STOCK ASSESSMENT AND SOCIO-ECONOMIC CHARACTERIZATION OF FISHERIES IN LAKE BARINGO, KENYA

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A thesis submitted to the Graduate School in partial fulfilment for the requirements of the award of Doctor of Philosophy Degree in Natural Resources Management 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 family including Teresia Macharia, Steve Macharia, Bernice Macharia and Rose Macharia for their support to an extent of accompanying me while sampling. To my mother Bernice Njuguna and siblings including Steve Njuguna, Lydia Wanjiru, Rahab Wairimu and Francis Njehia for their faith in me.

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ABSTRACT

The fisheries sector is significant to socio-economic development through provision of employment, income and food security. Global fisheries resources face unsustainable fishing pressure. In Kenya, unsustainable harvesting is due to use of management measures not informed by stock assessment studies. The aim of this study was to conduct stock assessment and characterize socio-economic dynamics for Lake Baringo Fisheries management. Stock assessment studies featured estimation of biological reference points, optimal fishing scenario, gear selectivity and socio-economic dynamics of fishermen and fish trader's. Daily fish samples were taken from 40% of boats in the lake, five (5) days in a week between August 2013 and July 2014. A sub-sample constituting 40% of each fish species representing various size classes were obtained for length (to the nearest 0.1 cm) and weight (to the nearest 0.1 g) measurements. A total of 3,155 *Protopterus aethiopicus,* 2,769 *Oreochromis niloticus baringoensis* and 1,922 *Clarias gariepinus* were sampled. A structured questionnaire was administered to 42 fishermen and 34 fish traders' selected randomly for socio-economics studies. Statistical analyses were conducted at 95% significance level. The steady state biomass for *Protopterus aethiopicus, Oreochromis niloticus baringoensis* and *Clarias gariepinus* was 474,779kg, 564 kg and 21,383 kg respectively. The maximum sustainable yield for *Protopterus aethiopicus*, *Oreochromis niloticus baringoensis* and *Clarias gariepinus* was 237,390, 451 and 10,692 kg respectively. The results of the study suggest that the exploitation rate for *Protopterus aethiopicus* ($E = 0.68 > E_{max} = 0.25$ yr^{-1}) exceeded maximum exploitation rates indicating growth overfishing. *Oreochromis niloticus baringoensis* and *Clarias gariepinus* exploitation rates were at congenial state with no growth overfishing. Hence, *Protopterus aethiopicus* ($F = 1.34$ yr^{-1}) fishing mortality's should be reduced by 41.6% for reference maximum sustainable yield. The current spawning stock biomass-per-recruit (SSB_{CURR}) for *Protopterus aethiopicus* (5.46%) and *Oreochromis niloticus baringoensis* (1.46%) show a level of recruitment overfishing. Logistic gear selection indicates L 50% of 63.48 cm selection of *Protopterus aethiopicus* before size of first maturity (85 cm) further adducing recruitment overfishing. Logistic gear selection indicates L 50% of *Oreochromis niloticus baringoensis* (15.57 cm) and *C. gariepinus* (35.08 cm) shows no recruitment overfishing. The age, traditions and culture of fishermen had effect on fishing effort. Fishermen changed gears from nets (for *Oreochromis niloticus baringoensis*) to hooks (for *Protopterus aethiopicus* and *Clarias gariepinus*) with age advancement and was accounted for by enhanced experience and target for high valued fish species. Shift dependence of fishing from domestic to commercial purpose relative to fishermen increased with age. Fish trade was entirely controlled by fishermen daily catches while their local and external markets had no significant difference. Management measures to control overfishing should target reduction of fish mortality rates for sustainable utilization of the lake Fisheries.

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ABBREVIATIONS AND ACRONYMS

BMU:	Beach Management Unit
B`R:	Biomass-per-Recruit
BRP:	Biological Reference Points
ELEFAN:	Electronic Length Frequency Analysis
FAO:	Food and Agriculture Organization
FiSAT:	Fisheries Stock Assessment Tool
GDP:	Gross Domestic Product
KFD:	Kenya Fisheries Department
KMFRI:	Kenya Marine and Fisheries Research Institute
KNBS:	Kenya National Bureau of Statistics
KSDF:	Kenya State Department of Fisheries
KWS:	Kenya Wildlife Services
MEY:	Maximum Economic Yield
MOFD:	Ministry of Fisheries Development
MSY:	Maximum Sustainable Yield
NACOSTI:	National Commission for Science, Technology and Innovation
SSB/R:	Spawning Stock Biomass-per-Recruit
ST&I:	Science, Technology and Innovations
VPA:	Virtual Population Analyses
Y`R:	Yield-per-Recruit

CHAPTER ONE

INTRODUCTION

1.1 Background information

The fisheries sector plays an important role in the world for socio-economic development through employment creation, revenue generation and food security. Global capture fisheries production in 2014 was at 93.4 million tons of which 87.3% were from marine waters and 12.9% from inland waters (Silva, 2016). The national fish production in Kenya was at 196,969 tons in 2013. This comprised fish production from freshwater capture fisheries (139,232 tons, 70.70%), aquaculture (48,790 tons, 24.80%) and marine capture fisheries (8,947 tons, 4.50%) respectively (KSDF, 2013). The sector earns Kenya over 4 billion shillings in foreign exchange from export of fish and fisheries products (KSDF, 2013). It contributes 0.6% of Gross Domestic Product (GDP). Fisheries resources are located in rural areas playing an important role in these area's micro-economies. The sector supports about 3 million people directly and indirectly, working as fishermen, traders, processors, suppliers and merchants of fishing accessories and employees and their dependants (KSDF, 2013).

Major sources of capture fisheries in Kenya include the Indian Ocean, Lake Victoria, Lake Turkana, Lake Naivasha and Lake Baringo. Fish production in Lake Baringo has been on decline from 2000 (465 tons valued at 11.4 million shillings) to 2011 (101 tons value at 9.5 million shillings) mainly due to fishing pressure and changes in environmental factors (KFD, 2011; Macharia *et al.*, 2009; Mageria and Kibwage, 2009; Harper *et al.*, 2002). The fisheries of Lake Baringo based previously on the tilapiine species. However, owing to changes in the lake's biophysical processes such as siltation and species introductions, the fisheries is currently composed of *Protopterus aethiopicus*, *Oreochromis niloticus baringoensis* and *Clarias gariepinus*. Fish catch composition by 2011 was *P. aethiopicus* (72%), *O. niloticus baringoensis* (17%) and *C. gariepinus* (10%) (KFD, 2011).

The management measures implemented in Lake Baringo have not satisfactorily sustained the yield *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* utilization (KSFD, 2013). The closed season interventions instituted by the State Department of Fisheries in 1993 and 2002 was short lived. Fish production declined once more two to three years after a closed season.

Assessment of these important fish stocks in Lake Baringo is paramount to assist in making conservation decisions. There are few studies on the fisheries of Lake Baringo resulting to gaps in knowledge and difficulty in management decision-making process. This study aimed at providing this information on *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* biological reference points, optimum-fishing scenarios, gears selectivity and characterize socio-economic dynamics of the lake fisheries.

1.2 Statement of the problem

The yields from *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo have been on the decline with negative impacts to the fishing industry and livelihood of fisher communities who depend on the resource. Further, the declining trends in catches is an indicator of overfishing and may affect fish biodiversity in the lake. The results of this scenario is the implementation of conservation measures to facilitate natural stock regeneration such as closed season in 1993 and 2002 and mesh size regulation by the State Department of Fisheries. However, measures implemented on the lake fisheries resource has not achieved sustainable utilization. Lack of information on biological, limit and target reference points to inform the fisheries management conservation decisions has been exacerbated problem. This study sought to establish biological reference points, optimum-fishing levels, and gear selectivity for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* and to characterize socio-economic dynamics of the lake fisheries. Information obtained from the study would aid the formulation of management and conservation measures for sustainable utilization of the lakes fisheries.

1.3 Study objectives

1.3.1 Broad objective

To carry out stock assessment of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* and characterize the fisheries socio-economic dynamics for the management and conservation of Lake Baringo fisheries resource.

1.3.2 Specific objectives

The specific objectives of the study were:

1. To determine the biological reference points (BRPs) for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo.
2. To determine optimum fishing scenarios for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo using Yield Modelling.
3. To determine the gear selectivity on *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* population in Lake Baringo.
4. To characterize the socio-economic dynamics of Lake Baringo fisheries.

1.4 Research questions

1. What are the biological reference points (BRPs) for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo?
2. What are the optimum fishing scenarios for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo?
3. How does the fishing gear selectivity affect *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* stock in Lake Baringo?
4. How does the socio-economic dynamics influence Lake Baringo fisheries?

1.5 Justification

A management strategy of a fish resource base that relates BRPs, optimal fishing regimes, gear selectivity and socio-economic dynamics forms a classical basis for management and conservation of fisheries. There is presently no information on stock status of Lake Baringo fisheries while identifying these BRPs and socio-economic characteristics is necessary for developing and defining harvest controls. The lake's fish production trends has been declining in the last two decades thereby compromising natural stock regeneration. The study sought to provide not only stock indicators but also important BRPs and socio-economic dynamics that are necessary for management decision-making, harvest control rules and development of fisheries management plan for the lake.

1.6 Scope of the study

The study covered aspects of Lake Baringo fisheries in reference to *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* stock and socio-economic dynamics survey. It focused on estimation of these fish species BPRs, Yield Models and gear selectivity. Socio-economic dynamics studies focused only on fishermen and fish traders surveys'. Other factors along stock assessment that may affect fish production in Lake Baringo during the study period were outside the scope of this study. Results of the study based on the study period between August 2013 and July 2014, which may vary beyond the study's duration due dynamic changes in Lake Baring fisheries.

1.7 Limitation of the study

Selective fishing gears may have introduced bias in the part sampled population. However, use of yield models capable of backward projections of the unfished stock assisted in minimizing gears selectivity errors.

1.8 Assumption of the study

The assumption of the study was that there was no interruption of fishing in the lake during the period of the study.

1.9 Definition of terms

Definition of the following terms are from Food and Agriculture Organization (FAO) fisheries stock assessment manual by Cadima (2003), and Sparre and Venema (1998).

Asymptotic length (L_∞): This is the length that an individual fish would reach if they were to grow indefinitely.

A fishery: This refers to a set composed of a particular fish stock plus the fishing activities related to its harvest, inclusive of fishermen, area of water/ seabed, vessels, gears and associated facilities.

Biological Reference Point: This refers to an estimated value derived from a scientific procedure and/or a model, which corresponds to a state of the resource and/or of the fisheries and used as a guide for fisheries management.

Fishing mortality rate (F): This refers to the instantaneous rate of change of fish numbers over time on a cohort due to fishing.

Maximum sustainable yield: This refers to the greatest fish biomass achieved over time while maintaining the stock's productive capacity with regard to fish biomass.

Natural mortality: This refers to the removal of fish from the stock due to causes not associated with fishing. Such causes can include diseases, competition, cannibalism, old age, predation, pollution or any other natural factor that causes the death of fish.

Overfishing: This refers to high intensity fishing which depletes fish stock beyond fish stock growth or recruitment rate.

Steady state biomass: This refers to the actual rate of increase of fish through recruitment. In the presence of fishing, the instantaneous rate of change in biomass is equal to productivity.

Stock: This refers to a relatively homogenous and self-contained group of a fish species whose decrease by emigration or increase by immigration is insignificant in relation to the growth and mortality in their area of distribution.

Stock assessment: This refers to the part of fisheries science that studies the status of a fish stock as well as the possible outcomes of different management alternatives. It indicates if the abundance of a stock is below or above a given point. This shows if the stock is over-utilized or not. It also indicates if a catch level will maintain or change the abundance of the stock.

Utilization rate: This refers to the fish proportion in numbers or biomass removed by fishing. If the biomass is 1,000 tons and the harvest during a year is 200 tons, the annual utilization rate is 20%.

CHAPTER TWO

LITERATURE REVIEW

2.1 Stock assessment in fisheries

According to Hilborn and Walters (1992), the need for fisheries management stems fundamentally from the fact that fish resources are a common property. Such resources are over-utilized and often irreversibly depleted. Management measures needs subjected to fisheries resources to mitigate resource overutilization. A sustainable fisheries management strategy employs a set of scientific and social prescriptions and procedures that control the fishing activity (Puthy, 2007). Science based fisheries management invokes the knowledge on the fish stock assessment that provides reference to fish stock standing biomass, maximum sustainable yield and fishing mortality rates that will sustainably utilize the fish stock within maximum limit (Mateus and Estupinan, 2002).

Musick and Bonfil (2005) observed that fish stock assessment makes use of diverse information on the status of fisheries and the possible outcomes of management actions. The main purpose of studies on fish stock assessment is to obtain information on the optimum utilization of aquatic living resources. This provides a background for the elaborate management plans envisioning optimum long-term utilization of natural aquatic resources (Mateus and Estupinan, 2002). Stock assessment studies involve estimates based on information on age, growth rate, recruitment rates and mortality rates. The results of such studies assist in making quantitative predictions about the reaction of fish standing biomass to alternative management choices (Hilborn and Walters, 1992).

Fisheries utilization shows a great complexity due to socio-economic factors that affect fishing trends. The demand for fish in the market has continued to increase with the rise in population resulting to reduction of fish stock in an ecosystem. Calculations of fish mortality rate are therefore vital in fish stock assessment studies. This includes estimation of fish standing biomass through Virtual Population Analysis (VPA) (Chen *et al*., 2008; Sparre and Venema, 1998), Maximum Sustainable Yield (MSY) and fishing effort (Hoof and Salz, 2001; Punt and Hilborn, 1997). Stock assessment studies rely a lot on the rate of change of fish in length and length-frequency distributions (Anderson and Gutreuter, 1985) and the numbers and sizes of available fish in a population. A stock assessment studies therefore determine the fisheries potential to provide benefits for commercial utilization.

One of the basic parameter used in stock assessment calculations is the mortality rate for each age of fish. For VPA, mathematical formulae used for analysing the history of fisheries transforms the knowledge of the past and assist to predict future yields and biomass at different levels of fishing effort (Chen *et al*., 2008; Sparre and Venema, 1998). An important component in VPA is to calibrate abundance estimates with a time series of abundance indices with the assumption that a portion of the population dies each year.

Mertz and Myers (1996), Hilborn and Walters (1992) and Petrere (1983) observed that most of the world's major fisheries are managed using statistical catch-at-age models that relate commercial catch-at-age to indices of abundance such as research surveys or commercial catch per unit effort indices. These models describe the relationship between population abundance, fishing mortality, natural mortality, and the commercial catch. The most common assumption made is that fishing mortality is constant throughout the year. Two primary types of assessment methods used including index and age structured models. Age structured models include VPA and stock synthesis. An assessment based on VPA use estimates of catch at age data from the fisheries to determine the numbers at age. The VPA computations simply involve transforming the catch at age estimates into historical population estimates through a series of equations. The process of changing assumptions typically involves "tuning" population parameter values. As the parameter values change, the VPA (or other models) become more or less consistent with survey observations (Mertz and Myers, 1996; Hilborn and Walters, 1992; Petrere, 1983).

Kolding (1993) carried out studies on Nile tilapia (*O. niloticus*) population dynamics and life history in Lake Turkana. The study revealed that the lake's primary productivity and various predators that lead to natural fish mortalities were affecting fish population. However, the observable variation in tilapia population dynamics was due to changes in oxygen concentrations and fishing mortality.

Petrere (1983) carried out studies on yield per recruit to evaluate fresh water fisheries stocks in Brazil. Based on data from 1977 and 1978 he concluded that the stock of Tambaqui (*Colossoma macroponum*) was not overfished. Isaac and Ruffino (1996) later pointed out the overfishing of this species in Santarem, while Barthem and Petrere (1995) indicated overfishing of the Piramutaba (*Brachyplatystoma vaillantii*).

Mateus and Estupinan (2002) study on stock assessment of Piraputanga (*Brycon microlepis*) in the Cuiba River Basin; Pantanal of Mato Grosso, Brazil estimated growth and mortality parameters. Yield per Recruit model growth coefficient K = 0.28 yr^{-1}, natural mortality rate M = 0.59 yr^{-1}, total mortality rate Z = 0.82 yr^{-1} and fishing mortality F = 0.24 yr^{-1}. The results suggested that stocks of *B. microlepis* were not overexploited.

Nabi *et al.* (2007) estimated population parameters of *Polynemus paradiseus* using the length-frequency data on Chittagong and Cox's Bazar region in Bangladesh. The asymptotic total length (L_∞) and growth constant (K) were estimated as 20.48 cm and 0.48 yr^{-1} respectively. The instantaneous rate of natural mortality (M), fishing mortality (F) and total mortality (Z) were estimated at 1.21 yr^{-1}, 3.17 yr^{-1} and 4.38 yr^{-1} respectively. The value of utilization rate (E) was 0.72, which clearly pointed toward over-fishing condition (E > 0.50) for *P. paradiseus*. The length-weight relationship was found to be $W = 0.0087L^{2.74}$ signifying isometric growth for this species. Virtual Population Analysis estimated maximum numbers of *P. paradiseus* are caught between 3.5 cm to 11.5 cm with maximum F value (2.09 yr^{-1}) in the mid length of 8.5 cm. Relative yield per recruit (Y'/R) and biomass per recruit (B'/R) suggested that the fishing mortality should be reduced to 1.56 yr^{-1} to obtain maximum sustainable utilization rate (E_{max} = 0.36) for *P. paradiseus* (Nabi *et al.*, 2007)

The yield per-recruit analyses for the *Diplotaxodon limnothrissa* fish in the southeast arm of Lake Malawi indicated that the stock was fully exploited. This was indicated by the current spawner biomass-per-recruit ratios of 31-55% $(SB/R)_{F=0}$. The prediction model indicated that the age-at-capture was lower than the age at which yield was optimised (Kanyerere, 2003).

2.2 Optimal stock utilization

According to Punt and Hilborn (1997), basic purpose of fisheries stock assessment is to provide advice on the optimum utilization of aquatic living resources, which are limited but renewable. The assessment may be described as the search for the utilization level, which in the long run gives the maximum sustainable yield (MSY) in weight from the fisheries. The maximum sustainable yield is the largest amount of fish that can be taken out of an ecosystem and leaving sufficient to ensure sustainability. Maximum sustainable yield is therefore the greatest yield achieved over time while maintaining the stock's productive capacity (Puthy, 2007 and Sparre and Venema, 1998).

Sparre and Venema (1998) indicated that factors affecting the removal of biomass by natural deaths in an un-fished stock are almost constant. Introduction of fishing in such a stock results to greater rate of recruitment, faster growth and reduced natural mortality. Fish stock growth is affected by overfishing in an ecosystem that may affect fish recruitment. Fish are caught before they grow to a sufficient large size to substantially contribute to the biomass. Fishing mortality therefore exceeds Maximum Sustainable Yield (F_{MSY}) (Puthy, 2007; Sparre and Venema, 1998). The fisheries management therefore specifies the regulatory framework for the fishing activity to mitigate on overfishing. It consists of all the rules that the fishing activity must obey such as gear and area restrictions, fishing licenses, catch quotas, closed seasons and area closures.

Fish utilization in an ecosystem increases with increasing fishing effort. However, increasing effort exceeds the level of renewal of the fish resources through recruitment. Further increase in utilization level leads to reduction in yield. The fishing effort level, which in the long term gives the highest yield, is indicated by F_{MSY} and the corresponding yield is indicated by maximum sustainable yield (Puthy, 2007; Sparre and Venema, 1998).

Hastings and Botsford (1999) observed that the remedy for overfishing and declining aquatic biodiversity is a creation of fisheries reserves and management of fishing effort. Maunder (2002) indicated that the allocation of effort among gear is as important as controlling effort with respect to both sustainable yield and ecosystem management. Differences in age-specific vulnerability to the fishing method can modify the Maximum Sustainable Yield that is obtainable from a fish stock (Maunder, 2002; Die and Caddy, 1997).

Wudneh (1998) carried out a study on stock of fish in Lake Tana, Ethiopia from 1990 and 1993. The study found that motorized boats were used to exploite *Barbus spp*., *C. gariepinus*, and *O. niloticus*. Breeding of these species was associated with the rainy period and increase in Lake water level. The study estimated maximum sustainable yield as 32 kg ha^{-1} yr^{-1} while fishing effort was below MSY providing a scope for some expansion of the fisheries.

Coulter (1981) carried out a study on biomass, production and potential yield of fish in Lake Tanganyika. The fish community in the lake consisted of two short-lived clupeid species, of which *Stolothrissa tanganyicae* was dominant than *Limnothrissa* spp, and four much larger, long-lived *Lates* species. The annual production/mean biomass ratio for *S. tanganyicae* estimates was 3.5 – 4, which approximated the instantaneous mortality rate. The fish potential yield was 1.1 tons per year. Purse seining removed *Lates* species faster than clupeids, leaving more clupeid production for yield. With increasing dependence on clupeid species, the study found that the lakes fisheries was becoming more seasonal and more susceptible to annual environmental fluctuations and fishing mortalities.

2.3 Gear selectivity

Gear selectivity is the capacity of any method or gear type to capture certain fractions or sections of the fish population whether grouped by species, age, size or behaviour, and to exclude others (Thompson and Ben-Yami, 1984). Normally, gears are selective on larger sizes and some on certain length range of fish. This excludes capture of very small and very large fish (Sparre and Venema, 1998). When the gear targets small fish before sexual maturity or at exceedingly high rate of spawning stock biomass, recruitment overfishing may occur in fisheries. Similarly, growth overfishing takes place when fishing effort is so high that total yield decreases with increasing effort. Gear selectivity strongly relates to recruitment overfishing and growth overfishing due their effect on total fish mortality (Z). This property of gear selectivity is an important tool for fisheries management achieved through regulating the minimum gear sizes of a fishing fleet hence may determine the minimum sizes of the target species of certain fisheries (Sparre and Venema, 1998; Thompson and Ben-Yami, 1984).

