THE IMPACTS OF INTRODUCTION OF *Cyprinus carpio L.* (COMMON CARP) TO FISHERIES OF LAKE NAIVASHA, KENYA

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A thesis submitted to the Graduate School in partial fulfilment for the requirements of the Master of Science degree in Environmental Science of Egerton University

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DECLARATION AND RECOMMENDATION

DECLARATION

I declare that this thesis is my original work and has not been submitted in part or in full to any other university for award of any degree

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DEDICATION

To my lovely beautiful wife Teresia Wanjiru Macharia, my son Steve Njuguna Macharia and daughter Bernice Wambui Macharia for their tireless support when I was carrying out the study. To my dear mama Bernice Wambui Njuguna for her full faith in me

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ABSTRACT

New species introduction in an ecosystem have diverse ecological impacts that are deleterious or beneficial. *Cyprinus carpio L.* has recently been introduced in L. Naivasha of which its impacts in the lake ecosystem have not been studied. The fishery of Lake Naivasha Kenya is based on introduced species namely *O. leucostictus, T. zillii, M. salmoides* and the more recent *C. carpio L.* The objective of this study was therefore to determine the impacts of introduction of *C. carpio L.* to fisheries of Lake Naivasha. Monthly representative samples of water and fish were obtained from five sampling sites between November 2005 and April 2006. Secondary data on fish production between 1995 and 2007 was obtained from Kenya Fisheries Department. The distribution of water temperature, pH and dissolved oxygen across the sampling period had no significance difference ($P>0.05$). The distribution of water temperature and pH across the sampling stations had no significance difference ($P>0.05$). The distribution of dissolved oxygen across the sampling station had a significant difference ($P<0.05$). Water temperature, dissolved oxygen and pH were 20.9±0.7°C, 6.7±0.9mg/l and 8.7 respectively. Detritus material was the most shared food forming 58%, 48% and 24% prominence value among *C. carpio L.*, *O. leucostictus* and *T. zillii* respectively. *T. zillii* was found to have shifted from its previous most preferred food of detritus to macrophytes. Introduction of *C. carpio L.* was found to have introduced new food competition with negative impact to the lake ecosystem. The length-weight relationship **b** factor of *C. carpio*, *T. zillii* and *O. leucostictus* was 2.6, 2.3 and 1.5 respectively. Optimum growth of *C. carpio L.* was found to be affected by the high pH level (8.7). Low water temperatures (20.9±0.7°C) inhibited optimum growth of *O. leucostictus* and *T. zillii.* It was noted that production trend of *O. leucostictus* was in decline having achieved a peak of 428MT in 1999. *C. carpio L.* production (97%) trend have dominated other fish species between 2002 and 2007. *C. carpio L.* introduction had impact to the fisheries of L. Naivasha through its effects to changes in water quality, food competition and dominance in lake fish production.

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LIST OF ABBREVIATIONS

D.O.: Dissolved Oxygen

EMCA: Environmental Management and Coordination Act

MoLFD: Ministry of Livestock and Fisheries Development

KFD: Kenya Fisheries Department

KMFRI: Kenya Marine and Fisheries Research Institute

DEFINITION OF TERMS

Aquatic environment:

Refers to the physical and biological factors of animals and plants surrounding the water environment

Ecology:

The dynamic complex of living (biotic) and non-living (abiotic) factors in an environment

Ecosystem:

A dynamic complex of plant, animal, micro-organism communities and their non-living environment interacting as a functional unit

Environment:

Includes the physical and chemical factors of the surroundings of organisms including land, water, atmosphere, climate, sound, odour, taste, the biological and chemical factors of animals and plants and the social factor of aesthetics and includes both the natural and the built environment

CHAPTER ONE

INTRODUCTION

1.1.0 Background

The African lakes including Lake Naivasha are extremely important ecosystems that are subject to a lot of study relating to species introductions and loss of biodiversity (Hart and Pitcher, 1995). Due to their crucial ecological and socio-economic functions these lakes are vital fish and wildlife habitats. Introduction of new species have had impacts to the lakes ecology resulting to ecosystem instability. New fish species introduction triggers ecosystem instability due to introduced organisms' competitions at cellular, organismic, individual, population and community levels. Newly introduced species in an environment prompts an increase in competition of food and space in a stable ecosystem. Such competitions among fish species may be more pronounced in reservoirs. This is because of the nature of these system and the continuous anthropogenic influences that may not allow natural process to regulate their densities (Lowe-McConnel, 1987 and Rabon, *et. al.*, 2004). On the other hand such new introductions may have positive effects to an ecosystem. The positive effects range from increasing fish production to improved food web. The increased fish production has a positive impact to the socio-economics of communities relying to the lake for fishing activities.

Major introductions of non-native or non-indigenous fish species from an aquatic ecosystem to another occur through several pathways. These pathways include human activities, birds' movement and streams & ponds outburst (Welcomme, 1988 and Leffler, 2002). The mode of fish introduction to another aquatic environment is through transportation of live fish or viable eggs that eventually hatch and become established to the new environment. Human introduction of fish in an environment have been used as a management tool to enhance fish production (Ogutu-Ohwayo, 1987).

Lake Naivasha has had only one native species believed to have become extinct in 1960s (Raburu, *et. al.,* 2002). The other five exotic species were introduced between 1926 and 1965. These are *Oreochromis leucostictus, Tilapia zillii, Macropterus salmoides*, *Barbus amphigramma* and *Poecilia reticilata. Oreochromis leucostictus, Tilapia zillii* and *Macropterus salmoides* formed the basis of commercial fishery of Lake Naivasha until the year 2001 when catches of *Cyprinus carpio L.* started getting recorded by fishermen (KFD, 2002).

Cyprinus carpio L. is believed to have invaded Lake Naivasha, in the year 2001 from fish ponds in the Lake Naivasha watershed through the rivers (Britton, 2002 and KFD, 2002). There is also a possibility that the fish was introduced by migratory birds in the lake. The effects of *Cyprinus carpio L.* in Lake Naivasha either positive or negative have not been studied. *Cyprinus carpio L.* is considered a pest and a nuisance species in many world aquatic ecosystems due to its dominance nature. The fish is able to dominate an environment with suitable water physicochemical parameters overtaking other fish species in their well being and population. In Kenya *Cyprinus carpio L.* was criticised for its digging habits and its capability of replacing tilapias as dominant species in Masinga reservoir on the Tana River (Welcomme, 1988).

The commercially exploited fish feeding habit examined by Hickley *et. al*., (2002) and Britton, (2002) indicates that small black Bass depend heavily on micronecta and large black Bass mostly take crayfish. Detritus predominates in the diet of *O. leucostictus* and *Tilapia zillii. Tilapia zillii* also eats micronecta and macrophytes while *O. leucostictus* also eats algae. Mavuti, (1990) recommended the introduction of zooplanktivorous fish that has a commercial value to exploit un-cropped zooplankton. His studies observed that there was no fish that permanently occupied the limnetic zone. He indicated that zooplankton production directly entered the decomposers food chain. Hickley *et. al.,* (2002) also recommended a benthic feeding fish such as *Mormyrus* spp. because no benthivorous fish was present in Lake Naivashas' food chain. The feeding habit and food overlap of *Cyprinus carpio L.* with other fish species needs to be studied to establish its occupation to the lake food web. Such study would be beneficial in ascertaining if, as per the earlier proposition to introduce new species, the invasive species is of better economic value or is destructive to the environment.

Lake Naivasha commercial fishery has been in decline in the recent years. Fish landed in the year 2000 saw a reduction of 15% from 449 Metric tonnes to 383 Metric tonnes caught in 1999. This prompted the Kenya Fisheries Department (KFD) to ban fishing from the lake in the year 2001. Consequently, the Department introduced an annual fishing closed season. The appearance of *Cyprinus carpio L.* in the lake is presumed to pose a new challenge to the fishery of Lake Naivasha. Already catch data suggests that the fish is gradually replacing commercial fish species that have hitherto been the main fish species harvested by fishers from the lake. For example, in the year 2004, the fish dominated the annual catch composition commanding a 77% of total fish caught. *P. clarkii, M. salmoides, O. leucostictus* and *T. zillii* followed with 10%, 6%, 5% and 2%, respectively (KFD, 2004). KFD observes that it is imperative for lake managers and researchers to understand the impacts of *Cyprinus carpio L.* on other fish species in the lake. More importantly, it is imperative to understand the effects *Cyprinus carpio L.* feeding and breeding behaviour has on the breeding grounds/nests of the tilapia fish species and the implication on the lake's fishery (KFD, 2004).

Developing suitable and viable methodologies for predicting environmental impacts posed by the introduction of *Cyprinus carpio L.* is necessary for the sustainable management of flora and fauna of such water bodies. This is particularly so for lakes of international and national conservation importance like Lake Naivasha. Suffice it to state that, the Lake is registered as a Ramsar (Betch and Harper, 2002) and world heritage site and earns Kenyan income through foreign exchange every year from tourism, commercial fisheries and horticulture. These results will therefore be useful in initiating a predictive model to be used in formulation for sustainable watershed and wetland assessment, conservation and management of the lake's fishery.

1.2.0 Problem Statement

The introduction of *Cyprinus carpio L.* fish by the year 2001 in Lake Naivasha posed a new environmental problem to the ecosystem of the lake. The fish is predicted to shifts ecosystem balance from the previous ecological stability. The *Cyprinus carpio L.* fish feeding habit leads to the destruction of other fish feeding and breeding grounds resulting in reduced populations of other fish species. Deterioration in water quality favours the survival of *Cyprinus carpio L.* at the expenses of other less adaptive fish species leading to fish population declines and an overall loss of fish diversity. *Cyprinus carpio L.* has been associated with the capacity to dominate an ecosystem suppressing other fish species. This study, hence sought to investigate the impacts of the introduced *Cyprinus carpio L.* on the Lake Naivasha fishery.

1.3.0 Main Objective

To determine the impacts of the introduced *Cyprinus carpio L.* to the fisheries of Lake Naivasha, Kenya

1.4.0 Specific objectives

1. To determine how the introduction of *Cyprinus carpio L.* has impacted the water quality parameters including temperature, dissolved oxygen and pH across Lake Naivasha
2. To determine the *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* fish species length and weight relationship in Lake Naivasha
3. To determine and compare the food constituent of omnivorous fish species including *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* in Lake Naivasha
4. To study *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* fish species production trends between 1995 and 2007 in Lake Naivasha

1.5.0 Research questions

1. How has water quality parameters including temperature, dissolved oxygen and pH varied on introduction of *Cyprinus carpio L.* in Lake Naivasha?
2. What is the distribution of water quality parameters including temperature, dissolved oxygen and pH across the lake and are they suitable for *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* fish species survival in Lake Naivasha?
3. What are the length and weight relationships of *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* fish species in Lake Naivasha?
4. What are the food constituent of omnivorous fish species including *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* and how are their food contents comparable in Lake Naivasha?
5. What have been *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* fish species production trends between 1995 and 2007 in Lake Naivasha?

1.6.0 Justification

Lake Naivasha aquatic system is a lifeline for several domestic and commercial activities. Among these activities are the lake commercial fishery, bird's sanctuary, geothermal, tourism sport fishing, domestic and commercial water use, wildlife and wetland. These activities support livelihood of more than 300,000 people as food and a major source of income (Gitahi, 2005). The introduction of *Cyprinus carpio L.* fish in the Lake is predicted to shift the ecosystem balance with either positive or negative effect to the lake ecosystem. Research is therefore prerequisite to establishing any deleterious or significant effects that the fish has to the lake's fish habitats. The research therefore aims at identifying these effects through the study of water quality parameters variation, food constituents, fish length-weight relationship and fish production trends. The study is imperative for establishing a predictive model critical to the lake management and conservation plan by the stakeholders.

1.7.0 Study limitations

The research on the impacts of introduction of *Cyprinus carpio L.* to the fisheries of Lake Naivasha had the following limitations;

1. The research period was within six months to synchronise with the study duration of two years. A full year study could be more preferable to study variations of water quality parameters throughout the year
2. Only temperature, dissolved oxygen and pH water quality parameters were assessed. Other physicochemical parameter like heavy metals and persistent organic pollutants could not be determined due to financial resources limitation

CHAPTER TWO

LITERATURE REVIEW

2.1.0 Fish introductions in Lake Naivasha

Lake Naivasha had only one fish species by 1925. The fish species was endemic zooplanktivorous small-tooth carp, *Aplocheilichthyes antinorii* (Vina). In 1925 *Oreochromis spilurus niger* (Gunther) was introduced by Kenya Game and Fisheries Department. American large mouthed bass (*Macropterus salmoides* Lacepede) was later introduced in the Lake by 1927. These fish species successfully dominated the lake until 1950 when water level reduced. Large mouthed bass were reintroduced on several occasions between 1950 and 1956. *Tilapia zillii* (Gervais) was introduced in 1956. The batch of *Tilapia zillii* unintentionally contained some individuals of *Oreochromis leucostictus* (Trewavas). In 1970 the Louisiana Red (swamp) crayfish *Procambarus clarkii* (Girard) was introduced to broaden the range of the commercial fishery. *Barbus ampigramma (*Boulenger) migrated down to the lake from the Malewa River during the high water levels of the 1982. Other species were introduced for mosquito control including *Gambusia spp., Poecilia spp* and *Lebistes reticulata* Peters (Harper, *et. al.,* 1990). *Cyprinus carpio L.* was later introduced in the Lake in the year 2001 (Britton, 2002).

2.2.0 *Cyprinus carpio L.* distribution and biology

The *Cyprinus carpio L.* (Plate 1) is a widespread freshwater fish. It gives its name to the carp family Cyprinidae. Welcomme, (1988) indicated that *Cyprinus carpio L.* is native to Asia and Eastern Europe. It has been introduced into environments worldwide, and is often considered an invasive species. The fish has been introduced to other water bodies through escape from confinement and stocking for aquaculture. It was introduced to Kenya from Uganda in 1969 for aquaculture.

Riehl and Baensch, (1991) classified *Cyprinus carpio L.* under the following category;

Kingdom	Animalia
Phylum	Chordata
Class	Actinopterygii
Order	Cypriniformes
Family	Cyprinidae
Genus	*Cyprinus*
Species	*C. carpio*
Binomial	*Cyprinus carpio* Linnaeus

2.2.1 Physiology

Cyprinus carpio L. has been found to grow to a maximum length of 150cm. The fish has been observed to grow to a maximum weight of over 37.3 Kg and an oldest recorded age of at least 65 years (Howard and Matindi, 2003).

