THE UNIVERSITY OF HULL

Assessment and management of Nile perch (*Lates niloticus* L.) stocks in the Tanzanian waters of Lake Victoria

being a Thesis submitted for the Degree of Doctor of Philosophy in the University of Hull

By

Oliva Charles Mkumbo
B.Sc (Hons), (1982.), MSc (Biology), (1986) University of Dar, Tanzania

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SUMMARY

Lake Victoria contributes more than 60% of the total fish yield in each of the respective riparian countries, Kenya, Uganda and Tanzania. Nile perch *Lates niloticus* contributed more than 60% to the total yield from the lake. Although accused of causing ecological instability of the ecosystem due to its predatory effects, the fishing industry became socially and economically dependable on the Nile perch. In the mid 1990s signs of overfishing were observed and concerns for the sustainability of the fishery were raised.

To properly manage a fishery, knowledge of the factors that regulate the dynamics of the stock(s), their abundance and distribution is essential. Unfortunately data on the status of the Nile perch stocks are inadequate. This study was conducted on the Tanzanian part of Lake Victoria from 1997 to 2001 to address this problem. Reference is also made to the Kenyan and Ugandan national waters for comparison.

Bottom trawl and catch assessment surveys were conducted to assess the status of the stocks. Abundance estimates and distribution patterns were determined. Current exploitation levels and practises were analysed and linked to growth and mortality, feeding and reproductive characteristics of the stock to determine status. Key environmental parameters were investigated and linked to the variations in the biological aspects and distribution patterns observed. There was an indication of reduced anoxic problems in the offshore deep waters and signs of improvement in the eutrophic state of the lake. Mean oxygen concentrations in the waters sampled varied from 8.02±0.73 mg L^{-1} in the surface waters to 3.2±4.36 mg L^{-1} in the bottom waters of 68 m deep, while Secchi disk readings at stations of 5-10 m depth ranged from 0.84±0.3 m in November to 1.9±1.02 m in August/September and in offshore waters of 50-60m depth the readings were 3.08±0.62 m in February to 5.52±1.7 m in August/September. Distribution patterns of fish were highly aggregated but variable and were greatly influenced by seasonal patterns of oxygen and temperature, while reproduction and recruitment were related to rainfall patterns. Using the swept area method, biomass was estimated at 306,000 t for the Tanzanian waters and around 620,000 t for the whole lake, with a mean density of 9.87 t km^{-2} and 10.56 t km^{-2} respectively. Very high fishing mortality (1.55 yr^{-1}) and exploitation rates (0.84) were estimated using an L_∞ of 218 cm TL and a growth constant (K) of 0.16 estimated during the study. Excessively high fishing effort was observed in the 2000 frame survey while catch compositions reveal high dependence on juveniles for the Nile perch fishery. The size at first maturity was at 54.3 cm TL (1.6-yr.) and 76.7 cm TL (2.5 yr.) for males and females respectively. About 83% of the catch survey data were below size at first maturity for males and 99% for females. Bottom trawl data (88% juveniles) suggested high recruitment in the stock. However the models indicated unsustainable exploitation of the fishery. A reduction of exploitation rate by 50% and increase of size at capture for optimum yield is recommended. The dominance of juveniles in the catch with the current yields (estimated at 138 323.85±6 229.14 t) higher than the sustainable yield (calculated at 108 941.9 t yr^{-1}, using Cadima's formula) demands immediate management initiatives.

Co-management is singled out as the most effective option for a functional system to implement control, monitoring and surveillance strategies within management process. With dynamic systems within the stocks, the environment as well as socio-economic influences, and with continuous monitoring, adaptive and precautionary management strategies are recommended. Without reliable catch trend data it is difficult to confidently make predictions. The need to have a well-structured catch assessment survey system for reliable catch statistics is recommended. Priority areas to further research are also identified.