Dadzie *et al.* (2005) studied *Liza klunzingeri* in Kuwaiti Bay. They noted that short-lived fish species like *L. klunzingeri* breed before they reach half of their life span. The results obtained from logistic gear selection model suggested that selection of 50% fish was at 4.8 cm for fish that reaches 20 cm total length. This condition had serious consequences for the management of *L. klunzingeri* with the evidence of recruitment overfishing. Management measures proposed by the study were imposition of a ban during critical time in the fish life history and a consideration on the impact of the fishing gear.

Goudswaard *et al.* (2002) reported that the size at first maturity of *P. aethiopicus* is 65 – 75 cm for males and 75 – 85 cm for females in Lake Victoria. The percentage of immature fish less than 70 cm in the catches was 22%, which may have contributed to the modest reduction in stock recruitment. The gear selectivity did not lead to recruitment overfishing.

Njiru *et al.* (2006) studied the life history characteristics of introduced Nile tilapia (*O. niloticus*) in Lake Victoria. The study evaluated fish sex ratio, fecundity, reproduction, length-weight relationship and growth constant. The lake *O. niloticus* length at first maturity was 30.81 cm for females and 34.56 cm for males. In another study, *O. niloticus* length at first maturity estimates was 14 cm for females and 17 cm for males in Lake Beseka, Ethiopia (Hirpo, 2013). Length at 50% gear selectivity should be above length at first maturity to avoid recruitment overfishing of *O. niloticus.*

Yusuf *et al.* (2013) studied length-weight relationship, fecundity and gonadal development of *C. gariepinus* in Doma dam, Nigeria. The study observed that the length for first maturity of females was 26.13 cm and males was 25.55 cm. The time for gonads maturation of males and females was similar. This was an indication that the length at 50% gear selectivity should be over and above the length at first maturity for *C. gariepinus* to prevent a fisheries recruitment overfishing.

2.4 Length-Weight relationship in fisheries

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 $W=\mathbf{a}L^{\mathbf{b}}$ 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.

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 changed with seasonal changes in physicochemical conditions of water. 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 and varied with seasonal changes.

Durbin *et al*. (1979), Werner and Hall (1979) and Reed (1978) found species diversity in aquatic micro-ecosystems influenced by ecosystem stability, environmental heterogeneity and primary production. The environmental heterogeneity is a function of water physicochemical parameters. Barretto and Uieda (1998) found 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 leads natural fish mortality (Calheiros and Hamilton, 1998). 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.

2.5 Fisheries socio-economic dynamics

Fish stocks assessment has received considerable attention while the dynamics of human communities who depend on the fisheries are equally important (Freire and Garcia-Allut, 2000). Changes in commercial fish stock is due to biological impacts such as diminishing standing biomass or reduced maximum sustainable yield and possible socio-economic losses incurred by variation of fishing effort (Freire and Garcia-Allut 2000; Charles 1989). Stock assessment results combined with socio-economic studies are therefore crucial in formulating appropriate management policies of fisheries (Freire and Garcia-Allut 2000; Charles 1989).

Gupta (2010) observed that the major focus of fisheries management relates to the unsustainable levels of utilizing a fish resource. Emphases put to such practices that lead to the depletion of fish stocks, disruption of ecological equilibrium and reduction in diversity. Over utilization of fish diminishes species population thereby reducing economic returns. Over utilization of valuable commercial fish species begets quick replacement of fish yield by less desirable species (Gupta, 2010). This scenario is similar to Lake Baringo where *P. aethiopicus* has replaced the valuable *O. niloticus baringoensis*, which formed the basis of Lake Baringo fisheries between 1960s and early 1990s (Aloo, 2004). Currently, a large share of global fish yield consists of previously unused, less valuable fish species. The fishing sequence and demand or supply driven fishing have an impact on fish biodiversity with a change in composition and relative abundance of harvested species. The desire to increase profits in fisheries by the fisher folks hampers economic biodiversity conservation affecting the value of fisheries (Gupta, 2010).

The socio-economic studies that carried out in Lake Baringo basin have mainly focused on human land-use effects to the lake ecosystem and climate variability. Information on the effects of fishing effort and market demand or supply to fish biodiversity is lacking for the lake. Climate variability cause both direct and indirect impacts on Lake Baringo ecosystem. The direct impacts of extreme climate events (floods and droughts) include fluctuation of lake levels, salinity and aquatic life disturbance. The indirect impacts that are anthropogenic in nature include; siltation, soil compaction, illegal abstraction of feeder waters to the lake, change in aquatic species composition and famine (Ngaira, 2006).

Wasonga *et al.* (2011) studied the socio-ecological change dynamics using local knowledge in the semi-arid lowlands of Baringo district. Results from the study indicated that the technical advances in the recent past have led to rapid ecological changes at local, regional and global scales. The most obvious and pronounced change was caused by human land-use pattern. The most affected ecosystems are the arid and semi-arid land owing to their inherent climate variability that renders them more susceptible to land-use pressure than other ecosystems. The degradation of pastoral areas has led to the erosion of economic livelihood of pastoralists reflected in increased destitution among pastoral households. The study revealed that the changing vegetation structure, declining diversity and increasing soil erosion attributed to rise in both human and livestock populations have affected fish production due to heavy siltation of Lake Baringo ecosystem.

Aloo (2004) also reported that since the beginning of the last century Lake Baringo ecosystem has undergone several ecological changes. Most of the changes are a result of human activities within the catchment basin and changes in climatic conditions. The most notable change is the limnological feature of the lake with extreme turbidity shown by the low average secchi disc reading of 9.5 cm. The change is due to considerable siltation resulting from high rates of soil erosion caused by overgrazing by livestock and deforestation in the catchment area. The bed of the lake is therefore virtually devoid of invertebrate life while primary production in the open waters is very low (Aloo, 2004; Schagerl and Oduor, 2003).

2.6 Lake Baringo fish production trends

Aloo (2006) indicates that Lake Baringo ecosystem and its catchment areas face environmental and socio-economic threats resulting to declining fish stocks, low economic returns from fisheries and loss of biodiversity. The lake fisheries has been on a declining trend since 1970s while fish composition and quantity targeted for commercial fisheries continued to fluctuate within this period. For instance *O. niloticus baringoensis*, which previously dominated the catch, has declined in size and quantity while *Labeo cylidricus*, once abundant in the river mouth is now rare. Catches of *Barbus spp* are currently too low. On the other hand *C. gariepinus* and *P. aethiopicus* annual yield have been increasing slowly, becoming the main fish species targeted for commercial utilization, with declining *O. niloticus baringoensis* production (Aloo, 2006).

The management of Lake Baringo fisheries have attempted to regulate the fluctuating trends of fish production. These measures have included closure of the lake from fishing in 1994 on decline of fish harvest towards the end of 1993 (Fig. 1). Another decline in fish production was experienced in 2001 necessitating another lake closure between 2002 and 2003 (Nyamweya, 2011; Aloo, 2006). Muli (2011) indicated that the lake fisheries used to be the economic mainstay of the local population and supported a fish-processing factory, which collapsed in 1986 due to inadequate fish catch from the lake for processing. In the 1960s, the annual total landing for tilapia was over 600 tons while in 1984 it had declined to less than 3 tons (Hickley *et al.*, 2004).

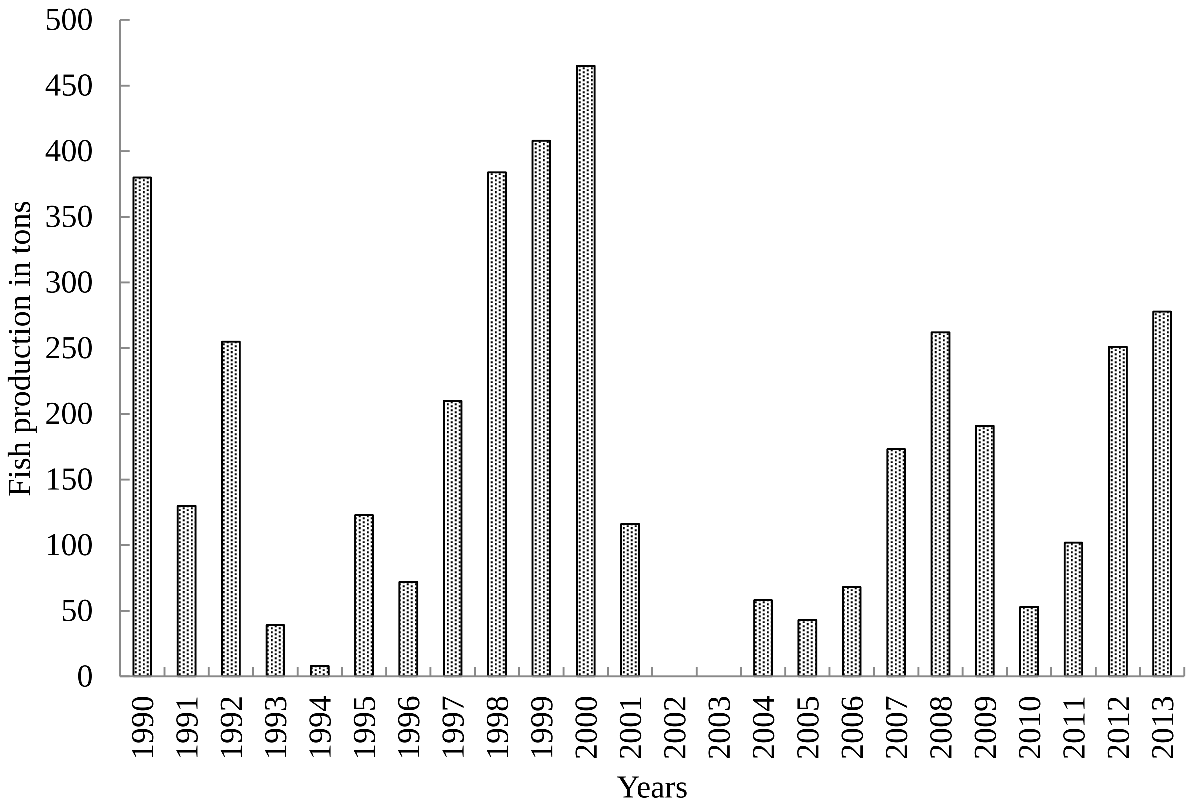

Figure 1: Fish production between 1990 and 2013 in Lake Baringo (Data source: State Department of Fisheries).

Fish production trend seems closely related to climatic changes with respect to rainfall and drought patterns. Ngaira (2006) reported that there was extremely high equatorial rainfall in East Africa leading to high lakes level in early 1960s (Table 1). It is at the same time that fish production reached its peak in the lake at 600 tons. Severe drought in 1984 resulted in collapse of fish processing industry in the lake with only 3 tons recorded in the year. Kenya experienced another drought between 1991 and 1992, which led to the closure of fishing in the lake between 1993 and 1994. El-Niño phenomenon experienced between 1997 and 1998 coincided with high fish production between 1998 and 2001. The lake levels also increased as from 2012 displacing human settlements around the lake as experienced in the 1960s and its evident fish production has assumed an upward trend.

Table 1: Climatic changes between 1961 and 1998 in Africa (Source; Ngaira, 2006).

Year	***Event***
1961	Extremely high equatorial rainfall in East Africa which led to East African lakes rising in levels to above all twentieth century record.
1968 - 1973	Severe phase of drought (Sahelian drought) in Ethiopia and the Sahel region, which caused severe famines, animal loss, desertification and reduced the size of Lake Chad.
1977	Highest rainfall ever recorded in Kenya which caused severe gulley erosion, Lake level rise in semi - arid regions
1984	Severe droughts in Kenya led to the introduction of "food queues" in supermarkets.
1991 – 1992	Severe droughts in most arid areas in Kenya led to the introduction of "food for work" programs, and reduced surface areas of the lakes in the region.
1997 - 1998	Kenya experienced the worst floods in 36 years caused by El-Niño, which increased surface area of Lakes in the rift valley.

2.7 Fisheries policy and legal framework in Lake Baringo

Lake Baringo has low fish species diversity unlike other tropical lakes. Aloo (2006) indicated that the lakes' ecosystems is fragile as reflected by its fluctuating fish production and change in fish species forming the highest percentage in the catch over the years. The National fisheries and Ocean Policy 2010 proposes co-management of fisheries resources based on frame survey coupled with fish stock assessment to provide advice on the standing biomass and the rate of annual fish utilization at Maximum Sustainable Yield (MOFD, 2008). The Fisheries Department in Kenya has implemented several measures to manage fish utilization in the lakes guided by fisheries Act (2012) chapter 378. The measures have included periodical ban on fishing, mesh size regulation, imposition of closed seasons and co-management through Beach Management Unit (MOFD, 2007).

These measures have not improved fish stock recovery while declining fish yield is still experienced with continued fish utilization (Aloo, 2006). Imposition of these measures do not base on fish stock assessment studies that would determine the lake's biological reference points, optimal fish yield, gear selectivity and socio-economics dynamics to sustain the fisheries utilization. This has resulted in loss of employment and income to the fisher folks dependent on the lake during the closures and a threat to food security in absence of fish production (MOFD, 2007).

The government of Kenya through the fisheries Department established co-management of freshwater and marine fisheries resources in 2007 (Mwaka *et al*., 2008). This was in response to declines in fish stocks and decreasing aquatic biodiversity. The co-management of fisheries in Kenya is a concept started with the purpose of engaging the local community in fish resource management because they would be the first casualties should the resource collapse. This was legalised through Beach Management Units (BMU) regulation 2007 (MOFD, 2007). The aim is to integrate local and national management, making use of both traditional knowledge and scientific findings. Beach Management Units (BMUs) bring together everyone involved in fisheries on a local level including fishermen, boat owners, boat crew, traders, processors, boat builders and repairers, net repairers and others. It constitutes the link between local fishing communities and the government for facilitating co-management of fisheries resources (Kundu *et al*., 2010; MOFD, 2008; Mwaka *et al*., 2008). A fisherman heads the Beach Management Unit in Lake Baringo with all stakeholders operating in the lake forming the membership to the BMU. The BMU has been involved in enforcement of fishing gear regulations; monitoring daily fish catch size and coordinating fish marketing.

2.8 Commercial fish species description in Lake Baringo

The commercial fish species in Lake Baringo comprised of *Protopterus aethiopicus, Oreochromis niloticus baringoensis* and *Clarias gariepinus*. *Protopterus aethiopicus* occurs in freshwater with temperature ranging from 25 - 30°C. The fish is a smooth slimy fish with a cylindrical body, found in Lake Baringo, Lake Victoria, Lake Tanganyika and Nile River. Mature *P. aethiopicus* inhabit open lakes and marginal swamps and are capable of living in completely dry streams and swamps. Male parent prepares a nest for female to lay eggs. Female leaves the nest and does not return leaving males to guard and aerate the eggs and young for nearly eight weeks (Gosse, 1984).

Kingdom	Animalia
Phylum	Chordata
Class	Sacropterygii
Order	Lepidosireniformes
Family	Protopteridae
Genus	*Protopterus*
Species	*Protopterus aethiopicus*

Common name	African lungfish
Local name	“Kamongo”

Plate 1: *Protopterus aethiopicus* in Lake Baringo.

Oreochromis niloticus habitats includes both freshwater and blackish water with temperature range between 8 – 42°C. It feeds on phytoplankton or benthic algae. The fish sexual maturity is at 3 – 6 months and spawns after every 30 days. Females incubates eggs inside their mouths where larvae hatch (Trewavas, 1983).

Kingdom	Animalia
Phylum	Chordata
Class	Actinopterygii
Order	Perciformes
Family	Cichlidae
Genus	*Oreochromis*
Species	*O. niloticus*
Binomial	*Oreochromis niloticus baringoensis*
Common name	Tilapia

Local Name "Ngege"

Plate 2: *Oreochromis niloticus baringoensis* in Lake Baringo.

Clarias gariepinus is native to the Orange River in South Africa. It is a freshwater fish found in waters with pH range of 6.5 – 8.0 and temperatures between 8 and 35°C. It found in lakes and pools preferring shallow and swampy areas with soft muddy substrate. The fish is tolerant to extreme environmental conditions. The fish are omnivore's bottom and surface feeders. It migrates upstream during rainy season for spawning (Teugels, 1986).

Kingdom	Animalia
Phylum	Chordata
Class	Actinopterygii
Order	Siluriformes
Family	Clariidae
Genus	*Clarias*
Species	*Clarias gariepinus*
Common name	Catfish
Local name	"Singiri"

Plate 3: *Clarias gariepinus* in Lake Baringo.

2.9 Research in for Lake Baringo Basin

Several studies carried out in Lake Baringo basin and the catchment provide adequate amount of data on vegetation cover, land-use, biodiversity, aquatic ecology and fish production. The research carried out has attracted a large number of articles, Master and Doctor of Philosophy theses, reports and posters. The Ministry of Agriculture, Livestock and Fisheries through State Department of Fisheries (SDF) and Livestock, Kenya Wildlife Service (KWS), Kenya Marine and Fisheries Institute (KMFRI), Kenyan and foreign universities have all been actively involved in research on Lake Baringo. The most important researches carried out on Lake Baringo and relevant to this study are summarized in Table 2.

Table 2: Some of the fisheries related studies carried out on Lake Baringo Basin.

Research area	***Topic of interest***	***Reference***
Fishing production trends.	Changes in fish production trends due to Fishing effort and changes in climate and habitat condition.	Muli, 2011; Hickley *et al*., 2004

Socio-ecological change dynamics in Baringo district.	Land-use effects to vegetation structure, biodiversity and soil erosion and subsequent effect to Lake Baringo ecosystem.	Wasonga *et al.,* 2011; Schagerl and Oduor, 2003
Ecological changes of Lake Baringo.	Changes of limnological features of Lake Baringo due to human activities within the catchment basin and changes in climatic conditions.	Aloo, 2004; Odour *et al*., 2003; Ngaira, 2006
Primary production of Lake Baringo.	Effects of turbidity to primary production.	Schagerl and Oduor, 2003

2.10 The research gaps

Code of conduct for responsible fisheries by FAO indicates that unavailability of adequate data is not an excuse for not implementing fisheries management measures (Cadima, 2003). The limitations, uncertainties or lack of data for the assessment or for the estimation of parameters, cannot be justification for not applying regulatory measures, especially with information regarding overexploited stocks (Honey *et al*., 2010; Cadima 2003). The management of Lake Baringo fisheries has been on the base on annual fish yield data in absence of research on reference points for fish standing biomass, maximum sustainable yield and gear selectivity, and fisheries socio-economic dynamics. Management decisions including closed season (in 1994 and between 2002 and 2003), and determination of mesh size and fish standard length regulation as directed by fisheries Act (2012) chapter 378 have been applied to the lake resource. However, these measures have not successfully controlled overfishing since information on fish stock assessment to advice their applications is lacking.

Most of the researches done in Lake Baringo ecosystem and its catchment area has featured biophysical and socio-economic aspects with reference to land-use characterization but no linkage to the lake fisheries. This study aimed at providing information on BRPs, Yield Modelling, gear selectivity and the lake socio-economic dynamics for sustainable lake resource utilization.

2.11 Conceptual framework

The long-term objective of a resource management takes into consideration scientific fish stock assessment. The precautionary approach of fisheries resource management suggests that management in formulating regulatory measures should adopt the best available research results.

Such measures should also take into consideration the socio-economic pressure to fishing (Cadima, 2003). In order to define these long-term objectives, considerations on values of the fishing level allow sustainable resource utilization. In essence, adoption of fishing mortality rate that allow sustainable utilization is prerequisite for Lake Baringo fisheries resource.

The conceptual framework (Fig. 2) identifies and suggests the flow of Lake Baringo fisheries resource management decisions based on information of the Biological Reference Points, optimum fishing scenarios, gear selectivity and the socio-economic dynamics of the lake fisheries to;

1. Aid in the analyses of Lake Baringo Biological Reference Points for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus*.
2. Provide clear and rigorous conceptual information on the optimum fishing scenarios for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo.
3. Aid in analyses of gear selectivity of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in the lake.
4. Characterize the socio-economics dynamics of fishermen and fish traders in Lake Baringo fisheries.