2.2.2 Habitat

Smith, (2005) observed that *Cyprinus carpio L.* fish is most abundant in streams enriched with sewage and substantial run-off from agricultural land. The fish is rare in clear cold waters and streams of high gradient. It prefers water bodies with stagnant and slowly flowing waters with sand and/or silt bottom with shell incorporations. *Cyprinus carpio L.* exploits large and small manmade and natural reservoirs and pools in slow or fast moving streams. It prefer larger slower moving bodies of water with soft sediments but it is tolerant and hardy fish that thrive in a widely variety of aquatic habitats. Potential reduction in predator recruitment combined with high fecundity fast growth rate, wide physiological tolerance and omnivorous diet result in *Cyprinus carpio L.* having the ability to spread into nearly any aquatic habitat (Smith, 2005 and Welcomme, 1988).

2.2.3 Trophic Interactions

Cyprinus carpio L. is an omnivore, showing some preference for chironomids, cladocerans, oligochaetes, other invertebrates, and plankton and macroalgae (Astanin and Trofimova, 1969). Juvenile *Cyprinus carpio L.* may feed on larval fishes, when invertebrates are scarce (Lachner *et al.,* 1970 and Panov *et al.,* 1973). *Cyprinus carpio L.* disturbs sediments when feeding which results to increase in water turbidity. This may cause serious problems in certain systems (Lachner *et al.*, 1970) ranging from ecosysteme destruction to reduced primary productivity in water.

2.2.4 Reproduction

Cyprinus carpio L. may be sexually mature as early as by the end of its first year (Kuliyev and Agayarova, 1984). According to Balon (1995) wild *Cyprinus carpio L.* are multiple spawners, spawning two or three times over a 14 day interval. Mating groups of one female and several males swim actively before spawning in flooded grass flats. Eggs are not guarded, but are deposited on grass blades and hatch in three days. *Cyprinus carpio L.* has a relative fecundity of 100,000 to 300,000 eggs per kilogram with reports of as many as 360,000 to 599,000 eggs per female (Moroz, 1968, Bishai *et al.*, 1974, Gromov, 1979 and Linhart *et al.*, 1995). Eggs vary from 1.2-1.4 mm in diameter and are yellowish green in colour (Moroz, 1968 and Linhart *et al.*, 1995).

Plate 1: ***Cyprinus carpio L.* a Cyprinidae fish**

2.3.0 *Cyprinus carpio L.* effects to water quality

Cyprinus carpio L. is an omnivorous fish and acts as 'nutrient pumps'. It consumes sediments bound nutrients and subsequently excretes them into the water column (Leslie, *et. al.,* 1994). The feeding habit of *Cyprinus carpio L.* where it is constantly stirring up the substrate, mean that the fish can greatly increase the turbidity of water (Smith, 2005). This is through the re-suspension of bottom sediments. This makes the fish unwanted species in some water bodies especially those which serve as source of drinking water. Leslie, *et. al.,* (1993) observed that the presence of *Cyprinus carpio L.* in some shallow Dutch Lakes is the major role in increased turbidity resulting from re-suspension of sediments. The fish is one of the few fish species tolerant of high suspended sediments concentration such as phosphorous rich colloidal sediments of some South Africa rivers and Australia water bodies. The fish is attributed to high turbidity and high conductivity in Argentina water bodies. *Cyprinus carpio L.* is therefore capable of rendering the water unsuitable for swimming or drinking by human and livestock.

2.4.0 *Cyprinus carpio L.* effects to aquatic macrophytes

Emergent macrophytes act as a sieve to pollutants and nutrients from watersheds with detrimental impacts to access the lakes (Gitahi, *et. al.*, 2002, Raburu, *et. al.*, 2002 and Harper, *et. al.*, 2002a). Many wetlands plants have the capacity to remove toxic substances that come from pesticides, industrial discharge and mining activities. Wetland plants have been used to treat wastewater from mining areas containing high concentrations of heavy metals including cadmium, zinc, mercury and nickel as well as faecal coli form bacteria. Jones and Humphries, (2002) indicates that papyrus (*Cyperus papyrus* L.) forms the dominant emergent vegetation in most permanently flooded wetlands of tropical Africa.

Mitchell, (1980) found that *Cyprinus carpio L.* increases water turbidity which reduces the abundance of aquatic plants. The fish feeding behaviour disrupts rooted aquatic plants that provide habitat for native fish species and food for waterfowls. Leslie, *et. al.*, (1993) found that when aquatic vegetation was eliminated by Grass carp in Conroe reservoirs in Texas, increase of nutrients (phosphorus and nitrogen) concentrations were noted. Water transparency declined by 40% as a result of a build up of phytoplankton. Once the aquatic vegetation was removed algal biomass increased twofold as measured by chlorophyll **a**. A relative increase of planktivorous fish was noted in the Conroe reservoirs. The re-suspension of sediment by *Cyprinus carpio L.* fish causes the loss of macrophytes cover due to low water clarity reducing photosynthesis rate. The fish uproots macrophytes and releases phosphorus locked up within bottom sediments causing nutrients imbalance in aquatic environment (Niesar, *et. al.*, 2004).

By reducing submerged vegetation and water clarity *Cyprinus carpio L.* create conditions under which other fish especially large predators may suffer. *Cyprinus carpio L.* has adverse effects on biological system including destruction of vegetated breeding habitats used by both fish and birds. They also lower the abundance of macro-invertebrates by predation and loss of habitat. Smith, (2005) found that the decline of Sacramento perch (*Archoplites interruptus)* fish stock to be attributed by the destruction of their spawning grounds. Leslie, *et. al.*, (1994) found that the deleterious effects on fish population in two Florida ponds was caused by the reduction of macrophytes by Grass carp.

Leslie, *et. al.*, (1993) found that at densities of 400 carps/ha in ponds the *Cyprinus carpio L.* actively controlled submersed aquatic plants in Alabama. At densities of 448 carp/ha the carp destroyed submersed vegetation in enclosures placed in a Lake Erie marsh. In India *Cyprinus carpio L.* is considered to be indirectly useful in controlling submerged rooted vegetation because of its rolling habit. This leads to increased turbidity, which suppresses the growth of submerged aquatic plants (Osborne and Riddle, 1999). In Australia where the exotic *Cyprinus carpio L.* has spread rapidly through the Murray-Darling Basin, since the early 1960s the residents along the rivers attributed the decline in aquatic macrophytes since the early 1970s to the expansion of *Cyprinus carpio L.* (Sanders, *et. al.*, 1991)

Adams, *et. al.,* (2002) and Harper, *et. al.,* (2002a) observed that intense horticulture development in the last two decades has accelerated papyrus clearance, drainage and application of fertilisers in Lake Naivasha. These have affected the aquatic plant species composition and abundance as well as phytoplankton biomass. The invasion of *Cyprinus carpio L.* coupled with the adverse impacts of anthropogenic activities and *P. clarkii* environmental degradation on the macrophytes is projected to intensify the predicament in Lake Naivasha ecosystem.

2.5.0 Water physicochemical parameters

Physiological and biochemical responses of aquatic organisms to stressful environment have recently been reviewed but little is known about stress and alterations in food synthesis relationships and/or growth synthesis relationships (Rankin and Jensen, 1993). Some physiochemical parameters might be extreme for the survival of early introduced fish species in Lake Naivasha. They may however be providing adequate environment for proliferation recently introduced *Cyprinus carpio L.* Water temperature, pH and dissolved oxygen have been observed to have varying effects on aquatic ecosystem.

2.5.1 Water Temperature

Rankin and Jensen (1993) found that all aquatic organisms from microbes to fish were dependent on certain temperature ranges for their optimal health. They indicated that optimal temperatures for fish depended on the species while some survive best in colder water, whereas others prefer warmer water. Temperature tolerance differed with different fish species. Balon (1995) observed that if temperatures are outside organisms' optimal range for a prolonged period of time, organisms are stressed and could die.

Cyprinus carpio L. occurs in temperate fresh waters but not limited to by cold waters. Wang, *et al.*, (1997) observed that *Cyprinus carpio L.* ideal temperature range varied between 3 - 24 °C. However, warmer waters are required for spawning. Over their natural range Balon (1995) reported 17 °C as the lower limit for spawning. *Tilapia zillii* and *Oreochromis leucostictus* are very sensitive to cold waters. Hauser (1975) reported that both the fish species become lethargic and respond irregularly to stimuli, when exposed to waters of below 16°C. He observed that optimum temperature range for *Tilapia zillii* and *Oreochromis leucostictus* to be between 20 and 32°C with death beginning at a lower temperature of 11.2°C, (some fish surviving to 6.5°C), and at a higher temperate of 39.5°C (some fish surviving to 42.5°C). Platt and Hauser (1978) reported a narrower range for optimum feeding and growth of between 28.8 to 31.4°C. Successful reproduction may be limited to waters between 22.5 and 31.5°C (Hauser, 1975) while is inhibited at water temperature below 20°C (Yadav, 2006). The poor cold tolerance of this species has limited its dispersal in the many waters bodies (Platt and Hauser, 1978).

2.5.2 Dissolved Oxygen (DO)

Fox (2003) refers water Dissolved oxygen to the volume of oxygen present in water and it is a basic indicator of ecosystem health. The amount of oxygen that can be held by water depends on the water temperature, salinity and pressure. Some organisms require more oxygen than others and are more sensitive to sudden changes in dissolved oxygen quantity. Dissolved oxygen levels of at least 4-5 mg/l are needed to support a wide variety of aquatic life. Exposure to less than 2mg/l of dissolved oxygen for one to four days may kill most of the aquatic life in the aquatic ecosystem. Prolonged exposure to low dissolved oxygen levels less than 5-6mg/l may not directly kill fish but increases its susceptibility to other environmental stresses.

Yadav (2006) indicated that low dissolved oxygen was the first water quality that constrained *Tilapia zillii* and *Oreochromis leucostictus* growth in water bodies. He observed that commonly cultured species of tilapia could survive at dissolved oxygen concentrations less than 0.5 mg/L. This was considerably below the tolerance level for most fish species. Survival in water with less dissolved oxygen was due to their ability of extracting dissolved oxygen from the film of water at the water-air interface.

2.5.3 Water pH

Rankin and Jensen (1993) observed that water pH was crucial for living organisms and biochemical processes. They indicated that pH was an indicator of the existence of biological life as most of them thrive in a quite narrow and critical pH range. In too acidic or too basic water biological life was extinct. They further observed that exposure to very low or high pH may cause death or reproductive problems for fish and other aquatic life. He indicated that slight variations of pH on a daily basis or major changes over time could cause extreme stress to fish species.

Yadav (2006) observed that Tilapia fish species seemed to grow best in water that is near neutral or slightly alkaline. He indicated that tilapia growth was reduced in acidic waters possibly due to less production of natural food organisms. Commonly cultured tilapia species survived up to pH 10 while the lethal alkaline limit was pH 11 or greater. Wang, *et al.* (1997) indicated that the optimum pH range for growth of *Cyprinus carpio L.* was between 7.0 - 7.5.

2.6.0 Fish Length-weight relationship

The length-weight relationships regression is a useful tool for measuring changes in robustness and health of fish populations. The change of fish condition is relative to variation of food availability in different seasons (Schneider, *et. al.*, 2000). A variety of useful concepts surrounding on the shape of individual fish arises from the consideration on the combined length-weight data (Anderson and Gutreuter, 1985). The power function $W=aL^b$ equation is a useful model for the weight as a function of length. In general **b** less than 3.0 represents fish that become less rotund as length increases and **b** more than 3.0 represents fish that become more rotund as length increases. For many fish species **b** is greater than 3.0. If **b** equals 3.0 it indicates that growth may be isometric.

Rahman, *et .al.* (2004), obtained the standard length-weight relationship equation of Silver Pomfret fish (*Pampus argenteas*) in Bangladesh as $W= -1.1L^{2.8}$. The **b** value for Silver pomfret was 2.8. Abdullah (2002) observed that the length-weight relationship parameter for 29 fish species belonging to 16 families from Egyptian Mediterranean waters ranged from 2.5 to 3.4 with a mean of 2.9. In all these studies the fish had a **b** value less than 3.0 indicating that the fish were less rotund as the length increased.

The exact relationship between length and weight differs among species of fish according to their body shape and within a species according to the condition of individual fish (Schneider, *et. al.*, 2000). Conditions sometimes reflect food availability and growth within weeks prior to sampling. Individual fish within the same sample vary considerably and average condition of each population varies seasonally and yearly.

Bernardes and Rossi-Wongtschowski, (2000) found length-weight relationship of 23 small pelagic fish species of Southeast and South Brazilian Exclusive Economic Zone to have a **b** value between 2.7 and 3.5. These fish condition was presumed to change with seasonal changes in physicochemical conditions of water. Kaewnuratchadason, *et. al.*, (2005) determined **b** value for relative length-weight relationship of Skipjack tuna, Yellowfin tuna and Bigeye tuna to be 3.3, 2.9 and 3.2 respectively and varied with seasonal changes.

Studies on *Harpodon neherus* fish established the **b** value to be 3.1 with the relative fish condition variation in months. The highest peak condition denoted *Harpodon neherus* spawning periods and the small peak represented the cyclic gonads development (Amin, 2001). The **b** value of the lake sturgeon (*Acipenser fulvescens*) in the St. Clair River System was 3.4 and differed with gear used for sampling or sex. The St. Clair River System lake sturgeon population was near the upper ends of growth indicating favourable water physiochemical parameters (Craig, *et. al.*, 2005).

Getabu (1987) found fish age to have significance in length-weight relationship. Juvenile fish feeds on planktons with high nutritive value improving their condition. Boothby and Avault, (1971) observed the mature Red drum fish (*Sciaenops ocellata*) feeding on crustaceans in South-eastern Louisiana to have slight difference in food habit due to size and sex. Bass and Avault, (1975) determined the juvenile Red drum **b** value to be 4.2 higher that the mature fish. The juvenile were found in the nursery area with abundant high nutritive food supply.

