltestosterone to generate monosex fingerlings (Bhujel, 2009).

Several methods have been used to try and control excessive breeding and stunted output in mixed sex tilapia ponds. This include stocking the mixed sex tilapia ponds with catfish fingerlings (usually 10% of the tilapia population in the pond) after about 2-3 months of stocking the ponds with tilapia. African catfish being a carnivorous fish is added to the pond to feed on the tilapia fries and fingerlings hatched in order to control tilapia population (De Graaf, 2004). There is however a shortage of catfish fingerlings and many farmers are not able to access them (Munguti *et al*., 2014). The other method of controlling excessive breeding in mixed sex tilapia ponds is by using monosex fingerlings, "male only tilapia fingerlings" that neither lay eggs or brood (Lazard, 1996; Mair *et al.,* 1997; Shelton, 2002).

2.4 Challenges of monosex culture of Nile tilapia

The all-male fingerlings required are obtained through either hand sexing, hybridization or hormone-induced sex reversal (De Graaf, 2004). There is low uptake and use of monosex culture technology of Nile tilapia fish in Kenya (Munguti *et al*., 2014). This is attributed to: the relatively large size (35 g and above) fingerlings needed for successful hand sexing, difficulty to maintain pure strains of parent stock for hybridization and low production or unavailability of "sex-reversal‟ feed that is already treated with the sex reversal hormone, 17α-methyltestosterone (MT) (Osofero *et al.,* 2014). To a large extent, farmers and hatchery workers do not also have technical knowledge on the oral administration of MT.

Leakage of MT into the pond environment may occur from uneaten or un-metabolized food posing a risk of unintended exposure of hatchery workers, as well as fish or other non-target aquatic organisms to the steroid or its metabolites (Mair, 1997; López *et al.*, 2007; Osofero *et al*., 2014). The presence of hormone residue in adult fish has also not been studied adequately, thus its effect on consumers is not well known, further restricting its use (Fuentes –Silva *et al*., 2012). Due to these constraints and environmental concerns, cage mixed sex Nile tilapia production needs to be assessed for an environmentally safe and simple way of production of this popular fish. In cages, its breeding cycle is disrupted such that the eggs fall through the net pens and the female doesn't get to incubate them in the mouth (Masser, 1988). Besides, cage culture has other advantages for example, it can be stocked intensively for higher productivity, has a relatively low capital investment compared to ponds and raceways, has flexibility of management, ease and low cost of harvesting, close observation of fish feeding response and health as well as ease and economical treatment of parasites and diseases (McGinty & Rakocy, 1996). Cage culture can also be done in open waters such as in lakes, dams, reservoirs and rivers.

2.5 Length-weight relationship and condition factor

Length-weight relationship gives the condition and growth patterns of fish. Fish is said to be growing isometrically if its length increases proportionally to its body weight for constant specific gravity (Olurin & Aderibigbe, 2006; Taylor *et al*., 2010). Allometric growth implies the increase in length of the fish during growth is not proportional to the increase in weight (Riedel *et al.,* 2007. It is therefore possible to estimate the weight or length of a fish from either of the two parameters that is available.

Condition factor refers to the well-being of the fish in question and by extension its health status (Blackwell *et al*., 2000). It is therefore an index reflecting interactions between biotic and abiotic factors to the physiological condition of fish. Condition factor is estimated by comparing individual fish weight of a given length to a standard weight. It is based on the assumption that heavier fish at a particular length reflect a healthier physiological state. It is an important concept in fisheries and aquaculture management and can be used to assess the health and potential of any fishery. Studies of condition factor of fish take into consideration the health and well-being of a fish in relation to its environment indicating the robustness in fish (Olurin & Aderibigbe, 2006). Growth of any fish is affected by several physiological, nutritional and environmental factors. Among the environmental factors, temperature has been recognized as one of the most important abiotic factors affecting growth as well as sex ratios in most fish species including Nile tilapia (Azaza *et al*., 2008). Growth, mortality rates and size at maturity particularly of juvenile fish have been shown to depend so much on the prevailing environmental conditions (Britton & Harper, 2008). Recruitment is therefore determined by growth condition and mortality of juvenile fish in their first year of life.

Fish of good condition factor are assumed to have faster growth and the ability to adapt well to their environment. Condition factor studies therefore, give an indication of the status of the environment within which the fish lives and its adaptability, thus robustness in growth. This therefore can aid in the development of intervention measures by fishery and aquaculture managers especially with respect to maintaining a healthy fish population.

2.6 Nile tilapia production in semi intensive pond system

In Kenya, Nile tilapia is the most cultured fish accounting for 75% of the production, mostly in ponds because of its highly adaptive nature and easy management. Most of the ponds constructed and stocked under the government funded Economic Stimulus Program for fish farming (FFEP) were stocked with mixed sex Nile tilapia fingerlings mainly obtained from the National Aquaculture Research and Development Training Center-Sagana (NARDTC)

(Munguti *et al*., 2014). African catfish accounts for about 21% of local production while the other species such as Common carp (*Cyprinus carpio*), Rainbow trout (*Oncorhynchus mykiss*), Koi carp (*Cyprinus carpio carpio*) and Goldfish (*Carassius auratus*) make up the rest. The latter two are ornamental fish while the former two are primarily farmed for food. Recently, Kenyan researchers have begun culturing native fish species such as African carp, *Labeo cylindricus and Labeo victorianus* at NARDTC- Sagana, because they are threatened species in the wild and they are also popular as food fish hence the need for conservation (Munguti *et al*., 2014).

Nile tilapia production in Kenya and many other parts of the world is largely done in semi-intensive ponds where fertilizers and manure are used to increase yields at low levels of production (Green *et al*., 1989; Knud-Hansen *et al*., 1991). However, at higher levels of production, more rigorous management practices are applied to optimize production (Diana *et al*., 1991). One such management practice is giving the fish supplementary feeds in addition to the natural feed in the pond (Liti *et al.*, 2005). The supplementary feeds however not only increases the cost of production, but also, degrades pond water quality (Boyd & Tucker, 1998). Manure, fertilizer and feeds applied to ponds to enhance production may only be partially converted to fish, phytoplankton and zooplankton biomass, the excess decomposes and causes deterioration of water quality. The toxins produced notably ammonia (un-ionized ammonia) usually accompanied by depressed oxygen levels results in loss of fish stocks in addition to economic losses through wastage of expensive fish feeds (McGinty, 1991). In less severe situations, the deteriorated water quality stresses the culture species leading to poor growth, greater incidences of disease, increased mortality and low production (Hargreaves & Tucker, 2004).

According to Diana *et al*., (1994) who studied feed input reduction in tilapia production based on stage feeding, where feeding was initiated at various tilapia sizes (stages of growth), ponds receiving a combination of feed and fertilizer were more cost effective in Nile tilapia production than those receiving feed alone. Their findings showed that fish growth, efficiency of feed utilization and pond water quality were significantly improved than in ponds where only feed was given to the fish (Diana *et al.*, 1994; Yi & Lin, 2001). They also reported that satiation level could be reduced by 50% and feed input by 42 % without compromising the growth of tilapia fish.

A more recent management strategy for optimization of tilapia production is based on the concept of cage-cum pond integration (Liti *et al.*, 2005). In this, part of the fish biomass is fed in cages while the other part is held in the open water (McGinty, 1991; Lin & Diana, 1995). This is because rearing fish in either cages or semi-intensive ponds alone may comparatively produce lower yields to sustain profitability in commercial aquaculture, besides the obvious inefficient use of unit space. A management strategy based on the concept of integrating intensive and semi-intensive culture practices in cages and ponds simultaneously (cage-cum-pond-integrated system) has been suggested in an endeavor to increase unit fish production (Mokoro *et al*., 2013).

Fish in the cages are fed on high protein artificial feeds (intensive part of the component), while fish in the open ponds are not fed. The uneaten artificial feed from the cage could be utilized by two different processes: direct consumption by open pond fish and indirectly contributing to nutrients for natural feed production after being decomposed (Mokoro *et al*., 2013). Therefore, the open water pond fish satisfy their bio-energetic needs from the cage wastes either directly as uneaten food, faeces or indirectly from natural pond productivity after decomposition (semi-intensive component). It is intended to optimize fish production per unit area (Lin *et al*., 1989; Yi *et al*., 1996). The success of this system is dependent on the yields obtained from cages and open ponds, which is a function of food availability to fish in both cages and open ponds. Larger sized tilapia in cages have been raised to 500 g within a period of 90 days, which is relatively shorter than in the conventional semi-intensive culture techniques (Yi & Lin, 2001).

Studies have also focused on the effects of both caged and open-pond fish density on growth of tilapia in these integrated systems. Yi *et al.* (1996) observed that cage cum-open pond integration improved growth of tilapia and pond water quality. Liti *et al.* (2005) also worked on the effects of open-pond density and caged biomass of Nile tilapia on growth, feed utilization, economic returns and water quality in fertilized ponds. They found out that growth of open pond tilapia was significantly higher in treatments where the number of fish in the cages was equal to those in the open pond. At the same time, it was found that feed utilization, dissolved oxygen (DO) and economic returns were better in caged than controlled ponds. Lin *et al.* (1989) reported that high open-pond fish density reduced the growth rate of caged tilapia but improved the growth rate of open-pond tilapia. Despite all the work that has been done on the cage culture of Nile tilapia especially cage-cum open pond system of aquaculture, little work has been done on cage polyculture of mixed sex Nile tilapia with other warm water teleost fish species cultured in the region.

2.7 Cage culture of tilapia and other species

Tilapia is one of the most cage cultured freshwater fish, especially in Asia. However, it accounts for only 4% of cage culture productivity globally (FAO, 2005). Most of the species produced in cage culture globally are marine. This is in mostly Europe and Asia. Cage culture was introduced on a test basis in Sub-Saharan Africa in the 1980s when momentum for aquaculture development grew and the need for aquaculture research received government recognition as part of national development plans (Masser, 1988). Since then, in Kenya, pilot cages were set up but went defunct and few small-scale projects and trials on cage culture for Nile tilapia have since been done (Blow & Leonard, 2007).

In Kenya, just like in the other Sub-Saharan countries, inland freshwater cage culture is very low and predominated by Nile tilapia. A few examples include Dominion farms in Yala that had about 30 cages which produced around 200kg/m^3 in the year 2005 (Blow & Leonard, 2007). Cage culture of tilapia is therefore, in fact, an underutilized asset in the aquaculture sector in Kenya (Munguti *et al*., 2014). In the last three years, Kenya Marine, Fisheries and Research Institute (KMFRI) initiated preliminary trials of mixed sex tilapia cage culture off Dunga beach in Kisumu (Munguti *et al*., 2014). In these trials, Nile tilapia was reported to have registered better growth rates over the native *O. esculentus* and *Tilapia zillii*. Nile tilapia was reported to have gained 175 g within four months while *T. zillii* reached 150g in the same duration of time. However, the fingerlings used had been obtained from a selected breeding program in Sagana and not the non-improved Nile tilapia fingerlings sold to farmers. There have also been one or two trials with African catfish in Kenya (Blow & Leonard, 2007). Due to little work done on cage culture, there is generally scarce data on cage culture productivity in Kenya and by extension the region (Gupta & Acosta, 2004; Liti *et al*., 2005; Kaggwa *et al.*, 2011; Otachi *et al*., 2011), let alone cage poly-culture.

There are other species that have been researched on and successfully reared in cages in other parts of the world. They include Atlantic salmon, halibut (*Hippoglossus hippolglossus*), cod (*Gadus morhua*), carp, striped bass, red drum, trout (a cold water fish), bluegill, sunfish, red tilapia, milk fish (*Chanos chanos*) and crappie, among others. The first three species of fish are marine species while the rest are freshwater species. In Kenya, cage culture of Nile perch is also anticipated (Ministry of Agriculture, Livestock and Fisheries, 2016). Carps are almost always grown in polyculture where the varied feeding habits of the various species of carps are used for optimum utilization of the various niches (surface, column and bottom) of the culture environment (Singh, 1996). As interest in cage culture continues to grow, more research into cage culture techniques and alternate species needs to be done.