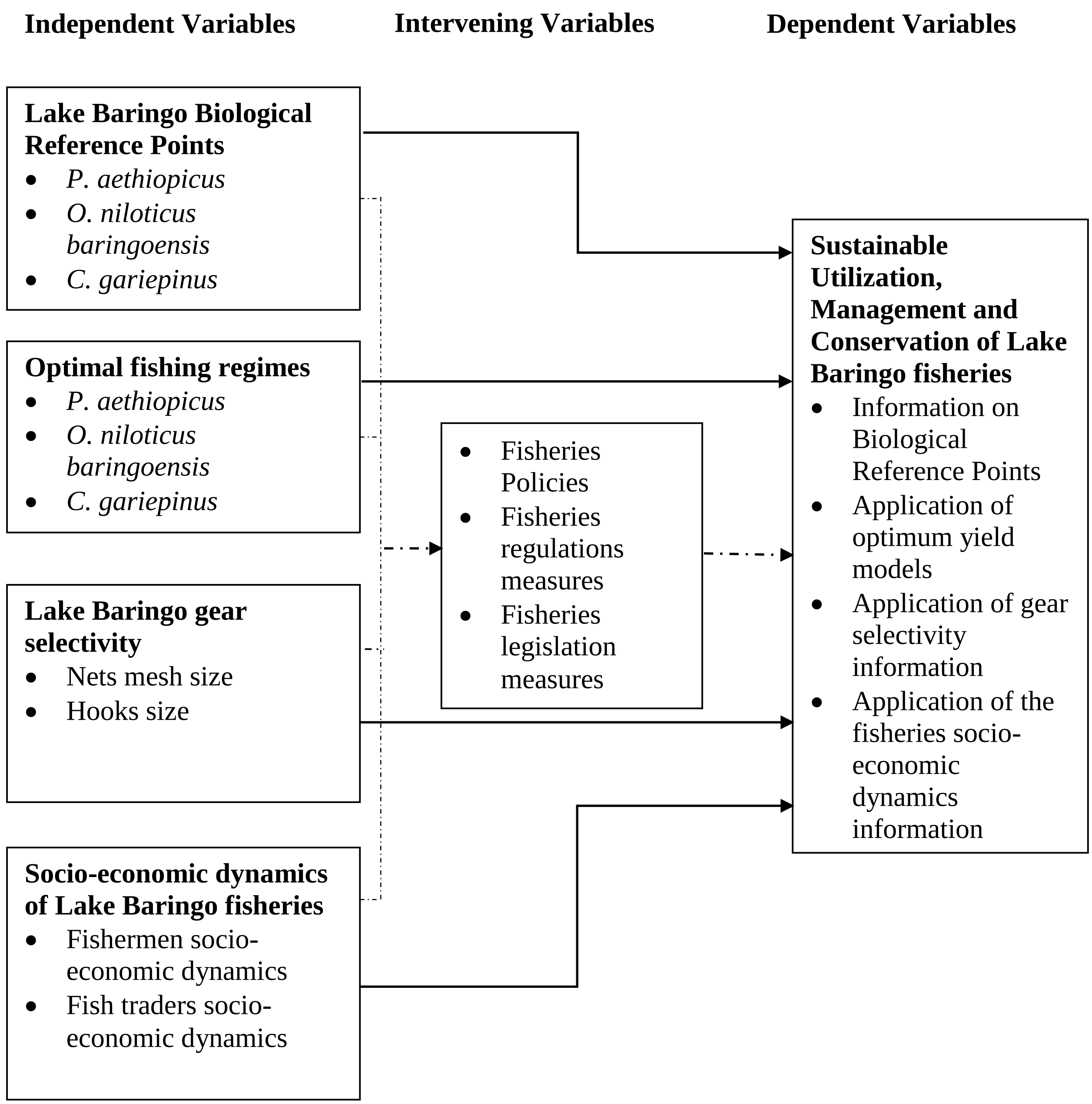

Figure 2: Sustainable utilization of Lake Baringo fisheries with reference to stock assessment and socio-economic dynamics.

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study area

Lake Baringo is among a series of 23 major lakes in the Eastern Rift Valley; eight in central Ethiopia, eight in Kenya and seven in Tanzania. The lake is within the Gregory Rift Valley system that extends northwards from Lake Malawi through Tanzania, Kenya, and Ethiopia. It is part of the valley that contains the Red Sea, and the Jordan valley. The overall climate of the eastern Rift Valley is semi-arid. Most Eastern Rift Valley lakes are thus alkaline or saline. However, Lake Baringo is unique within the central latitudes of the valley in being fresh, and indeed within the Kenyan series of lakes (from north to south are Turkana, Baringo, Bogoria, Nakuru, Elmentaita, Naivasha, Magadi) (KFD, 2011; Kiage and Liu, 2009).

3.1.1 Formation of Rift Valley Lakes

The Great Rift Valley in the eastern part of Africa extending for over 5600 km is the most impressive rift valley system in the world. There are several theories attempting to explain formation of Rift Valley with only two that appear plausible. One theory relies on the forces of tension while the other on the forces of compression. Both theories base the formation of rift valley on the upward swelling of the earth along fault line (Bunnet, 2003). The lakes found in the Great Rift Valley are therefore tectonic in origin; also known as fault lakes, where water is in faulted valleys. These lakes formation is during the Miocene period, 25 million years ago (Ngaira, 2006). The Western part of this rift valley passes through Lakes Tanganyika, Albert (Mobutu) and Edward (Amin). The Eastern part passes through Lakes Turkana, Baringo, Bogoria, Nakuru, Elmentaita, Naivasha, Magadi, and Logipi (Ngaira, 2006; Bunnet, 2003).

The eastern Rift Valley lakes include some of the oldest, largest and deepest lakes in the world. They hold great biological diversity, majority being alkaline “soda lakes” and some fresh water. In Kenya, only lakes Naivasha, Baringo and Turkana are fresh water while Lakes Magadi, Bogoria, Logipi, Elmentaita and Nakuru are alkaline. Lakes Naivasha and Baringo have fresh water due to underground water seepage (Harper *et al.*, 1990). Most of Rift Valley lakes holds evolution of at least 800 cichlid fish species that live in their water systems. Lakes Baringo support an ecosystem with high but uneven biodiversity, which is also rich in birds and plants but no native fish (Harper *et al*., 1990).

3.1.2 Location

Lake Baringo is located in a sparsely populated Marigat Division of semi-arid Baringo County about 120 Km north of Nakuru town. It lies at an altitude of 970 m above sea level between longitudes 36º 00´ E - 36 º 10´E and latitude 0 º44′- 0º 34′N (Fig. 3) with a surface area of 129 km^2 (Kiage and Liu, 2009). The main perennial rivers are Perkerra and Molo while the seasonal rivers include Endao, Chemeron, Ol Arabel and Mukutani (KFD, 2011; Kiage and Liu, 2009).

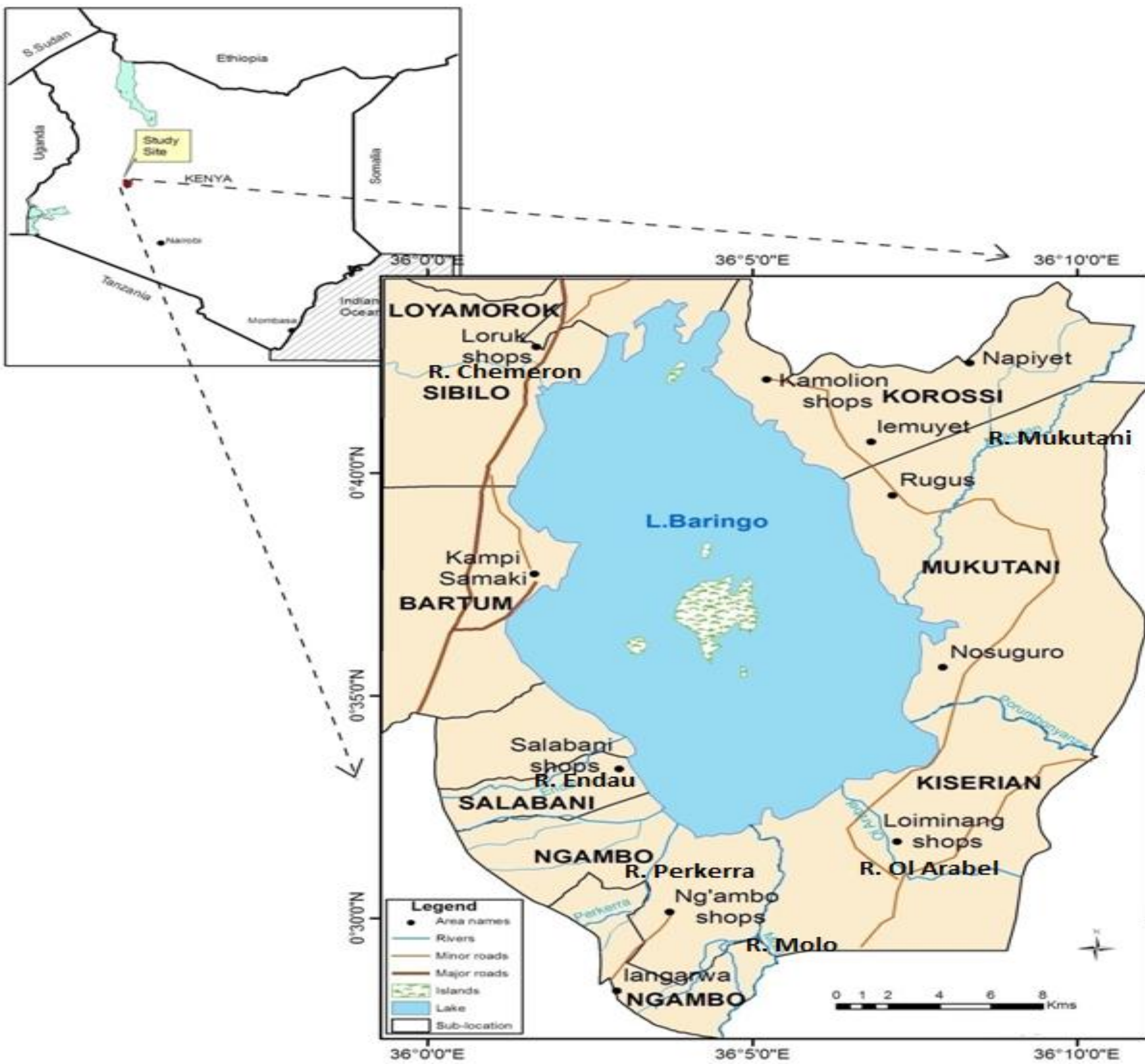

Figure 3: Location of Lake Baringo (Source; Survey of Kenya, 2014).

3.1.3 Human Population

Human populations around the lake basin have increased during last 40 years (KNBS, 2009). Kenya National Bureau of Statistics (KNBS, 2009) estimated human population in Baringo County at 555,561 in 2009 population census. Historical immigration and natural population growth led to a tenfold increase in population between 1984 and 1999. Population density increased from 4.4 to 44 persons per km^2. Population growth rate in Baringo district was 2.65% per annum (Wasonga *et al.*, 2011).

3.1.4 Geology and hydrology

Lake Baringo is a shallow freshwater lake with predominantly siliciclastic sediments. The lake shape and basin morphology are due to two regional tectonic trends. These trends influence the patterns of drainage and sedimentation (Simiyu *et al.*, 2011). The west of the lake composes Tugen Hills, which are 1,500 metres above the rift floor. About 30 km east of Lake Baringo is the Laikipia Escarpment forming the eastern edge of the rift. The extinct Pleistocene central volcano forms the indented northern shoreline of Lake Baringo. The upper Pleistocene trachyphonolites and basalts form the northward-dipping rift floor to the lake (Renaut *et al*., 2000).

The lake drains through underground seepage to a catchment of approximately 6,200 km^2, which is located mainly in wetter volcanic uplands to the southwest. The annual rainfall is about 600-900 mm on the rift valley floor rising to more than 1,000 mm yr^{-1} in the adjacent highlands. Most annual recharge comes from perennial rivers Molo and Perkerra, which flow northward (Renaut *et al*., 2000).

3.1.5 Importance of Lake Baringo Fisheries

Lake Baringo Fisheries plays a significant role in the social and economic development of the lakes populace and surrounding environs. This is through positive contribution to employment creation, revenue and income generation and food security. Lake Baringo fish production in 2011 was 101,000 kg, which earned 9.5 million shillings to fishermen. The lake Fisheries supports livelihood of more than 5,500 people directly and indirectly, working as fishermen, traders, processors, suppliers and merchants of fishing accessories and employees and their dependants (KFD, 2011).

3.2 Research design

The study of fish stock assessment and socio-economic characterization of Lake Baringo fisheries used quantitative and qualitative research design respectively. Determination of BRPs, estimation of optimal fishing levels and determination of gear selectivity was on measurements of length and weight of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus*. Surveys were done on the fishermen and fish traders for socio-economic dynamics of the lake Fisheries studies.

3.3 Sampling sites

Fish samples were obtained from Kampi ya Samaki landing beach used by all fishermen as a collection point for all fish caught from the lake. Samples of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* were taken from their boats. Sampling for Lake Baringo Fisheries socio-economic survey was done in Kampi ya Samaki shopping centre, which is the lakes hub of fishing activities.

3.4 Sampling for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus* stock assessment

Fish samples were collected for stock assessment studies between August 2013 and July 2014 from boats landings for estimating length and weight. During sampling period, 62 boats were involved in fishing. On a sampling day 25 boats (40%) constituted the sample size. The numbers of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in each boat were separately recorded, and then a sub-sample of 40% for each species representing various size classes from each boat was used for the measurements. The total length was measured using a fish measuring board graduated to 0.1 cm. The total length was considered to be the distance from the snout to the tip of the caudal. Each fish was individually weighed using a top loading pan balance to the nearest 0.1 g. The length measurements were used to prepare the monthly length-frequency tables for estimation of population parameters while the weight was used in conjunction with length to determine the length-weight relationship and fish condition. These measurements were taken five

(5) days in a week for a period of 12 months. A total of 3,155 *P. aethiopicus*, 2,769 *O. niloticus baringoensis* and 1,922 *C. gariepinus* were sampled during the study.

3.4.1 Determination of Length-Weight relationship

Total length (*L*, cm)-weight (*W*, g) relationship were developed by regression of log *W* against log *L* for each species, producing values for the parameters ***a*** and ***b*** in the length-weight equation:

$$W=aL^b$$

where,

W = weight of the fish in grams

L = total length of the fish in cm

a = constant (Weight intercept)

b = exponential value (regression co-efficient)

3.4.2 Determination of growth parameters (L_∞ and K)

Growth parameters were determined using the ELEFAN I routine in Fish Stock Assessment Tools (FiSAT) (Gayanilo *et al*., 2005). The response surface analyses routine was used and the highest ratio of expected to observed peaks in the frequency distribution (R_n) was used to determine the best growth parameters for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus* as follows:

$$R_n = 10^{ESP/ASP}/10$$

where the ASP (Available Sum of Peaks) is computed by adding the 'best' values of the available 'peaks' and the ESP (Explained Sum of Peaks) is computed by summing all the peaks and troughs in the length-frequency "hit" by a non-oscillating growth curve of the form:

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

In all the analyses, the inverse Von Bertalanffy Growth Formula was used to convert the mid-length of each length class to their relative age for further analyses:

$$t' = -1/KLn[1 - \left(\frac{L_t}{L_\infty}\right)]$$

3.4.3 Determination of mortality rates

The L_∞ and K were used as input into the length-converted catch-curve to provide estimates of total mortality coefficient Z. The fishing mortality coefficient (F) was established from the difference between natural mortality (M) and total mortality coefficient (Z). To estimate M, the average annual surface temperature of 25.5 °C, L_∞ and K were used as inputs. This procedure allowed for the estimation of current exploitation rate ($E_{CURR} = F/Z$). The total mortality coefficient (Z) was estimated from the length-converted catch curve using the following relationship:

$$Ln\left(\frac{N_i}{\delta t_i}\right) = a + bt_i$$

where,

N_i is the number of fish in length class *i*,

δt_i is the time needed for the fish to grow through length class *i*,

t_i is the age (or the relative age, computed with $t_o = 0$) corresponding to the mid-length of class *i* , and where b, with sign changed, is an estimate of *Z:*

thus,

$$Z = M + F$$

and exploitation ratio,

$$E = F/Z$$

3.4.4 Standing biomass analyses for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

Total length of fish was measured using a measuring board with accuracy of 1 mm. Recorded length was then classified into length-classes of fish during the year. This presented a picture that reflected cohort peaks during the fish entire life span. The cohort analyses were based on Jones' length-based model applied by Sparre and Venema (1998). L_∞, K, M, F_t, length-weight parameters

a and **b** (obtained above from Length-Weight relationship) were then used for VPA to determine the Steady State Biomass (B_{CURR}), where:

$$N_{L1} = [N_{L2} \text{ x } H_{(L1,L2)} + C_{(L1,L2)}] \text{ x } H_{(L1,L2)}$$

where,

$N_{L1} = Nt_{L1}$ = the number of fish that attain length L1

= the number of fish that attain age t_{L1} (also called the number of survivors)

$N_{L2} = N(t_{L1+\delta t})$ = the number of fish that attain length L2

= the number of fish that attain age $t_{L2} = t_{L1} + \Delta t$

$C_{(L1,L2)} = (C(t, t + \delta t)$ = the number of fish caught of lengths between L1 and L2

= the number of fish caught of ages between $t(_{L1})$ and $t(_{L2})$

$$H_{(L1,L2)} = \left(\frac{L\infty - L1}{L\infty - L2}\right)^{M/2K} = \begin{pmatrix} the\ fraction\ on\ N(L1)\ which\ survive\ natural\ deaths\ during \\ the\ same\ time\ period\ from\ t(L1)\ to\ (L1) + \delta T/2 \end{pmatrix}^{-1}$$

The numbers for length were then converted to weight (biomass) using the length-weight relationship to estimate steady state biomass.

3.4.5 Yield-Per-Recruit (Y'/R) and Biomass-Per-Recruit (B'/*R*)

The Beverton and Holt (1957) yield-per-recruit (*Y/R*) and average biomass-per-recruit (*B/R*) model was used to estimate proxies biological reference points E_{MSY}, $E_{0.1}$ and $E_{0.5}$. The model used *M/K* and L_c/K ratios for the estimations, where;

$$\frac{Y'}{R} = EU^{M/K}\left(1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{3U^2}{(1+2m)}\right)$$

where,

$$U = 1 - \left(\frac{L_c}{L_\infty}\right)$$

$$m = (1 - E)/\left(\frac{M}{K}\right) = (K/Z)$$

$$E = F/Z$$

Relative biomass-per-recruit (*B'/R*) was estimated from the relationship

$\frac{B'}{R} = (\frac{Y'}{R})/F$, while

E_{max}, $E_{0.1}$ and $E_{0.5}$ were estimated by using the first derivative of this function. Plots of *Y'/R* vs *E* (=*F/Z*) and of *B'/R* vs *E*, from which E_{max} (exploitation rate which produces maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of relative yield-per-recruit is 1/10th of its value at E=0) and $E_{0.5}$ (value of E under which the stock was reduced to 50% of its unexploited biomass) were also estimated.

3.4.6 Optimal fishing scenario for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus* analyses

The yield model developed by Branch *et al.* (2000) was used to determine the lake MSY. Yield model and scenario analyses required L_∞, K, M, L_c, L_{m50}, ***a*** and **b** from both length-weight relationship and from Stock Recruitment (SR) relationship. Yield per Recruit analyses (models) calculated the equilibrium yield per recruit for a given value of fishing mortality (F) and a given length (L_c) or age (T_c) at first capture. The outputs provided a scenario of current reference points against the limit reference points consisting of Yield-per-R/FishB_o (at F_{CURR}), Yield-per-R/SSB_o (at F_{CURR}), Yield-per-R/FishB_o (at F_{MSY}), Yield-per-R/SSB_o (at F_{MSY}), F_{CURR}, F_{MSY} and $F_{0.1}$.

3.4.7 Gear selectivity estimation for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

Gear selectivity was estimated with gear probability of capture for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus*. Backward projection of the number of fish that would be expected if no selection had taken place was used for the catch curve analyses (*N´*) (Dadzie *et al*., 2005), where;

$$N_{I-1'} = N'i.e^{(Z\delta t)}$$

with

Δt being the time needed for the fish to grow through length class i;

$$Z = \frac{Z_i + Z_{i+1}}{2}$$

$$Z_i = M + F_i$$

$$F_{i-1} = F_i - X$$

$$X = F/(number\ of\ classes\ below\ P_{i+1})$$

P_i is the first length group with a probability of capture equal to 1.0, and whose lower limit is an estimate of $L´$. From this, probabilities of capture by length were computed from the ratios of $N_i/N´_i$. An extension of the length-converted catch-curve provided a linkage to the estimation of probability of capture for each length class and further estimated selectivity by a logistic curve to produce L25%, L50% and L75%.

3.5 Sampling for socio-economic dynamics

The sample for socio-economics studies in Lake Baringo was obtained from the fishermen and fish traders' survey through simple random sampling technique. Sampling for fishermen and fish traders was done through random numbers obtained from register held by the Fisheries Department. The sample size constituted 40% of registered fishermen and fish traders who were randomly selected for the survey using the approach by Kronen *et al.* (2007).

Socio-economic data was collected by means of structured questionnaire (Appendix 1). The questionnaires were administered through interviews on fishermen and fish traders to cater educated and un-educated respondents. The survey data collected included; gender, age, education level, source of income and fish marketing patterns.

Data collected from fish traders enabled estimation of the impact of commercial fisheries activities including; quantities by species marketed and preservation methods of fish species marketed, targeted consumers and consumer preferences.

3.6 Data analyses

A combination of descriptive and inferential statistics was used to analyse data collected over the study period on different aspects of stock assessment and socio-economic surveys (Table 3). The analyses were conducted in Windows EXCEL and MINITAB software's.

Table 3: Stock assessment objectives, measurements and analyses in Lake Baringo.

No.	Objectives	Measurements	Analyses
1	Determining the Biological Reference Points of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo.	• Fish length • Fish weight	Descriptive statistics (means, standard deviations and trends) Inferential statistic
2	Establishment of optimal fishing scenario for *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo.	• Fish length • Fish weight	Descriptive statistics (means, standard deviations, and trends) Inferential statistic
3	Determination of gear selectivity on *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* in Lake Baringo Fisheries.	• Fish length • Fish weight	Descriptive statistics (means, standard deviations, and trends) Inferential statistics
4	Characterizing the socio-economic dynamics of Lake Baringo Fisheries.	• Number of fishermen and fish traders • Administration of questionnaires	Descriptive statistics (means, standard deviations, and trends) Inferential statistics

CHAPTER FOUR

RESULTS

4.1 Population parameters and BRPs for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The standing biomass was analysed for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus.* Evaluation of these fish growth parameters including asymptotic length, growth coefficient and length-weight relationship were conducted. These fish mortality rates, exploitation rates, Yield-Per-Recruit (Y'/R) and Biomass-Per-Recruit (B'/R) maximum sustainable yield and gear selectivity results are shown below.

4.1.1 Length and weight frequency distribution for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The length at first capture (L_c) of *P. aethiopicus* captured was 12.51 ± 9.50 cm and the highest length was 171 cm with 185.64 cm asymptotic length (L_∞). The mean length of the fish targeted for fishing was 86.55 ± 21.58 cm. Majority of fish were caught at lengths 55 - 105 cm (Fig 4). The fish weight ranged between 112 and 26,000 grams with mean weight of 3,267.10 ± 66.40 grams. The growth constant (K) for *P. aethiopicus* was 0.47 yr^{-1}.