Reed, (1978), Durbin, *et. al.* (1979) & Werner and Hall, (1979) found that species diversity in aquatic micro-ecosystems was influenced by the ecosystem stability, environmental heterogeneity and primary production. The environmental heterogeneity is a function of water physicochemical parameters. Barretto and Uieda, (1998) found that water dissolved oxygen, pH, temperature and water salinity had an influence on fish diversity seasonal and spatial variation. The changes of water physicochemical parameters beyond tolerance range of fish leads to fish death (Calheiros and Hamilton, 1998). The water physicochemical parameters including temperature, oxygen (D.O.), salinity, conductivity and pH and quality and quantity of food are among the most important factors affecting phenotypic responses in fishes (Stergiou *et. al.,* 1997). Fish grow rapidly towards a small size or leisurely towards a large size in open waters depending on these parameters.

CHAPTER THREE

MATERIALS AND METHODS

3.1.0 Study Area

Lake Naivasha is situated on the floor of the Eastern Rift Valley at an altitude of 1884 metres above the sea level between longitudes $36^0 16'$- $36^0 26'$E and latitudes $0^0 42'$- $0^0 50'$S. The lake is in Naivasha District, Rift Valley Province, about 100 km northwest of Nairobi as shown in Figure 1 and 2. It is one of a series of 23 major lakes in the Eastern Rift Valley; eight in central Ethiopia, a further eight in Kenya and seven in Tanzania. The Lake is roughly circular, measuring 14km from the north to the south and 17km from east to west with an area of about 140km^2 (Everard, *et. al.,* 2002)

3.2.0 Sampling sites

Four sampling sites were chosen randomly 150 metres off the lake shore. The four representative sampling sites were at Crescent Island, Sher, Oserian, and Kasarani (Figure 2). A fifth site was identified at the centre of the lake as shown in Figure 2. Crescent Island was characterised by rocky shore line to the south and macrophytes to the northern side. Sher sampling site had a shoreline covered by macrophytes with muddy lake bottom. Oserian sampling site formed a bay characterised by macrophytes shoreline to the south and rocky shoreline to the north. Beyond the macrophytes was the acacia tree lining around the sampling site. Kasarani sampling site was characterised by shallow lake water level. River Malewa entered the lake through this area. The site had macrophytes distributed along the shoreline. The Main open lake sampling site was characterised with muddy lake bottom. The site formed more than 55% of the total lake area. A boat with an outboard engine was used for transport on the lake during sampling.

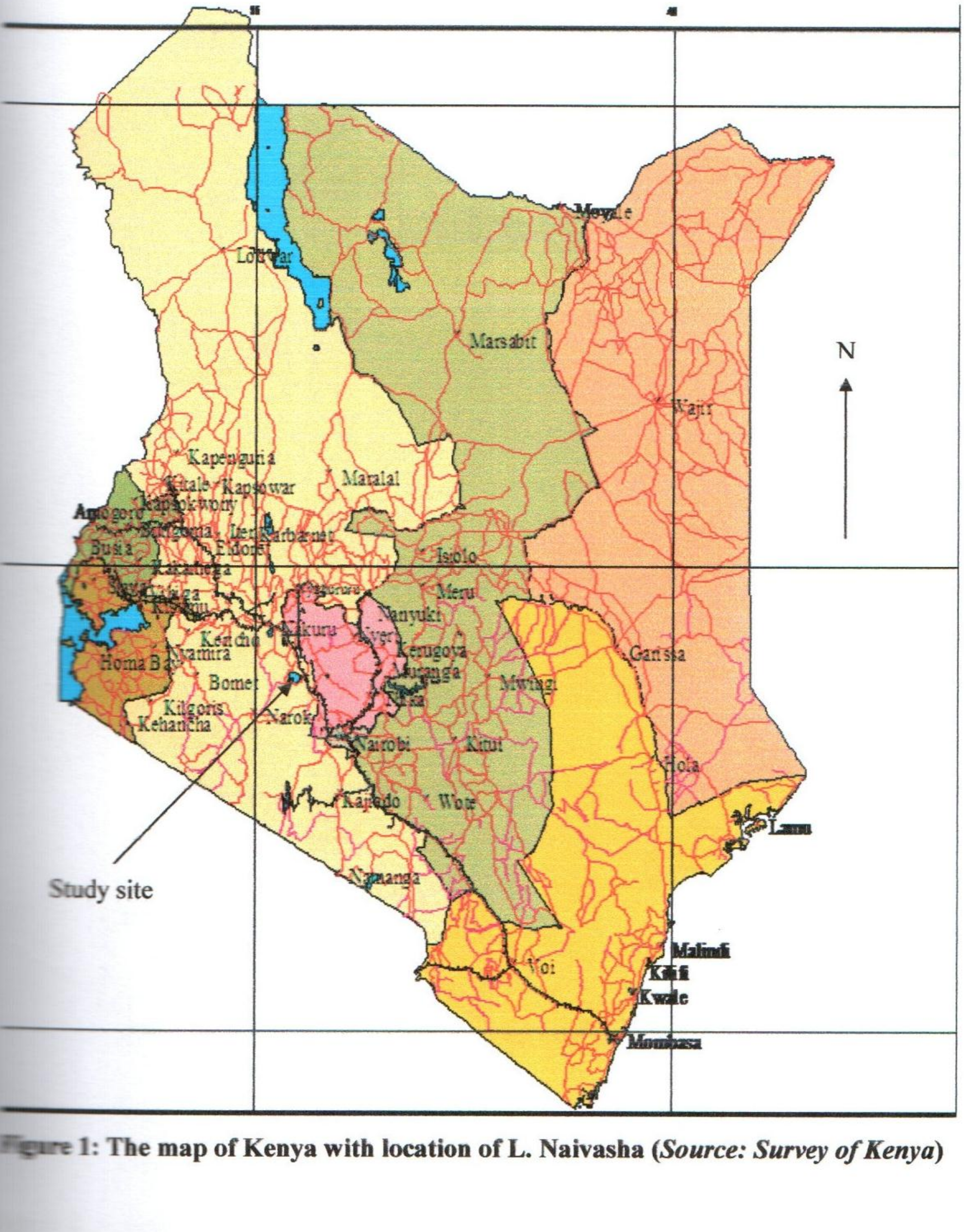

Figure 1: The map of Kenya with location of L. Naivasha (*Source: Survey of Kenya*)

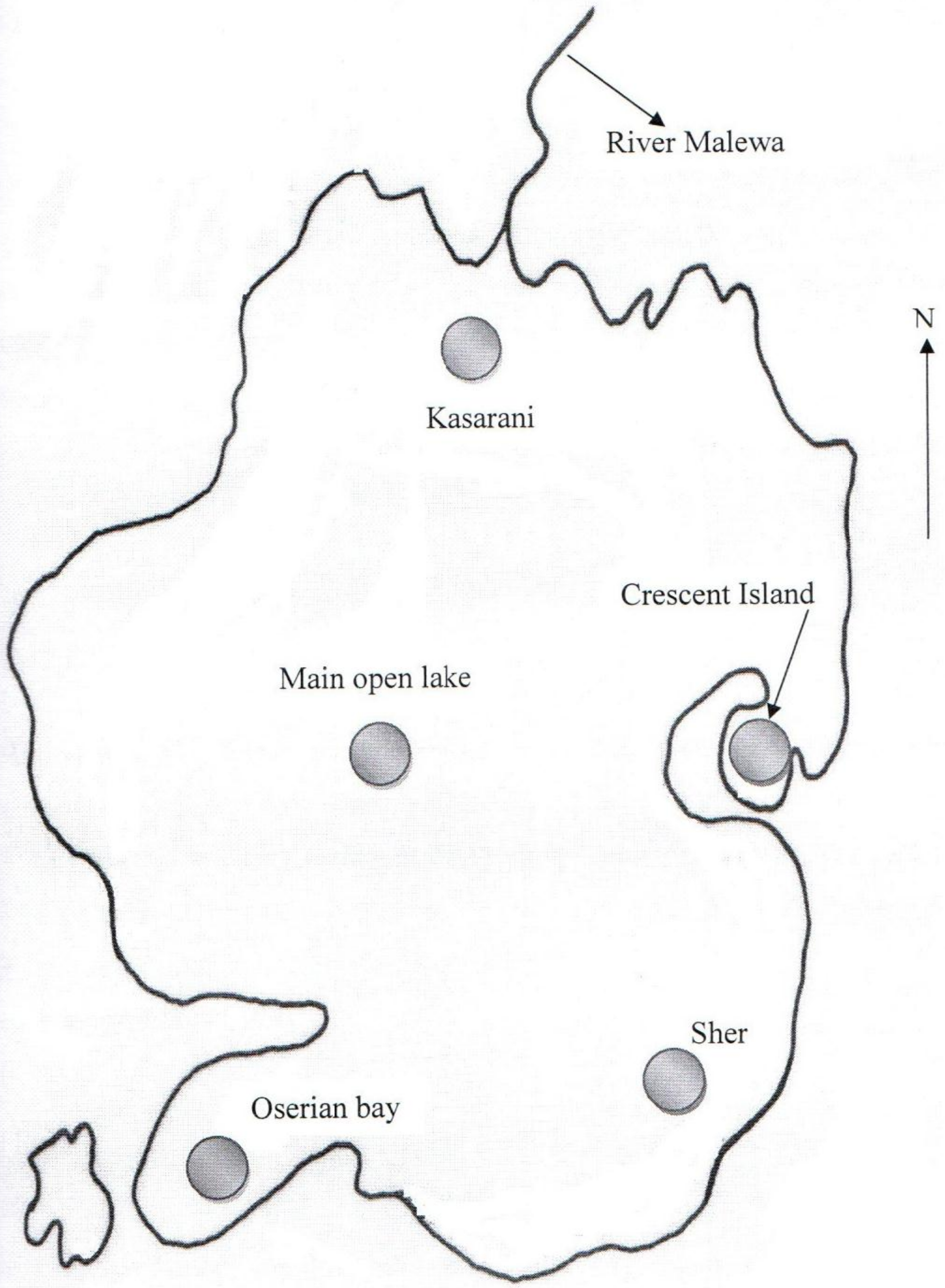

Figure 2: A map of Lake Naivasha, Kenyan (*Source: Survey of Kenya)*

3.3.0 Research design

Specimen analysis and secondary data analysis was adopted for this research. Water quality parameters were measured and fish samples were collected for food analysis and length weight relationship studies. Time, date, month and year of sampling for all samples collected were recorded appropriately. Secondary data was acquired on fish production for eleven years. This data assisted in drawing deductions on the lake fishery trends for thirteen years. Both specimen and secondary data analyses were fundamental in the study of ecological impacts of *Cyprinus Carpio L.* in Lake Naivasha.

3.3.1 Sampling design

Water quality and fish samples were taken from the selected sampling sites that included Crescent Island, Sher, Oserian, Kasarani and Main open lake. Mean samples of water quality parameters and fish were collected once a month for a period of six months. Lake Naivasha is a shallow lake with complete mixing of water quality parameters taking place. Sampling took place between November 2005 and April 2006. Secondary data on fish production was collected from the Kenya Fisheries Department for thirteen years between the years 1995 and 2007.

3.3.2 Water quality parameters

At Crescent Island sampling site water quality parameters that included water temperature, pH and dissolved oxygen were measured using a Quantum hydro-lab probe. Three measurements of water temperature were recorded along water column depth profile at intervals of 100cm using the probe. The three water temperature measurements were done randomly in ten sampling stations within Crescent sampling site. In total 30 samples of water temperature were recorded in Crescent Island in every sampling month between November 2005 and April 2006. The same procedure was repeated for the measurement of dissolved oxygen and pH.

Similarly measurement of water quality parameters was carried out in Sher, Oserian, Kasarani and Main open lake sampling sites. The determination of water quality parameters was fundamental in the elaboration of ecological impacts of *Cprinus carpio L.* fish in Lake Naivasha.

3.4.0 Length and weight data

Samples of *Cyprinus carpio L.*, *Oreochromis leucostictus,* and *Tilapia zillii* were taken once per month for duration of six months from November 2005 to April 2006. Fish samples were taken in the selected sampling sites of Crescent Island, Sher, Oserian, Kasarani and Main open lake. Fish were captured using gill nets of mesh sizes 1.9", 2", 2.5", 3", 3.5", 4" 4.5", 5", 6", 7", 8" and 9". These nets targeted fish of all size range necessary for the study. The nets were joined together to form a single chain.

All sampled fish specimen length and weight relationship were established. Total length (TL) was measured using a measuring board with accuracy of 1mm. The total length was measured from the most anterior projecting part of the head to the tip of the caudal fin (Anderson and Gutreuter, 1985 and Rahman, *et. al.*, 2004). A weighing balance with accuracy of 0.01g was used to measure each specimen weight (W). The excess water on the body of fish was removed by blotting papers just before taking the weight of fish.

The length and weight data was used to determine the length and weight relationship on a regression model, regression co-efficient (slope), correlation co-efficient (r) and the weight intercept. Data was converted to Log_{10} values to obtain a straight line length-weight relationship.

The length-weight relationship was calculated using the following formula given by Anderson and Gutreuter (1985)

$$W=aL^b$$ ....Equation 1

Where, W=weight of the fish

L=length of the fish

a=constant (Weight intercept)

b=exponential value (regression co-efficient)

The values of **a** and **b** were calculated for total length-body weight relationship using Log-Log relation. Data was transformed to

$$\text{Log } W=\text{Log } \mathbf{a} + \mathbf{b} \text{ Log } L$$ ....Equation 2

The values of **a** and **b** were obtained from a regression model generated by MINITAB (version 13.1) statistical software.

3.5.0 Fish sampling for determination of gut constituents'

Samples of *Cyprinus carpio L.*, *Oreochromis leucostictus,* and *Tilapia zillii* were taken once per month for duration of six months from November 2005 to April 2006 from the designated five sampling sites. Fish were captured using gill nets of mesh sizes 1.9", 2", 2.5", 3", 3.5", 4" 4.5", 5", 6", 7", 8" and 9". These nets targeted fish of all size range necessary for the study. The nets were set in water column for a duration of 24 hours. Sampled fish specimen was then classified into groups of 5cm interval category. A knife was used to dissect individual fish sample in each length category to remove the stomach. All the removed specimen stomach from each length category was then preserved in 4% formalin in clearly labelled containers box ready for analysis. In each length category individual stomach contents were stored in clearly labelled containers. These containers were then stored in cool box ready for laboratory analysis.