2.8 Biology of African catfish

The African catfish also known as African sharp tooth catfish is a species of catfish of the family Clariidae, **(**the air breathing catfishes**)**. It is a large, eel-like fish, usually of dark gray or black coloration on the back, fading to a white belly. These fish have slender bodies that are strongly compressed towards the caudal fin, flat bony heads, notably flatter than in the genus *Silurus*, and broad, terminal mouths. The species has 61–75 dorsal rays and 45–60 anal fin rays (FAO, 2016). Dorsal fin extends from behind head nearly to base of caudal fin (Fig 2). Anal fin extends from base of anus to base of caudal fin**.** Caudal fin is rounded. Pectoral fin has barbed spine, used for defense or "walking" overland. Eyes are small and lateral. It has a large subterminal mouth with the jaws having broad band of fine, pointed teeth. It has four pairs of long filamentous barbels with the maxillary barbels being the longest. A large chamber above gill arches contains the suprabranchial organs (multibranched accessory air-breathing organs). These function like a lung and render clariids capable of aerial respiration and thus able, under conditions of low dissolved oxygen, to still meet 80–90 percent of their oxygen requirements (Moreau, 1988). The species is thus an obligate air breather.

Figure 2 Photograph of African catfish (Clarias gariepinus Burchell, 1822 (Courtesy of W.A. Djatmiko, Indonesia)

The species is euryphagous and generally regarded as an opportunistic and omnivorous predator. It has the ability to efficiently utilize and/or switch between alternative food sources such as plants and detritus when prey animals become scarce (Hecht and Applebaum, 1988). Normally catfish are bottom feeders, but their feeding habits are adaptable and they occasionally filter feed in groups at the water surface (Bruton, 1979). They have been observed to snatch sinking pellets before they reach the substratum, then feed off the substratum (Hecht, Uys and Britz, 1988). It can then be combined in polyculture with other species like the tilapia that are surface feeders to maximize on feed utilization for increased productivity and water quality. This needs to be assessed.

It reaches sexual maturity at sizes between 150-750 mm total length and average fecundity is between 20000 to 25000 eggs/kg bodyweight. In the natural habitat, spawning takes place at night in newly inundated shallow water. Pair formation takes place and prenuptial aggression may be intense. Courtship behaviour is fairly complex and culminates in the release of gametes. Fertilized eggs are adhesive and are distributed vigorously and adhere to submerged vegetation. Under natural conditions, a pair may consecutively mate 2–5 times (FAO, 2016). Pair formation takes place and prenuptial aggression may be intense. Fertilized eggs are adhesive and are distributed vigorously and adhere to submerged vegetation. Depending on temperature the eggs hatch after 24–48 h. Larval development is rapid and commences exogenous feeding after about 80 hours of hatching (Bruton, 1979). In captivity however, artificial breeding is done with varying success rate.

The fish is a native of Africa but has been widely distributed for aquaculture purposes to many parts of the world (Na-Nakorn & Brummett, 2009). It is a suitable species of fish for aquaculture because; It grows fast and feeds on a large variety of agriculture byproducts, it is hardy and tolerates adverse water quality conditions, it can be raised in high densities, resulting in high net yields (6–16 t/ha/year). In most countries, it fetches a higher price than tilapia, as it can be sold live at the market and it grows and matures fast especially with a high protein diet. In addition to a food source, *C. gariepinus* has been used as a biocontrol species in mixed-sex tilapia farms, as well as a bait fish (FAO, 2016).

The farming of catfish is important to many large producing countries, more evidently in Nigeria such that it provides a source of income, create employment opportunities, contributes towards Gross Domestic Product (GDP). It is more crucially, important in addressing food insecurities and providing animal protein to the majority of African populace and has low cholesterol content (Inter African bureau for animal resources, 2016).

Despite its importance and widespread culture in ponds, tanks and raceways in other parts of Africa and the world, little work has been done on its culture in cages and especially cage polyculture in Kenya and the region (Munguti *et al*., 2014). It has largely been used as a 'police fish' to control the overbreeding of tilapia in mixed sex tilapia culture ponds (Inter African bureau for animal resources, 2016).

2.9 Classification of African carp

African carp (*Labeo victorianus*) commonly known as Ningu, is a fresh water cyprinid endemic to the Lake Victoria basin (Greenwood, 1966). It belongs to the family Cyprinidae of the order Cypriniformes of fish. Also called 'ningu' locally, this potamodramous fish faces numerous natural and anthropomorphic pressures such as the introduction of Nile perch (*Lates niloticus)* and over-fishing. This has resulted in species extinction and declining fish population trends, particularly for cichlid fishes (IUCN, 2016: Witte *et al*., 1992). It inhabits shallow inshore waters and influent rivers but spends most of its life span in lakes. It however, spawns in flooded grassland beside both permanent and temporary streams. This fish feeds on detritus, algae and rotifers growing on the bodies of other fishes (Fig. 3) and grows to a maximum size of 41 cm (Cadwalladr, 1965).

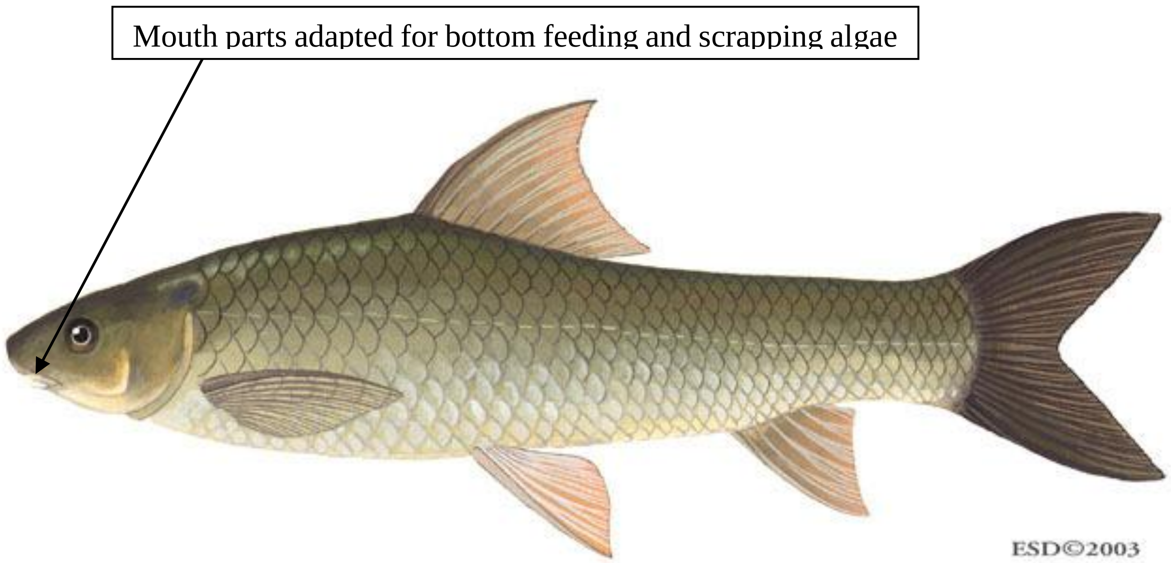


Figure 3 Photograph of African carp (*Labeo victorianus* Boulenger, 1901) (Courtesy of Bayona, J.D.R)

Its feeding habits are different from the feeding habits of the other two warm ware teleost fish cultured in the region, Nile tilapia and African catfish.

In the natural habitat, it is threatened by extinction through fishing with small meshed nets across rivers or river mouths during migration for spawning; predation impact by the Nile perch; silting and destruction of spawning/nursery grounds; competitive displacement by introduced fish species such as Nile perch (*Lates niloticus)* and loss of marginal vegetation around lakes and rivers due to agriculture extension. It has thus been brought into aquaculture research with an objective of conservation but also propagating it for consumption since it is also a popular delicacy (Rutaisire & Booth, (2005). It has only been brought into aquaculture research recently and so its interaction in cages with other warm water teleost fish species cultured in the region in cages is not yet known.

Aquaculture production in semi-intensive culture systems (feed and waste-fed ponds) can be optimized by culturing two or more species of fish with different feeding habits in the same pond (Boyd &Tucker, 1998). This strategy, referred to as 'poly-culture' helps make efficient use of the wide variety of foods available in semi-intensive waste-fed ponds (Boyd & Tucker, 1998). During species selection for polyculture, fish with varied feeding, niche and habitat preference are chosen for optimum utilization of feeds in the pond environment for optimum productivity and water quality improvement (Masser, 1997). Polyculture of Nile tilapia, African catfish and African carp need to be assessed for cage polyculture productivity and water quality because of their different feeding niches in the water column.

3.0 Challenges of water quality in warm water cage culture

Water quality problems in cage culture include biofouling: growth of algae on the sides of the cage, clogging the meshwork and restricting water flow. This causes water quality problems such as low dissolved oxygen concentrations (Masser, 1988) especially in cages made of very small mesh size (hapas). The degradation of water quality leads to reduced growth, a greater risk of disease incidences and even death (McGinty & Rakocy, 1996). A major problem of water quality degradation occurs when the cages are put in smaller, shallower aquaculture ponds/ reservoirs with relatively stagnant water (usually of less than 5 acres in size) (Masser, 1997). As feed input is increased with time and waste materials produced accumulates, water quality also starts to deteriorate.

Fish feed leftovers and wastes may not only decompose and degrade water quality causing anoxia but may lead to production of ammonia causing fish mortalities and losses. In less severe situations, the deteriorated water quality stresses the culture species leading to poor growth, greater incidences of disease, and low production (Boyd & Tucker, 1998; Durborow *et al*., 2004). Caged tilapia are particularly more susceptible than non-caged tilapia to stress from poor water quality, particularly low dissolved oxygen concentration (DO) and ammonia (Hargreaves & Tucker, 2004). Expensive fish feeds that are uneaten also go to waste.

In cage cum-open pond integrated systems, the excess feed is fed on by the fish in the open pond, the remainder and wastes decompose in the water and become the source of nutrients that are taken up by phytoplankton and then zooplankton in the aquatic food chain and then ultimately fed on by the fish in the pond. This improves water quality (Wang & Lu, 2015). Polyculture (species combination) intensifies feeding and due to the different feeding niches, make more efficient use of the wide variety of feeds available in aquatic systems. Such simple, cost effective and easy to apply water quality management procedures can be powerful tools in enhancing the quality of pond effluents to minimize adverse environmental effects besides assuring both the quality and safety of the final fish product (Boyd & Tucker, 1998).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The experiment was conducted using twelve fixed net cages, each of size 2m × 1.5m × 1.5 m (4.5 m^3) staked in an earthen fertilized pond of depth 1.2m and area of 800m^2. The pond had water flowing in from a canal that branches from the River Ragati and flowing out through an outlet at the National Aquaculture Research, Development and Training Centre (NARDTC) – Sagana for four months from mid-August to mid-December 2015. NARDTC is situated at coordinates $0^0$39' and E $37^0$12'and an altitude of 1230 meters above sea level in Kirinyaga County of the central region of Kenya, about 105 km North of Nairobi. It comprises 20 hectares of fish ponds on 50 hectares of land (PD/CRSP, 1998) (Fig 2).

Figure 4 Map of the location of the National Aquaculture Research, Development and Training Center (NARDTC-Sagana) (Source: PD/CRSP, 1998 Scale 1:50000)

3.2 Experimental design

The twelve net cages were each stocked with a total of 200 juvenile fish as illustrated in (Fig.3) below. The framework of the cages was made of plastic pipes (diameter 5cm) and covered with nylon net with a mesh size of 1.4 cm. There were four treatments and each was replicated; A set of three cages were used for monoculture treatment (control) with mixed sex Nile tilapia fish only, initial mean length 7.13±1.01 cm and weight 7.19±3.31 g; another set of three were used for a combination treatment of mixed sex Nile tilapia (50%) of initial mean length 7.89±1.2 cm and weight 8.89±3.42 g and the African catfish at 50% of fish density per cage of mean length 8.32±0.66 cm and weight 3.99±0.88 g; another set of three were used for a combination treatment of mixed sex Nile tilapia (50%) of mean length 7.03±1.31 cm and 6.47±3.63 g and African carp, mean length 13.07±1.87 cm and weight 16.62±7.91 g (50% of the total fish population in each cage) and the last set of three were for a treatment combination of mixed sex Nile tilapia (mean length 7.08±1.49 cm and weight 6.96±4.58 g), African catfish (mean length 8.02±1.00 cm and weight 3.61±1.38 g) and the African carp (mean length 13.16±1.72 cm and weight 15.19±6.59 g) in the ratio of 5:3:2 per cage to make 200 fish using a Completely Randomized Design (CRD). The African catfish fingerlings stocked were smaller in size than the other fish species as indicated. All the cages were stocked on the same day. The Nile tilapia used in this study were the Non-Improved Breed (NIB) purchased from the National Aquaculture Research Development and Training Center-Sagana.