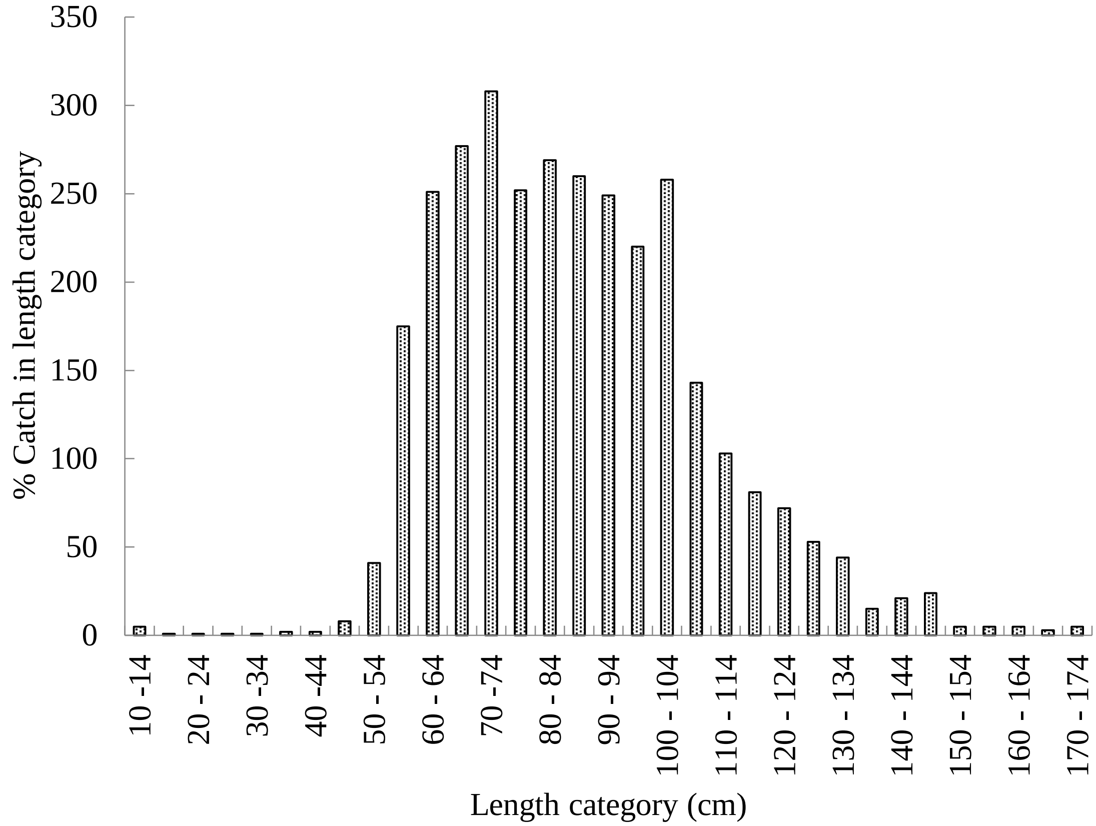

Figure 4: Length frequencies distribution of *P. aethiopicus* in Lake Baringo between August 2013 and July 2014.

The mean length of *O. niloticus baringoensis* mostly caught was 22.37 ± 2.02 cm weighing 202 ± 61.29 grams. The fishermen targeted fish ranging from 18 cm and 42 cm with highest fishing mortality rate (F) experienced at 20 – 25 cm (Fig. 5). The length at first capture (L_c) was 12.53 ± 2.81 cm. The fish weight ranged between 100 grams and 575 grams during the sampling period with a mean weight of 202 ± 61.29 grams. The growth parameters of von Bertalanffy growth formula of *O. niloticus baringoensis* estimated asymptotic length (L_∞) = 37.39 cm and growth constant (K) = 0.83 yr^{-1}.

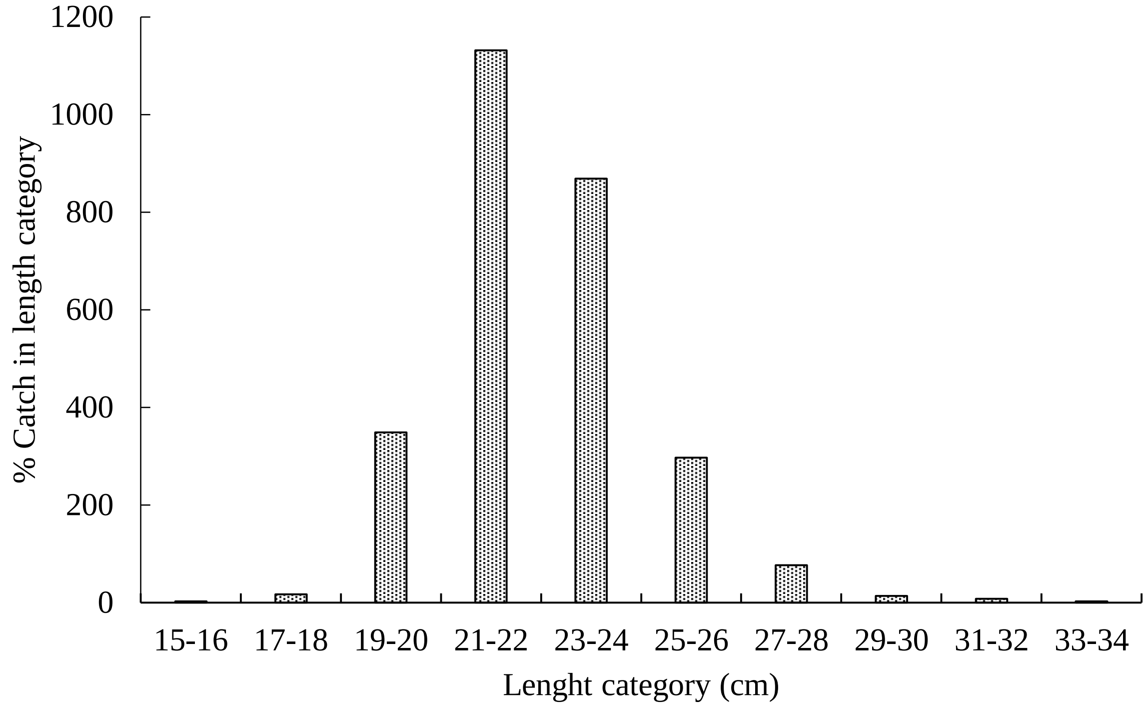

Figure 5: Length frequencies distribution of *O. niloticus baringoensis* in Lake Baringo between August 2013 and July 2014.

The *C. gariepinus* length in Lake Baringo ranged between 19 cm to 112 cm with corresponding weights that ranged between 120 grams and 7,500 grams. The length at first capture was $L_c = 18.22 \pm 3.31$ cm. Fishing mortality rate was observed to be high at mean length of 54.93 ± 15.25 cm (Fig 6) weighing 1,344.70 ± 1,238.10 grams. The mean value of growth parameters were $L_\infty = 114.3$ cm and $K = 0.37$ yr^{-1}.

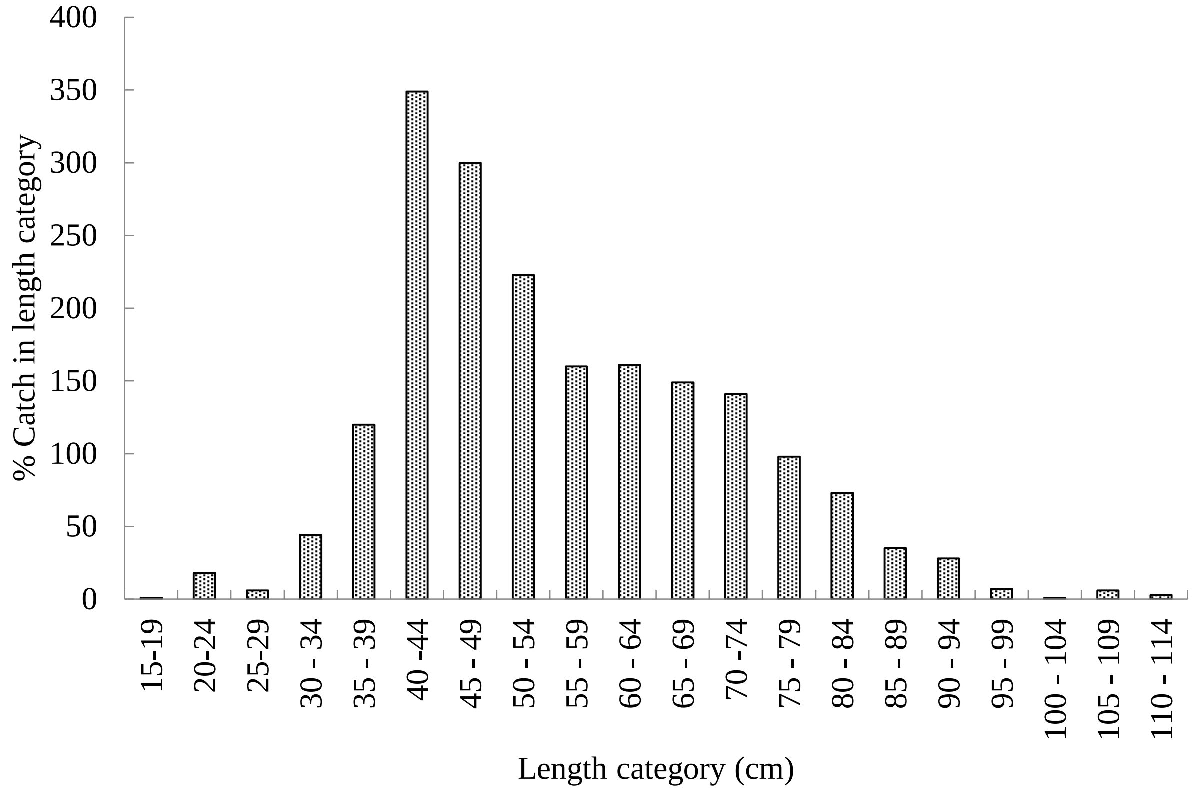

Figure 6: Length frequencies distribution of *C. gariepinus* in Lake Baringo from August 2013 to July 2014.

4.1.2 Length-weight relationship for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The fish length-weight relationship for *P. aethiopicus* gave $W = 0.0016L^{3.22}$ with a coefficient of determination (r^2) indicating that 85.72% of fish weight was explained by their total length (Fig. 7).

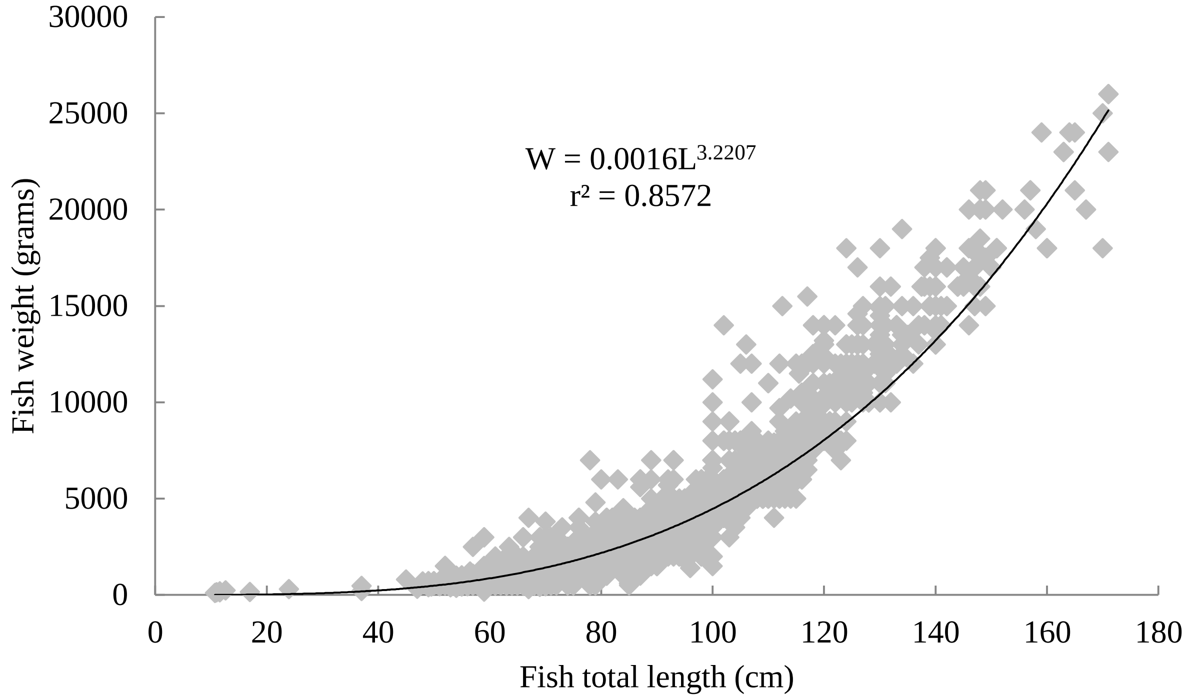

Figure 7: Length-weight relationship of *P. aethiopicus* in Lake Baringo between August 2013 and July 2014.

The length-weight relationship for *O. niloticus baringoensis* gave $W = 0.0575L^{2.62}$ (Fig. 8). The coefficient of determination show that variation in fish length explains 63.31% of variation in fish weight.

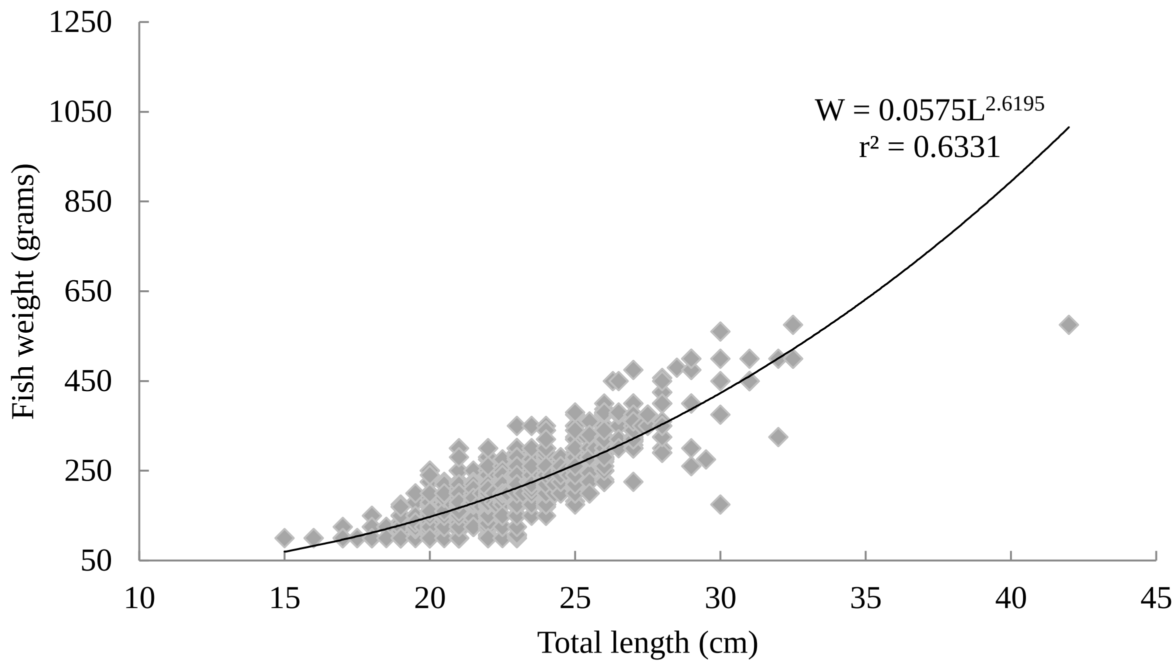

Figure 8: Length-weight relationship of *O. niloticus baringoensis* in Lake Baringo between August 2013 and July 2014.

Length-weight relationship function for *C. gariepinus* was $W = 0.0147L^{2.81}$ (Fig. 9) with a coefficient of determination (r^2) of 0.92 which mean that variation in fish weight was explained by 92.02% of variation in fish length.

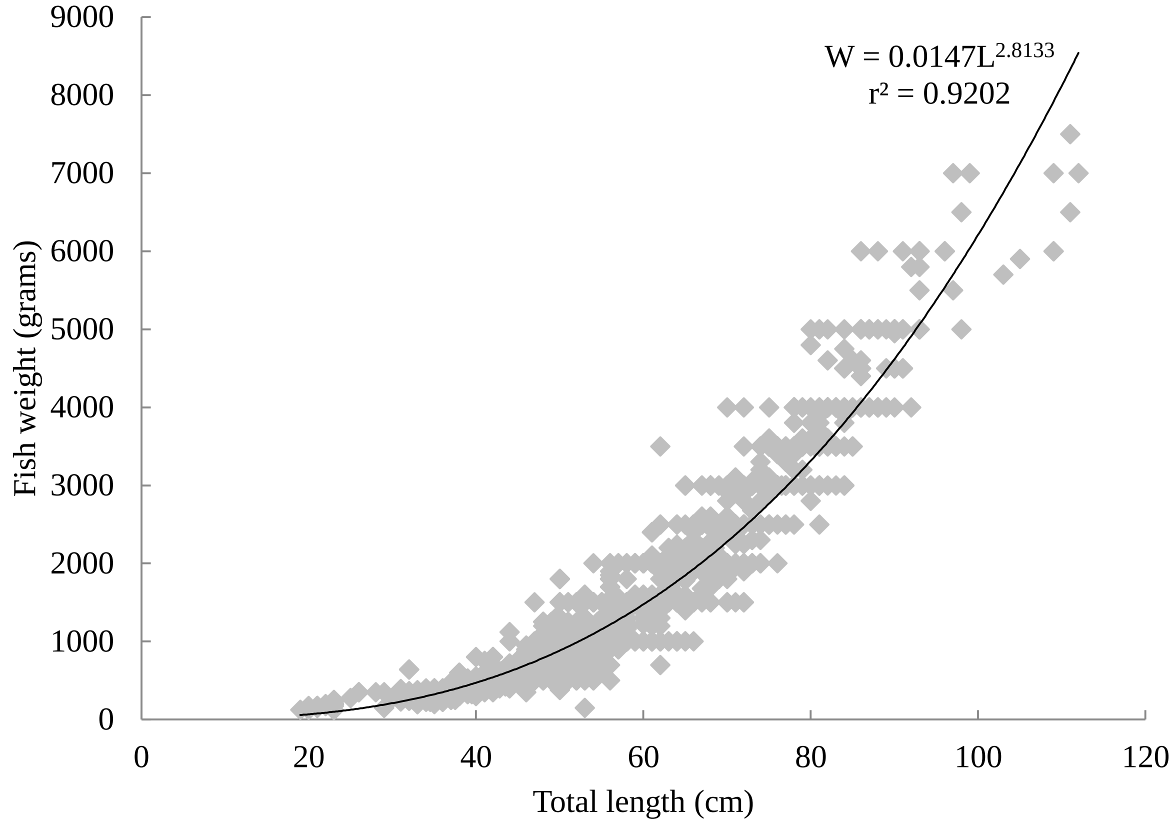

Figure 9: Length-weight relationship of *C. gariepinus* in Lake Baringo between August 2013 and July 2014.

4.1.3 Mortality and exploitation rates for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The *P. aethiopicus* values for instantaneous total mortality coefficient (Z), natural mortality coefficient (M) and fishing mortality coefficient (F) was $Z = 1.97\ yr^{-1}$, $M = 0.63\ yr^{-1}$ (at mean annual temperature of 25.5^{o}C) and $F = 1.34\ yr^{-1}$ respectively with 0.68 yr^{-1} exploitation rate (Fig. 10).

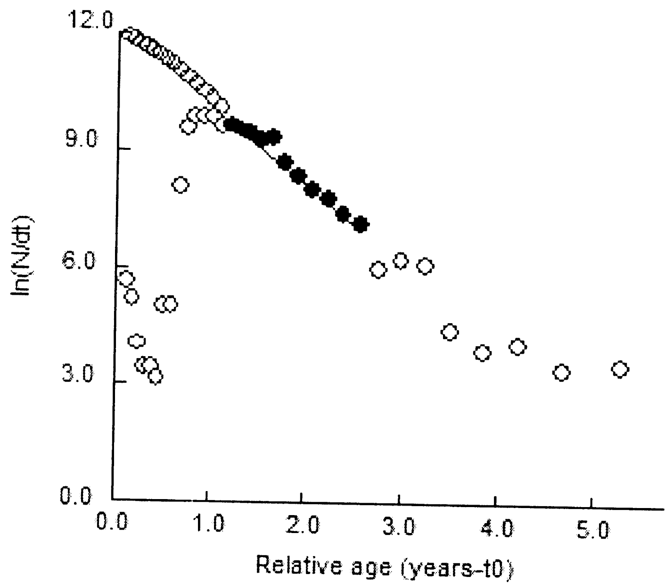

Figure 10: Length-converted catch curve for *P. aethiopicus* giving estimate of mortality coefficient.

The *O. niloticus baringoensis* instantaneous total mortality coefficient (Z) rate was 2.83 yr^{-1}. Annual natural mortality rate was 1.42 yr^{-1} (at mean annual temperature of 25.5°C) and fishing mortality (F) was F = 1.41 yr^{-1} with an exploitation rate of 0.50 yr^{-1} (Fig. 11).