In the laboratory all stomachs specimen were removed from the cool box for analysis. Stomach contents were emptied into a Petri dish and food items sorted into categories using a binocular (X50) microscope. The percentage proportion of different food items for individual stomach were calculated as the count of a food item expressed as a percentage of the total count for all food items. To assess the relative importance of each food category consumed, a Prominence Value (PV) was calculated from the product of its percentage proportion and the square root of its percentage occurrence. This was based on methods developed by Bowen (1985), Bal and Rao (1990) and adopted by Muchiri (1990) and Njiru, *et. al*. (2004)

where

PV = Percentage proportion X ($\sqrt{}$Percentage Occurrence)................................Equation 3 (Bowen, 1985 & Bal and Rao, 1990).

3.6.0 Fish production

Secondary data on fish production for the period between 1995 and 2007 was acquired from Kenya Fisheries Department statistics department. The data was transformed to graphs for statistical analysis. Trend analysis was performed to study the fishery trend of Lake Naivasha. This was used to predict short term future of the lake fishery inclination. These analyses assisted in the establishment of the ecological studies on the impact of *Cyprinus carpio L.* introduction to Lake Naivasha fishery.

3.7.0 Data analysis

Statistical analysis for water quality parameters, fish production and marketing data, food prominence and length-weight relationship were performed using windows based MINITAB (version 13.1) statistical software. Analysis of Variance at 95% significance level was used to assess the significance difference of Lake Naivasha water quality parameters in all the sampling sites.

Regression analysis was done on the length and weight data of all fish species sampled. The linear regression analysis was conducted at 95% significance level. The fish robustness level with regard to length increase or decrease was determined through the use of regression co-efficient (slope) and the co-efficient of determination (R^2).

Food prominence was analysed from the product of food items percentage proportion and the square root of food item percentage occurrence. High food item prominence value indicated the most preferred food item for the particular fish species sampled. Pie charts were used to assign the food items percentage prominence in the fish species diet.

Fish production data between 1995 and 2007 was subjected to time series analysis. This statistical analysis helped in the determination and prediction of *Cyprinus carpio L., Oreochromis leucostictus,* and *Tilapia zillii* current and short term future production trends analysis.

CHAPTER FOUR

RESULTS

4.1.0 Lake Naivasha water quality

4.1.1 Water temperature

The average water temperature of Lake Naivasha was 20.9 ± 0.7°C between the November 2005 and April 2006. Highest water temperature was 21.9 ± 0.9°C recorded in the month of February. This was closely followed by 21.6 ± 0.9°C recorded in the month of March. Approximately average water temperatures of 20.9 ± 0.3°C, 20.7 ± 0.2°C and 20.6 ± 0.8 °C were recorded in the months of January, December and April respectively. Least water temperature of 19.8 ± 2.0°C was recorded in the month of November as shown in Figure 3. There was no significant difference of water temperature across sampling period between November 2005 and April 2006 using a 2 tailed ANOVA ($P>0.05$).

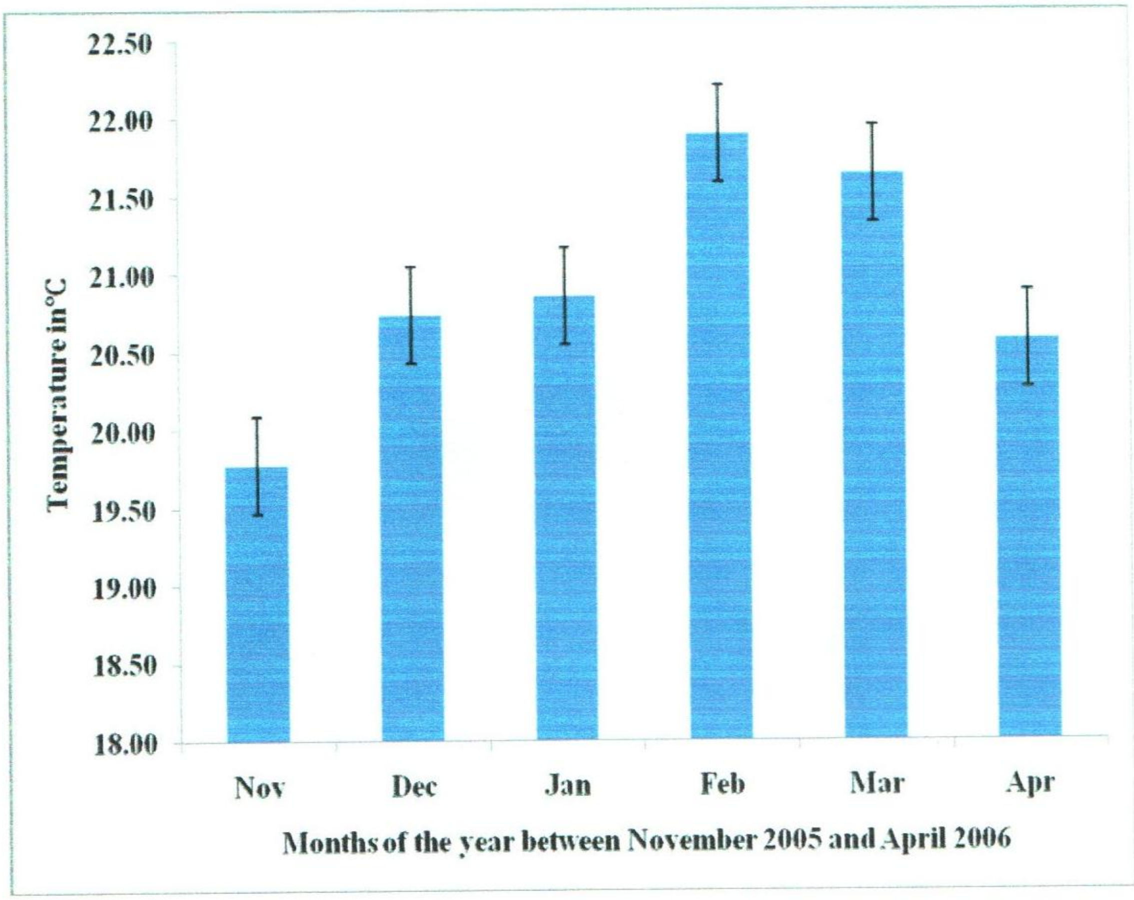

Figure 3: Lake Naivasha temperature distribution across the sampling period

The highest mean temperature 21.9 °C was recorded at Crescent Island. This was followed by Oserian Bay and Sher with 21.1 °C and 21 °C respectively. Least water temperatures of 20.7 °C and 20 °C were recorded in Main open lake and Kasarani respectively as shown in Figure 4. The distribution of water temperature across Crescent Island, Kasarani, Oserian Bay, Sher and Main open lake sampling sites had no significance difference using ANOVA ($P>0.05$) during the sampling period.

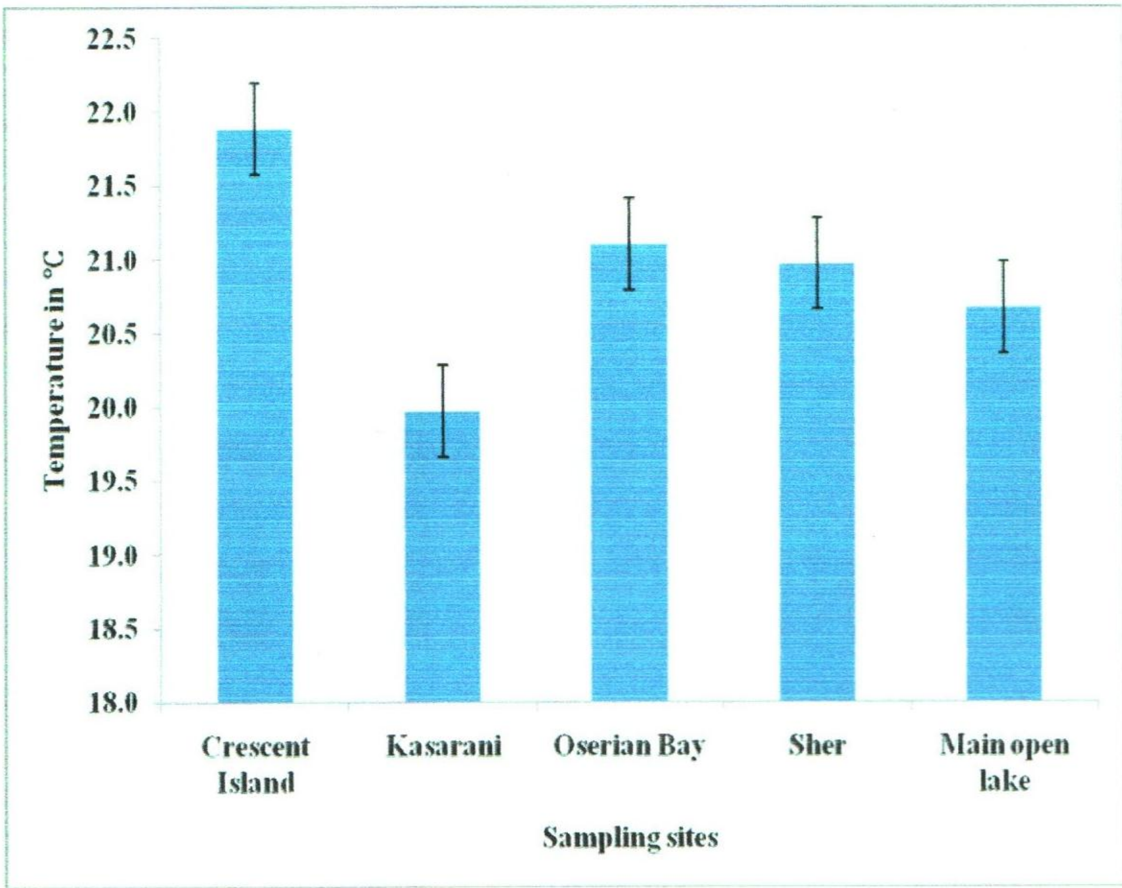

Figure 4: Lake Naivasha temperature distribution across the sampling sites

4.1.2 Dissolved oxygen

The mean dissolved oxygen in Lake Naivasha was found to be 6.7 ± 1.2 mg/l. The highest dissolved oxygen was recorded in the month of April being 7.3 ± 0.9 mg/l. This was followed by March, February, January, December and November with 7.1 ± 0.9, 6.7 ± 0.2, 6.5 ± 2.3, 6.4 ± 1.3 and 6.4 ± 0.8 mg/l respectively as shown in Figure 5. The distribution of dissolved oxygen across the sampling period in the lake had no significance difference ($P>0.05$).

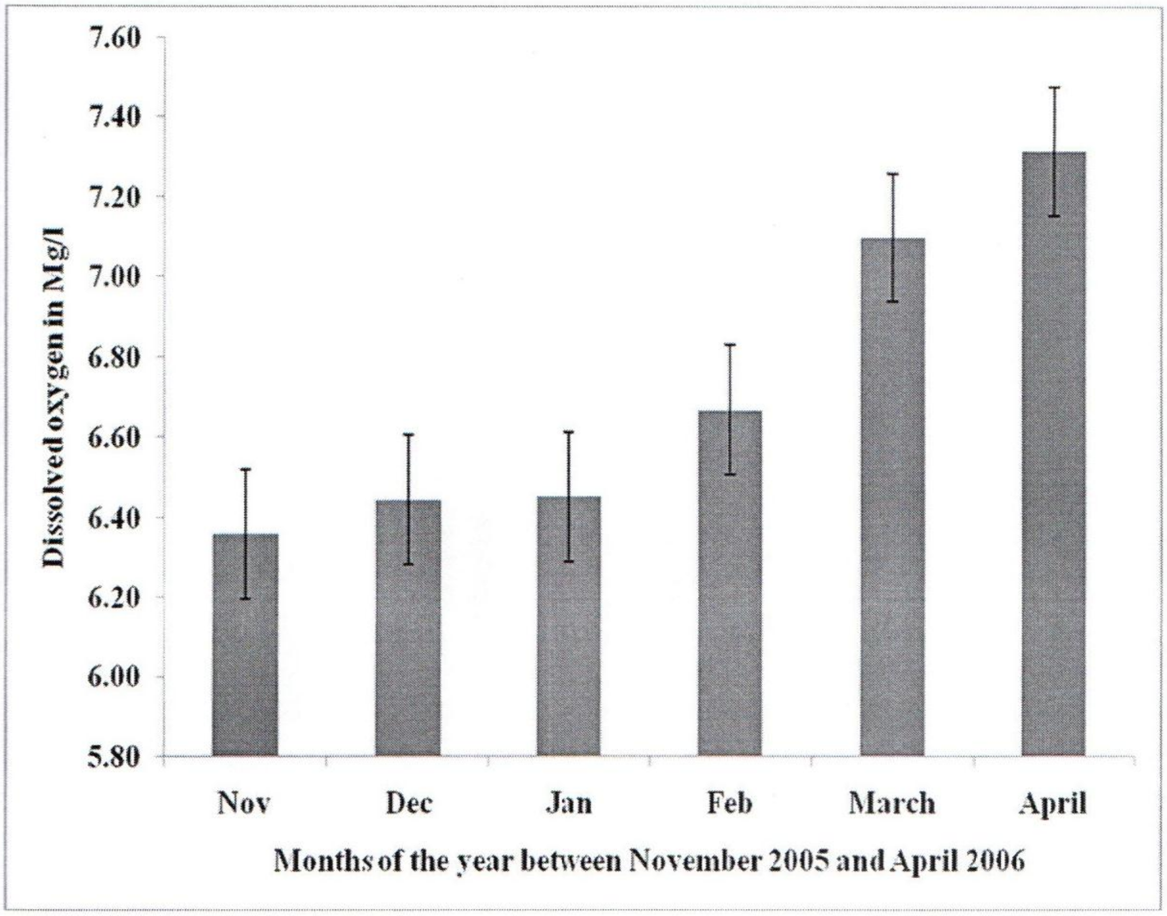

Figure 5: Lake Naivasha Dissolved oxygen distribution across the sampling period

The highest mean dissolved oxygen was recorded in Main open lake (8.0 mg/l) followed by Kasarani with 7.4 mg/l. Crescent Island and Oserian bay had equivalent dissolved oxygen content of 6.1mg/l. These were followed by Sher sampling site with a low of 6.0mg/l dissolved oxygen content as shown in Figure 6. The distribution of dissolved oxygen across the lake sampling sites had a significant difference (P<0.05).