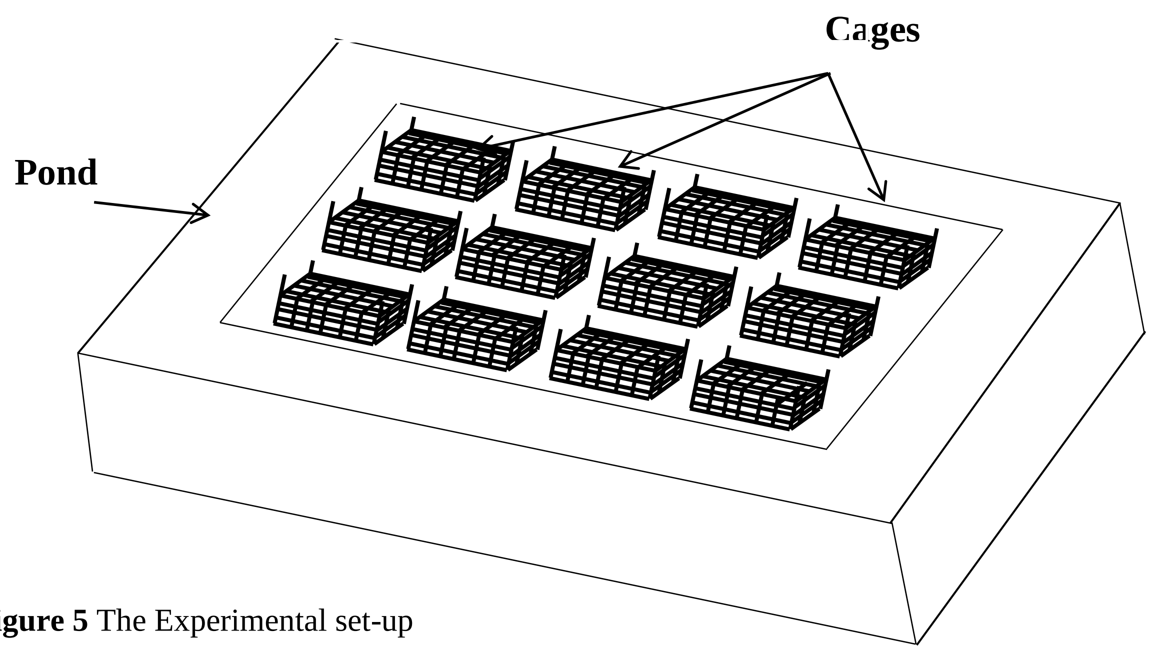


Figure 5 The Experimental set-up

All the fish were fed on a 30% protein content (CP) formulated feed at 3% body weight under semi-intensive approach due to high cost of feed. This feed was ground and pelleted using the ordinary meat mincer from a mixture of wheat bran, freshwater shrimp (*Caridina nilotica)* and cotton seed cake (table 1). They were fed twice a day at 10.00 am and 3.00 pm for the entire period of the experiment. To avoid loss of feed through wave action from the cages, the feed were put in feeding rings (circular rubber rings) to confine the feed within the cages (appendix 1).

Table 1 Nutritional content and percentage ingredient inclusions in the formulated feed

Feedstuffs	% ingredient inclusion	% protein	% lipid	% crude fibre
Freshwater shrimp	12.0	8.0	0.7	0.5
Cotton seed cake	44.4	15.9	3.0	3.2
Wheat bran	43.6	6.1	2.8	7.0
TOTAL	100	30	6.5	10.7

(Adapted from BOMOSA final activity report 2006-2010, Formulation Diet composition for Kenya)

3.3 Sampling

3.3.1 Water quality parameters

Water temperature, transparency, conductivity, dissolved oxygen (DO), percentage oxygen saturation (DO%), salinity and pH were measured *in situ* between 5.00 am and 6.00 am in the morning and in the afternoon (2.00 pm to 4.00 pm) on the day of stocking and biweekly thereafter, just before fish sampling using HANNA Multiprobe meter (model Hi-9828, Hanna Instruments Inc., USA) (appendix 4). 200ml of integrated water samples were collected in replicates from three points in the pond and biweekly just before fish sampling. They were stored in a cool box with ice and taken to the laboratory. Samples for nutrients such as soluble reactive phosphorous (SRP), Nitrates, Nitrites, ammonia and Chlorophyll a were filtered and analyzed using standard methods. Total soluble solids (TSS) and Total phosphorous were analyzed without filtering the samples APHA, (2004).

3.3.2 Growth rates of the fish

The total length (cm) and weight of fish (g) were measured and recorded during stocking to establish the initial length and weight and biweekly thereafter. Total length was measured from the snout to the tip of the caudal fin. This was done using a standard measuring board as described by Lagler, (1970) while the weight was measured using a standard digital weighing scale (model Kern 572, Kern & Sohn GmbH, Germany). During the biweekly sampling, representative samples of 30 fish per species per cage were obtained using a scoop net (appendix 2), taken to the pond side and length (cm) and weight (g) of individual fish taken and recorded (appendix 3). During the final sampling, the number of fish in each cage for each species was also counted and recorded to determine Survival Rates (SR) for each species of fish. The length-weight relationships were calculated from the final length and final weight data for each species of fish.

The weight data obtained from the entire period of study was then used to calculate growth parameters; Mean Weight Gain (MWG), Daily Weight Gain (DWG), Percentage Weight Gain (PWG) and Specific Growth Rate SGR) for each species of fish. MWG and DWG for each species were calculated using equations according to Osofero *et al.*, (2014) while survival rates (SR), Specific growth rates (SGR) and Percentage Weight gain (PWG) for each species was estimated using the equations of Jauncey & Ross (1982).

MWG = $W_f – W_i$; ………………………………………………………………………... (1)

Where W_f = Final average weight at the end of the experiment and W_i = Initial average weight at the beginning of the experiment.

DWG = $W_f – W_i$ / (Rearing days); …………………………………………………..……… (2)

Where W_f = Final average weight at the end of the experiment; Wi = Initial average weight at the beginning of the experiment.

SR (%) = Number of fish that survived x 100/Total no. of fish stocked …………………….(3)

SGR (%)/day = [log Final weight-log initial weight/Rearing period (days)] x 100. ……….. (4)

PWG (%) = (Final weight-Initial weight/Initial weight) x 100 ……………………………...(5)

The Length-Weight (L-W) relationship were calculated using the equation,
$W = aL^b$ (Pauly, 1983) ……………………………………………………………………….(6)
Where W= weight of fish (g); L= Total Length of fish (cm); a = describes the rate of change of weight with length while b = weight at unit length. Regression plots were then generated from this equation from where the values of regression coefficient (b) were then obtained.

The condition factor (K) which shows the degree of wellbeing, health and fatness of the fish in their habitat was determined by using the equation, $K = 100W/ L^b$ (Ricker, 1975) …………(7)
Where K = condition factor; W = the weight of the fish in grams (g); L = the total Length (cm) and b = the value obtained from the length-weight equation.

3.4 Data Analysis

Descriptive and inferential statistics were done using MS Excel (2010) and SPSS version 22. The growth parameter data as well as the condition factors data were compared using one way ANOVA for the four mixed sex Nile tilapia treatments and Tukey's Honest Post Hoc Test used to separate the means. Independent samples T test was carried out for each of the African carp and African catfish treatments for both growth parameters and condition factors data. In all the analyses, 5% level of significance was used as the critical level for the rejection of the null hypothesis.

CHAPTER FOUR

RESULTS

4.1 Water quality

Values of DO ranged between 1.1±0.08 to 5.74±0.07 mg/l at 6.00 p.m in the morning (6-7 am) and between 8.18±0.02 to 14.0±0.47 mg/l in the afternoon (2-3 pm). The water temperature varied from 21.97±0.07 °C to 24.92±0.04°C in the mornings and 26.17±0.10°C to 31.16±0.25°C in the afternoons. Conductivity values ranged between 119.33±0.33 to 148.00±0.00 µscm^{-1} in the mornings and between 121±0.58 µscm^{-1} and 147.33±1.67 µscm^{-1}. Chlorophyll a values ranged between 0.004±0.001 and 1.053±0.521 µgL^{-1} while values for transparency (Secchi depth) ranged between 14.27±0.07 cm and 20.22±0.51 cm. Total ammonia values ranged between 0.030±0.000 µg/l and 0.032 µg/l while pH values ranged between 8.14±0.05 to 9.09±0.02 in the mornings and 9.29±0.02 to 10.49±0.01 in the afternoons (Table 2).

4.2 Growth rates of mixed sex Nile tilapia, African catfish and African carp in various species combination treatments

4.2.1 Growth rates of mixed sex Nile tilapia in cage monoculture and in different species combination with African catfish and African carp

There were no significant differences in mean weight gain (MWG), daily weight gain (DWG) percentage weight gain (PWG) and specific growth rate (SGR) values between the Nile tilapia treatments (One way ANOVA, p> 0.05). Mixed sex Nile tilapia polycultured with African carp however achieved a relatively higher final weight 36.6±7.3 g than the rest followed by those polycultured together with African catfish that achieved a final weight of 34.2±7.7 g. On the other hand, mixed sex Nile tilapia polycultured together with both the African catfish and African carp in the same cages achieved the lowest final weight of 32.0±9.0g. There was however significant differences in the survival rates of the mixed sex Nile tilapia between the treatments (One way ANOVA, p<0.05). The mixed sex Nile tilapia cultured alone had the highest survival rate of (72.5±7.2) (%) followed by mixed sex Nile tilapia polycultured with African carp (61.7±2.5) (%), mixed sex Nile tilapia poly-cultured with both African catfish and African carp 48.7±5.5 g while mixed sex Nile tilapia poly-cultured with African catfish had the lowest survival rates (42.3±4.51) (%) (Table 3).

Table 2 Water quality parameters monitored during the experiment

Week	Time of day	Electrical Conductivity (µscm^{-1})	DO Concentration (mg/l)	DO (%saturation)	Temperature (°C)	Ph	Transp. (secchi depth) (cm)	Chloro. a (µg/l)	Total ammonia (TAN) (µg/l)
1	M	134.0±0.6	4.0±0.1	88.2±0.5	22.0±0.1	8.9±0.4			
	A	122.7±1.8	8.2±0.02	120.5±1.7	28.1±0.2	9.3±0.0	20.2±0.5	0.004±0.0	0.03±0.0
3	M	125.3±0.3	4.0±0.25	58.2±6.2	23.0±0.1	8.3±0.1			
	A	125.3±0.3	9.1±0.5	142.2±5.3	28.1±0.5	9.5±0.1	18.7±0.2	0.004±0.0	0.03±0.0
5	M	119.3±0.3	5.7±0.1	78.4±0.9	22.1±0.0	9.1±0.0			
	A	121±0.6	14.0±0.47	200.8±4.4	26.2±0.1	10.5±0.0	17.9±0.3	0.01±0.0	0.031±0.0
7	M	127.7±0.3	3.9±0.1	54.2±1.7	23.8±0.0	8.1±0.1			
	A	129.7±0.3	11.0±0.3	167.2±2.6	30.7±0.4	9.8±0.2	18.5±0.7	0.01±0.0	0.036±0.0
9	M	145.0	3.9±0.1	54.2±2.5	23.8±0.0	8.7±0.1			
	A	139.3±1.9	11.0±0.2	151.6±17.3	27.4±0.1	10.1±0.1	18.8±0.1	1.05±0.5	0.03
11	M	144.3±0.3	4.2±0.2	61.3± 3.3	24.9±0.0	8.7±0.0			
	A	147.3±1.7	12.2±0.5	194.1±6.0	31.2±0.3	10.2±0.0	18.0± 0.2	0.06±0.0	0.0308±0.0
13	M	148	1.1±0.1	16.4±1.1	23.7±0.0	8.2±0.0			
	A	146±0.6	10.3±0.5	157.6±9.8	28.5±0.4	9.9±0.1	15.3±0.1	0.03±0.0	0.03±0.0
15	M	146.7±0.3	1.5±0.2	22.7±3.2	23.8±0.0	8.4±0.1			
	A	146.0±0.6	10.3±0.5	157.6± 9.8	28.5±0.4	9.9±0.1	15.7±1.0	0.04±0.0	0.03±0.0
17	M	147.7±0.3	1.6±0.2	21.6±4.0	23.6±0.3	8.4±0.1			
	A	146.7±0.7	10.3±0.5	160.1±7.6	29.0±0.3	9.8±0.1	14.3±0.1	0.04±0.0	0.032±0.0

Key: A-Afternoon (2.00pm -3.00 pm); M-morning (6.00 am- 7.00 am)

Table 3 Growth parameters for mixed sex Nile tilapia in various species combination with African carp and African catfish.