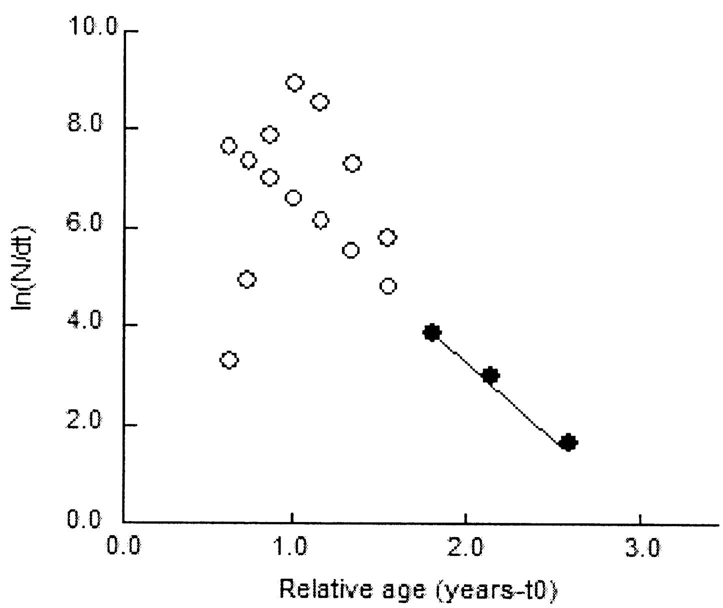

Figure 11: Length-converted catch curve for *O. niloticus baringoensis* giving estimate of mortality coefficient.

The *C gariepinus* instantaneous total mortality coefficient (Z) rate was 1.14 yr^{-1}. The annual natural mortality rate (M) was 0.61 yr^{-1} (at mean annual temperature of 25.5°C) while the annual fishing mortality rate was 0.53 yr^{-1} and an exploitation rate of 0.46 yr^{-1} (Fig. 12).

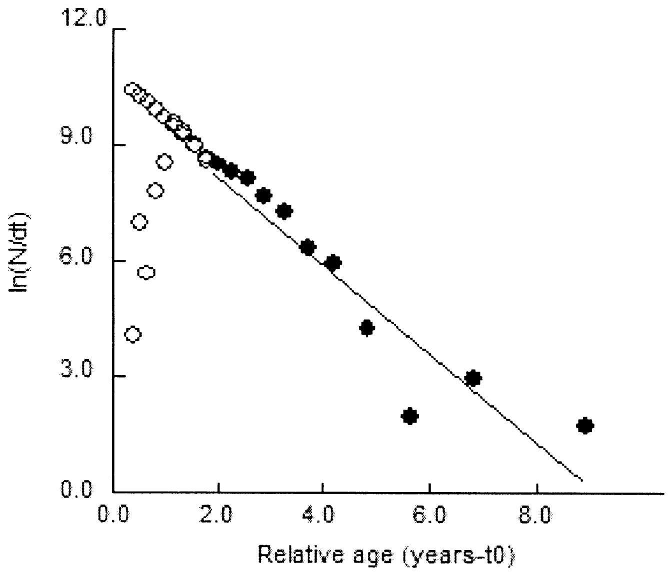

Figure 12: Length-converted catch curve for *C. gariepinus* giving estimate of mortality coefficient.

4.1.4 Steady state biomass of *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The steady state biomass of *P. aethiopicus* estimates was 474,779 kg. The total population, catch (in number), fishing mortality and steady state biomass per length class is presented in Fig. 13.

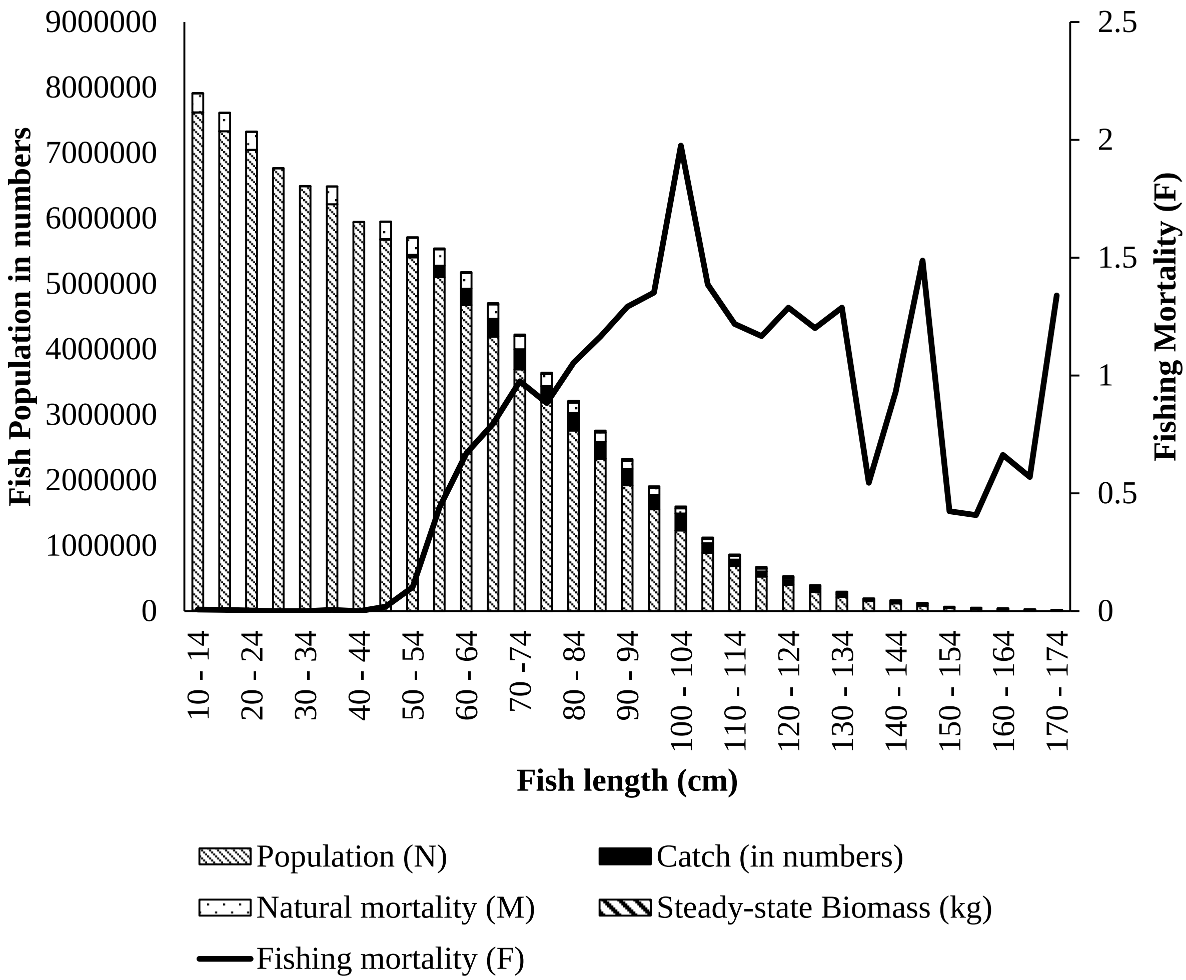

Figure 13: **Total population, catch (in number), natural mortality, fishing mortality and steady-state biomass (kg) per length class of *P. aethiopicus*.**

The steady state biomass of *O. niloticus baringoensis* estimates was 564 kg. The distribution of total population, catch (in number), fishing mortality and steady-state biomass per length class is as shown in Fig. 14.

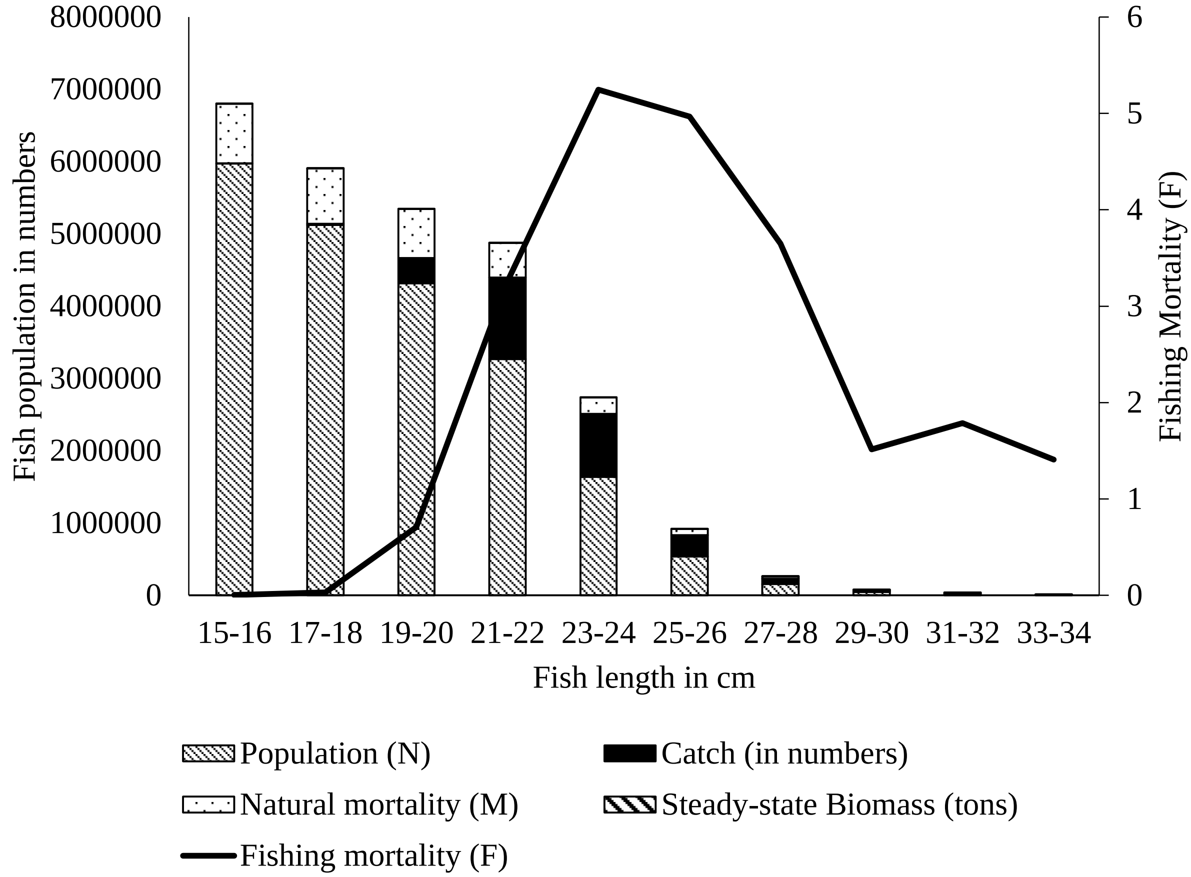

Figure 14: Total population, catch (in number), natural mortality, fishing mortality and steady state biomass (kg) per length class of *O. niloticus baringoensis*.

The steady state biomass of *C. gariepinus* was estimate at 21,383 kg. The total population, catch (in number), fishing mortality and steady state biomass (kg) per length class are presented in Fig. 15.

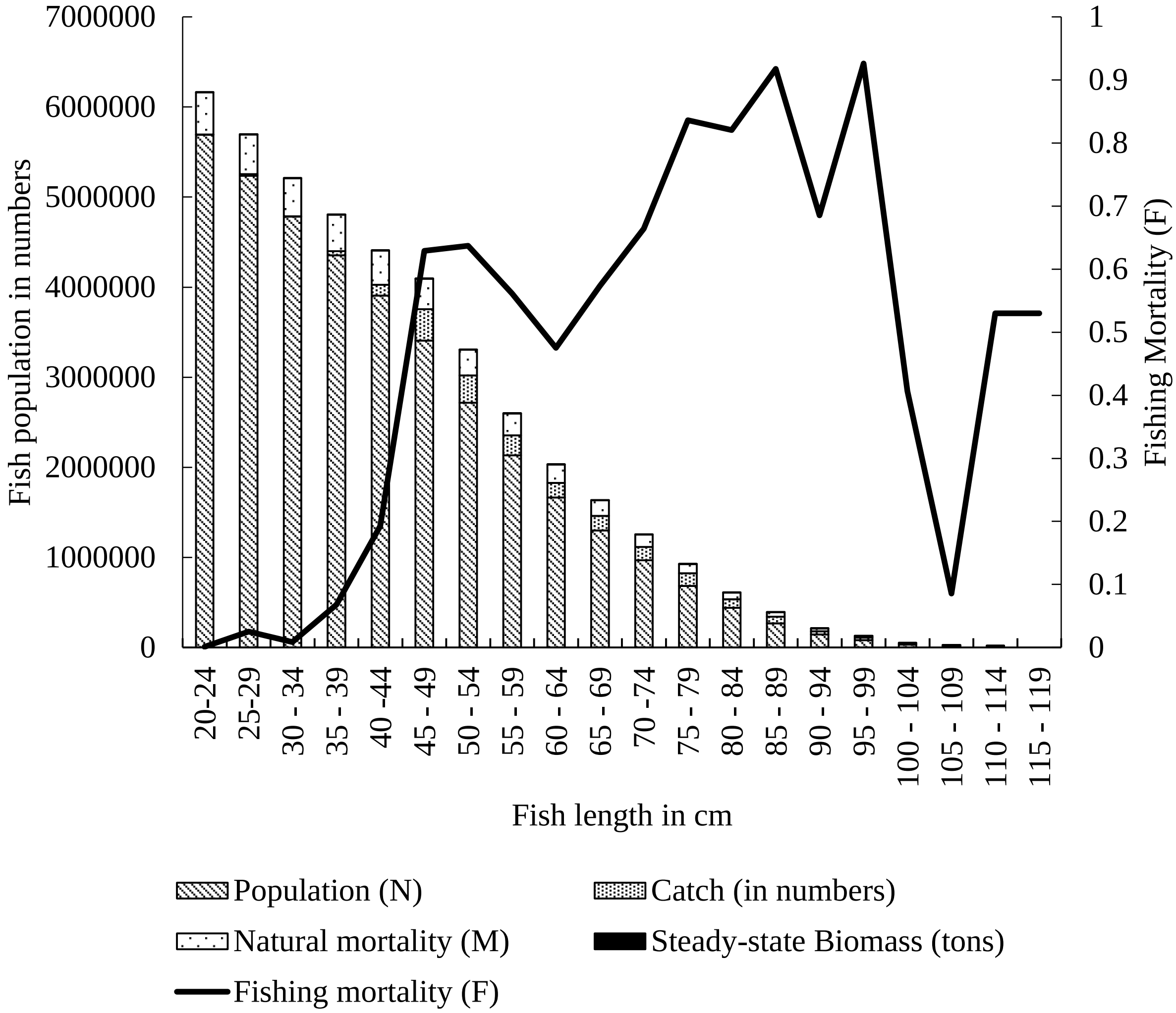

Figure 15: **Total population, catch (in number), natural mortality, fishing mortality and steady-state biomass (kg) per length class of *C. gariepinus*.**

4.1.5 Yield-Per-Recruit (Y'/R) and Biomass-Per-Recruit (B'/R) for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The Yield-Per-Recruit (Y'/R) and Biomass-Per-Recruit (B'/R) curve (Fig. 16) for different Exploitation rates (E_i) produced a E_{max} value from which F_{max} was calculated and in the case of *P. aethiopicus* the value of E_{max} and corresponding F_{max} value were computed. From the calculation, values of $E_{max} = 0.40$, $E_{0.1} = 0.32$ and $E_{0.5} = 0.26$ and fishing mortalities $F_{MSY} = 0.79$ yr^{-1}, $F_{0.1} = 0.63$ yr^{-1} and $F_{0.5} = 0.35$ yr^{-1} respectively.

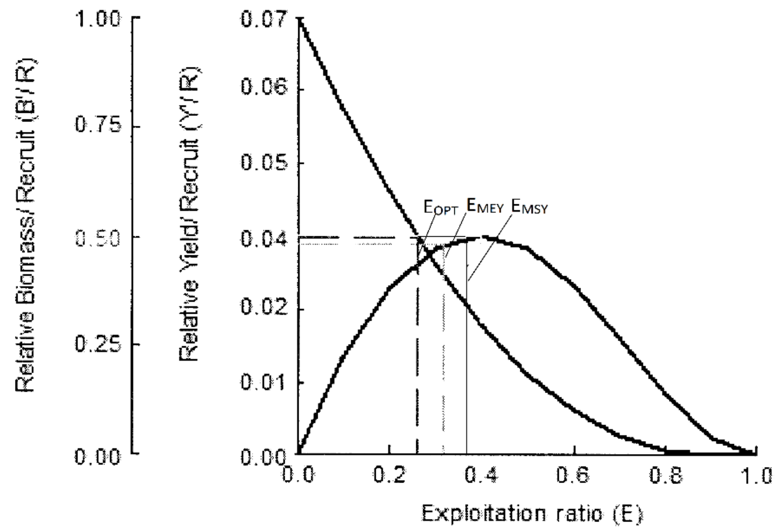

Figure 16: Yield-Per-Recruit and Relative-Biomass-Per-Recruit against *P. aethiopicus* exploitation ratio.

The Yield-Per-Recruit (Y'/R) and Biomass-Per-Recruit (B'/R) curve (Fig. 17) for different Exploitation rates (E_i) produced a E_{max} value from which F_{MSY} was calculated and in the case of *O. niloticus baringoensis* the value of E_{max} and corresponding F_{MSY} value were computed. This gave the values of $E_{max} = 0.55$, $E_{0.1} = 0.47$ and $E_{0.5} = 0.31$ with corresponding $F_{MSY} = 1.56\ yr^{-1}$, $F_{0.1} = 1.32\ yr^{-1}$ and $F_{0.5} = 0.44\ yr^{-1}$ respectively.

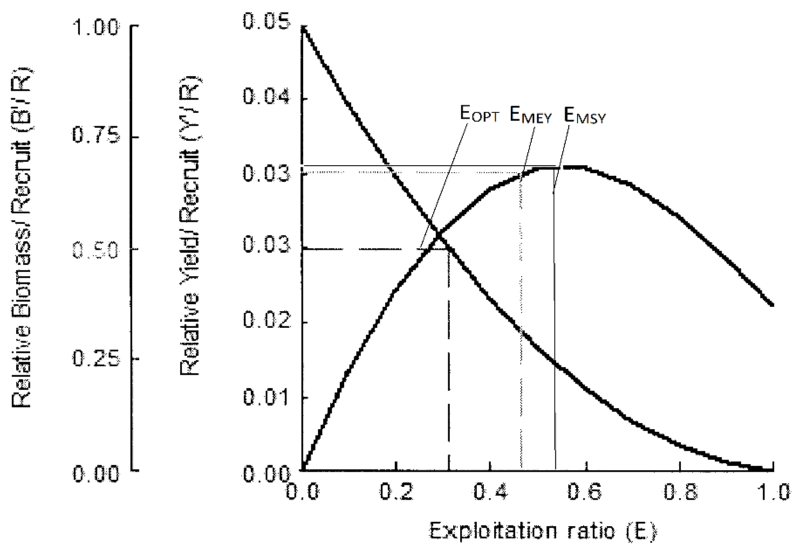

Figure 17: Yield-per-Recruit and Relative-Biomass-per-Recruit against *O. niloticus baringoensis* exploitation ratio.

The Yield-Per-Recruit (Y'/R) and Biomass-Per-Recruit (B'/R) curve (Fig. 18) for different Exploitation rates (E_i) produced a E_{max} value from which F_{MSY} was calculated and in the case of *C. gariepinus* the value of E_{max} and corresponding F_{MSY} value were computed. From the calculation, the values of $E_{max} = 0.44$, $E_{0.1} = 0.36$ and $E_{0.5} = 0.27$. Relative Yield-Per-Recruit (Y'/R) and Biomass-Per-Recruit (B'/R) for *C. gariepinus* computations gave $F_{MSY} = 0.50\ yr^{-1}$, $F_{0.1} = 0.41\ yr^{-1}$ and $F_{0.5} = 0.14\ yr^{-1}$ respectively.

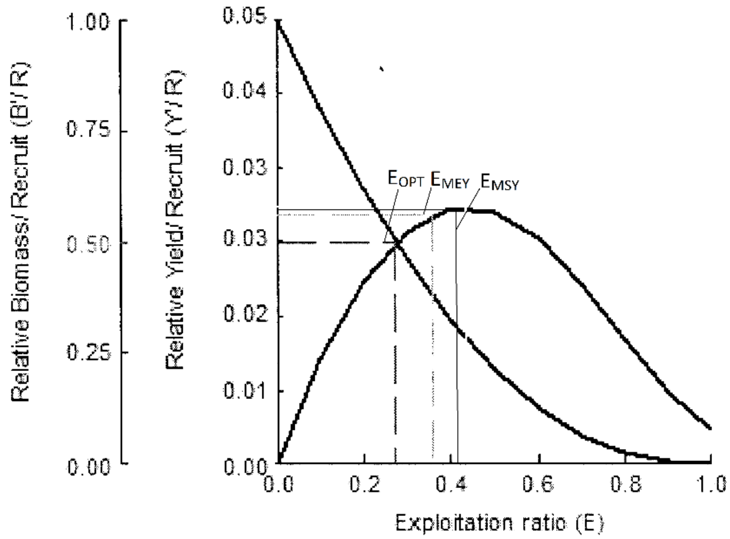

Figure 18: Yield-per-Recruit, Relative-Biomass-per-Recruit against *C. gariepinus* exploitation ratio.

4.2 Optimal fishing scenario for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The yield per recruit analyses gave the following maximum sustainable yield, spawning stock biomass and fishable biomass with respective fishing mortality for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*.

The yield-per-recruit ratio at maximum sustainable yield for *P. aethiopicus* was 11.80% steady state biomass (B_{CURR}) at F_{MSY} 0.5. This is relative to SSB_{MSY} per recruit ratio was 21.82%, Fishable Biomass-per-recruit of 23.59% and MSY of 237,389.49 kg. The current yield-per-recruit ratio is at 9.05% with relative SSB_{CURR} per recruit ratio of 5.46% and Fishable Biomass per recruit ratio of 6.96% at F_{CURR} 1.34 current fishing mortality (Fig. 19).