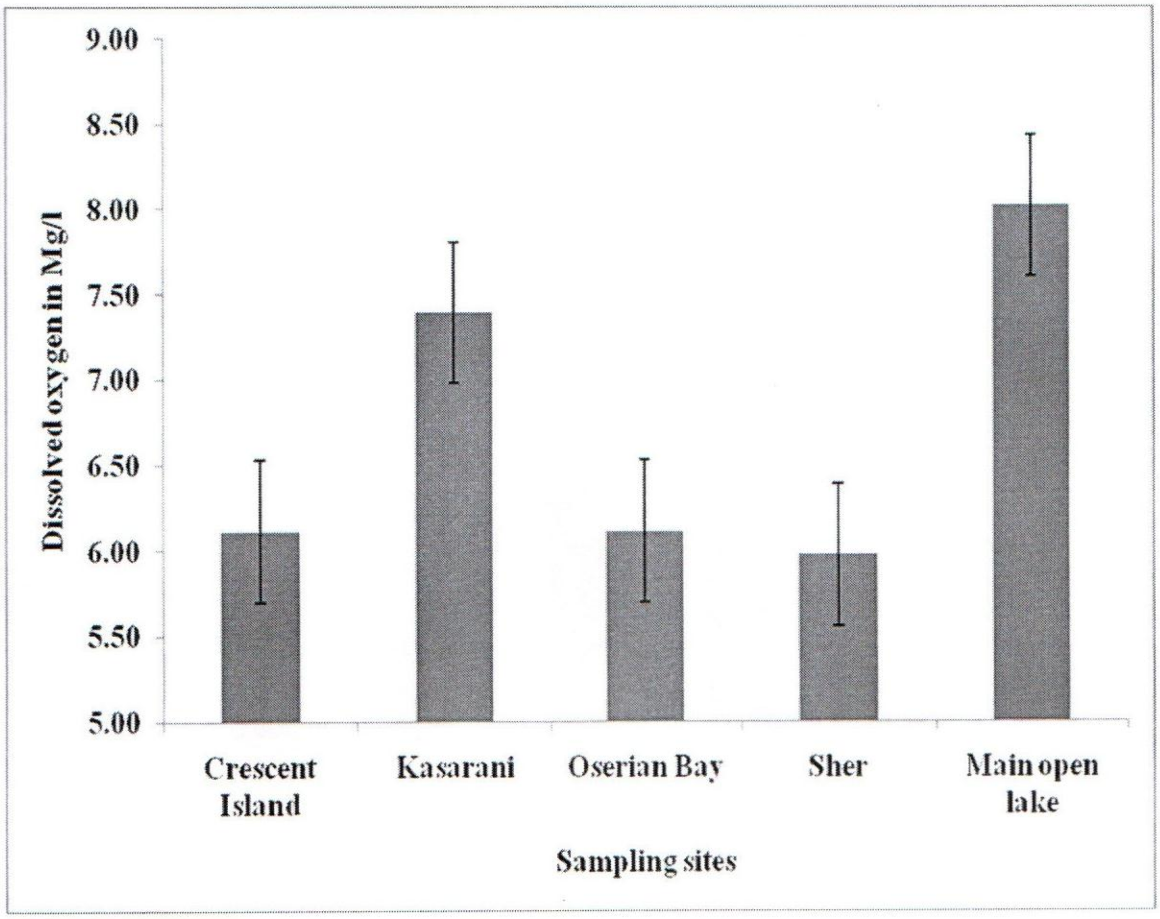

Figure 6: Lake Naivasha Dissolved oxygen distribution across the sampling sites

4.1.3 Water pH

Lake Naivasha pH was 8.7 from November 2005 and April 2006. The highest pH was recorded in the month of January being 8.8. This was followed closely by the months of November, February, April, March and December with 8.8, 8.7, 8.7, 8.6 and 8.6 respectively as shown in Figure 7. The distribution of water pH across the sampling period was found to have no significance difference in the lake since P>0.05.

The highest pH was recorded in Main open lake (8.85) followed by Sher, Kasarani, Oserian bay and Crescent Island with 8.8, 8.7, 8.6 and 8.5 respectively as shown in Figure 8. The distribution of water pH across the sampling stations was found to have no significance difference in the lake (P>0.05).

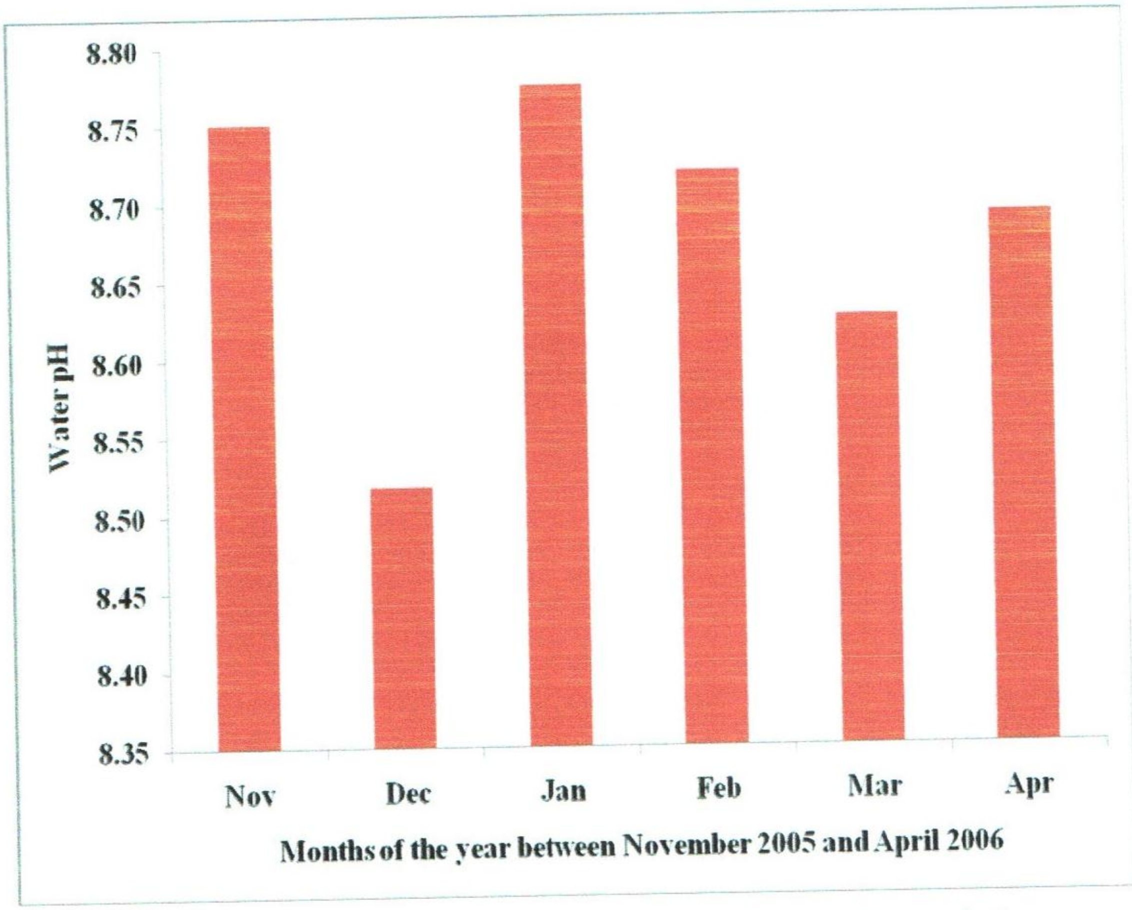

Figure 7: Lake Naivasha water pH distribution across the sampling period

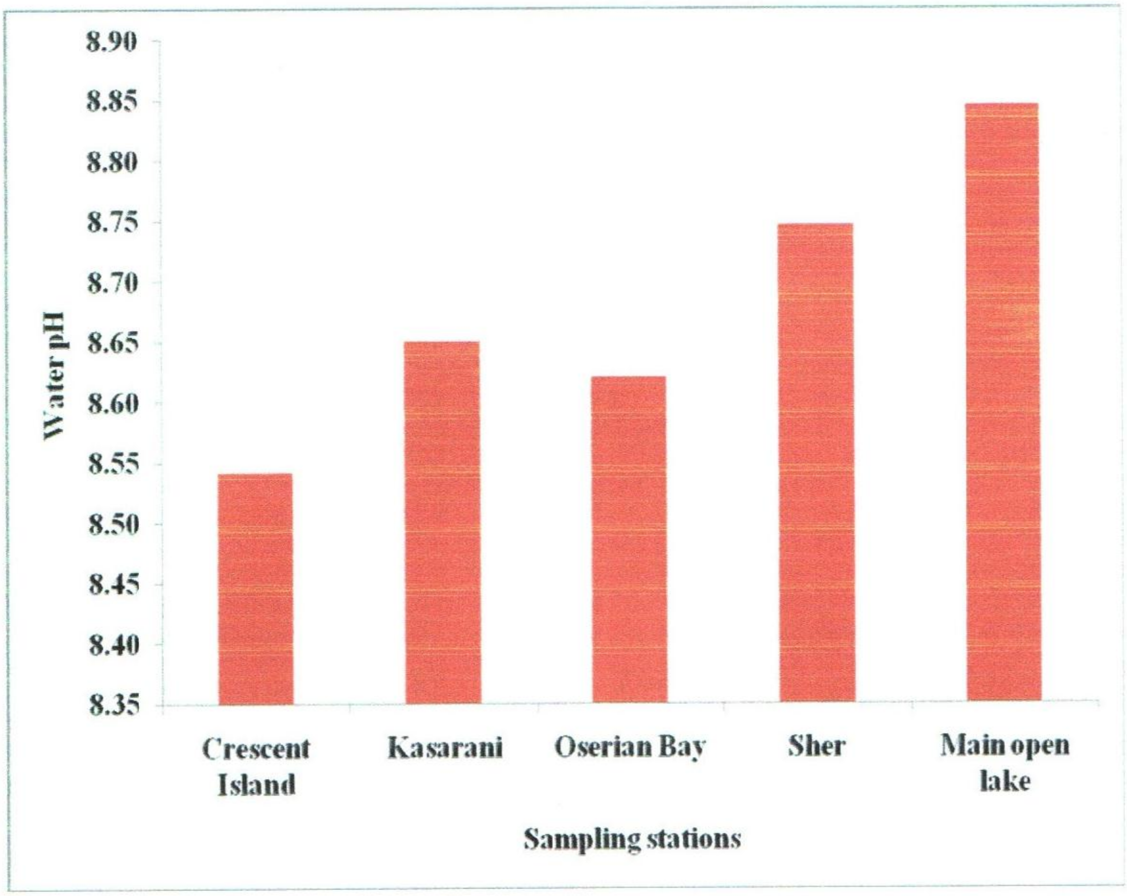

Figure 8: Lake Naivasha water pH distribution across the sampling sites

4.2.0 Length and weight relationship

The length and weight relationship of *Cyprinus carpio L*, *Oreochromis leucostictus* and *Tilapia zillii* fish species are shown in Figure 9, 10 and 11.

4.2.1 *Cyprinus carpio L* length weight relationship

Cyprinus carpio L became less rotund as length increased. The regression co-efficient (**b**) of *Cyprinus carpio L* was 2.6 as shown by the regression output (Figure 9). It was observed that the increase in the fish weight was directly proportional its length increase.

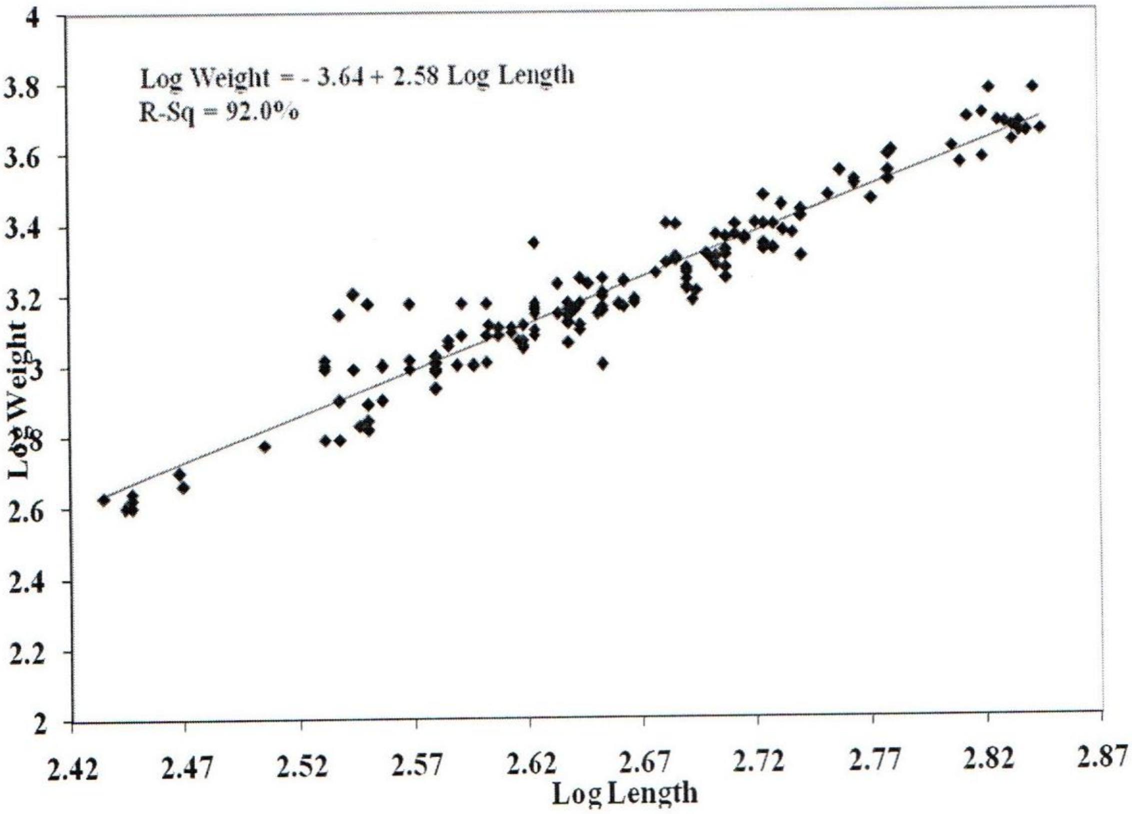

Figure 9: *Cyprinus carpio L* Log Weight and Log Length relationship

A regression analysis of *Cyprinus carpio L.* Log weight and Log length had significance difference (P<0.05).