Treatment / *Growth parameters*	**Mixed sex Nile tilapia only(n=30)**	**Mixed sex Nile tilapia cultured with African carp(n=30)**	**Mixed sex Nile tilapia cultured with African catfish(n=30)**	**Mixed sex Nile tilapia cultured with both African carp and African catfish(n=30)**
Initial length (cm)	7.1±1.0	7.03±1.3	7.9±1.2	7.1±1.5
Final length (cm)	12.5± 1.1	12.9±0.9	12.5±0.7	12.2±1.2
Initial weight (g)	7.2±3.3	6.5±3.6	8.9±3.4	7.0±4.6
Final weight (g)	32.6±8.8	36.6±7.3	34.2±7.7	32.0±9.0
Mean weight gain (MWG)(g)	25.1± 0.6	29.9±3.0	25.9±5.0	25.1±2.2
Daily weight gain (DWG) (g)	0.22± 0.01	0.27± 0.03	0.23±0.04	0.224±0.02
Percentage Weight Gain (PWG)	351.8±94.0	444.8± 15.1	312.9±45.0	372.4±95.8
Specific Growth Rate (SGR)	0.58±0.1	0.66 ± 0.01	0.55±0.04	0.6±0.1
Survival Rate (%)	72.5±7.2[a]	61.7±2.5[a]	42.3±4.5[c]	48.7±5.5[c]

*Means followed by different small letters in the rows are significantly different (ANOVA, $p<0.05$).

The growth trends of the mixed sex Nile tilapia in monoculture and different species combination treatments with the African catfish and African carp were almost similar but the growth trends for mixed sex Nile tilapia poly-cultured with African carp indicated a relatively higher growth rate than the rest (Fig. 6).

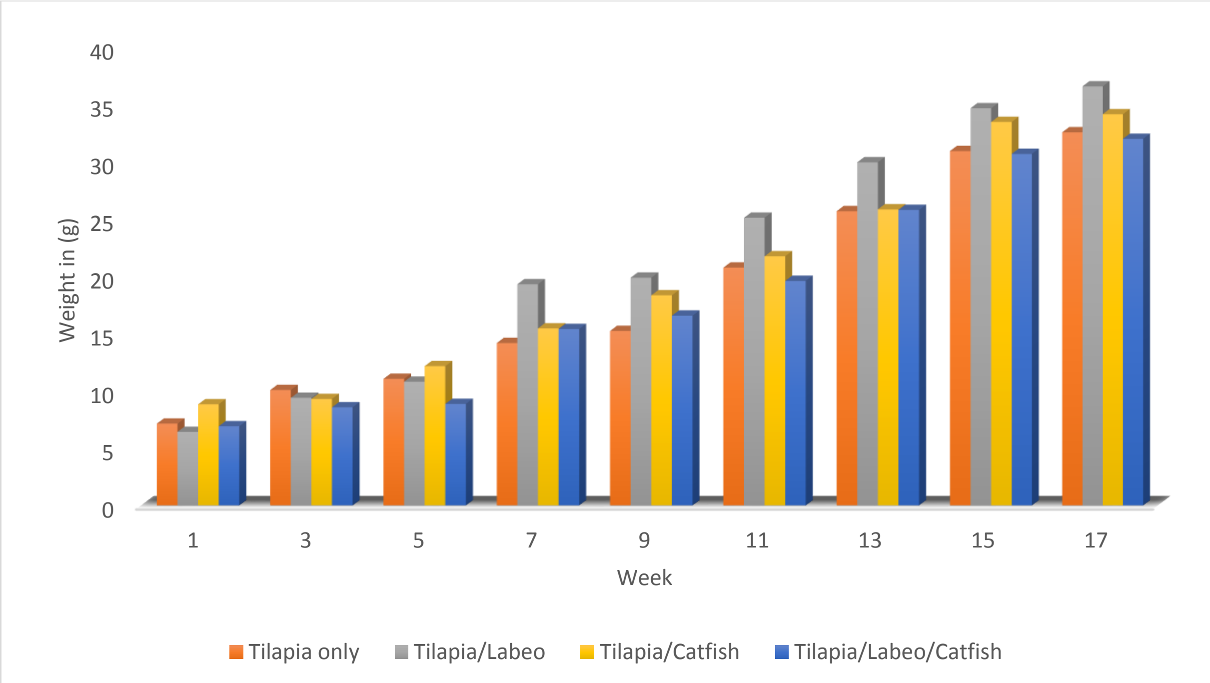


Figure 6 Growth trends of mixed sex Nile tilapia in cage monoculture and poyculture with African catfish and African carp in different species combination treatments.

4.2.2 The growth rates of African catfish in cage poly-culture with mixed sex Nile tilapia and African carp

The MWG, DWG, PWG, SGR, final length and weight analysis revealed that there were no significant differences between the two African catfish polyculture combinations (T-test, p>0.05). The former had an initial weight of 4.00±0.9 g and the latter 3.6±1.4 g. The daily weight gain for the former was 0.9±0.03 g and the latter 0.8±0.1g, close values and thus no significant difference between them. There were also no significant differences in their survival rates (T-test, p>0.05) (Table 4).

Table 4 Growth parameters for African catfish in cage poly-culture with mixed sex Nile tilapia and African carp.

Treatment / *Growth parameter*	**African catfish cultured with Mixed sex Nile tilapia(n=30)**	**African catfish cultured with both Mixed sex Nile tilapia and African catfish(n=30)**
Initial length (cm)	8.3±0.7	8.02±1.0
Final length (cm)	23.9±0.3	23.4±0.5
Initial weight (g)	4.00±0.9	3.6±1.4
Final weight (g)	99.7±3.1	90.36±5.9
Mean weight gain (MWG)(g)	95.7±3.0	86.5±5.83
Daily weight gain (DWG) (g)	0.9±0.03	0.8±0.1
Percentage Weight Gain (PWG)(%)	2380.85±25.9	2231.9±111.5
Specific growth rate (SGR)	1.3±0.0	1.2±0.02
Survival rate (%)	64.3±6.5	61.7±6.7

* Means in the same row are not significantly different (T-test, p>0.05)

4.2.3 The growth rates of African carp in cage polyculture with mixed sex Nile tilapia and African catfish

The African carp growth parameters: mean weight gain (MWG), daily weight gain (DWG), percentage weight gain (PWG) and specific weight gain (SWG) were not significantly different in their polyculture combinations (T-test, p>0.05). The final weight for African carp polycultured with mixed sex Nile tilapia was 23.8±7.3 g while the final weight for those polycultured with both African catfish and mixed sex Nile tilapia had a final weight of 23.20±8.4 g (Table 5). These were also not significantly different. However, the latter treatment had a relatively higher mean weight gain of 8.08±0.8 g, daily weight gain of 0.072±0.01g, percentage weight gain 53.9±9.6 % and specific growth rate of 0.17±0.02 than the former 7.4±1.1g, 0.07±0.01 g, 45.13±8.7 % and 0.14±0.02 respectively.

Table 5 Growth parameters for African carp in cage polyculture with mixed sex Nile tilapia and African catfish.

Treatment / *Growth parameter*	**African carp cultured with mixed sex Nile tilapia(n=30)**	**African carp cultured with mixed sex Nile tilapia and African catfish (n=30)**
Initial length (cm)	13.1±1.9	13.2±1.7
Final length (cm)	14.5±1.6	14.4±1.7
Initial weight (g)	16.6±7.9	15.2±6.6
Final weight (g)	23.8±7.3	23.2±8.4
Mean weight gain (MWG)(g)	7.4±1.1	8.08±0.8
Daily weight gain (DWG) (g)	0.07±0.01	0.072±0.01
Percentage Weight Gain (PWG)(%)	45.13±8.7	53.9±9.6
Specific growth rate (SGR)	0.14±0.02	0.17±0.02
Survival rate (%)	63±4.00	60.8±11.8

* Means in the same row are not significantly different (T-test, p>0.05)

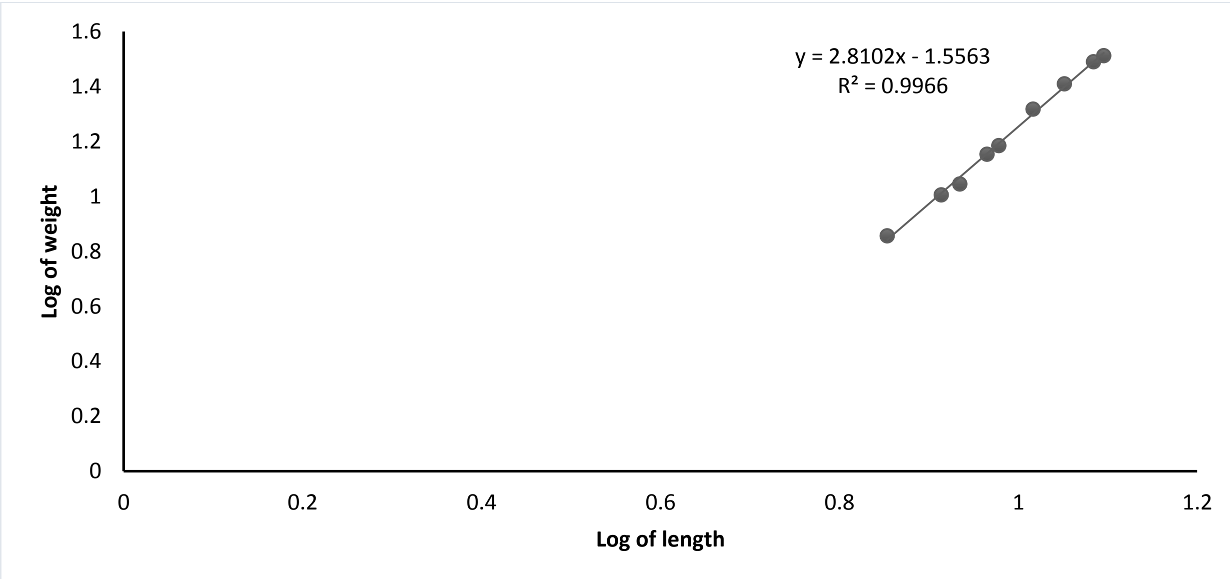
4.3 Length-weight relationships and condition factors for the three species of fish

4.3.1 Length-weight relationships

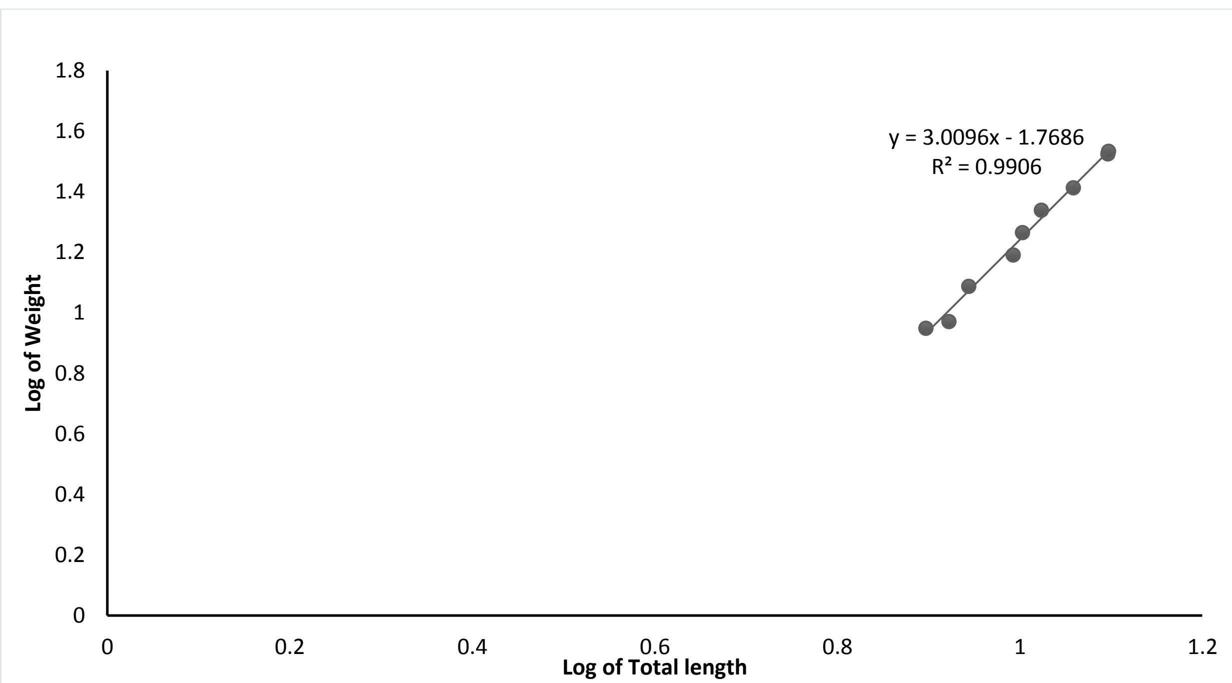
Mixed sex Nile tilapia polycultured with African catfish in cages showed isometric growth, with regression slope/weight at unit length (b) value of 3.01. However, mixed sex Nile tilapia fish monocultured and those polycultured with both African catfish and African carp in cages had weight at unit length (b) values of 2.81 and 2.73, respectively while those polycultured with African carp had a b value of 2.84 (table 6). They had values slightly lower than 3. The weight at unit length (b) values and the length-weight relationships as shown in the Table 6 were obtained from the regression plots/equations (Fig 7, 8, 9 and 10).