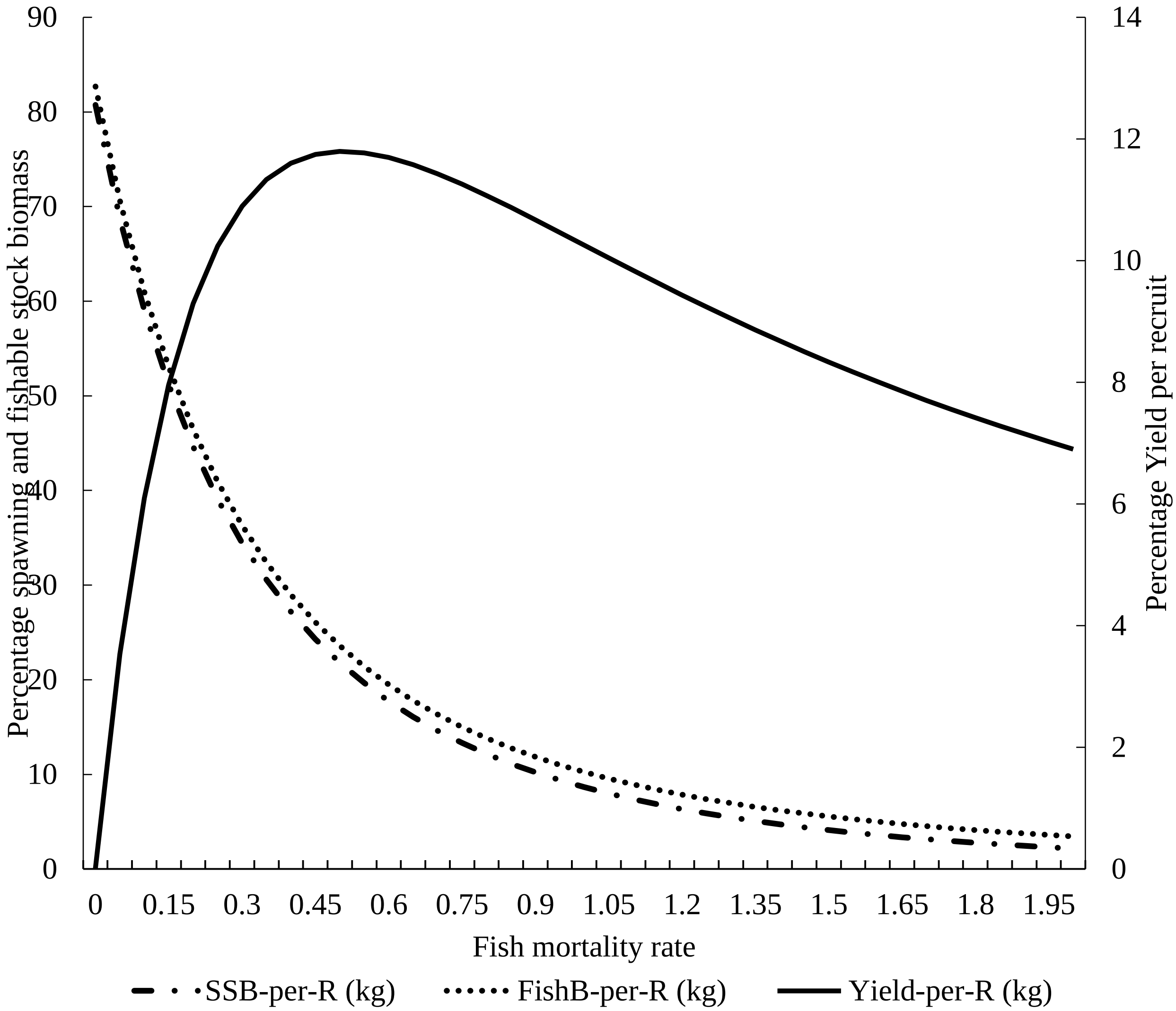

Figure 19: Spawning, fishable biomass ratios and yield per recruit ratio verses fish mortality rate for *P. aethiopicus* in Lake Baringo.

The yield-per-recruit ratio at maximum sustainable yield for *O. niloticus baringoensis* was 2.46% steady state biomass (B_{CURR}) at F_{MSY} = 0.8. This is relative to SSB_{MSY} per recruit ratio = 3.08% and Fishable Biomass per recruit ratio of 3.08% and a MSY of 451 kg. The current yield-per-recruit ratio is at 2.05% with relative SSB_{CURR} per recruit ratio of 1.46% and Fishable Biomass per recruit ration of 1.46% at F_{CURR} 1.41 current fishing mortality (Fig. 20).

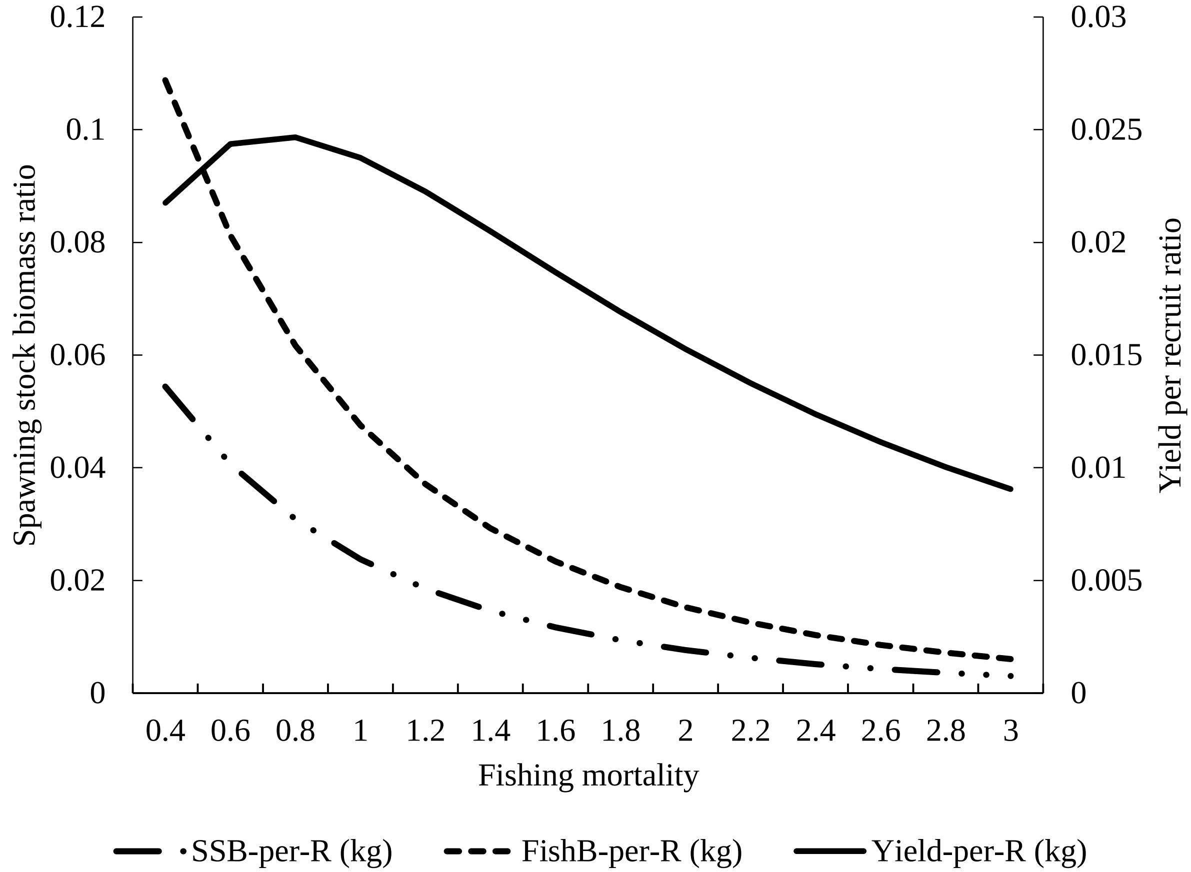

Figure 20: Spawning, fishable biomass ratios and yield per recruit ratio verses fish mortality rate for *O. niloticus baringoensis* in Lake Baringo.

The yield-per-recruit ratio at maximum sustainable yield for *C. gariepinus* was 29.12 % steady state biomass (B_{CURR}) at F_{MSY} = 0.5. This is relative to SSB_{MSY} per recruit ratio = 56.10% and Fishable Biomass per recruit ratio of 58.23% at MSY of 10,692 kg. The current yield-per-recruit ratio, SSB_{CURR}, Fishable Biomass per recruit ratio and F_{CURR} 0.53 were the equal with the reference MSY (Fig. 21).

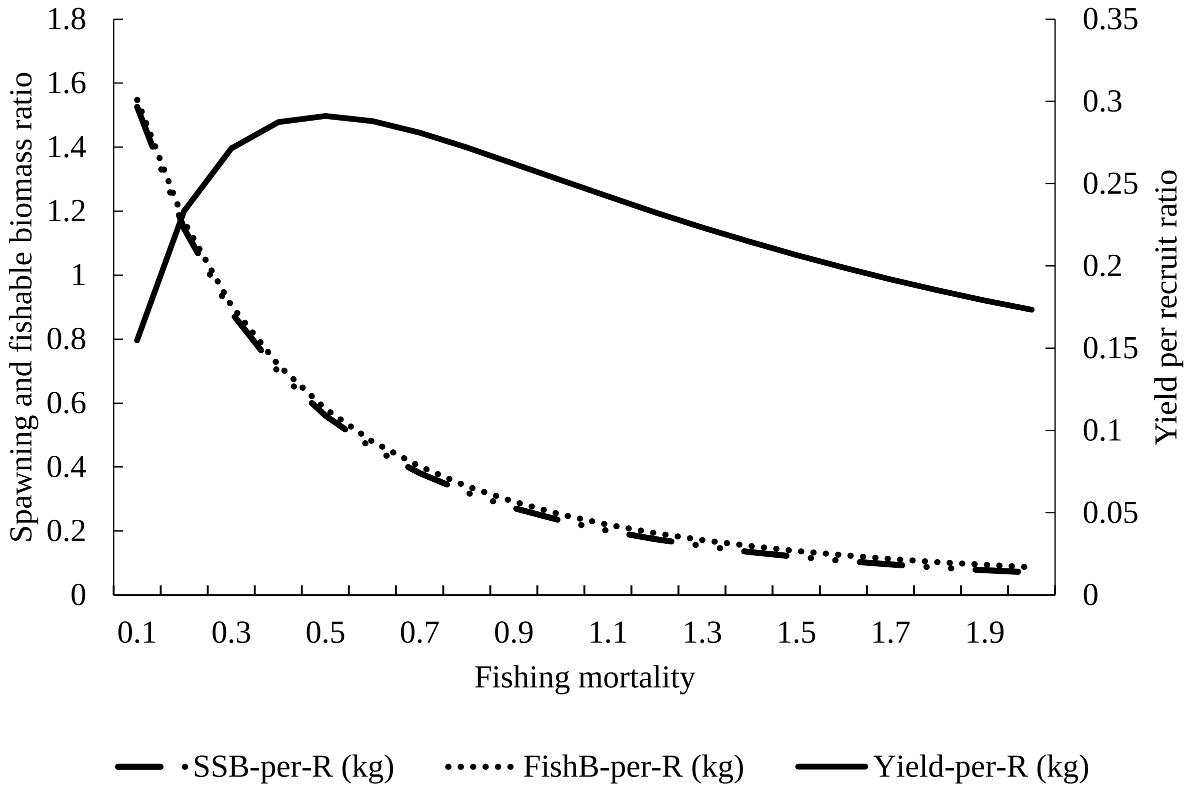

Figure 21: Spawning, fishable biomass ratios and yield per recruit ratio verses fish mortality rate for *C. gariepinus* in Lake Baringo.

4.3 Gear selectivity for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

The gear selectivity indicating the probability of captures results for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus* was computed. The gears used by fishermen captured 25% of all fish attaining 54.88 cm according to logistic gear selection model. Another 50% of all fish attaining 63.48 cm were captured while gears also selected 75% of the fish attaining 74.77 cm (Fig. 22).

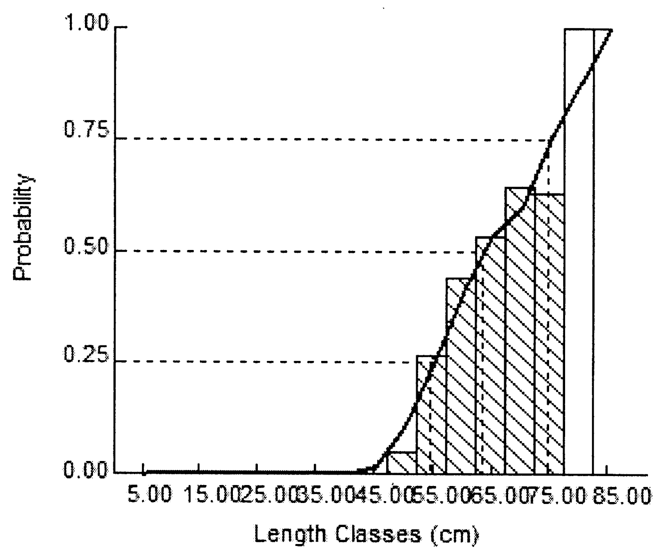

Figure 22: Logistic selection curve for *P. aethiopicus* in Lake Baringo.

The logistic selection curve indicated that 25% of *O. niloticus baringoensis* were selected at 14.75 cm by fishing gears. Another 50% of all the fish were selected at 15.57 cm. A total of 75% of all fish attain 16.39 cm by were selected (Fig. 23).

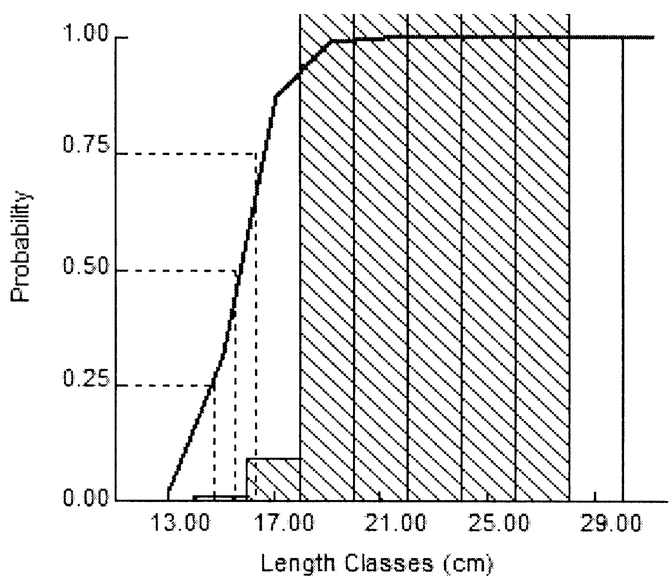

Figure 23: Probability of capture for *O. niloticus baringoensis* in Lake Baringo.

A total of 25% of *C. gariepinus* attaining 31.48 cm were selected by fishing gears in Lake Baringo. The gears selected another 50% of all fish attaining 35.08 cm. The logistic selection curve further suggests that the gears selected 75% of all fish attaining 38.89 cm in the ecosystem (Fig. 24).

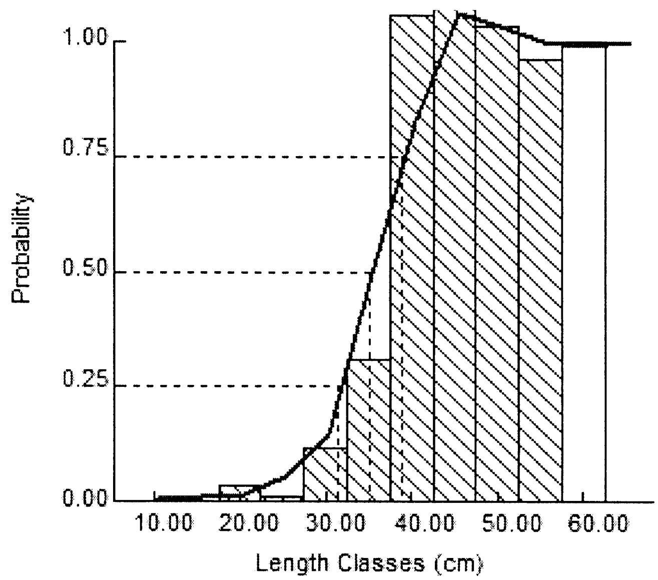

Figure 24: Probability of capture for *C. gariepinus* in Lake Baringo.

4.4 Socio-economics dynamics of Lake Baringo Fisheries

The socio-economic characterization of Lake Baringo Fisheries was done for the fishermen and fish traders. The Fishermen age and gender distribution, education level, economic activity, purpose of fishing, and fishing gears usage attributes in Lake Baringo are detailed below.

4.4.1 Fishermen socio-economics dynamics

A higher percentage (38%) of fishermen age ranged between 19 and 30 years. These were followed by ages 31 - 50 years (33%) and above 50 years (26%) as shown in Fig. 25. Male fishers constituted 93% while female fishers constituted 7%. Age distribution among Lake Baringo fishers had significant difference ($0.02 \leq p < 0.05$).

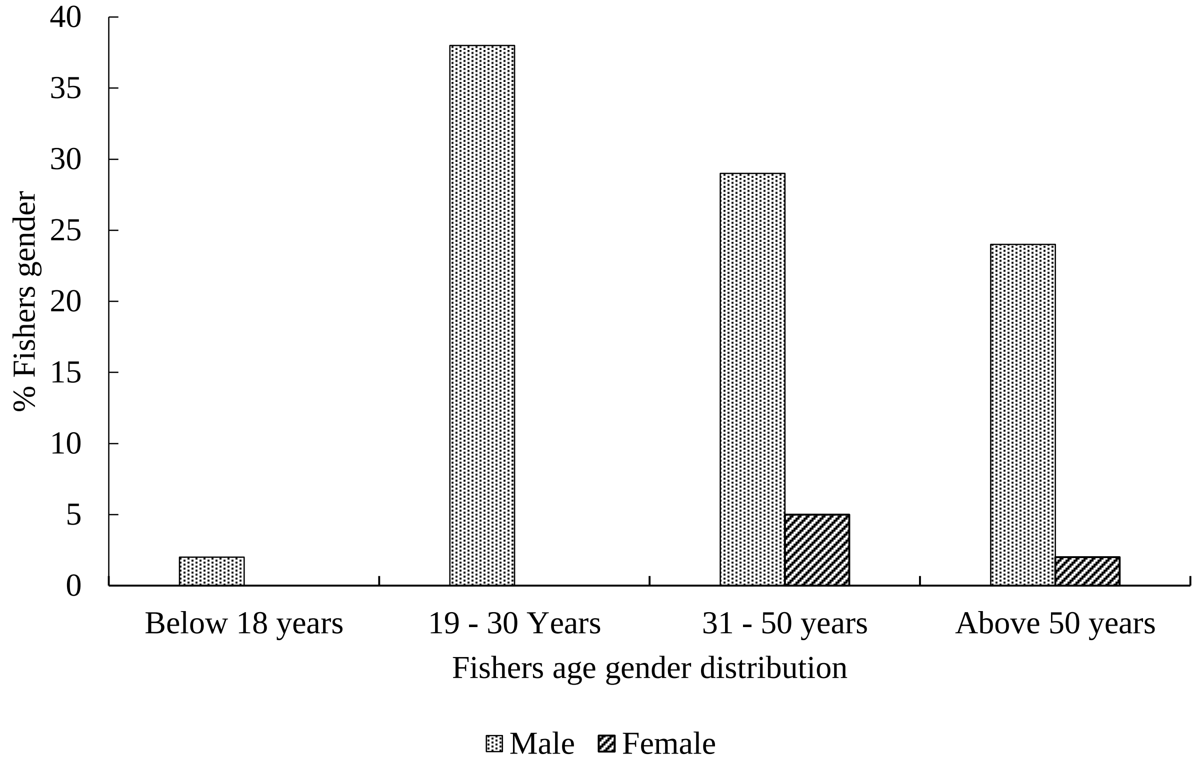

Figure 25: Fishermen age and gender distribution in Lake Baringo.

Majority (43%) of Lake Baringo fishermen had secondary school education. 33% fishermen had primary school education while 2% had university education. A total of 21% of fishers had no basic education. Fishermen ages ranging 19 – 30 years composed a high percentage (36%) with primary and secondary education (Fig. 26). Fishermen with ages 31 – 50 years (24%) and above 50 years (15%) respectively followed. Only 2% of fishermen had university education and fished for hobby once per week while catching fish for domestic consumption.