4.2.2 *Oreochromis leucostictus* length weight relationship

The fish length and weight relationship indicated that the fish become less rotund as length increased during the sampling period. The *Oreochromis leucostictus* regression co-efficient (**b**) was 1.5 as indicated by the regression output in Figure 10. *Oreochromis leucostictus* increase in length was directly proportional to the weight increase.

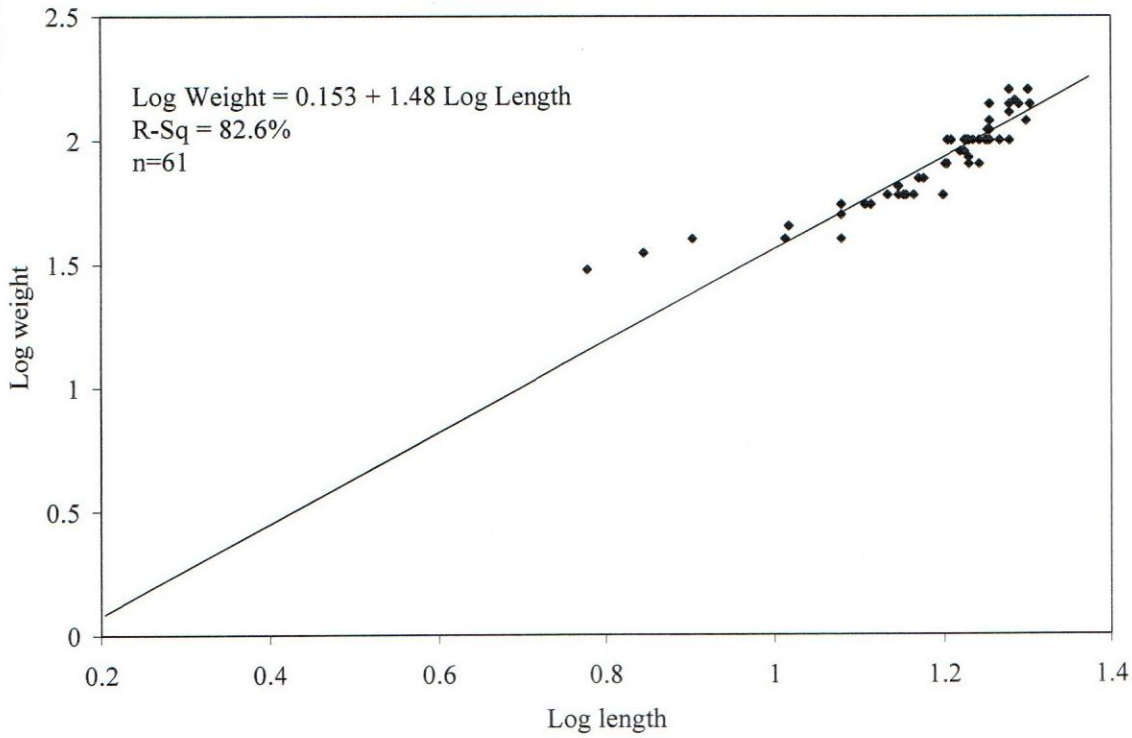

Figure 10: *Oreochromis leucostictus* Log Weight and Log Length relationship

A regression analysis of *Oreochromis leucostictus* Log weight and Log length had significance difference ($P<0.05$).

4.2.3 *Tilapia zillii* length and weight relationship

The *Tilapia zillii* length and weight relationship indicated that the fish become less rotund as length increased during the sampling period. *Tilapia zillii* length and weight relationship indicated that the fish had a regression co-efficient (**b**) of 2.3 as shown in the Figure 11.

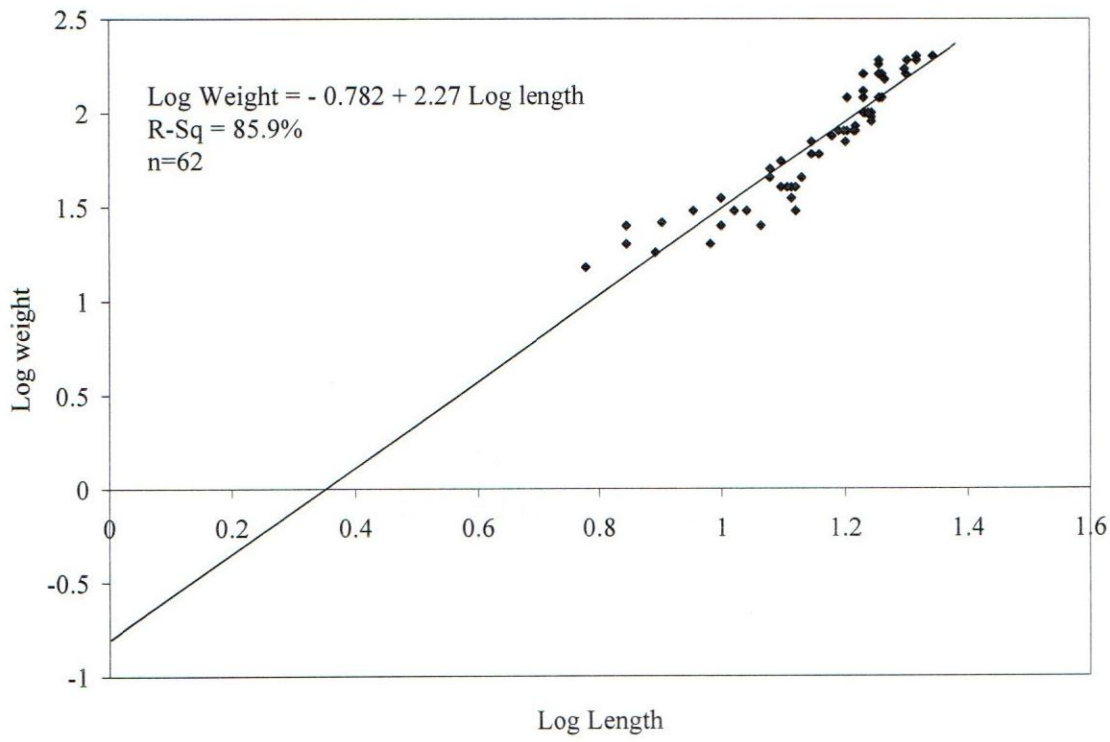

Figure 11: ***Tilapia zillii*** **Log weight and Log Length relationship**

A regression analysis of *Tilapia zillii* Log weight and Log length had significance difference ($P<0.05$).

4.3.0 Lake Naivasha fish species gut content

The gut content of omnivorous fish species in Lake Naivasha including *Cyprinus carpio L.*, *Oreochromis leucostictus* and *Tilapia zillii* were detritus material, macrophytes, diatoms, Trichoptera, micronecta and chironomid larvae. Detritus material formed the highest prominence value for *Cyprinus carpio L.* food at 0.3. This was followed by macrophytes and diatoms with 0.1 and 0.1 prominence values respectively as shown in Figure 12. Detritus material dominated gut content of *O. leucostictus* at 0.2 prominence value. This was followed by the chironomid larvae, macrophytes, diatoms, micronecta and trichoptera at 0.1, 0.09, 0.03, 0.01 and 0.0008 prominence values respectively (Figure 13). Macrophytes formed a higher prominence value in *T. zillii* food at 0.2. This was followed by detritus, chironomid larvae, diatoms, micronecta and trichoptera at 0.1, 0.04, 0.04, 0.02 and 0.001 prominence values respectively (Figure 14).

4.3.1 *Cyprinus carpio L.* food constituents

Detritus material was the most prominent food item in *Cyprinus carpio L.* diet. It formed the highest prominence value of 58% (Figure 12). This was followed by macrophytes and diatoms with 26% and 11% percentage prominence respectively.

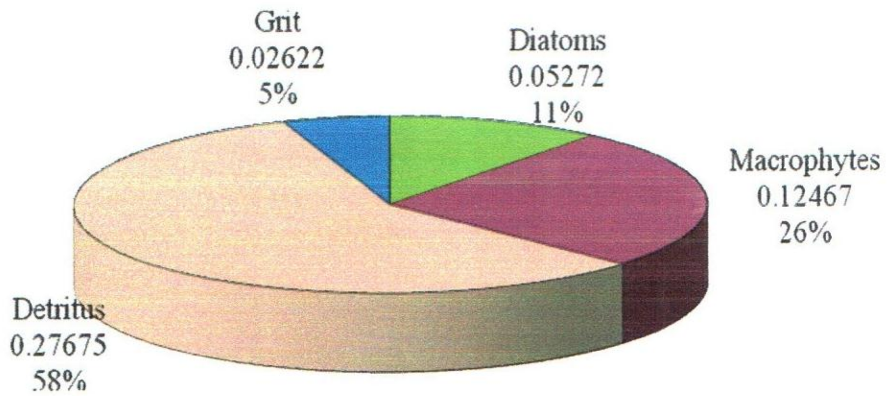

Figure 12: *Cyprinus carpio L.* food item constituents

4.3.2 *Oreochromis leucostictus* food constituents

Detritus material was the most preferred food in *O. leucostictus* diet at 48% (Figure 13). This was followed by the chironomid larvae, macrophytes, diatoms and micronecta at 20%, 18%, 6%, and 2% respectively.

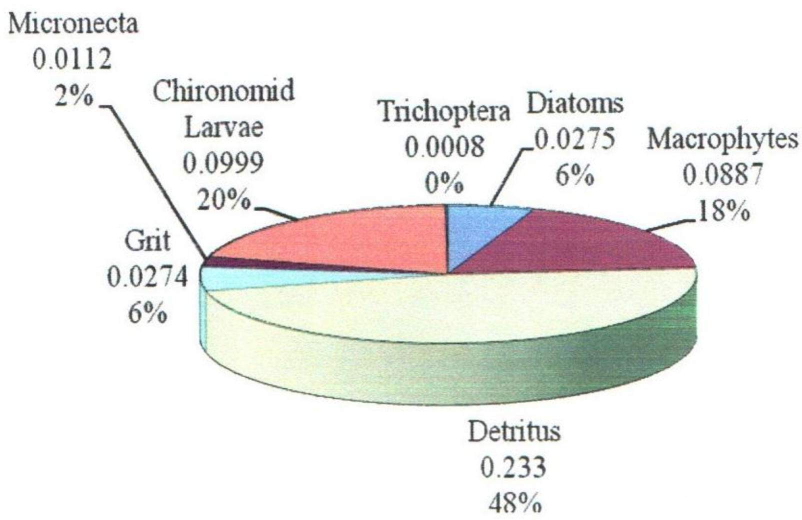

Figure 13: *Oreochromis leucostictus* food item constituents

4.3.3 *Tilapia zillii* food constituents

Macrophytes were the most preferred food item in the *T. zillii* food diet. This food item formed 49% of *T. zillii* diet (Figure 14). This was followed by detritus, chironomid larvae, diatoms and micronecta 24%, 9%, 9% and 5% respectively.

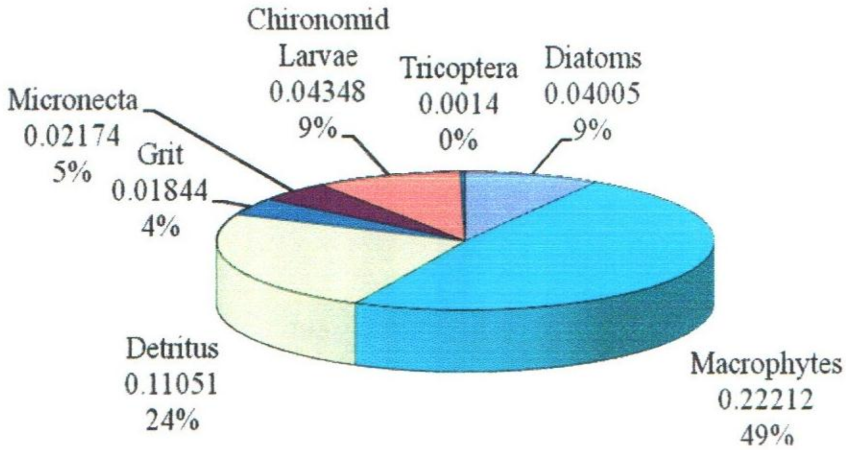

Figure 14: *Tilapia zillii* food item constituents

4.4.0 Fish production trends

Lake Naivasha fish production was observed to be shifting between 1995 and 2007. The highest fish production was 439 metric tons followed by 384 metric tons in 1999 and 2000 respectively. Least fish production was 5 metric tons recorded in 2002 (Figure 15).