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CHAPTER ONE

GENERAL INTRODUCTION

1.1 LAKE VICTORIA: THE GEOGRAPHY, HYDROLOGY AND LIMNOLOGICAL CHARACTERISTICS OF THE LAKE AND ITS BASIN

Lake Victoria, the second largest freshwater body in the world and the first in Africa is situated along the Equator between latitudes 0° 20′ N to 3° 0′ S, and longitudes 31° 39′ E to 34° 53′ E (Beadle, 1974; Welcomme, 1970) at an altitude of 1 134 m above sea level. The lake has a surface area of 68 800 km^2 of which 35 088 km^2 (51%) is in Tanzania, 29 171 km^2 (43%) in Uganda and 4 128 km^2 (6%) in Kenya. It has a mean depth of 40 m and maximum depth of 80 m. The shoreline is about 3 450 km, of which 1 150 km is in the Tanzanian part of the lake, 1 750 km in the Ugandan part and 550 km in the Kenyan part of the lake (Fig. 1.1).

The catchment area of Lake Victoria (referred to as its hydrological watershed or the lake basin) is approximately 184 000 km^2 shared by the three riparian countries and Rwanda and Burundi which border Tanzania and Uganda on the west side of the lake. About 85% of the water entering the lake comes from direct precipitation while the remainder comes from rivers, which drain the surrounding catchment. The main inflowing river, the Kagera, drains the mountains of Rwanda and Burundi and flows some 150 km through Tanzania. Most of the input water (85%) is lost through direct evaporation and only 15% as outflow through the Victoria Nile. The basin receives an annual rainfall of between 1250 mm – 2020 mm with seasonal oscillations reflected in the changes of water level in the lake. Two main rainy seasons occur, in the northern part, March – May and August – November with two dry spells of December – February and June – July (SIDA, 1999), while in the south, two main seasons are reported, a rain season from October to May and a dry season June to September (Talling, 1966; Akiyama *et al.*, 1977). Generally, water levels are high during May and June and low in October and November (Temple, 1964).

Wind speed is reported to be minimum in the morning and maximum in the afternoons with higher wind speeds between June and August (Crul, 1989).