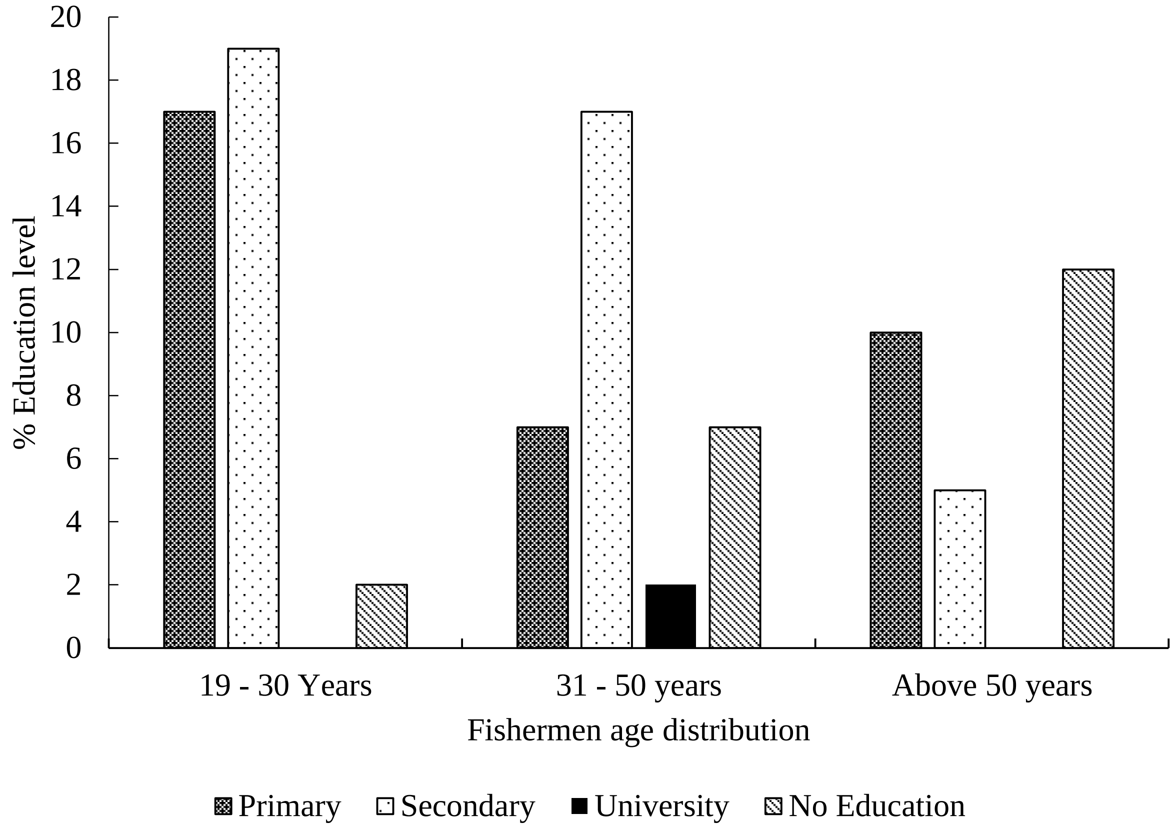

Figure 26: Education levels of fishers in Lake Baringo.

It was found that the fishermen education level had a significant difference ($0.01 \leq p < 0.05$).

A mean of 22.33% fishermen among all age groups depended on fishing as their economic activity. Another 10.67% fishermen among all the age groups depended on fishing and other economic activity as source of their livelihood (Fig. 27). The other economic activities fishermen practiced along Lake Baringo included selling of charcoal, livestock farming, honey trade, selling of second hand clothes and grocery shops.

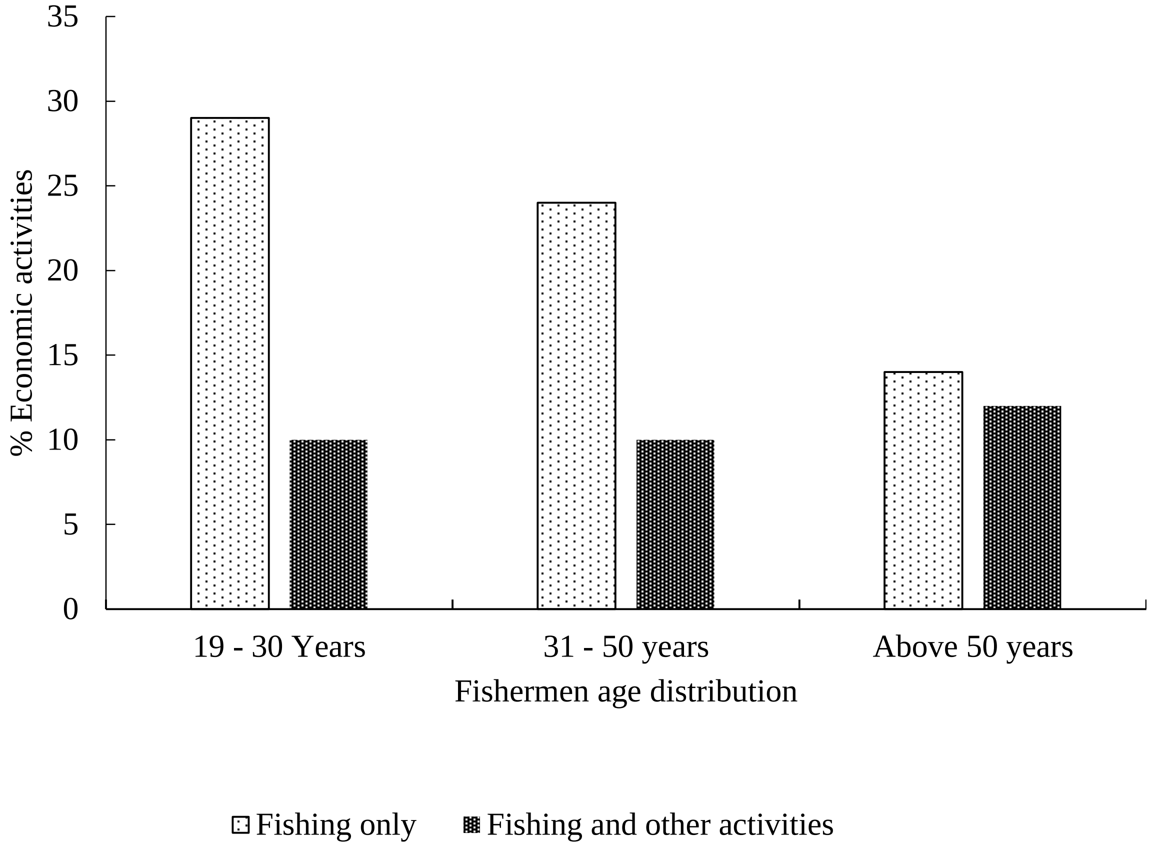

Figure 27: Fishermen economic activities in Lake Baringo.

The fishermen dependence on fishing and other economic activities with respect to age advancement was found to have significant difference ($0.01 \leq p < 0.05$).

A mean of 22.00 ± 11.14 fishermen practiced fishing for subsistence use while only a mean of 11.33 ± 5.13 fished for commercial purpose. It was observed that there was a high dependence to fishing for subsistence use at ages between 19 – 30 years of fishers. It was also noted that the fishermen purpose for fishing between subsistence and commercial purposes had significant difference ($0.021 \leq p < 0.05$). The dependence of fishing for subsistence use reduced as fishermen age advanced towards above 50 years (Fig. 28).

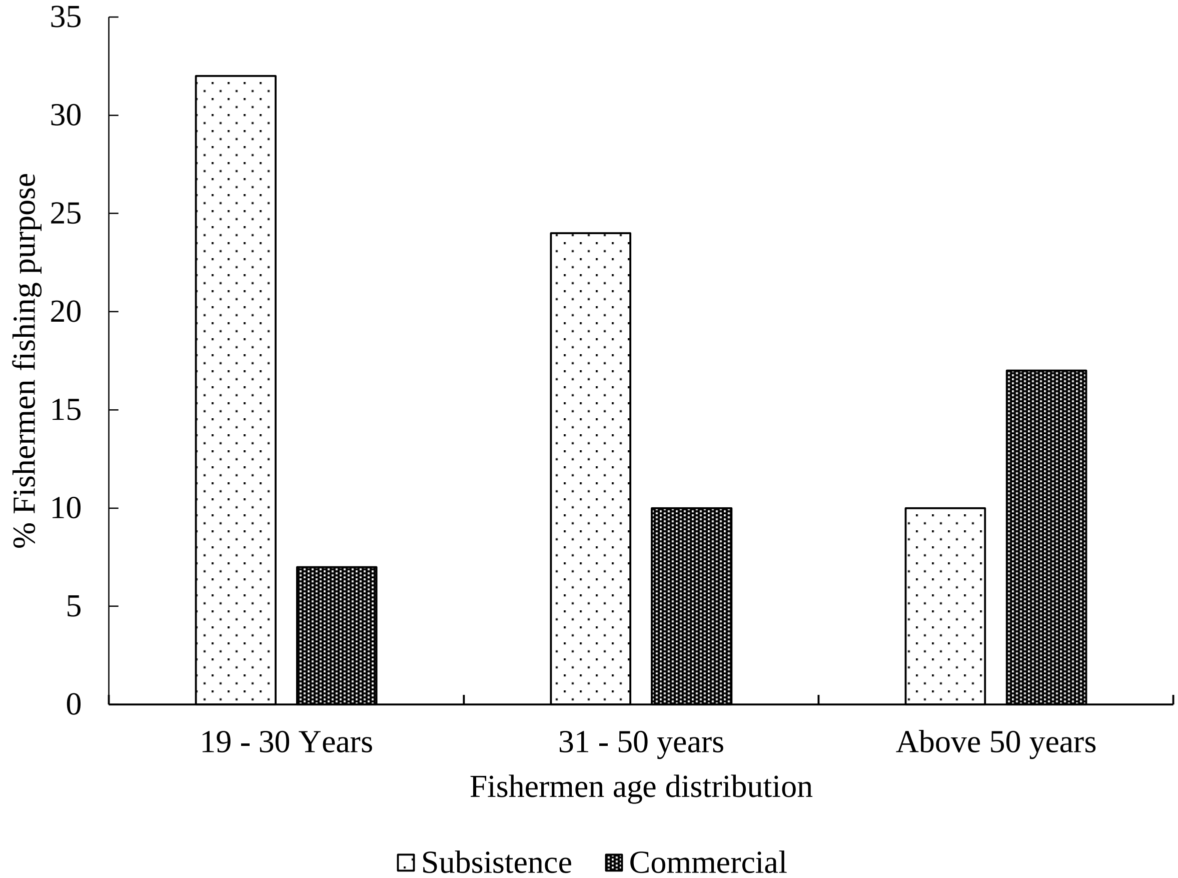

Figure 28: Fishermen purpose for fishing in Lake Baringo.

Lake Baringo fishermen preferred nets (71%) and hooks (29%) for their daily fishing exercise. Fishing nets were used to catch *O. niloticus baringoensis* and hooks used to catch *P. aethiopicus* and *C. gariepinus*. Preference of fishing gears was found to be relative to fishermen age. Fishing nets were the most preferred gear (29%) among 19 – 30 years fishers. It was observed that fishing nets usage decreased gradually with fishermen age increase (Fig. 29). Fishing hooks were the most used gear (12%) by fishers aged 31 - 50 years. Fishers followed these at ages 19 – 30 years (10%) and above 50 years (7%).

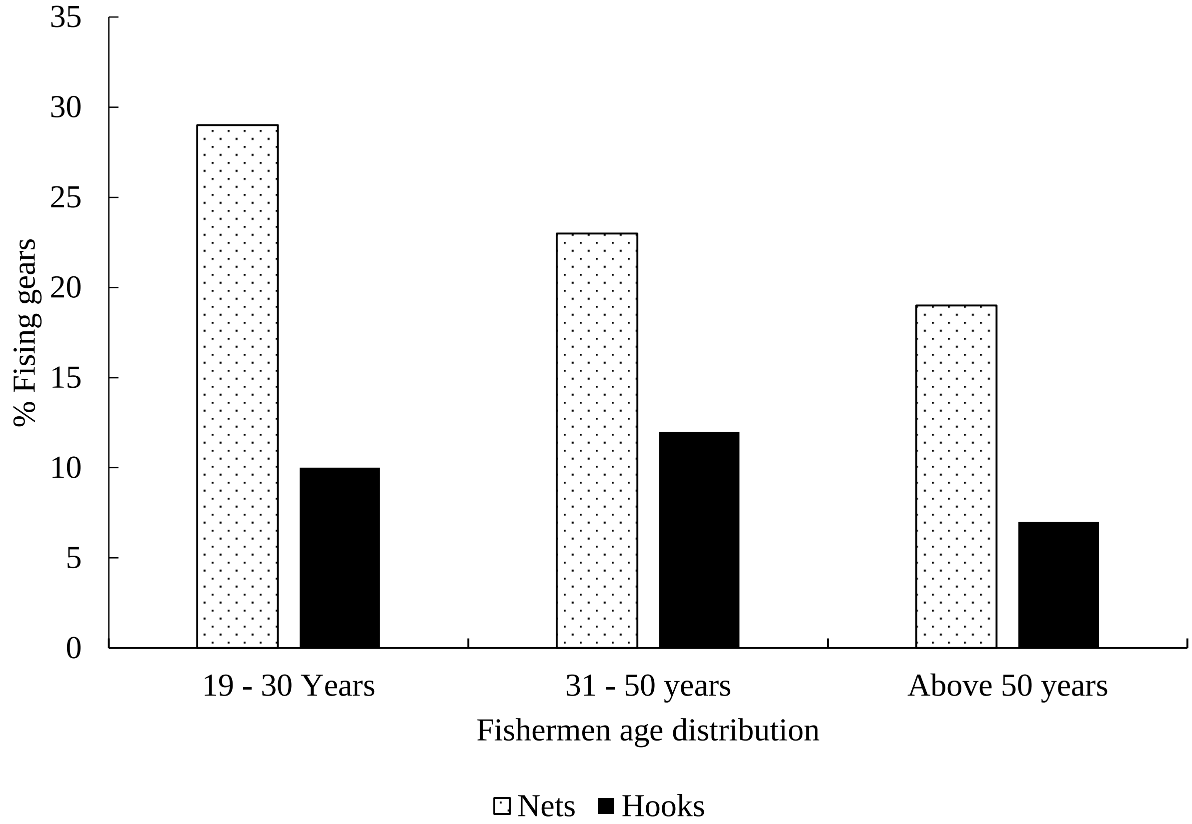

Figure 29: Fishing gears usage in Lake Baringo.

It was found that the fishermen usage of fishing nets and hooks with age advancement had significant difference ($0.01 \leq p < 0.05$).

4.4.2 Fish trader's socio-economic dynamics

The fish trader's education level, daily fish quantities marketed, fish species market share and fish processing methods are shown below.

Females who comprised 82% dominated the fish trade. Males who composed 18% followed the female in the trade. Majority of traders (21.50%) had primary school education. These were followed by secondary school education (13.50%) and university education (1.50%) respectively. A total of 13.50% were found to possess no basic education (Fig. 30).

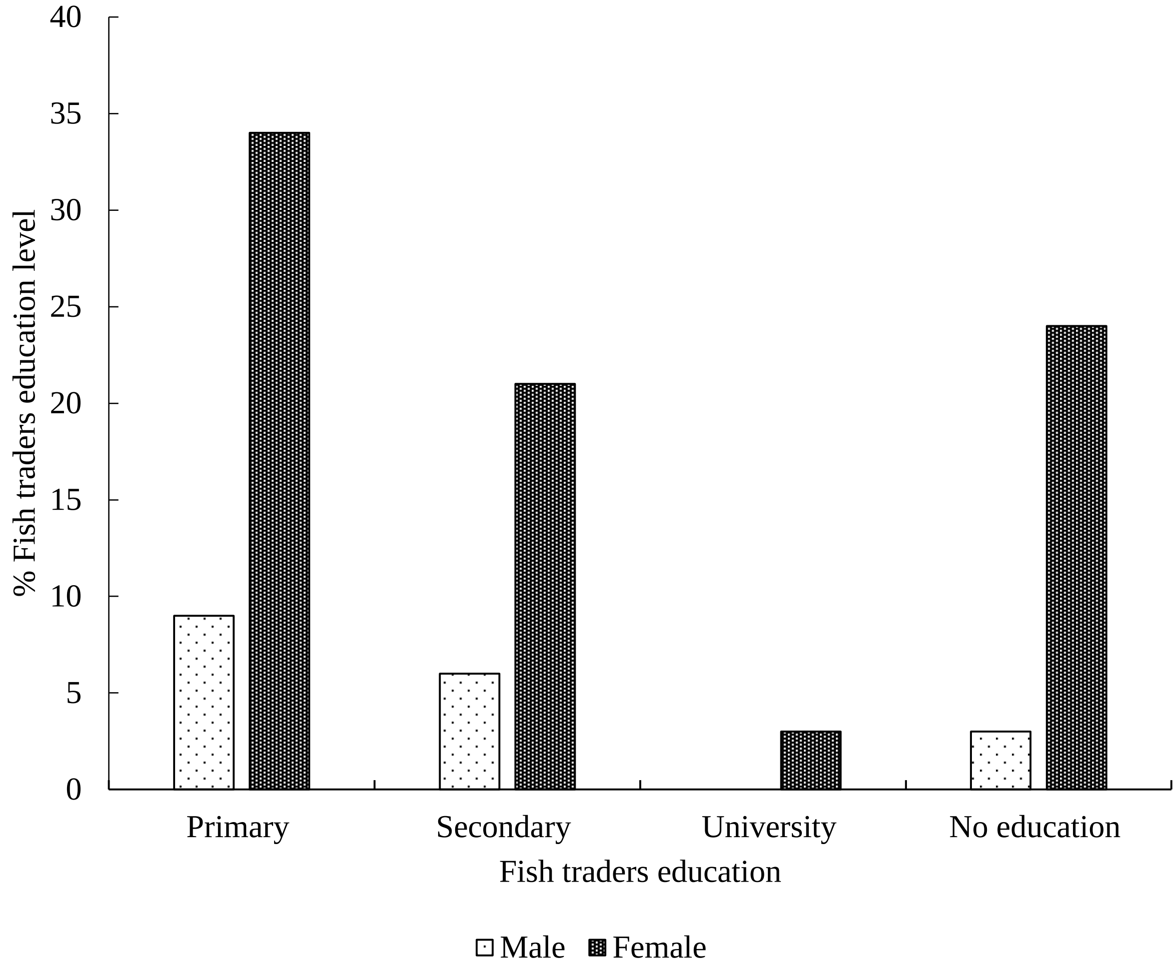

Figure 30: Fish trader's education levels in Lake Baringo.

Education level had no significant difference ($0.54 \leq p > 0.05$) between fish traders.

Majority of fish traders (15.50%) in the lake traded with fish weight below 35 Kilograms per day. 15.00% traders (36 – 70 Kgs), 10.50% traders (71 – 105 Kgs) and 9.00% traders (over 105 Kgs) respectively followed (Fig. 31).

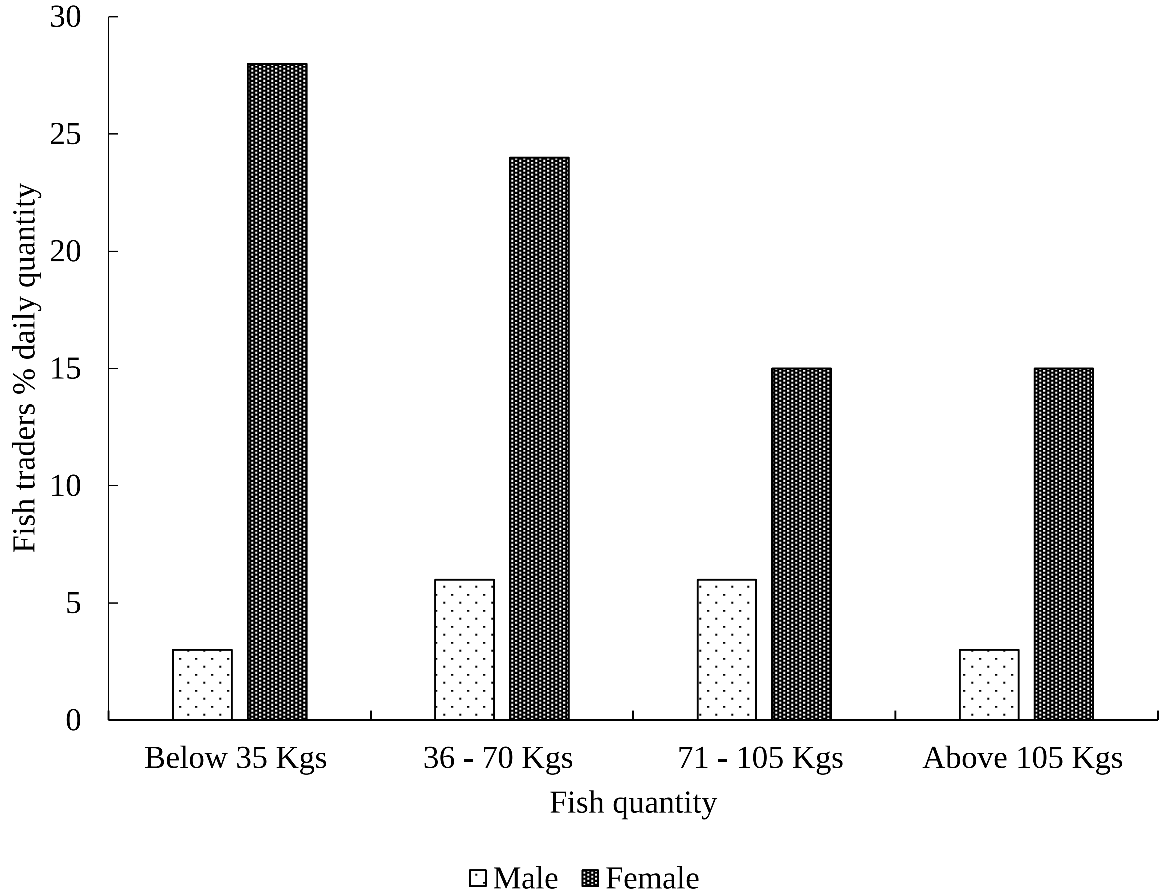

Figure 31: Fish trader's percentage daily quantity traded.

It was found that the quantity of fish traded had no significant difference ($0.93 \leq p > 0.05$) between the fish traders.

The most traded fish was *C. gariepinus* (36%) followed by *O. niloticus baringoensis* (34%) and *P. aethiopicus* (30%). The local market consumed 61% of all fish marketed while a total of 39% was marketed externally in Lake Baringo environs and distant markets. The most preferred fish species for the local market was *O. niloticus baringoensis* (46%). This was followed by *P. aethiopicus* (34%) and *C. gariepinus* (20%) respectively (Fig. 32).