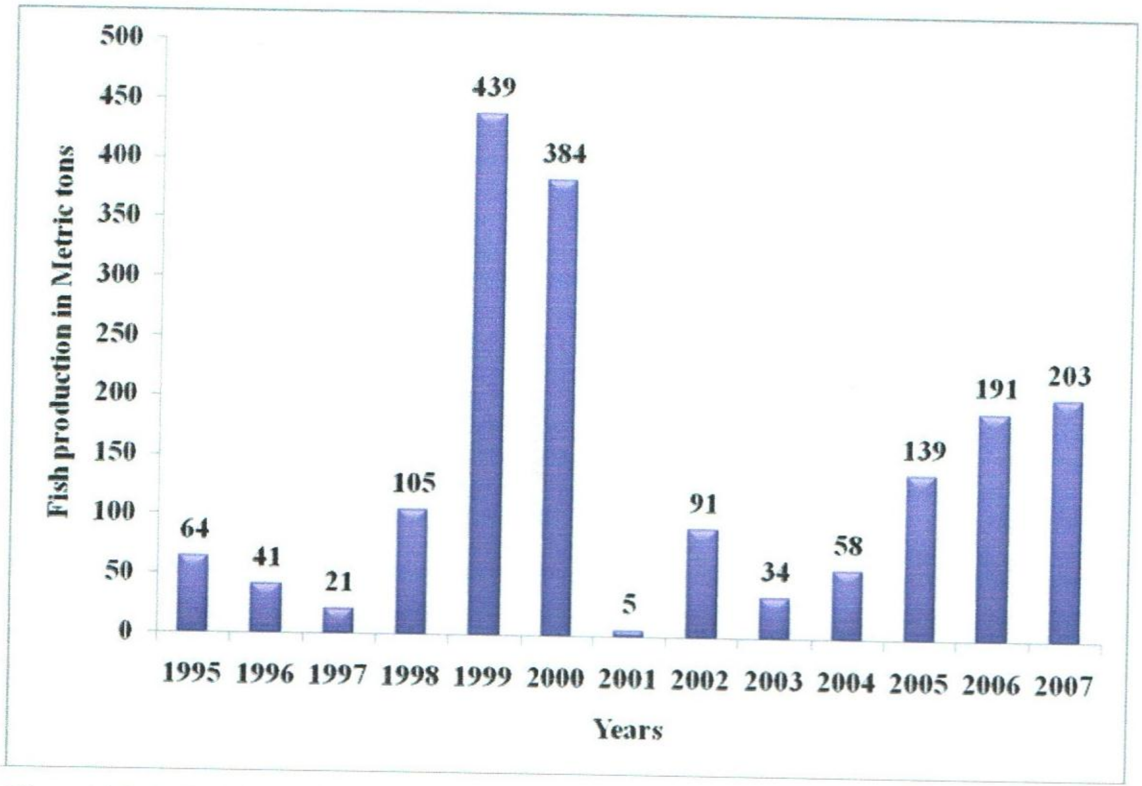

Figure 15: Lake Naivasha annual fish production between 1995 and 2007

4.4.1 Fish species production

Oreochromis leucostictus peak production was 428 metric tons achieved in 1999. This was followed by 363 metric tons in 2000 (Figure 16). Its production trend since 2000 has been on down ward trend with least production of 0.1 metric tons recorded in 2007. *Tilapia zillii* production had been varying with different years. Its peak production of 28 and 21 metric tons were recorded in 2005 and 2002 respectively. Least productions were recorded in the year 1995 and 2006 of 0 metric tons respectively. *Cyprinus carpio L.* production was zero between 1995 and 2001. Approximately one metric ton was produced in the year 2002. Peak production of 198 metric tons was recorded in the year 2007.

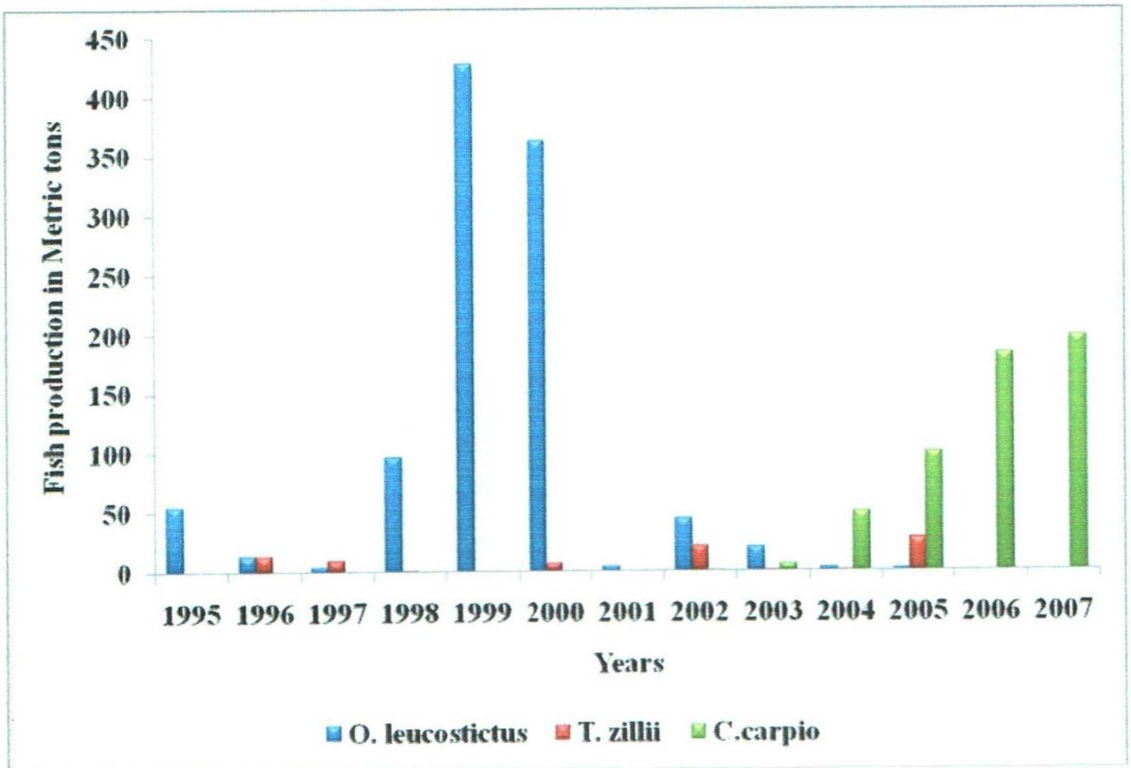

Figure 16: Fish species production between 1995 and 2007

4.4.2 Monthly fish production trends

The monthly fish production trend indicated a declining fish production between January and February and between August and December of the years 1998, 1999 and 2000. The peak total monthly fish production of 115 metric tons was recorded in July between 1998 and 2000. Towards the end of these years fish production reduced recording 57 metric tons (Figure 17).

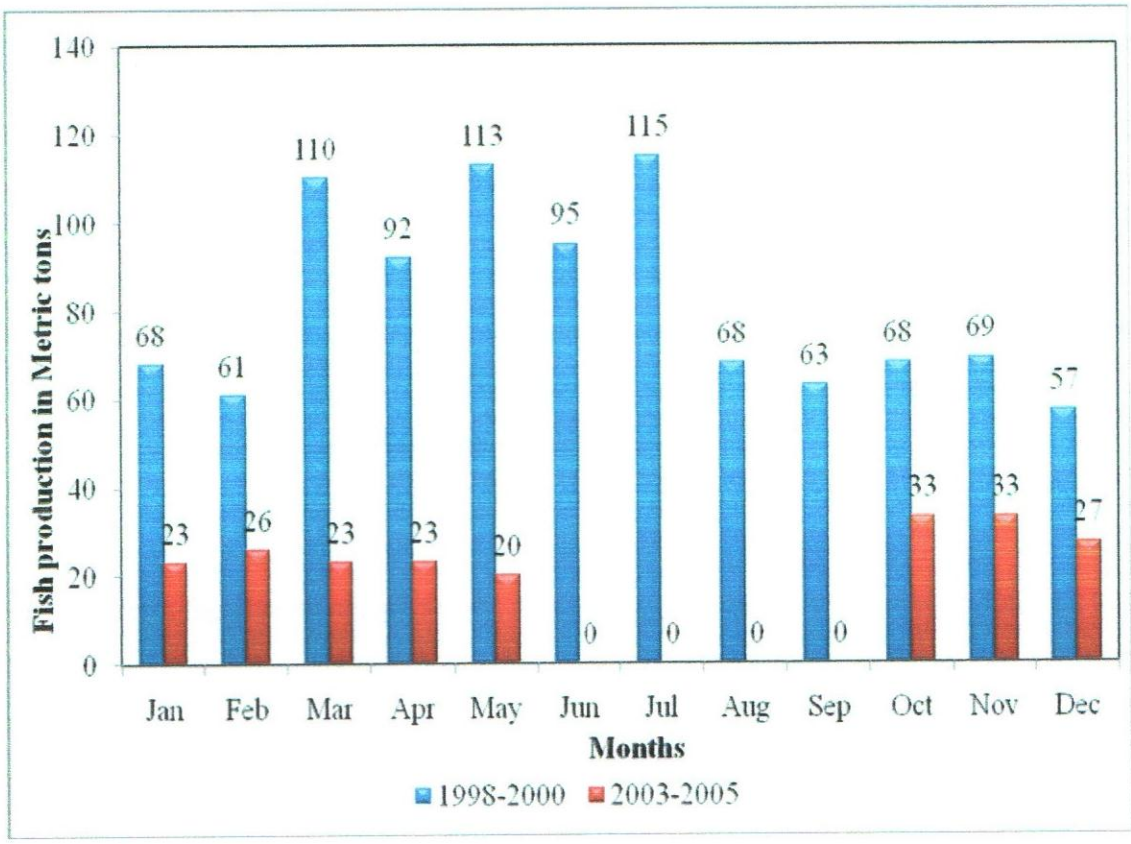

Figure 17: Total monthly fish production between 1998 & 2000 and 2003 & 2005

The monthly fish production trend was approximately constant between 2003 and 2005 (Figure 17). Peak fish production of 33 metric tons were recorded in October and November and the least production of 20 metric tons in the month of May.

CHAPTER FIVE

DISCUSSION

5.1.0 Water quality parameters

The mean water temperature of Lake Naivasha was 20.9 °C between November 2005 and April 2006. The highest temperature recorded in the lake was 21.9 ± 0.9°C. The least temperature was 19.8 ± 2.0°C. The lake temperature therefore ranged between 20 – 22 °C. The least lake temperature was recorded in November 2005 coinciding with air temperature that was low due to short rains experienced in the month. Highest temperature was recorded in February, the hottest month during sampling period. Water temperature in the lake therefore varied depending with the air temperature. Introduction of *Cyprinus carpio L.* in Lake Naivasha in 2000 did not have an impact to the lake temperature. The fish feeding habit leads to re-suspension of dissolved solids in water that leads to reduced sunlight penetration. This essentially results in reduction of water temperature. Clark (1992) recorded Lake Naivasha temperature to range between 19 – 21°C in 1992 which was lower than 20 – 22 °C recoded between November 2005 and April 2006.

The temperature range recorded was ideal for growth and reproduction of *Cyprinus carpio L.* Wang, *et. al.* (1997) found that the ideal temperature range for growth and reproduction of *Cyprinus carpio L.* to be between 3 - 24°C. The lower limit for *Cyprinus carpio L.* reproduction was reported by Balon (1995) to be 17°C. The Lake Naivasha temperature range therefore provided a good range for quick growth and reproduction of the introduced *Cyprinus carpio L.*

Lake Naivasha water temperature provided a suitable environment for the survival of *Tilapia zillii* and *Oreochromis leucostictus.* Hauser (1975) reported that both the fish species become lethargic and respond irregularly to stimuli, when exposed to waters of below 16°C. The minimum water temperature of 19.8 ± 2.0°C in Lake Naivasha was therefore above temperature suitable for biological functions of both *Tilapia zillii* and *Oreochromis leucostictus.* Platt and Hauser (1978) observed that optimum temperature range for *Tilapia zillii* and *Oreochromis leucostictus* to be between 20 and 32°C with death beginning at a lower temperature of 11.2°C. They indicated that both fish species had a narrow range for optimum feeding and growth of between 28.8 to 31.4°C. Lake Naivasha temperature range between 19.8 ± 2.0°C and 21.9 ± 0.9°C therefore did not provide both fish species with environment suitable for optimum feeding and growth. Hauser (1975) observed that both the fish species requires temperature range between 22.5 and 31.5°C for successful spawning. Yadav (2006) observed that *Oreochromis spp* and *Tilapia spp* spawning is inhibited at temperatures below 20°C. The temperatures recorded from Lake Naivasha during the study were therefore not adequate for successful spawning of both *Tilapia zillii* and *Oreochromis leucostictus.* The low temperature of 19.8°C in the month of November 2006 and 20 °C in Kasarani sampling site inhibited both fish species spawning.

Dissolved oxygen levels of at least 4-5 mg/l are needed to support a wide variety of aquatic life (Fox, 2003). The mean amount of dissolved oxygen in Lake Naivasha was 6.7 ± 1.2 mg/l. Dissolved oxygen ranged between 6.4-7.3 mg/l after the introduction of *Cyprinus carpio* in the year 2000. This was lower than 6.6-9.8 mg/l recorded before the fish introduction (Robotham, 1990). Feeding habit of *Cyprinus carpio* leads to reduced sunlight penetration affecting the photosynthesis process. This results to reduced dissolved oxygen content in water as observed in Lake Naivasha. Yadav (2006) observed that dissolved oxygen below 0.5 mg/L constrained *Tilapia zillii* and *Oreochromis leucostictus* growth and was below tolerance level for most fish. Although *Cyprinus carpio* led to reduction in dissolved oxygen content in the lake, the reduction was however not critical for aquatic life support.

Lake Naivasha average pH of 8.7 was above the neutral pH of 7. Introduction of *Cyprinus carpio L.* to Lake Naivasha brought a change in the lake water pH. The fish feeding habit leads to re-suspension of dissolved solids that result to increase in water pH. Gaudet and Muthuri (1981) recorded the lake pH to range between 7 and 8 before introduction of *Cyprinus carpio*. Water pH has risen to range between 8.6 and 8.8 since the introduction of *Cyprinus carpio* in the year 2000. Fish survival is minimal in very acidic or very basic water. Neutral pH is critical to survival, growth, and reproduction of fish and macro invertebrates (Rankin and Jensen, 1993). They observed that exposure of fish to very low or high pH caused death and impaired fish reproductive capacity. Yadav (2006) observed that Tilapia fish species survived pH up to 10. The optimum range for *Cyprinus carpio* growth was found by Wang, *et al*. (1997) to be between 7 and 7.5. Lake Naivasha pH of 8.7 was therefore within the range suitable for *Tilapia zillii* and *Oreochromis leucostictus* reproduction and growth. The lake pH was however above the range suitable for optimum growth of *Cyprinus carpio.*

5.2.0 Fish species food competition

Detritus was the most preferred food in *Cyprinus carpio L.* and *O. leucostictus* diets. It formed 58% of *C. Carpio* food, 48% of *O. leucostictus* food and 24% of *T. zillii* food. Macrophytes were the second most shared food among *Cyprinus carpio L.*, *Tilapia zillii* and *Oreochromis leucostictus* diets. They formed 49%, 26% and 18% of *Tilapia zillii Cyprinus carpio L.* and *Oreochromis leucostictus* food constituents respectively. Diatoms were the third most shared food item by *Cyprinus carpio L.*, *Tilapia zillii* and *Oreochromis leucostictus* fish species. This food item formed 11%, 9% and 6% of *Cyprinus carpio L.*, *Tilapia zillii* and *Oreochromis leucostictus* fish species diets respectively. The other food items were less shared among the three fish species.