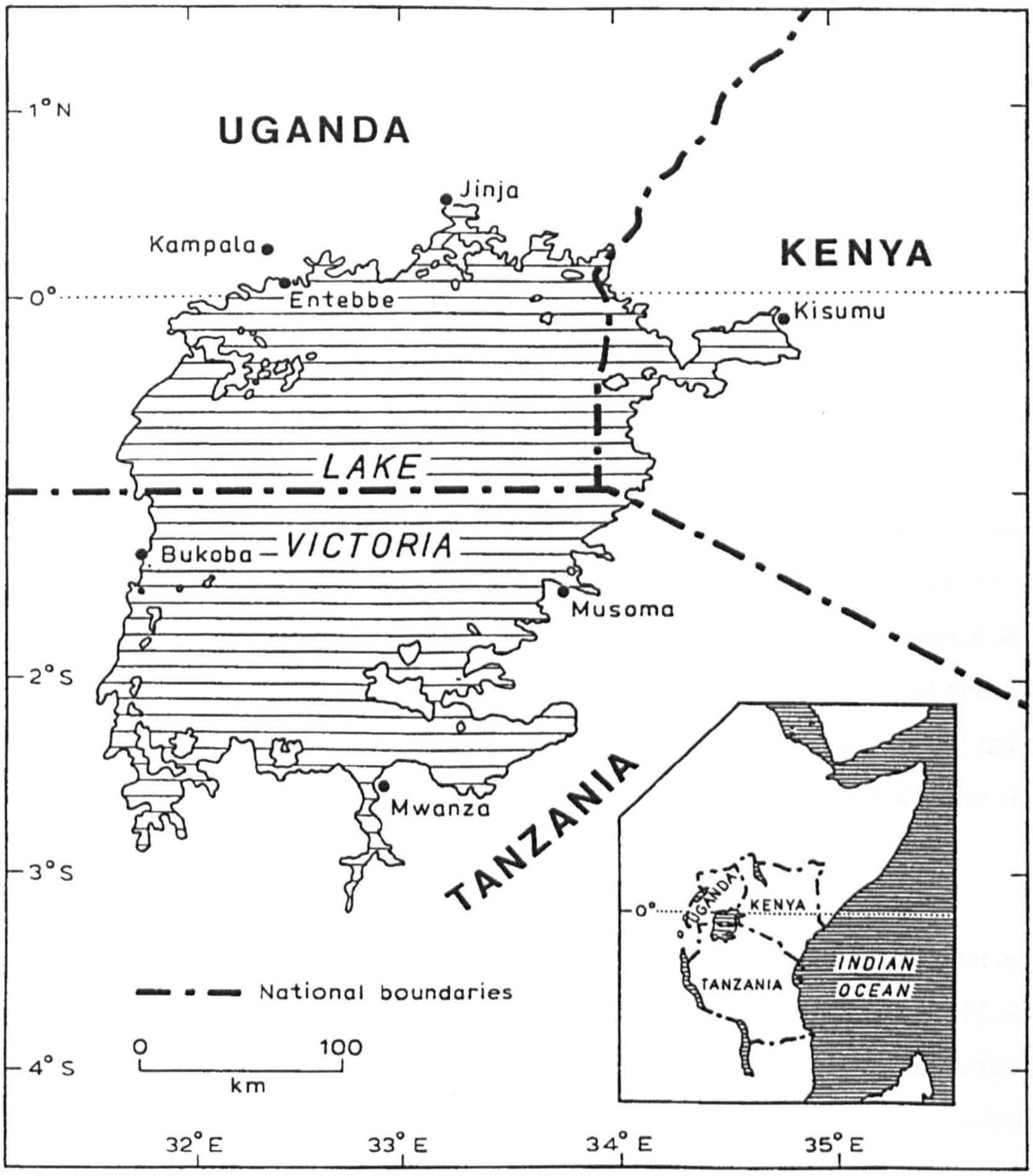


Figure 1.1 Lake Victoria showing the national boundaries and its location within the East Africa countries of Tanzania Uganda and Kenya

Thermal stratification and deoxygenation of the lower part of the water column occured in offshore waters during the rain season (November – May) before the mid 1980s (Fish, 1957; Talling, 1966; van Oijen *et al.*, 1981). A much longer annual stratification in areas more than 50 m deep with permanently hypoxic waters in the lower part of the water column was reported during the late 1980s to mid 1990s (Ochumba & Kibaara; 1989; Hecky & Bugenyi, 1992; Kaufman, 1992; Gophen *et al.*, 1993; Muggide, 1993; Hecky *et al.*, 1994). At the same time, oxygen levels in the surface waters increased and were attributed to increased eutrophication (Hecky, 1993) resulting to increases phytoplankton production. Through photosynthesis more oxygen was released to the habitat. Due to increased eutrophication and algal production, which were four to five times higher than the 1960s biomass, water transparency decreased four fold (Witte *et al.*, 1992a; Muggide, 1993; Gophen *et al.*, 1995). With the increased eutrophication in the lake, phytoplankton composition also changed remarkably. The predominance of large diatoms (*Melosira* or *Aulacoseira, Stephanodiscus* and *Nitzschia*) in the 1950s and 1960s (Talling, 1966), changed to a predominance of blue-green algae (Cyanobacteria) in the 1980s and 1990s (Ochumba & Kibaara, 1989; Gophen *et al.*, 1993; Hecky, 1993).

Following the changes that occurred in the phytoplankton community, the zooplankton community in the lake also changed. The relatively large herbivorous species of calanoid copepods (about 50%) and cladocerans (about 40%) dominant in the 1927 to 1960s (Worthington, 1931; Rzóska, 1957) decreased in abundance and the cyclopoid copepods increased in relative abundance by almost 90% (Mwebaza-Ndawula, 1998; Wanink, 1998a). The abundance of the detritivorous benthic atyid prawn; *Caridina niloticus* (Roux) simultaneously increased markedly (Witte *et al.*, 1992a; Goldschmidt & Wanink, 1993).