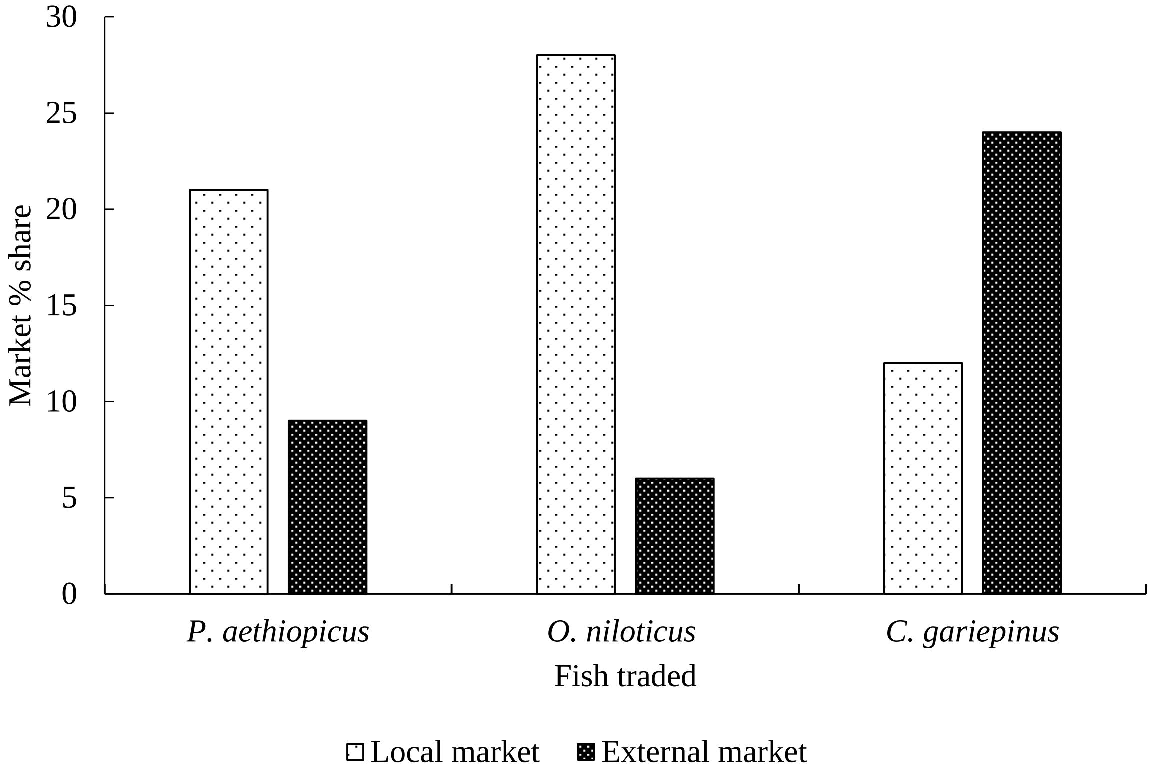

Figure 32: Fish marketing trends from Lake Baringo.

There was no significant difference ($0.37 \leq p > 0.05$) between local market and external markets.

Fish processing methods in Lake Baringo included deep-frying, refrigeration, smoking and sun drying. Deep-frying was mostly used for *O. niloticus baringoensis* while refrigeration, smoking and sun drying were mainly used for *P. aethiopicus* and *C. gariepinus* (Fig. 33). Smoking was the most preferred fish processing method accounting 40% of all fish processed. This was followed by refrigeration (35%), deep-frying (13%) and sun drying (12%) respectively.

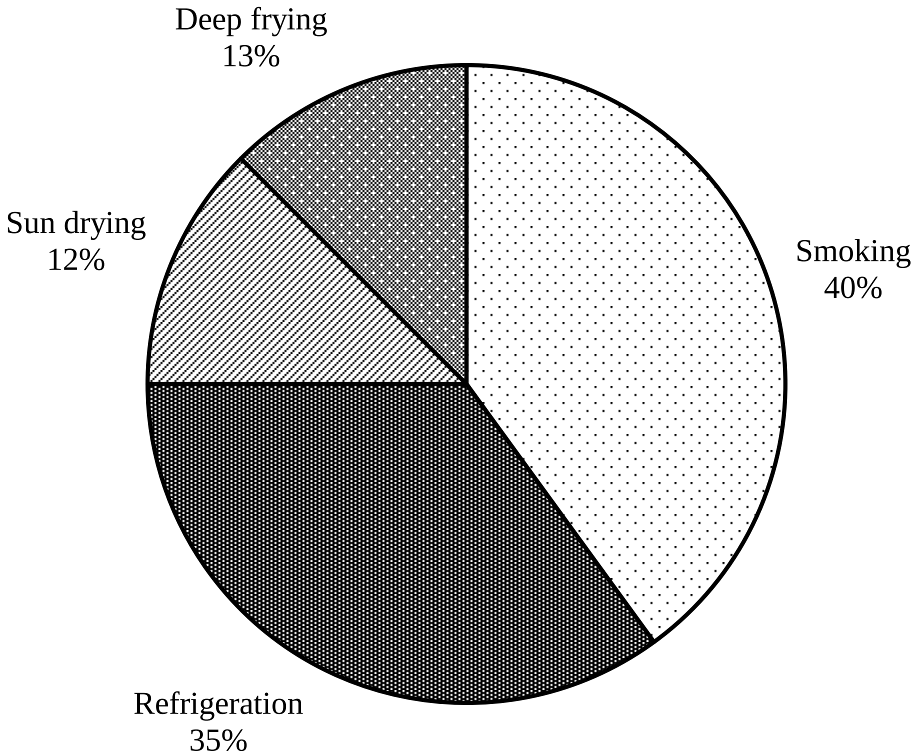

Figure 33: Fish preservation methods in Lake Baringo.

CHAPTER FIVE

DISCUSSION

5.1 Biological Reference Points for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

A relationship between various BRPs used to define thresholds and targets of fisheries management strategies gives a range of combinations of life history characteristics of fisheries (Mace, 1994). The BRPs for Lake Baringo shows overfishing for *P. aethiopicus* while *O. niloticus baringoensis* and *C. gariepinus* shows congenial fisheries. The growth parameters for *P. aethiopicus* show a lesser population growth probably due to fishing pressure and environmental parameters during the fish life history. The growth constant (K) for *P. aethiopicus* was less than 1.08 yr^{-1} reported in the same lake (Kembenya *et al.*, 2014). The fish length-weigh relationship indicated that the fish had isometric growth. The variation in annual environmental changes attributed to rainfall patterns (Ngaira, 2006) may have contributed to variations in the fish population growth parameters.

Length-weight relationship shows isometric growth of *O. niloticus baringoensis*. The asymptotic length of *O. niloticus baringoensis* in the lake was less than 44.5 cm reported by Tesfaye and Wolf (2015) at Lake Koka in Ethiopia and 55.59 cm reported by Ahmed *et al.* (2003) in Kaptai reservoir, Bangladesh. *O. niloticus baringoensis* in Lake Baringo is a genetically and morphologically distinct sub-species of *O. niloticus baringoensis* (Britton *et al*., 2009). This combined with variations in environmental parameters (Britton *et al*., 2009; Ngaira, 2006) in the lake could account for the low asymptotic length. The total mortality may also not be allowing fish population indefinite growth. On the other hand, the fish growth coefficient was higher than 0.41 yr^{-1} (Tesfaye and Wolf, 2015) and 0.39 yr^{-1} (Ahmed *et al.* (2003). This expressed that *O. niloticus baringoensis* fast approached asymptotic length within a year to compensate growth in an adverse ecosystem.

Length-weight relationship for *C. gariepinus* show isometric growth. However, the fish asymptotic length and growth coefficient were low in comparison to total length of 121 cm and growth constant 0.16 yr^{-1} reported by Tesfaye and Wolff (2015). The low asymptotic length and growth coefficient was probably due the reported adverse environmental factors in the lake. This may have resulted to a high growth rate at which the fish approached asymptotic length.

Length structured virtual population analyses of *P. aethiopicus* in Lake Baringo shows that the current exploitation rate is higher than optimum and economic rates ($E = 0.68 > E_{max} = 0.40\ yr^{-1}$). This indicates that the fish population is experiencing growth overfishing where total yield is decreasing with additional fishing effort. The fishing mortality exceeds the fishing mortality at maximum sustainable yield justifying *P. aethiopicus* stock growth overfishing. This scenario results to more fish caught before they could grow to a sufficiently large size and substantially contribute to the total biomass. The remedy for growth overfishing would be to reduce the current fishing mortality by 41.04% to attain sustainable fishing mortality and achieve exploitation rate that produces maximum yield. This can be achieved through control of fishing effort including the number of hooks and line, the number of fishermen and attempt elimination of illegal fishers that could be in the lake.

Results from length structured virtual population analyses of *O. niloticus baringoensis* in the lake indicates that the current fish exploitation rate is 10.64% below the maximum exploitation rate ($E = 0.50 < E_{max} = 0.55\ yr^{-1}$). This explained amiable fishing mortality below maximum sustainable yield where the fishable stock fishing mortality was pertinent. The current fishing mortality was below the fishing mortality at maximum sustainable yield justifying limited evidence of *O. niloticus baringoensis* stock growth overfishing. Less fish were caught before they could grow to a sufficiently large size to substantially contribute to the total biomass. The steady state of fish yield should be maintained at the current exploitation rate to further allow sufficiently large size of fish population to substantially contribute to the total biomass.

Length structured virtual population analyses for *C. gariepinus* in the lake indicates that the fish exploitation rate is almost equal to maximum sustainable exploitation rate. This shows *C. gariepinus* population utilization is at congenial state in the lake where the total yield is at par with fishing effort. The current fishing mortality that is equal to the fishing mortality at maximum sustainable yield further explains this. The steady state of fish yield should be maintained at the current exploitation rate or below to allow sufficiently large size of fish population to substantially contribute to the total biomass.

5.2 Optimum fishing scenarios for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus*

Maximum sustainable yield for *P. aethiopicus* and *O. niloticus baringoensis* was not attainable at the current fish mortality rate. Further, the spawner stock biomass-per-recruit (SSB/R) was below threshold for pristine condition for the two fish species. The recommended SSB/R lie between 25% and 50% of unexploited stocks (Kanyerere 2003; Punt and Hilborn 1997). Mace (1994) and Clark (1991) suggest that recruitment overfishing occurs when the relative SSB/R is reduced to less than 20-30% of the un-fished stock. It was therefore concluded that *P. aethiopicus* and *O. niloticus baringoensis* are experiencing recruitment overfishing at the current mortality rates in Lake Baringo.

The Beverton and Holt yield-per-recruit (Y/R) and average biomass-per-recruit (B/R) model indicated growth overfishing of *P. aethiopicus.* The Branch *et al.* (2000) yield model showed recruitment overfishing for both *P. aethiopicus* and *O. niloticus baringoensis*. This indicated that the two fish species are generally overfished necessitating controls of the F_{CURR} towards F_{MSY} and other regulatory measures based on the life history of these fish in the lake.

The yield-per-recruit analyses for *C. gariepinus* indicates that the current spawning stock biomass-per-recruit over and above the recommended ratio. This indicated that *C. gariepinus* spawner stock biomass-per-recruit is congenially reduced from its pristine level with limited recruitment overfishing. The current fishing mortality should be sustained at equal or below reference F_{MSY}.

5.3 Gear selectivity for *P. aethiopicus, O. niloticus baringoensis* and *C. gariepinus.*

The *P. aethiopicus* in Lake Baringo waters breeds before they reach half of their lifespan as shown by the fish asymptotic length. The size at first maturity of *P. aethiopicus* is 65 – 75 cm for males and 75 – 85 cm for females in Lake Victoria (Goudswaard *et al*., 2002). Results obtained from logistic gear selection model indicate that 50% of the fish are selected just before they reach sex at first maturity. This scenario explains an evidence of recruitment overfishing in the lake waters where the parent stocks are being fished before spawning. This is projected to leave low parent stock to support successive stock recruitment a situation that needs to be addressed. It is therefore critical to impose a ban on fishing during critical time of *P. aethiopicus* life history. Gear impact on L50% of 63.48 cm should be adjusted upwards through increase of the size of hooks to capture the fish after the size on first maturity above 85 cm.

The gear selectivity for *O. niloticus baringoensis* did not lead to recruitment overfishing. The length at first maturity for *Parastromateus niger* in Kuwaiti waters studied by Dadzie *et al*., (2008) is almost similar to that of *O. niloticus baringoensis* in Lake Baringo. The length at first maturity for *P. niger* ranged from 15 to 32 cm in males and 20 to 42 cm in females. The length at first maturity for *O. niloticus* in Lake Victoria is 30.81 cm for females and 34.5 cm for females as reported by Njiru *et al.* (2006). This is high for *O. niloticus* in adverse environmental condition as observed in Lake Beseka Ethiopia where sexual maturity length estimates was 14 cm for females and 17 cm for males (Hirpo, 2013). Similarly, the asymptotic total length of Lake Baringo *O. niloticus baringoensis* shows adverse environmental parameters in the lake. This therefore indicates that *O. niloticus baringoensis* in Lake Baringo waters breeds before they reach half of their lifespan with respect to their total length. In this respect, the gear selection model (L50% of 15.57 cm) indicates that the fish did not experience recruitment overfishing. However, *O. niloticus baringoensis* spawner stock biomass-per-recruit (SSB/R) indicated that the fish experienced recruitment overfishing. Further, the Length-converted catch curve shows that the fish natural mortality is almost equal to the fishing mortality. A fish which approaches its ultimate length quickly (meaning a high value of *K*) as observed by *O. niloticus baringoensis* is likely to have a high natural mortality unlike a fish that grows slowly (Gulland, 1969). This could further be accounting for the low spawner stock biomass explaining the recruitment overfishing due to absolute mortality. The declining production of *O. niloticus baringoensis* in Lake Baringo is therefore not entirely due to fishing mortality but also the effect of natural mortality.

The *C. gariepinus* in Lake Baringo waters breeds before they reach half of their lifespan as shown by the fish total length. Yusuf *et al*. (2013) observes that the size at first maturity of *C. gariepinus* is 26 cm for both females and males. Results obtained from logistic gear selection model indicate that 50% of fish in Lake Baringo are selected far beyond attaining sex at first maturity. This point out that evidence of recruitment overfishing is not experienced for *C. gariepinus* in the waters of Lake Baringo. It is therefore significant to maintain the current gear selectivity for *C. gariepinus* in the lake.

5.4 Socio-economics dynamics of Lake Baringo Fisheries

The study found that the variation in numbers of fishers with respect to age classes and gender parity was due to the risky nature of fishing exercise. The traditional and cultural beliefs of the fishing community contributed to dominance of fishing by men in the lake. Most fisheries in the globally are dominated by men (Mohammed *et al*., 2014; Inoni and Oyaide, 2007). Women are more involved in lower end of the value chain in most world fisheries (Chando, 2002; Medard *et al.*, 2001).

The fisheries of Lake Baringo was not restricted to certain age groups. All age groups were represented in fishing and trade. Fishermen age distribution was found to have an effect to fish production. Fishermen opted for other economic activities with their age advancement towards 50 years. Overall age distribution showed that 90% respondents fell within the productive age of 20 – 50 years accounting 90% of fish yield from the lake. Probably this was due to intensive energy required for fishing negating full participation of elderly fishers (Mohammed *et al*., 2014).

The study found that fishermen with secondary education exited from fishing exercise to other formal employment while others upgraded from fishing to other economic activities. It was also observed that the population of fishermen with no education increased as their age advanced. This was attributed to lack of minimum education requirement for fishermen registration in the lake by the State Department of Fisheries. The fishing activity was therefore noted to be the main employer of fishermen with minimum or no education in Lake Baringo. Education level among fishermen in the lake is similar to fisheries if central region in Ghana (Acquah and Abunyuwah, 2011) and Old Brahmaputra River in Bangladesh (Kabir *et al*., 2012). On the other hand, the study revealed that fish traders had relatively lower education level as compared to the fishermen in Lake Baringo. Education level did not play a major role on fish trader's involvement to fish trade. It was also noted that some fishermen graduated to fish trade with age advancement while retaining contracted fishermen for continued supply of fish.

It was observed that fishermen reduced dependence on fishing as their main economic activity as their age advanced towards 50 years and above. On the other hand, it was observed that they increased dependence on other economic activities on age advancement. Some fishermen completely stopped fishing as their age increased from 19 to above 50 years. Fishermen involvement in other economic activities is mainly attributed to reduced performances on strenuous fishing exercise (Onyango *et al.*, 2006).

The study found that the use and application of hooks in the lake required more knowledge, which was found to be more prevalent to the older fishermen. There was a notable decrease hooks usage by fishermen with 50 years mainly due to abandonment of fishing within this age group. Fish yield from hooks was higher than yield from nets although fishing hooks usage was low in comparison with fishing nets. This was attributed to the fact that catches of *P. aethiopicus* and *C. gariepinus* with hooks were more in weight and volume as compared to *O. niloticus baringoensis.* Yield models indicates growth and recruitment overfishing of *P. aethiopicus* and *C. gariepinus* necessitating the control of fishing effort from these fishers fishing.

The dependence of fishing for commercial purpose increased from 19 years towards above 50 years. The changing trend from domestic to commercial purposes with fishermen age advancement was found attributed by the increase in family budgetary needs with respective family growth. Variation of the quantity of fish traded was entirely dependent on fish yield from fishermen. External market consumed more of *C. gariepinus* followed by *P. aethiopicus* and *O. niloticus baringoensis*.

CHAPTER SIX

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary of findings

The steady state biomass analyses of Lake Baringo fisheries indicate isometric growth of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* population. *Protopterous aethiopicus* experienced growth overfishing, recruitment overfishing for *O. niloticus baringoensis* and amiable fishing mortality for *C. gariepinus*. Gear selectivity for *P. aethiopicus* fisheries shows recruitment overfishing where 50% of the stock selected before attaining sex at first maturity. Contrary to yield-per-recruit model, the gear selectivity model indicated that *O. niloticus baringoensis* did not experience recruitment overfishing. Notably, only the fisheries of *C. gariepinus* was at amiable situation in the lake.

The fishing effort applied in Lake Baringo was affected by the traditions and culture of fishermen gender, suiting male fishers unlike female counterparts. Fishermen age had an effect to fishing effort in the lake. Dependence on fish for subsistence and commercial purpose was relative to fishermen age. Fishermen changed their preferred fishing gears from nets to hooks based on fishing experience. Fishermen education level was higher than traders. Fish market volumes were dependent on the quantity of fish catches. The local and external fish markets were not significantly different.

6.2 Conclusions

The steady state biomass shows growth overfishing of *P. aethiopicus* fisheries where exploitation rates exceeded maximum, optimum and economic exploitation rates due to high fishing mortality rate. Fishing mortality for *O. niloticus baringoensis* and *C. gariepinus* is almost at par with the fish maximum sustainable exploitation rate resulting to congenial state of the fish population utilization. High fishing mortality for *P. aethiopicus* led to low spawning stock biomass-per-recruit due to recruitment overfishing. Gear selectivity shows low parent stock availability for *P. aethiopicus* to support effective recruitment due to high selectivity of fish before attaining sex at first maturity Low spawning stock biomass-per-recruit for *O. niloticus baringoensis* was due to recruitment overfishing from natural and fishing mortality. The *C. gariepinus* fisheries was at congenial state where the fishing mortality rate was at par with maximum, optimum and economic exploitation rates.

Fishing effort applied in Lake Baringo was influenced by the fishermen traditions and cultural beliefs, age and gender. Change of fishing gears preference from nets to hooks was on fishing experience.

6.3 Recommendations

The Kenya State Department of Fisheries should enforce seasonal management measures to control growth and recruitment overfishing of *P. aethiopicus* and *O. niloticus baringoensis.* This will be through control of fishing during peak recruitment seasons within the year at high rainfall duration. Other management measures should include introduction of fish catch quotas, control of the number of boats, fishermen, nets and hooks per fisherman. The management should also attempt to retain the current fishing effort for *C. gariepinus*. The management measures will enable economic utilization of the lake fisheries.

The Kenya State Department of Fisheries should consider imposing a ban on fishing during critical time of *P. aethiopicus* life history. Efforts should also be made to increase current L50% to length above first maturity through adjustment of gear upwards on the increase of hooks size. Maintain current gear selectivity for *O. niloticus baringoensis* and *C. gariepinus* upwards to avoid future incidences of recruitment overfishing.

The study recommends evaluation of *P. aethiopicus*, *O. niloticus baringoensis* and *C. gariepinus* relationships to climate changes and environmental parameters in the lake to determine peak recruitment seasons for effective management measures.

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APPENDICES

Appendix I: Socio-economic survey on Lake Baringo Fisheries

Part I Questionnaire for fishermen

I am a student at Egerton University pursuing a Doctor of Philosophy Degree in Natural Resource Management. I am carrying out a study to characterize the socio-economic aspects of Fisheries in Lake Baringo, the study is for academic purpose only, the information given will be confidential, I request for your cooperation.

Section A: personal information

1. Name..

2. Age: < 18yrs ( )   19-30 ( )
   31-50 ( )   > 50 ( )

3. Gender: Male ( )   Female ( )

4. Level of Education..

Primary ( )   Secondary ( )

University ( )   No formal education ( )

Section B: information on Lake Baringo Fisheries

5. Do you have any other activity apart from fishing that financially contributes to your income?

Yes ( )   No ( )

If yes,

Specify...

6. What types of gear do you use to fishing?

Nets ( )   Long line hooks ( )   Others ( )

If others specify………………………………….

7. How often do you fish?

Daily ( )   Monthly ( )

Weekly ( )   Others ( )

If others specify……………………………………………………

8. What is your main reason for fishing?

Subsistence ( )

Commercial ( )

Others ( ) if others specify……………………………………

9. Are women allowed to fish?

Yes ( ) No ( )

If No, why...

Part II: Socio-economic survey questionnaire for Traders

1. Name...
2. Area...
3. Do you get your fish from fisher in Lake Baringo?

a. Yes ( ) No ( )

b. If no, from where...

4. How much fish can you receive from fishers in a day?

5. What are the major fish species in the market?

	Species	Quantity
1		
2		
3		
4		
5		

6. What is the processing method of fish is used?
7. Who are your major clients or buyers?
8. What type of fish species is liked most by your clients and why?