Detritus material and macrophytes were therefore the most shared food items. Hickley *et. al.* (2002) found detritus food to dominate the diet of *Oreochromis leucostictus* and *Tilapia zillii* in Lake Naivasha. They observed that *Tilapia zillii* consumed significant amount of macrophytes beside detritus material being the most abundant food. *Tilapia zillii* in Lake Naivasha was therefore confirmed to have shifted from detritus material as dominant food to macrophytes. This was probably due to high detritus competition with *Oreochromis leucostictus* and *Cyprinus carpio L.* The introduction of *Cyprinus carpio L.* in Lake Naivasha therefore has brought a new food competition not existing earlier. *Cyprinus carpio L.* diet was found to be overlapping those of *Oreochromis leucostictus* and *Tilapia zillii* diets prompting food competition among these fish species. Mavuti (1990) observed that Lake Naivasha required introduction of a fish species that would consume underutilized phytoplankton and zooplankton than currently used by the current fish species. Introduction of *Cyprinus carpio L* in the lake therefore did not help in cropping plankton food instead added competition in consumption of detritus and macrophytes food diets. This had an impact on fish production in the lake. The resultant effect of this may probably be the reduction of some of fish species production that has high percentage preference to detritus which is the most consumed food. *Oreochromis leucostictus* appears to have mainly been affected since detritus dominated its diet.

5.3.0 Fish species length and weight relationships

Regression co-efficient (**b**) less than 3 represents fish that become less rotund as length increases and **b** more than 3 represents fish that become rotund as length increases (Anderson and Gutreuter, 1985).The regression co-efficient (**b**) of *Cyprinus carpio L.*, *O. leucostictus* and *T. zillii* in Lake Naivasha were 2.6, 1.5 and 2.3 with co-efficient of determination (R^2) of 92%, 82.6% and 85.9% respectively. This indicated that 92%, 82.6% and 85.9% of *Cyprinus carpio L.*, *O. leucostictus* and *T. zillii* respective weight was explained by their total length. All the three fish species became less rotund with their length increase since the regression co-efficient (**b**) was below 3.

Food is a fundamental factor that determines the fish robustness in an ecosystem. The food availability, nutritive value and accessibility are crucial for fish robustness with their length increase. Boothby and Avault (1971) observed the mature Red drum fish (*Sciaenops ocellata*) feeding on crustaceans in South-eastern Louisiana to have slight difference in food habit due to size and sex. Bass and Avault (1975) determined the juvenile Red drum **b** value to be 4.2 higher than the mature fish. The juvenile were found in the nursery area with abundant high nutritive food supply. Among the tilapia fish species in Lake Naivasha *Tilapia zillii* had a higher **b** value (2.3) compared to

Oreochromis leucostictus (1.5). *Tilapia zillii* was observed to have shifted from its most preferred food mainly detritus (Hickley *et. al.*, 2002) to macrophytes hence withstood food competition brought about by the introduction of *Cyprinus carpio L.* in 2001. This probably gave it a better **b** value as compared with *Oreochromis leucostictus* that retained the most shared food (detritus) as its most preferred food item. The lake temperature was 20.9°C which was far below the fish species requirement (28.8 to 31.4°C) for optimal feeding and growth as reported by Hauser (1978). This probably affected the tilapia fish species growth affecting their **b** value that was below 3.

Cyprinus carpio L. **b** value (2.6) indicated that the fish species became less rotund as its length increased. Fish condition has been noted to be affected by the water physicochemical parameters. Kaewnuratchadason, *et. al.* (2003) determined **b** value for relative length-weight relationship of Skipjack tuna, Yellowfin tuna and Bigeye tuna to be 3.3, 2.9 and 3.2 respectively. These values changed according to water physicochemical parameters that varied with seasonal changes. Wang, *et al*. (1997) found the optimum pH range for growth of *Cyprinus carpio L.* to be between 7.0 - 7.5. Lake Naivasha pH was 8.7 that may have probably inhibited its optimal growth lowering the **b** value.

5.4.0 Fish production in Lake Naivasha

Lake Naivasha fishery was being replaced by *Cyprinus carpio L.* The fish production was dominating the lake fisheries forming 97% of the total catch by the year 2007. The fish production had increased from 77% recorded in 2004. The positive aspect of *Cyprinus carpio L.* introduction was the increased fish production from 5 metric tons in 2001 to 203 metric tons in 2007. Introduction of *Cyprinus carpio L.* therefore had an impact to the fisheries of Lake Naivasha.

Fish production in Lake Naivasha was observed to be fluctuating depending on the lake fishery management measures. Peak fish production were realised between 1999 and 2000 of 439 and 384 metric tons respectively. During this period the Fisheries

Department of Kenya (KFD, 2005) reported that 120 boats were involved in exploitation of the lake fishery resource. The lake fishery status and future since 1962 was examined by Hickley *et al.* (2002) and reported by Hickley *et. al.* (2004). They observed that the lake fishery had three phases of development. These phases were the initial "boom and bust", a period of stability and, most recently, a fishery performing poorly. Maximum fish production of 1150 metric tons was recorded in 1970 (Hickley, *et. al.*, 2004) with minimum production of 21 metric tons recorded in 1997. The Fisheries Department closed the lake from fishing in the year 2001 to control the uneven fish production trend experienced between 1995 and 2000 and reduce the fishing pressure which had risen to 120 boats from 78 boats in 1995. The Fisheries Department reduced the fishing pressure to 40 boats on opening the lake to fishing from the year 2002 to 2007. This stabilised an upward fish production trend with a low of 34 metric tons in 2003 to a high production of 203 metric tons in 2007.

Oreochromis leucostictus fish production formed the major catch for Lake Naivasha fish production. The fish attained a maximum production in 1999 at 428 metric tons. Since the year 2000 the fish has been on downward trend and by 2007 only 0.1 metric tons was recorded. *Tilapia zillii* production has been low in comparison with *Oreochromis leucostictus*. Its production was almost negligible between 2006 and 2007. The lake temperature was found to be low and may have inhibited both *Oreochromis leucostictus* and *Tilapia zillii* fish species successful spawning hence the low production. *Cyprinus carpio L.* production was first recorded in the year 2002. This coincided with lake management measures enforced by the Kenya Fisheries Department in 2001 (KFD, 2002) where the lake had been closed from fishing for one year in 2001. Since then the lake fish production trend has been upward recording a high of 198 metric tons in 2007 as compared to 1 metric ton recorded in 2002.

The total monthly fish production trend between January and February for 1998, 1999 and 2000 years was observed to be on a declining trend towards December. The Kenya Fisheries Department instituted measures to correct this anomaly through a one year fishing closed season in 2001. After opening the lake to fishing in 2002, fish exploitation stability was achieved from 2003 to 2005. Subsequently, Fisheries Department introduced a four months fishing closed season between June and September every year starting from 2003. This helped the fishery resource base regeneration and sustainable lake fishery exploitation.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1.0 Conclusion

Introduction of *Cyprinus carpio L.* in Lake Naivasha had varying impacts to the fisheries of the lake. This ranged from the lake water quality, fish condition, food competition and fish production as listed below;

1. Introduction of *Cyprinus carpio L.* had an impact on water dissolved oxygen and pH. Water dissolved oxygen in the lake reduced while pH increased after the fish introduction. Reduction of dissolved oxygen content was however not critical to affect aquatic life. Changes in pH had impacts on optimum growth of *Cyprinus carpio L.* but suitable for *O. leucostictus* and *T. zillii* survival.
2. Length and weight relationship indicated that *Cyprinus carpio L., Oreochromis leucostictus* and *Tilapia zillii* fish species condition and growth was not sufficient. Introduction of *Cyprinus carpio L.* had an impact to growth of fish in the lake due to introduction of food completion limiting food availability.
3. Introduction of *Cyprinus carpio L.* led to shift of preferred food by *Tilapia zillii* from detritus to macrophytes. *Oreochromis leucostictus* was mainly affected by the *Cyprinus carpio L.* introduction since it retained its food diet. Introduction of *Cyprinus carpio L.* led to reduced production of *Oreochromis leucostictus* and *Tilapia zillii* fish species due to food competition. This had a negative impact *Oreochromis leucostictus* and *Tilapia zillii* fish species fishery in Lake Naivasha
4. Lake Naivasha fish production has gradually changed since introduction of *Cyprinus carpio L.* With increased fishing pressure by the end of 2000, the fishery of *Oreochromis leucostictus* and *Tilapia zillii* was headed to imminent collapse. Introduction of *Cyprinus carpio L.* however abetted the situation and formed 97% of total catch by the year 2007 posing a positive impact to the fisheries of Lake Naivasha

These impacts have assisted in developing a predictive model crucial for management and conservation of Lake Naivasha fisheries. *Cyprinus carpio L.* production is expected to increase dominating other fish species. This is positive for fisher folks and managers of capture fisheries. With attention of fishermen shifting from *Oreochromis leucostictus* and *Tilapia zillii* fish species capture to *Cyprinus carpio L.* it is predicted that the fishery of both *O. leucostictus* and *T. zillii* will recovery.

6.2.0 Recommendations

The research has come with the following recommendations;

1. The Kenya Fisheries Department should consider re-stocking Lake Naivasha periodically with *Oreochromis leucostictus* and *Tilapia zillii* fish species. This is because the lake temperature provides apt environment for their successful spawning. Other water quality parameters not covered by this study should be studied to ascertain impacts of *Cyprinus carpio L.* introduction to fisheries of Lake Naivasha. Anthropogenic activities impacts to water quality should also be studied.
2. Regeneration of Lake Naivasha fishery resource base was highlighted successful after the Kenya Fisheries Department enforced the fisheries conservation measures. The measures included the closed season, reduced fishing effort and stakeholders involvement on resource exploitation and management. These measures are recommended to continue to abet the lake fish production from a fall in future.

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APPENDICES

Appendix 1: Food constituent prominence values for C. carp, *O. leucostictus* and *T. zillii*

Food item	***Common carp***	***Oreochromis leucostictus***	***Tilapia zillii***
Diatoms	0.05272	0.0275	0.04005
Macrophytes	0.12467	0.0887	0.22212
Detritus	0.27675	0.2330	0.11051
Grit	0.02622	0.0274	0.01844
Micronecta	0	0.0112	0.02174
Chironomid Larvae	0	0.0999	0.04348
Trichoptera	0	0.0008	0.00140

Appendix 2: Common carp percentage food proportion, occurrence and prominence values

Number of fish examined	Total Length (cm)	Food items	Benthic diatoms	Macrophytes	Detritus	Grit	Copepod	Trichoptera	Chironomid larvae
23	35 - 40	**% Prop**	0.062857	0.308571	0.552857	0.075714			
		√%Occ	0.25	0.291667	0.291667	0.166667			
		PV	**0.0314**	**0.1666**	**0.2986**	**0.0309**			
29	40 - 45	**% Prop**	0.109	0.139	0.596	0.156			
		√%Occ	0.1875	0.21875	0.3125	0.28125			
		Pv	**0.047198**	**0.065011**	**0.333174**	**0.082731**			
38	45 - 50	**% Prop**	0.22625	0.313125	0.4425	0.016875			
		√%Occ	0.25641	0.307692	0.358974	0.076923			
		PV	**0.114566**	**0.17369**	**0.265122**	**0.00468**			
29	50 - 55	**% Prop**	0.21	0.060833	0.689167	0.034167			
		√%Occ	0.258065	0.129032	0.387097	0.225806			
		PV	**0.10668**	**0.021852**	**0.042878**	**0.016236**			
19	55 - 60	**% Prop**	0.113333	0.225	0.583333	0	0	0	0.078333
		√%Occ	0.214286	0.285714	0.357143	0	0	0	0.142857
		PV	**0.052463**	**0.120268**	**0.348608**	**0**			**0.029607**
15	60 - 65	**% Prop**	0.022	0.322	0.476	0.12	0.018	0.006	0.036
		√%Occ	0.111111	0.277778	0.277778	0.166667	0.055556	0.055556	0.055556
		PV	**0.007333**	**0.169709**	**0.250874**	**0.04899**	**0.004243**	**0.001414**	**0.008485**

12	65 - 70	**% Prop**	0.022	0.258	0.66	0	0	0	0.06
		√%Occ	0.181818	0.363636	0.363636	0	0	0	0.090909
		PV	**0.009381**	**0.15558**	**0.397995**	**0**	**0**	**0**	**0.018091**

Appendix 3: ***Oreochromis leucostictus*** **percentage food proportion, occurrence and prominence value**

Number of fish examined	Total Length (cm)	Food items	Benthic diatoms	Macrophytes	Detritus	Grit	Micronecta	Chironomid larvae	Trichoptera
37	10 - 15	**% Prop**		0.3500	0.1500	0.0500	0.0500	0.4000	
		%Occ		0.2000	0.2000	0.2000	0.2000	0.2000	
		√%Occ		0.4472	0.4472	0.4472	0.4472	0.4472	
		PV	**0.0000**	**0.1565**	**0.0671**	**0.0224**	**0.0224**	**0.1789**	**0.0000**
41	15 - 20	**% Prop**	0.1071	0.0643	0.6571	0.1000		0.0643	0.0071
		%Occ	0.2632	0.1053	0.3684	0.1053		0.1053	0.0526
		√%Occ	0.5130	0.3244	0.6070	0.3244	0.0000	0.3244	0.2294
		PV	**0.0550**	**0.0209**	**0.3989**	**0.0324**	**0.0000**	**0.0209**	**0.0016**
5	20 - 25	**% Prop**	nil						
		√%Occ	nil						
		PV							

Appendix 4: *Tilapia zillii* percentage food proportion, occurrence and prominence value

Number of fish examined	Total Length (cm)	Food items	Benthic diatoms	Macrophytes	Detritus	Grit	Chironomid larvae	Micronecta	Trichoptera
39	10 -15	**% Prop**	0.1250	0.1500	0.4500	0.0500	0.1250	0.1000	
		√%Occ	0.2000	0.2000	0.2000	0.2000	0.1000	0.1000	
		PV	0.0559	0.0671	0.2012	0.0224	0.0395	0.0316	0.0000
48	15 -20	**% Prop**	0.0625	0.6375	0.0625	0.0375	0.1500	0.0375	0.0125
		√%Occ	0.1500	0.3500	0.1000	0.1500	0.1000	0.1000	0.0500
		PV	0.0242	0.3772	0.0198	0.0145	0.0474	0.0119	0.0028