The African catfish poly-cultured in cages with mixed sex Nile tilapia and those polycultured with both mixed sex Nile tilapia and African carp had weight at unit length (b) values of 3 (b=3), obeying cube law thus showing isometric growth (Table 6).

The African carp poly-cultured in cages together with mixed sex Nile tilapia had weight at unit length (b) value of 3.11 thus obeying cube law and showing isometric growth while those polycultured together with mixed sex Nile tilapia and African catfish had b value of 2.91, and thus showing slight deviation from 3 (Table 6).

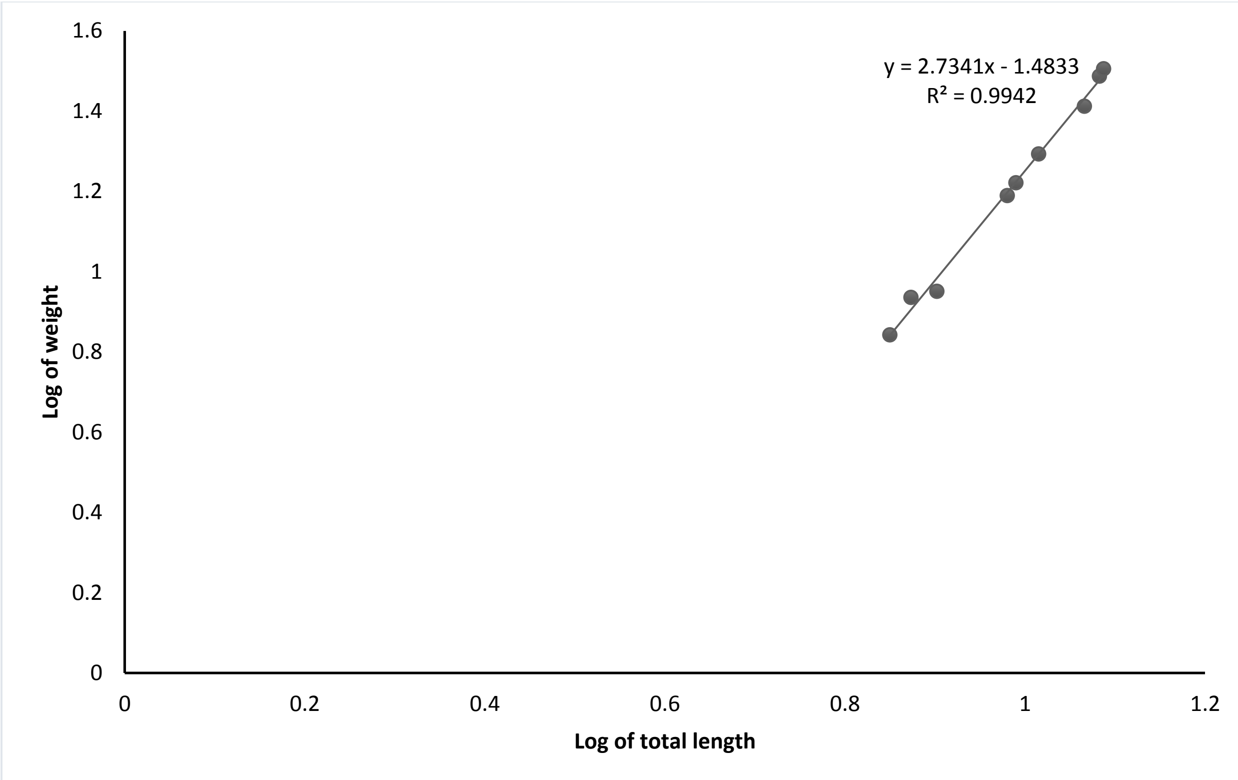


(a)

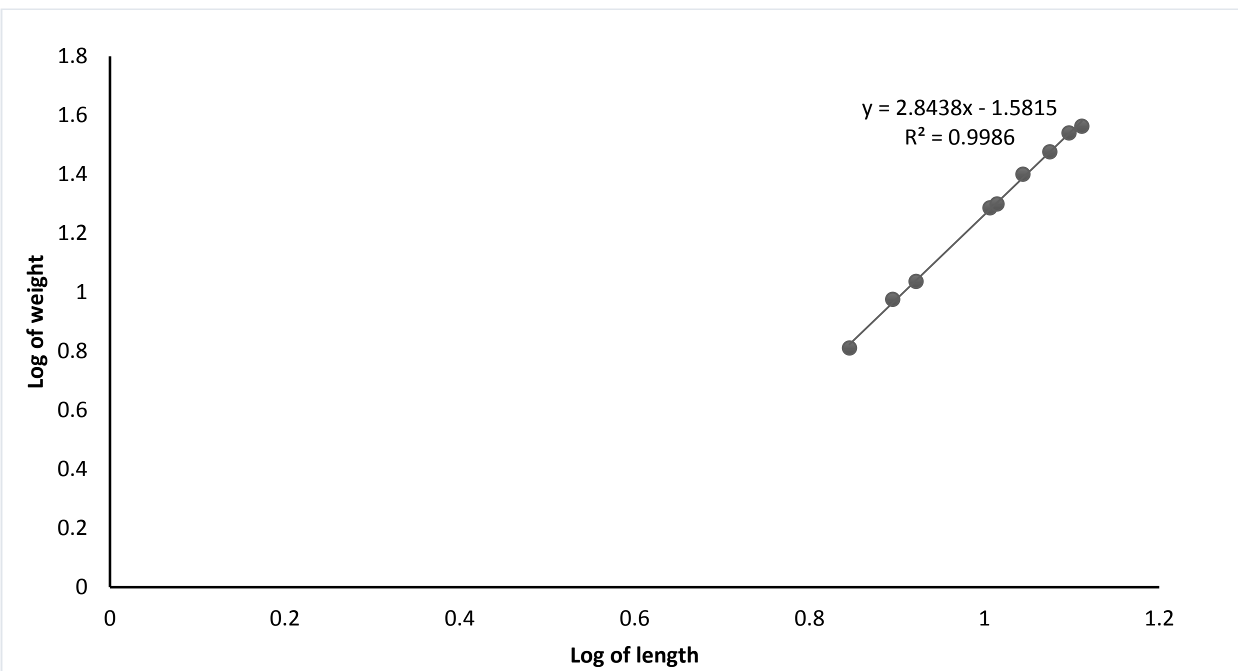


(b)

Figure 7 Length-weight relationship of (a) mixed sex Nile tilapia cultured alone and (b) polycultured with African catfish in cages.

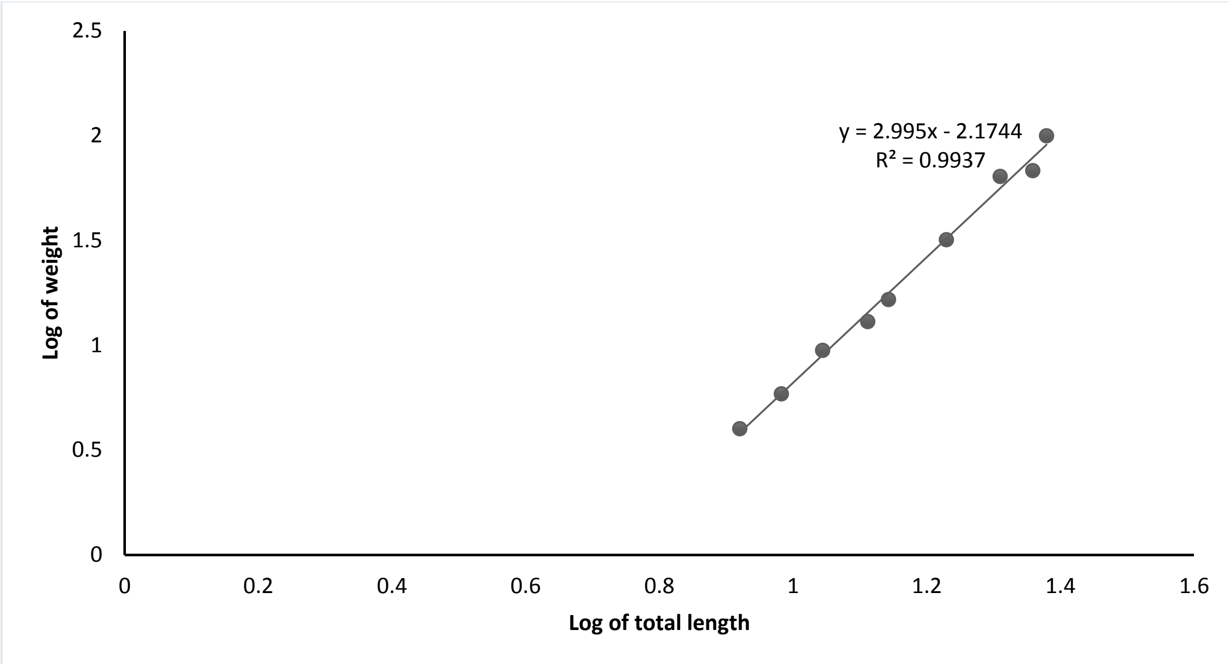


(a)

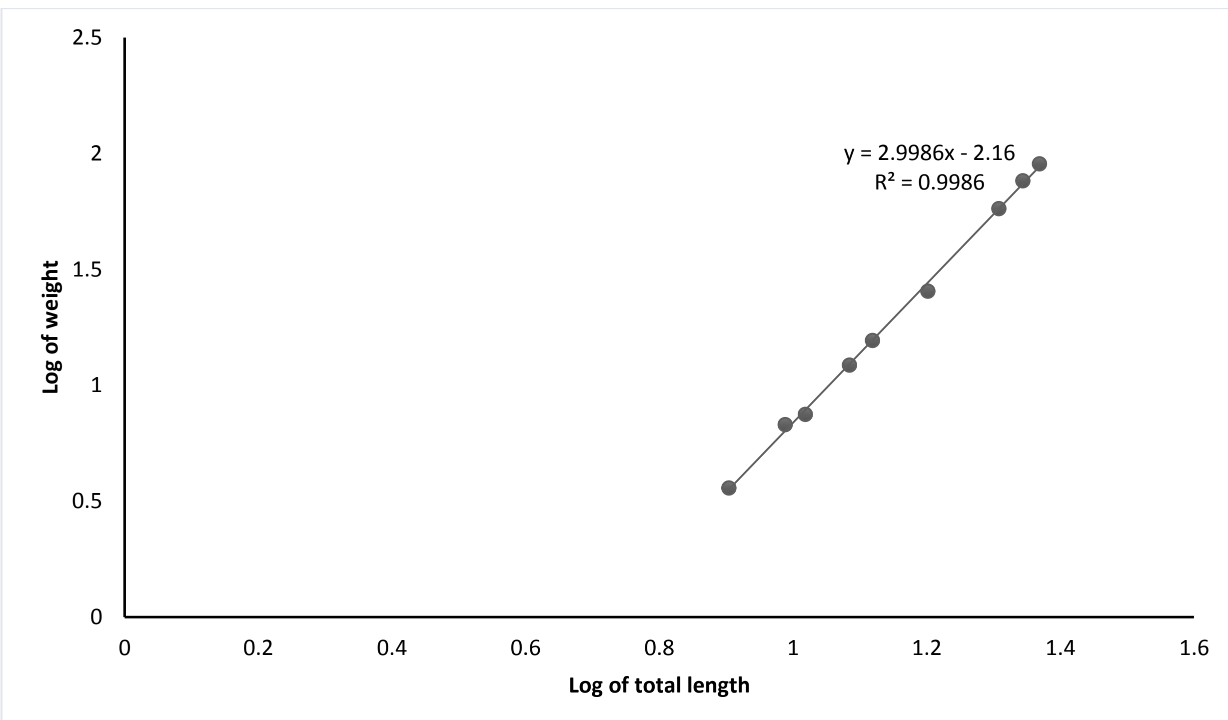


(b)