Pollutants from the surrounding basin, among other factors, are believed to have had an influence on the changes in the hydrology and limnological characteristics of Lake Victoria. This included untreated sewage and industrial waste from the urban centres, agro-chemicals and soil erosion from poor agriculture practices and deforestation. The excessive nutrients in the lake probably also resulted in proliferation of the noxious waterweed, water hyacinth that infested the lake in early 1990 (Twongo *et al.*, 1995), but it appeared to be controlled by early 2000.

1.2 THE LAKE VICTORIA FISH STOCKS AND FISHERIES: CHANGES IN THE FISH COMMUNITY AND DEVELOPMENTS IN THE COMMERCIAL STOCKS

The changes that occurred to the water quality and limnological characteristics from the 1960s did not happen in isolation. Remarkable changes in the ecology and the resource base also occurred. The lake supported a large number of endemic fish species. The fish fauna once comprised more than 28 genera with more than 350 species. Cichlids contributed the majority of these species, with about 300 haplochromine species and 2 tilapiine species, *Oreochromis esculentus* (Graham, 1929) and *O. variabilis* (Boulenger, 1906) (Greenwood, 1974; 1981; Witte & van Oijen, 1990; Graham, 1929). The fishery mainly targeted the tilapiines at low effort using simple fishing gears and thus was restricted on the inshore areas. The introduction of gill nets in the Nyanza (Kavirondo) Gulf in 1905 (Graham, 1929) and beach seines in the early 1920s increased the fishing pressure. Development in the infrastructure opened inland markets and enhanced developments in the fishing industry. Increased fishing pressure resulted in falls in catch per fishing effort, especially for tilapiines and *Labeo victorianus* Boulenger, 1901 in the 1950s (Worthington, 1933; Cadwalladr, 1965; Fryer, 1973). In addition to the tilapiine fishery, local fisheries for *Protopterus aethiopicus* Heckel, 1851, *Bagrus docmak* Forsskåll, 1775 and *Clarias gariepinus* (Burchell, 1822) also existed. Other species such as *Barbus altianalis* Boulenger, 1900 and *Mormyrus kannume* Forsskåll, 1775 also became rare in the catches (Garrod, 1961).

Efforts to develop and manage the fisheries of Lake Victoria started in the 1930s when signs of overfishing were recorded after the gillnet survey of 1927-28 (Graham, 1929; Beauchamp, 1956; Lowe-McConnell, 1997). Underlying these efforts was the recommended use of 127 mm (5") mesh size for gillnets in early 1930s and the introduction of exotic fish species to boost the production in early 1950s. *Tilapia melanopleura* Dumeril, 1859, *Tilapia zilii* (Gervais, 1848), *Oreochromis leucostictus* (Trewavas, 1933) and *Oreochromis niloticus* (Linnaeus, 1758) were introduced in the lake (Welcomme 1968). Nile perch (*Lates niloticus* Linnaeus, 1758) was also introduced in the late 1950s and early 1960s (Hamblyn, 1961; Arunga, 1981; Welcomme, 1988). The effect of these introductions to the fishery and ecology of the lake was not immediately realised. Catch rates and the total yield continued to decrease for the next twenty years. Haplochromines, were the only under-fished stocks, due to their small size and bony texture (Scully, 1975). With the decrease in catch rates smaller gillnets of 38 to 46 mm (1.5 to 2 inches) were used to harvest smaller fish such as *Synodontis* spp., *Schilbe intermedius* (Linnaeus, 1758), *Barbus profundus* Greenwood, 1972, *Brycinus* spp. and the haplochromines in the late 1960s (Marten, 1979; Scully, 1975). Beach seines also increased in the early 1970s to catch the haplochromines but captured large numbers of spawning and juveniles of tilapiines (Marten, 1979), escalating the effect of overfishing. In the same period, light fishing for the cyprinid *Rastrineobola argentea* (Pellegrin, 1904) (locally called dagaa in Tanzania, omena in Kenya and mukene in Uganda) developed in Tanzania and Kenya (Marten, 1979; Okedi, 1981). The dagaa light fishery used very small mesh sizes (8 to 13 mm), which was detrimental to juveniles of both haplochromines and tilapiines.