Figure 8 Length-weight relationship of mixed sex Nile tilapia polycultured with (a) African catfish and African carp and (b) with African carp in cages

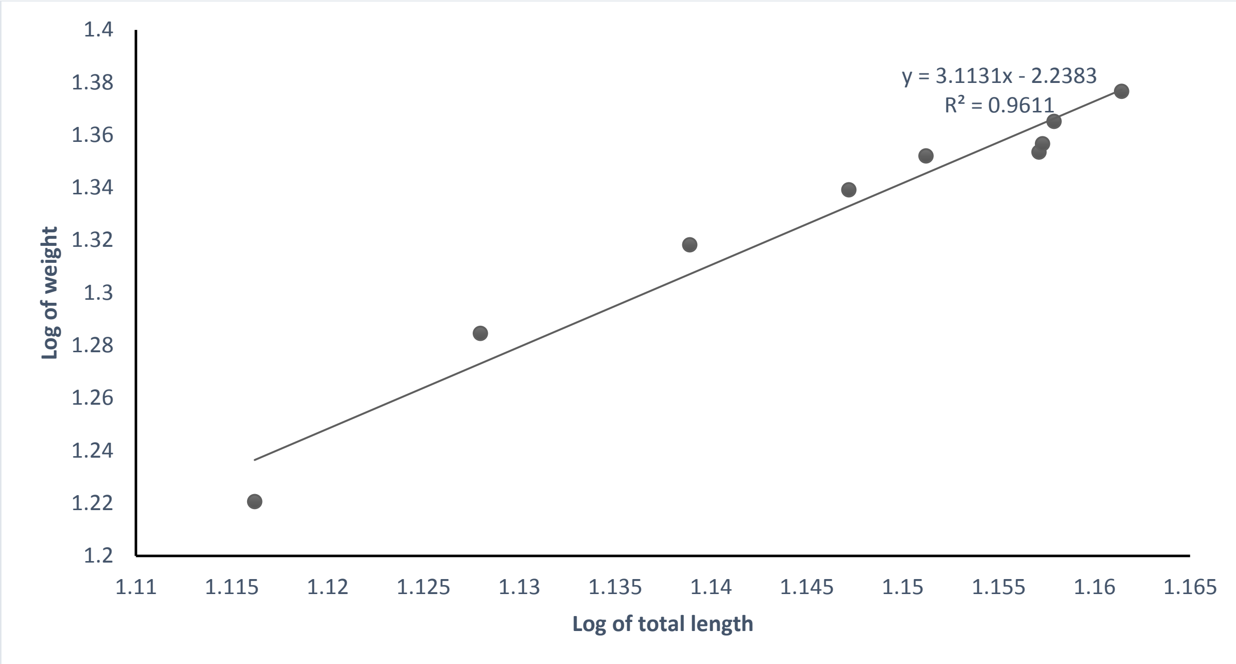


(a)

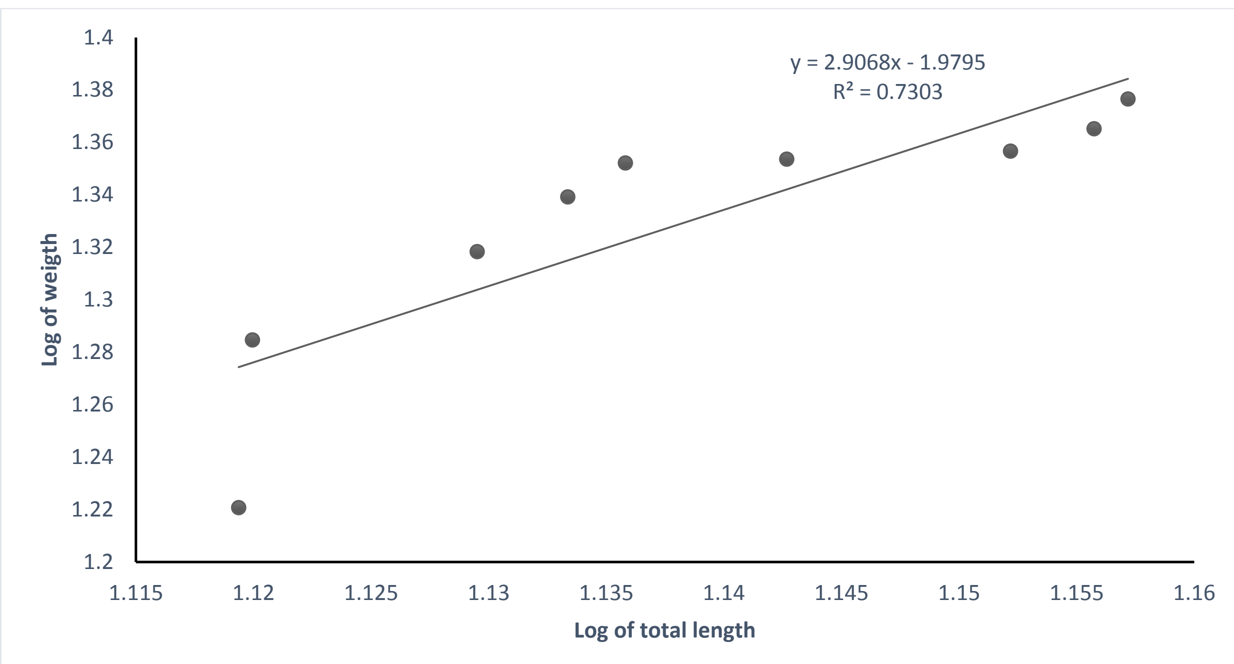


(b)

Figure 9 Length-weight relationship of African catfish polycultured with (a) mixed sex Nile tilapia and (b) mixed sex Nile tilapia and African carp in cages



(a)



(b)

Figure 10 Length-weight relationship of African carp polycultured with (a) mixed sex Nile tilapia and (b) mixed sex Nile tilapia and African catfish.

Table 6 Length-weight relationships and b values for mixed sex Nile tilapia, African catfish and African carp polycultured in different species combinations in cages.

Species of fish and species combination	Length-weight relationship	Weight at unit length (b value)
Mixed sex Nile tilapia alone	$Log_{10}W=-1.566 + 2.81l \text{ Log } L$	2.811
Mixed sex Nile tilapia with African catfish	$Log_{10} W= -1.769 + 3.01 \text{ Log } L$	3.01
Mixed sex Nile tilapia with African catfish and African carp	$Log_{10} W= -1.467 + 2.734 \text{ Log } L$	2.734
Mixed sex Nile tilapia with African carp	$Log_{10}W= -1.598 + 2.844 \text{ Log } L$	2.844
African catfish with mixed sex Nile tilapia	$Log_{10} W = -2.133 + 2.995 \text{ Log } L$	2.995
African catfish with mixed sex Nile tilapia and African carp	$Log_{10} W = -2.148 + 2.999 \text{ Log } L$	2.999
African carp with mixed sex Nile tilapia	$Log_{10} W = -2.239 + 3.113 \text{ Log } L$	3.113
African carp with mixed sex Nile tilapia and African catfish	$Log_{10} W = -1.987 + 2.907 \text{ Log } L$	2.907

4.3.2 Condition factors of the three species of fish

The condition factors recorded for the mixed sex Nile tilapia mono-cultured and polycultured in cages were higher than 1.5 as shown in table 7 below. The mixed sex Nile tilapia monocultured had the highest condition factor (2.719) followed by those polycultured with African carp (2.542), those polycultured with African catfish (1.704) while those polycultured with both African catfish and African carp had the lowest (1.544) (Table 7). There were significant differences in the condition factors between the monocultured mixed sex Nile tilapia and mixed sex Nile tilapia polycultured with African catfish and those polycultured with both African catfish and African carp (ANOVA, $p<0.05$). However, there were no significant differences in condition factor between the monocultured mixed sex Nile tilapia and those polycultured with African carp in cages (ANOVA, $p>0.05$).

There was also no significant difference in the condition factors (ANOVA, p>0.05) between the mixed sex Nile tilapia polycultured with the African catfish and those polycultured with both the African carp and the African catfish in the same cages (Table 7). The fact that the values of the condition factors were above one however suggests that the fish were generally in good condition.

Table 7 Condition factors for mixed sex Nile tilapia cultured alone and with other fish species in cages.

Treatment (Species combination)	Condition factor
Mixed sex Nile tilapia alone in cages	2.719[a]
Mixed sex Nile tilapia cultured with African carp in cages	2.542[a]
Mixed sex Nile tilapia cultured with African catfish in cages	1.704[b]
Mixed sex Nile tilapia cultured with African catfish and African carp in cages	1.544[b]

*Means followed by the same letters in the same column are not significantly different (ANOVA, p>0.05)

There was no significant difference in the values of condition factors between the two African catfish polyculture combinations (T-test, p>0.05). However, the African catfish reared with mixed sex Nile tilapia only and those reared with both mixed sex Nile tilapia and African carp in cages had lower values of less than 1 with the former having a slightly higher value than the latter (Table 8).

Table 8 Condition factors for African catfish reared with mixed sex Nile tilapia and mixed sex Nile tilapia and African carp in cages.

Treatment (Species combination)	Condition factor
African catfish reared with mixed sex Nile tilapia only in cages	0.74
African catfish reared with mixed sex Nile tilapia and African carp in cages	0.71

*Means in the same column are not significantly different (T-test, p>0.05)

There were significant differences in the condition factor values between the African carp reared with mixed sex Nile tilapia only and those polycultured with both African catfish and mixed sex

Nile tilapia in cages (T-test, $p<0.05$). The latter registered a significantly higher condition factor value of 1.03 while the earlier registered a value of 0.58 (Table 9). The condition factor for African carp that was reared with both mixed sex Nile tilapia and African catfish had a value of 1.03, slightly more than 1. This indicated that the condition of these fish in their species combinations in the cages was good. However, the condition factor for African carp reared together with mixed sex Nile tilapia only in cages had a value of 0.58 which was less than 1. The condition of these fish in these cages was therefore not good.

Table 9 Condition factors for African carp reared with mixed sex Nile tilapia only and with mixed sexes Nile tilapia and African catfish in cages.

Treatment (Species combination)	**Condition factor**
African carp reared with mixed sex Nile tilapia only in cages	0.58
African carp reared with mixed sex Nile tilapia and African catfish in cages	1.03

*Means in the same column are signicantly different, (T-test, $p<0.05$)

CHAPTER FIVE

DISCUSSION

5.1 Water quality

The most important water quality parameters that affect growth; temperature, dissolved oxygen concentration (DO), pH and ammonia were within the recommended range of 6.5-9.0 for pH, 22°C-31.2°C for temperature, 8.2-14 mg/l for dissolved oxygen during the day, high percentage saturation of between 88.2±0.5% and 200.8±4.4% and total ammonia of 0.03 ppm according to Boyd & Tucker, (1998); Masser, (1997) and FAO, (2014). Early morning temperatures and dissolved oxygen concentrations did not fluctuate to the extreme low levels. The day time dissolved oxygen (DO) concentration was generally high throughout the culture period. Dissolved oxygen concentrations at night only dropped to below 2mg/l in the last one month of the study which coincided with the cloudy, colder and rainy season but day temperatures remained relatively high.

Transparency (14.3-20.2 inches) was also within the recommended range of 15-24 inches for cage culture (Masser, 1997). This mean't that even chlorophyll a levels were also moderate in concentration. Lower levels of transparency of up to 6 inches would mean algal blooms which may cause fish deaths through anoxia. The total ammonia concentrations were also relatively low although the high temperatures in the afternoons and pH should have had the opposite effect (Hargreaves & Tucker, 2004). This was possibly because of the intensified feeding and thus little leftovers that would otherwise cause decomposition. This was confirmed by relatively moderate chlorophyll a levels, below critical levels. However, generally high temperatures in the afternoon as well as relatively high chlorophyll a levels most probably brought about a rapid uptake of ammonia by the phytoplanktons thus probably maintaining a low and stable ammonia concentration (Boyd & Tucker, 1998).

These conditions compared with those of other related works on growth performance of Nile tilapia and/with other fish species in the tropics and especially Africa were fairly similar. In BOMOSA cage culture of Nile tilapia in small dams in Machakos in Kenya, the temperature range recorded was 20-30°C; dissolved oxygen, above 3mg/l; pH ranged between 6-9 and TSS levels were around 20 inches (BOMOSA, 2009). Ighwela & Ahmed, (2011) in their study on condition factor as an indicator of growth and feeding intensity of Nile tilapia (*O. niloticus*) fingerlings, were found to be close to these values since dissolved oxygen varied from 5.38 to 6.50 mg/L and temperature from 27.24 - 27.75°C and pH from 6.43 - 6.98. However, electrical conductivity ranged from 24.0-32.0 μscm^{-1} and was much lower while total ammonia ranging from 0.8-1.0 mg/L, was much higher. The variations particularly for ammonia might have been due to the fact that the latter experiment was done in tanks. Limbu *et al.*, (2015), in their studies on the effect of initial stocking size of the predatory African sharptooth catfish (*C. gariepinus)* on recruits, growth performance, survival and yield of mixed sex Nile tilapia (*O. niloticus)* had water temperature ranging from 23.90 to 28.10°C, dissolved oxygen ranged from 2.90 to 10.19 mg/ l and pH values ranged from 5.59 to 7.20.

These water quality values were also fairly close to those recorded in a case study of cage culture of tilapia in a dam in the catchment area of Lake Victoria, Harambee dam (Charro-Karisa *et al.*, 2009) where the temperature ranged between 23.09°C and 27.23°C, dissolved oxygen concentrations was around 8.38 mg/l, conductivity ranged between 247 and 270, this being higher than in this study where the conductivity ranged between 119.3±0.3 and 147.7±0.3 µscm^{-1} possibly because of its bigger size, stagnant water nature and use as a water drinking place for cattle and other multiple uses. The range of pH was between 7.4 and 9.06, which was within the recommended range.

5.2 Growth rates of mixed sex Nile tilapia, African catfish and African carp in various species combination

There were no significant differences in the growth parameters viz Mean weight gain (MWG), Daily Weight gain (DWG), Percentage Weight Gain (PWG), Specific Growth rate (SRG) and final weight of mixed sex Nile tilapia monocultured or polycultured with African catfish or African carp or with both. This may mean that the mixed sex Nile tilapia fish in all the treatments were still in their early/juvenile (10-35 g size) stages of growth (FAO, 2016) and therefore no significant differences in their growth rates. Under good growth conditions this species of fish will reach sexual maturity in farm ponds at an age of 5-6 months and 100 to 200 grams (Popma & Masser, 2005). It may also mean that the breeding cycle of tilapia is disrupted in cages and therefore no problems of recruitment and stunting (FAO, 2006), that would be a source of variation in growth rates especially in ponds. Although not significantly different, the mixed sex Nile tilapia polycultured with the African carp showed relatively higher growth rate of all the species combination treatments. This was followed closely by mixed sex Nile tilapia polycultured in combination with African catfish.

Generally, polycultured mixed sex Nile tilapia showed relatively higher growth rates or higher values in terms of growth parameters than when mono-cultured in cages. These findings are in agreement with those of Shoko *et al*., (2014), Osofero *et al*., (2014) and Sweilum, (2001). Shoko *et al*., (2014) while investigating the effect of stocking density on growth, yield and economic benefits of mixed sex Nile tilapia in monoculture and polyculture with African catfish in Tanzania, in relatively similar tropical conditions as this study also reported that polycultured mixed sex Nile tilapia with the African catfish attained higher mean weight gain than those monocultured. The only differences between their study and this study is that the stocking density of the two fish species in polyculture treatments were varied such that there were high stocking density (HSD) of 90000 fish ha^{-1}, medium stocking density (MSD) of 60000 fish ha^{-1} and low stocking density (LSD) of 30000 fish ha^{-1} and also the experiment was conducted in large ponds and not cages as in this study. In agreement, Sweilum, (2001) while investigating growth performance and production of Nile tilapia using polyculture systems and fertilizers in fishponds in Egypt also found out that the growth rate of Nile tilapia was higher in polyculture with the African catfish and Mango tilapia (*Sarotherodon galilaeus*) than when in monoculture. As with the study of Shoko *et al.,* (2014), Sweilum, (2001) also used ponds and not cages with the fishes being stocked in seven earthen ponds with varied areas at a density of 4 fish/ m^2. In this case also, grow out period was longer than in the present study.

Interestingly, Osofero *et al*., (2014) while investigating the growth performance of mixed sex Nile tilapia in monoculture and polyculture with African catfish and prawns in cages in Nigeria, similar tropical conditions as this experiment, also found that mixed sex Nile tilapia polycultured in cages with the African catfish achieved a higher growth rate and final weight than those monocultured in cages. Additionally, Limbu *et al*., (2015) while investigating the effect of initial stocking size of the predatory African catfish on recruits, growth performance, survival and yield of mixed sex Nile tilapia in Tanzania (similar tropical conditions) also showed that the growth performance of mixed sex Nile tilapia was higher when polycultured with African catfish than when in monoculture. The difference being that the experiment was done with the stocking sizes of African catfish varied (large (62.50 ± 3.26 g) and small (40.00 ± 2.68 g) and the fish were fed on 29.75 % protein content (CP).

The mixed sex Nile tilapia cultured in the polyculture cages (fourth treatment) with both African catfish and African carp together had the lowest growth rate, most likely due to increased interspecific competition and also increased social stress or chronic stress response which may impair fish growth due to the mobilization of dietary energy by the physiological alterations provoked by the stress response (Kebus *et al*., 1992). This contrasted with the findings by Sweilum, (2001) who found in his work that Nile tilapia recorded higher growth rate when poly-cultured with both African catfish and mango tilapia together in ponds.

Although there were no significant differences in the growth rate, final weight and final length between the mixed sex Nile tilapia polycultured with the African carp and those polycultured with the African catfish, the former recorded a relatively higher growth rate than the latter. This was probably due to the different feeding behaviors of the fish species reared/cocultured with the mixed sex Nile tilapia in the cages, in this case the African carp and the African catfish. For example, Owori-wadunde, (2001) studied the feeding biology of African carp and found out that it is predominantly a detritus feeder. The position and structures of its mouth are adapted for bottom feeding and scraping epilithic materials from surfaces of submerged objects and for filtering detritus. It also has a long intestine which is typical of species feeding predominantly on plant diet. In this study, the African carp was found mainly on the side of the net cages where they could have been possibly scrapping algae.

However, the African catfish is euryphagous, omnivorous, opportunistic, a predator and voracious feeder with a wide sub terminal and transverse mouth that is capable of considerable vertical displacement that enables suction feeding (FAO, 2014). It was observed that every time the formulated feed was put in the feeding rings, they would be the first to feed vigorously at the water surface confirming the observations of some authors (Hecht & Applebaum, 1988 and Britz & Pienaar, 1992).

Therefore, the mixed sex Nile tilapia polycultured with the African catfish would most likely face not only more competition for food, space, and oxygen but also predation pressure (Wang & Lu, 2015) than mixed sex Nile tilapia polycultured with African carp in cages. Relating to this, there were significant differences in the survival rates of mixed sex Nile tilapia fish cultured alone in cages, those polycultured with African catfish, those polycultured with African carp and those polycultured with both African catfish and African carp at (ANOVA $p<0.05$) in cages.

The mixed sex Nile tilapia cultured alone in cages registered a higher survival rate than the latter three. These results agree with the findings of shoko *et al.,* (2014) and Osofero *et al*., (2014) in their study of comparative productivity of monoculture and polyculture of mixed sex Nile tilapia and African catfish, the latter in cages, where it was generally found that the survival rates for Nile tilapia were higher in monoculture than in polyculture. This was most likely because of predation by the fast growing catfish in the polyculture cages. Due to the higher survival rates in the monoculture cages and thus increased intraspecific competition for food, space and oxygen, the mixed sex Nile tilapia fish showed a lower growth rate than when they were in polyculture with African carp and African catfish. Hesler & Almcida, (1997) and Irwin *et al*., (1999) argued that competition for food could be a possible factor as well as space limitation (Islam, 2002). Yi *et al*., (1996) and Huang *et al*., (1997) argued that, generally, tilapia is a territorial and aggressive fish so that the differences in growth rates might be explained by their differential intraspecific competition for territories, as well as the stress caused by overcrowding.

Correspondingly, although there was no significant difference in the values of the growth parameters viz mean weight, daily weight gain, percentage weight gain and specific growth rate of African catfish when reared with mixed sex Nile tilapia and those polycultured with both the African carp and mixed sex Nile tilapia in cages, those cultured with mixed sex Nile tilapia recorded a higher final weight than those polycultured with mixed sex Nile tilapia and African carp. This probably explains the lower survival rates of mixed sex Nile tilapia in the former. Though there was no significant difference in the growth rate values (t-test, $p>0.05$) of catfish in the two species combinations, there was considerable reduction in the numbers of the fish from the originally stocked in each case. The deviation most likely due to predation/cannibalism. Coulibaly *et al.* (2006) reported that the main constraint of the culture of the African catfish is the high mortality due to mainly cannibalism and more so in cages.

There was also no significant differences in the values of the growth parameters viz mean weight, daily weight gain, percentage weight gain, daily weight gain, specific growth rate and final weight between African carp cultured together with mixed sex Nile tilapia only and those polycultured with both mixed sex Nile tilapia and African catfish (t-test, $p>0.05$). However, the African carp cultured together with mixed sex Nile tilapia only had a relatively higher final weight than the latter. This might have been due to reduced interspecific competition in the former case as compared to the latter case since the two fish species reared with them (Nile tilapia and African catfish) in the second case have different feeding habits and occupy different niches. However, the latter had a relatively higher mean weight gain, daily weight gain, percentage weight gain and specific growth rate than the former.

5.3 Length-weight relationships and condition factors for the three species of fish

5.3.1 Length-weight relationships

Length-weight relationships (LWR) are used to estimate the weight corresponding to a given length (Gomiero & Braga, 2003; Froese, 2006 and Gomiero *et al.*, 2008)) and may also be used to determine possible differences between separate unit stocks of the same species. It also gives information on the condition and growth patterns of fish in separate unit stocks of the same species (Bagenal & Tesch, 1978).

The results of the length-weight relationship showed that mixed sex Nile tilapia polycultured with African catfish in cages showed isometric growth which is ideal for cultured fish with a regression slope/weight at unit length (b) value of 3.01. The growth of these fish obeyed cube law, meaning that the increase in weight in this case was proportional to the increase in length (Froese, 2006). However, the b value of three (3) is only ideal because in reality the value cannot be exactly three but any value between 2.5 to 4 is taken to represent or depict isometric growth and so ideal for cultured fish (Wooton, 1990). Based on this, all the mixed sex Nile tilapia treatments showed isometric growth. Mixed sex Nile tilapia fish monocultured, those polycultured with African carp in cages had weight at unit length (b) values of 2.81 and 2.84 respectively, while those polycultured with both African carp and African catfish had the lowest weight at unit length (b) value of 2.73. A b value less than 2.5 means that the fish have negative allometric growth. The classical ontogenetic interpretation of the negative allometric growth is that the fish increased in weight at a lower rate than the length, and thus not maintaining constant body proportions (Tesch, 1968). Values of less than 2.5 are usually associated with a shortage of suitable food or overcrowding (Ricker, 1979; Murphy *et al*., 1991). In this cases however, the b values were all above 2.5, an indication that the food given was sufficient.

The results also showed that the weight at unit length (b) values obtained from length-weight relationships (LWR) which are indicative of isometric or allometric growths differed between the groups. This result agrees with the findings of Stewart, (1988) in his study of condition factor, length-weight relationships in growth and maturation of Tilapia in Lake Turkana in which he found growth differences in all groups due to differential feed availability. In the present study, the difference in weight at unit length values could be due to difference in food availability as a result of differential competition attributed to the different species combination unit stocks of mixed sex Nile tilapia in the cages.