While catches of the larger species continued to decrease, and fishermen concentrated on beach seines and smaller mesh gillnets, haplochromines became important as a protein source over a wide area being eaten fresh, smoked or even sun-dried (Scully, 1975). The necessity to define the status of the stocks was raised by the research institution of the three riparian states, EAFFRO (East African Freshwater Fisheries research Institute), and aided by FAO/UNDP carried out the first lake-wide bottom trawl survey in 1969/1971.

The total demersal fish biomass of Lake Victoria was estimated at 750 000 t, of which 80% (600 000 t) were haplochromines (Kudhongania & Cordone 1974). From these findings, bottom trawling and beach seining were advised to fully exploit the haplochromines. This led to the establishment of a small-scale trawl fishery in Tanzania, and a fishmeal-processing factory with a capacity of 60 t of wet fish per day became operational in Mwanza in 1976 (Bon & Ibraham, 1975). A trawl fishery, of about 10 trawlers for direct local consumption and sun dried for a local market was also operational in the Mwanza area by the end of 1970s. Exploratory fishing for haplochromines showed that a 13.7 m trawler with 130 hp engine and with a bottom trawl net of codend 20 mm could catch an average of 1 000 kg hr^{-1} in the late 1970s (Goudswaard & Ligtvoet, 1988). Highest yields of haplochromines were recorded in 1977 when annual landings were 36 158 t, 6 264 t and 1 560 t; contributed 45%, 32% and 10% of the national catches for Tanzania, Kenya and Uganda respectively, while Nile perch at that time contributed only 0.04%, 0.1% and 0.3% to the national catches respectively (CIFA, 1982; Annual Fisheries statistics). With the intensive fishing pressure signs of overfishing were observed in the Mwanza and the Wynam gulfs in the early and mid 1980s (Marten, 1979; Witte, 1981; Witte & Goudswaard, 1985).

In the 1980s an explosion of *Lates niloticus* stocks occurred and by 1987, Nile perch contributed 60% of the total yield in Tanzanian waters, (Ligtvoet *et al.*, 1988; Bwathondi, 1990). In Kenya catches increased from almost zero in 1979 to over

20 000 t in 1982 and Nile perch comprised about 60% of the catch (Okemwa, 1984; Ogari & Asila, 1990). The same trend was reported for Uganda (Okaronon *et al.*, 1985; Orach-Meza, 1992). As Nile perch increased to contribute up to 90% of the total catch in 1990 (Ligtvoet & Mkumbo, 1991), a decling trend in all the other species escalated. Adding to the other impacts of overfishing and poor water quality, predation of Nile perch exacerbated the situation. In 1989, bottom trawl surveys showed haplochromines to have almost disappeared from the catches (Witte *et al.*, 1992b). Although Nile perch preyed predominantly on haplochromines, all the other species were also recorded in the diet (Gee, 1964; 1969; Hamblyn, 1966; Okedi, 1971; Ogari, 1988; Hughes, 1986; Ogari & Dadzie, 1988; Ogutu-Ohwayo, 1990; Mkumbo & Ligtvoet, 1992).

Changes in species composition in an ecosystem have profound impact in the food web and eventually to the ecosystem in general (Carpenter *et al.*, 1985). The haplochromines encompassed many trophic specialisations (Greenwood 1974; van Oijen *et al.,* 1981; Witte & van Oijen, 1990). These included detritus/phytoplanktivores, zooplanktivores and the piscivores. Eradication or reduction of these trophic groups to very low levels resulted in unutilised niches in the system, which disrupted the integrity of the system. The increase in detritus material in Lake Victoria and depletion of oxygen in deep layers are partly attributed to this change and are coupled with the increase in some detritus feeders such as *Caridina niloticus* and zooplanktivores such as *Rastrineobola argentea* (Wanink, 1998a; Witte *et al.*, 1995a). These changes linked with the excessive fishing pressure, predation and competition among the species shifted the multispecies fishery of Lake Victoria to a three species fishery.

Currently the lake's fishery depends on Nile perch (*L. niloticus*), the pelagic cyprinid dagaa (*R. argentea*) and the introduced tilapiine (*O. niloticus*). The Nile perch fishery is the most important but has recently shown signs of a decline, although some few big specimens are still encountered in the catches (Photo plate. 1.1 & 1.2).

Plate 1.1 A catch from bottom trawl showing the dominance of Nile perch juveniles

Plate 1.2 A catch from bottom trawl showing one of the few big Nile perch specimens surviving in the Nile perch fishery

With the shift in species dominating the fish communities, a major transformation also occurred in the commercial fisheries. The high catches of Nile perch attracted more investors in the harvesting, marketing and processing sectors (Maembe, 1990). Some 27 fish processing factories were established around the lake by 1999 and frozen and chilled fillets are exported to a number of international markets in Europe, North America, Middle East and Asia (SEDAWOG, 1999a). With the high investments in the industry, fishing pressure increased enormously. There has been evidence of changes in the efficiency of fishing gears, motorisation of canoes and total fishing effort to maintain the yield. Extension of fishing grounds has occured but all against a continued decrease in catch per unit of effort and the mean size of fish caught (Ligtvoet & Mkumbo, 1991; Mkumbo *et al.*, 1996).

With these changes in the fishery resources a number of management measures were instigated. These include the ban of beach seines and nets of less than 127 mm in 1994 and a ban on trawlers in January 1996. However, none was effectively observed and there is a general belief that there are unexploited off shore and deep-water stocks.

1.3 THE RESEARCH: BACKGROUND, OBJECTIVES AND AN OVERVIEW

1.3.1 Background to the study

With the five-fold increase of Nile perch catches in the early 1990s, the fishing industry in Lake Victoria has attracted unprecedented levels of national and international capital investment. Nile perch became the backbone of the fisheries in the three countries contributing more the 60% of the national total landings (including marine catches) in each respective country (CIFA, 1992). The fisheries of the lake, in addition to being an important source of protein for the local communities are a source of foreign currency through exports, and have escalated employment opportunities through the development of the harvesting, processing and marketing sectors of the industry. All the investments in the industry were done without prior knowledge of the resource base, nor effective and reliable monitoring system.

The only previous lake-wide stock assessment was in 1969 to 1971 by the EAFFRO in collaboration with FAO/UNDP. This was before the Nile perch boom and other ecological perturbations in the lake. With the collapse of the East African Community in 1977, national fisheries research institutes (TAFIRI, KMFRI and FIRRI) continued with minimal research activities, localised in their respective waters. Lack of joint planning and resources limited the exchange of data and information as well as any collaborative research activities. It was during this time when drastic changes in the fisheries and the ecosystem of Lake Victoria were noted: a shift in abundances of haplochromines from 80% of the fish biomass in the lake in the 1970s to less than 1% in the early 1990s while Nile perch took-over the dominance and resulted to five-fold increase in the catches in late 1980s; an increase in eutrophication and deoxygenated bottom waters; changes in phytoplankton composition from dominance of large diatoms to blue green algae, which caused a four-fold decrease in water transparency; changes in zooplankton composition from a dominance of large calanoids to the small cyclopoid copepod; the increase in detritus material and the benthic invertebrates notably *Caridina niloticus*; and an increase in abundance of the zooplanktivorous cyprinid *Rastrineobola argentea* and the introduced tilapiine *Oreochromis niloticus* and Nile perch while all the other fish species were decreasing. With increased fishing effort, a decline in Nile perch catches was also noted in the mid 1990s.