The African catfish poly-cultured in cages with mixed sex Nile tilapia and those poly-cultured with both mixed sex Nile tilapia and African carp had weight at unit length (b) values of 3 (b=3), obeying cube law thus showing isometric growth. This indicated that there was a proportionate increase in weight for every corresponding increase in length that is ideal for farmed/cultured fish. The African carp cultured in cages together with mixed sex Nile tilapia had b value of 3.113 thus obeying cube law and showing isometric growth while those polycultured together with mixed sex Nile tilapia and African catfish had b value of 2.91, slightly lower than the ideal b value of 3 but still within the range (2.5 to 4) of isometric growth. Both weight at unit length values (b) were thus ideal for cultured/farmed fish.

5.3.2 Condition factors of the three species of fish

The condition factor (K) is used to compare the condition ('fatness') and the wellbeing of a fish and according to Bagenal, (1978) heavier fish at a given length are in better condition. It is used as an indicator of health of fish, growth and feeding intensity (Froese, 2006), even comparing the physiological status of unit stocks or populations living in different feeding, climate and other conditions (Le Cren, 1951, Lizama & Ambrosia, 2002 and Gomiero *et al*., 2008). It is thus used to determine the feeding activity of a species or members of a unit stock to determine if it is making good use of its feeding source (Weatherly, 1972, Lizama & Ambrosia, 2002, Gomiero *et al*., 2008). There were significant differences in the values of condition factors of the mixed sex Nile tilapia monocultured and polycultured with African carp and African catfish in different species combination treatments (ANOVA, $p<0.05$). However, generally, condition factors recorded for the mixed sex Nile tilapia monocultured and polycultured with other species of fish were all higher than 1.5. This showed that the fish were in a relatively good condition (Froese, 2006). This could possibly mean that the feed given was sufficient, as Ighwela & Ahmed, (2011) recorded values higher than 1.5 for intensively fed Nile tilapia in aquaculture ponds in Malaysia. The monocultured mixed sex Nile tilapia had a relatively higher value for condition factor of 2.72 followed closely by those polycultured with the African carp with a value of 2.542, while those polycultured with African catfish 1.704 and those polycultured with both African carp and African catfish had a value of 1.544 (Table 7). The higher the value of condition factor the better the health of the fish (Bagenal, 1978; Froese, 2006). Yet there were no significant differences between the condition factors of the monocultured mixed sex Nile tilapia and those polycultured with the African carp. Coincidentally, the growth rates of the mixed sex Nile tilapia polycultured with the African carp were relatively higher than the rest, possibly because of the relatively high condition factor and relatively high weight per unit length (b value) (Table 6). This could possibly be attributed to a relatively better health condition for these fish than in the other treatments. However, these results differ from the findings of Olurin and Aderibigbe, (2006) who recorded condition factors below 1 for Nile tilapia in polyculture ponds in Nigeria. They attributed this to inadequate food and overcrowding within the ponds.

There were no significant differences in condition factors between the African catfish poly-cultured with mixed sex Nile tilapia only and those polycultured with both mixed sex Nile tilapia and African carp in cages (T-test, $p > 0.05$). African catfish reared with mixed sex Nile tilapia and those reared with both mixed sex Nile tilapia and African carp in polyculture cages however, had condition factors less than 1. Their condition was therefore not as good possibly because of the relatively low feeding rate of 3% body weight and also relatively lower protein content in the feed for catfish culture (De Graaf, 2004). El-Gaedy, (2009) concluded that the dietary requirements of catfish fry were (40% crude protein and 8% oil) and for fingerlings were (35% crude protein and 8% oil) in terms of growth performance and economic evaluation. They require higher amounts of proteins particularly with their carnivorous nature.

The relatively lower value of condition factor may also have been due to intraspecific competition for refuge in the cages, increasing incidences of territorial aggression, fights, cannibalistic behavior and agonistic behavior when stressed (Hecht & Appelbaum, 1988 and Britz & Pienaar, 1992). This was confirmed by the presence of injury marks on some of them and especially in latter stages of growth in the cages. This aggression may directly affect the welfare of the fish. In addition, the resulting skin damage may also lead to the release of chemical alarm cues from the skin of the fish, possibly acting as a secondary stressor in a farming/culture situation (Van de Nieuwegiessen *et al*., (2009). Appelbaum & Kamler, (2000) recommended light restriction as a simple, low-cost technique for intensification of production of *C. gariepinus*. Since in dark, the ratio of total metabolism for body growth was depressed, the energy used for locomotor activity may be low, leading to sparing energy in growth. So, catfish reared in dark are larger than those reared in light.

There were significant differences in the values of condition factors between the African carp reared together with mixed sex Nile tilapia in cages and those polycultured with both mixed sex Nile tilapia and African catfish in cages (T test $p<0.05$). The latter had a significantly higher value of 1.03 more than the former with a value of 0.58. The condition factor for African carp that was reared with both mixed sex Nile tilapia and African catfish was slightly more than 1.This shows that the fish were in above average (good) conditions whereas those reared together with mixed sex Nile tilapia only in cages had a value of 0.58 which was less than 1. The condition of the latter fish was therefore below average (not as good). This might have been due to higher interspecific competition for food, oxygen and space in the second case relative to the first and especially by the fact that survival rates for mixed sex Nile tilapia in this treatment were significantly higher (ANOVA, $p<0.05$) in these cages than in the earlier case. The feeding niches (those of mixed sex Nile tilapia and African carp) are also close (Singh, 1996).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Several conclusions were drawn from the study:

1) Firstly, the water quality parameters were generally within the recommended values for warm water fish cage culture.
2) Secondly, there were no significant differences in the growth rate of mixed sex Nile tilapia in monoculture and those polycultured with the African catfish and African carp in different species combination treatments in cages. There were however, significant differences in the survival rates of mixed sex Nile tilapia when monocultured and when polycultured with the two species of fish in different species combination treatments in cages. Though not significantly different in growth rates, the mixed sex Nile tilapia polycultured with the African carp showed relatively higher growth rates and relatively high survival rates than the other mixed sex Nile tilapia treatments.

   There were also no significant differences in the growth and survival rates between African catfish reared with mixed sex Nile tilapia and those reared with both mixed sex Nile tilapia and African carp.

   There were also no significant differences in the growth and survival rates of African carp reared with mixed sex Nile tilapia and those reared with both mixed sex Nile tilapia and African catfish in cages.
3) The Length-weight studies revealed that all mixed sexes Nile tilapia treatments viz those reared together with African catfish in cages, those polycultured with African carp, those monocultured and those polycultured with both African carp and African catfish all had weight per unit length (b) values depicting isometric growth that is ideal for cultured/farmed fish.

   Similarly, the African catfish reared together with mixed sex Nile tilapia and those reared together with both mixed sex Nile tilapia and the African carp also showed isometric growth with a high weight per unit length value of three (3), ideal for farmed/cultured fish. African carp reared with mixed sex Nile tilapia and those reared with both African catfish and mixed sex Nile tilapia showed isometric growth as well, which is ideal for farmed/cultured fish.

4) Lastly, there were significant differences in the condition factors of the mixed sex Nile tilapia fish in their different species combination treatments. There were significant differences in condition factors between the monocultured mixed sex Nile tilapia and those polycultured with the African catfish as well as with those polycultured with both the African catfish and African carp in cages. There were however no significant differences in condition factor between the monocultured mixed sex Nile tilapia and those polycultured with the African carp in cages. There were also no significant differences in condition factors between those cultured with African catfish and those polycultured with both African catfish and African carp in cages.

   There were also no significant differences in condition factors between the African catfish reared with mixed sex Nile tilapia and those reared with both African carp and mixed sex Nile tilapia in cages.

   However, there were significant differences in condition factor between the African carp reared with mixed sex Nile tilapia and those reared with both mixed sex Nile tilapia and African catfish in cages.

   Generally, the condition factors for all mixed sex Nile tilapia treatments, African carp poly-cultured with both mixed sex Nile tilapia and African catfish had values more than 1 indicating that they were in good condition. However, the African catfish and the African carp reared with mixed sex Nile tilapia had values less than one (1) indicating that they were not in good condition.

6.2 Recommendations

Even though more studies incorporating a full grow out cycle of 8 months are highly recommended:

1) Water quality parameters for the culture of warm water species of fish like Nile tilapia, African catfish and the African carp ought to be monitored closely and maintained at the recommended level so as not to affect growth of fish in cages because of the water quality sensitivities in the cage culture environment.

2) This study recommends the cage poly-culture of mixed sex Nile tilapia with the African carp as a better polyculture combination option for the production of mixed sex Nile tilapia in cages. Mixed sex Nile tilapia cultured with the African carp showed a relatively higher potential for productivity with a relatively higher growth rate, isometric growth, high condition factor and relatively higher survival rates.

   The African carp is also recommended for safe polyculture with Nile tilapia because when Nile tilapia was polycultured with it, the former still performed relatively better than when in monoculture and polyculture with the African catfish or both African catfish and African carp.

   Both African carp treatments viz African carp polycultured with mixed sex Nile tilapia and those polycultured with both mixed sex Nile tilapia and African catfish showed isometric growth with weight at unit length values (b) of three (3) and relatively higher survival rates. These treatments are also recommended for polyculture production of both Nile tilapia and African carp.

   The treatments with African catfish were characterized by high levels of predation especially on the mixed sex Nile tilapia and even the African carp and thus polyculture with the latter two may result to lower production especially if the intention is to rear the latter two.

3) The rate of increase of weight against the length (length-weight growth relationships) and condition factors for fish (including their feeding environment and species for polyculture combination) are serious considerations in cage culture because they affect growth rate and survival rates of fish in cage culture. These ultimately affect cage culture productivity.

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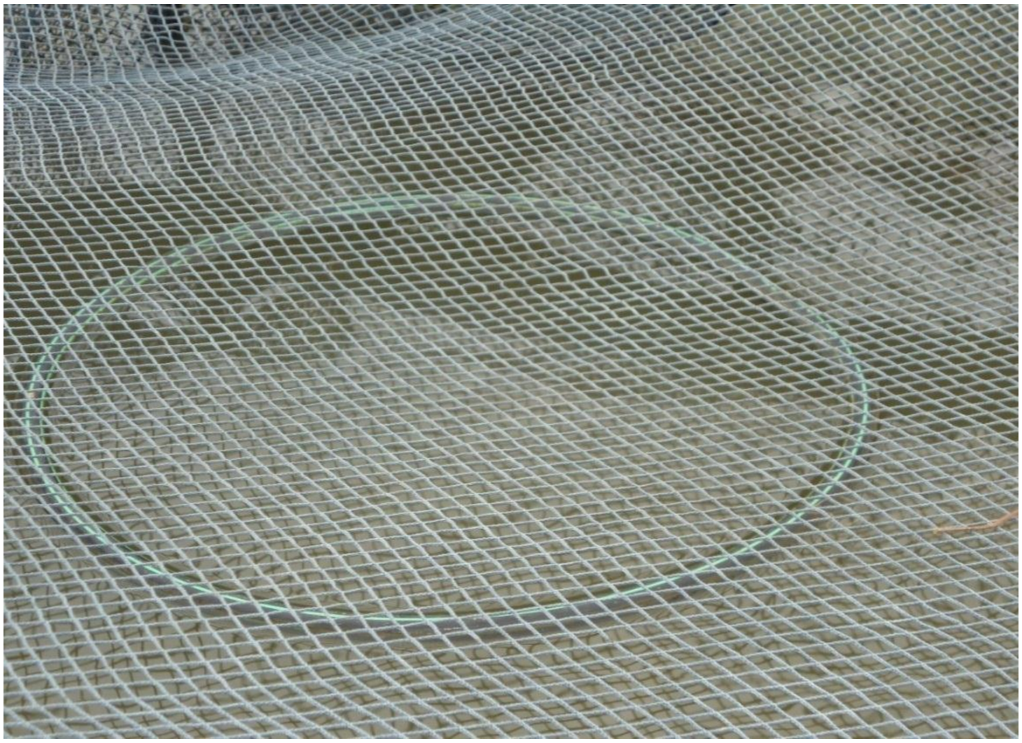
APPENDICES

APPENDIX 1: PHOTOGRAPH OF A FISH FEEDING RING



Source: Author, (2016)

APPENDIX 2: COLLECTING OF FISH SAMPLES FROM THE CAGES

Source: Author, (2016)

APPENDIX 3: TAKING AND RECORDING OF FISH LENGTH AND WEIGHT MEASUREMENTS AT THE PONDSIDE

Source: Author, (2016)

APPENDIX 4: TAKING OF WATER QUALITY MEASUREMENTS INSITU IN THIS CASE TRANSPARENCY

Source: Author, (2016)