The sustainability of the Lake Victoria fisheries in relation to the ecological changes and the developments in the fishery became a concern to both stakeholders of the lake resources and politicians as well as the international arena of scientists. Efforts to mobilize resources started in the mid 1990s. It was with the establishment of Lake Victoria Fisheries Organisation (LVFO) in 1996 being charged with the responsibility of co-ordinating and harmonising research initiatives within the region, when regional projects took-over. Among these projects is the Lake Victoria Environmental Management Programme (LVEMP), a World-bank GEF funded project charged with biodiversity, conservation and management of the lake and its environment; and the Lake Victoria Fisheries Research Project (LVFRP), a European Union funded project. The latter was charged specifically to create and develop the knowledge basis required for the rational management of the fisheries of Lake Victoria, and assisting the newly established Lake Victoria Fisheries Organisation in the creation and initial functioning of a viable management framework for the fisheries of Lake Victoria. The present study was developed within the framework of the objectives of LVFRP.

1.3.2 Objectives of the study

Management of the Nile perch fishery as a sustainable resource is crucial for the welfare of the local community and the national and the international arena at large. The objective of the study was therefore to assess the status of Nile perch stock to underpin sustainable utilization in the fisheries of Lake Victoria. The management of a fishery as a sustainable resource depends on a good understanding of the biology and the population dynamics of the main species contributing to the fishery, the environmental characteristics influencing the species' dynamics and the characteristics of the fishery that the species supports. On the basis of this information the specific objectives were

- To investigate the temporal and spatial variations of key environmental parameters in Lake Victoria.
- To establish changes in the exploitation patterns in the lake fisheries and the status on the Nile perch fishery.
- To determine the abundance and distribution of Nile perch stock in the Tanzanian waters of Lake Victoria.
- To investigate the food and feeding habits of Nile perch in the Tanzania waters of Lake Victoria.
- To determine the reproductive characteristics of Nile perch in the Tanzanian waters of Lake Victoria.
- To estimate the population parameters of the Nile perch stock namely growth recruitment and mortality and establish the dynamics of the population in the Tanzanian waters of Lake Victoria.
- To investigate on the existing management system in the fishery sector and formulate management options and strategies to ensure sustainable exploitation of the stocks.

1.3.3 Overview of the study

Within the overall objective of the LVFRP regional project to create and provide the knowledge basis required for the rational management of the fisheries of Lake Victoria, the study was conducted under a harmonised plan of activities for the whole lake executed by each of the research institutes of the three riparian countries. The project addresed two main research areas, stock assessment and socio-economics. A number of activities, bottom trawl surveys, hydroacoustic surveys, gillnet surveys, catch assessment surveys, fish biology appraisal, ecosystem dynamics and limnological surveys were conducted under stock assessment component.

This study mainly concentrated on the bottom trawl surveys (for fisheries independent data) and catch assessment surveys (for fisheries dependent data) including data from a regional frame survey conducted in the three countries. The biological aspects of Nile perch covered under the study relied on samples from the bottom trawl surveys only. Key environmental parameters from the limnological surveys are also used. The study area is limited to the Tanzanian waters of the lake with three main sampling zones demarcated according to the administrative regions surrounding the lake (Fig.1.2). Zone A refers to Mwanza region, zone B refers to Mara region and zone C refers to Kagera region. However, reference and comparison to the same work done in Uganda and Kenya is made, and the section on exploitation patterns in the fishery of Lake Victoria gives an overview for the whole lake. The project duration was from 1997 to 2001 but most of the data presented in this study cover the period from 1999 to 2001, with some exceptions depending on availability of equipment or other facilities.

An overview of the rainfall patterns and atmospheric temperatures which are known to influence the seasonal patterns in Lake Victoria, together with the seasonal and temporal patterns in the abiotic factors of the lake environment (Tanzanian part) is given in Chapter Two. The information is compared with the overall limnological changes occurred in Lake Victoria which are briefly outlined in the general introduction. Signs of reduction in the state of eutrophication in the lake and its impact on the food web and ecosystem stability for the sustainability of the Nile perch fishery is discussed.

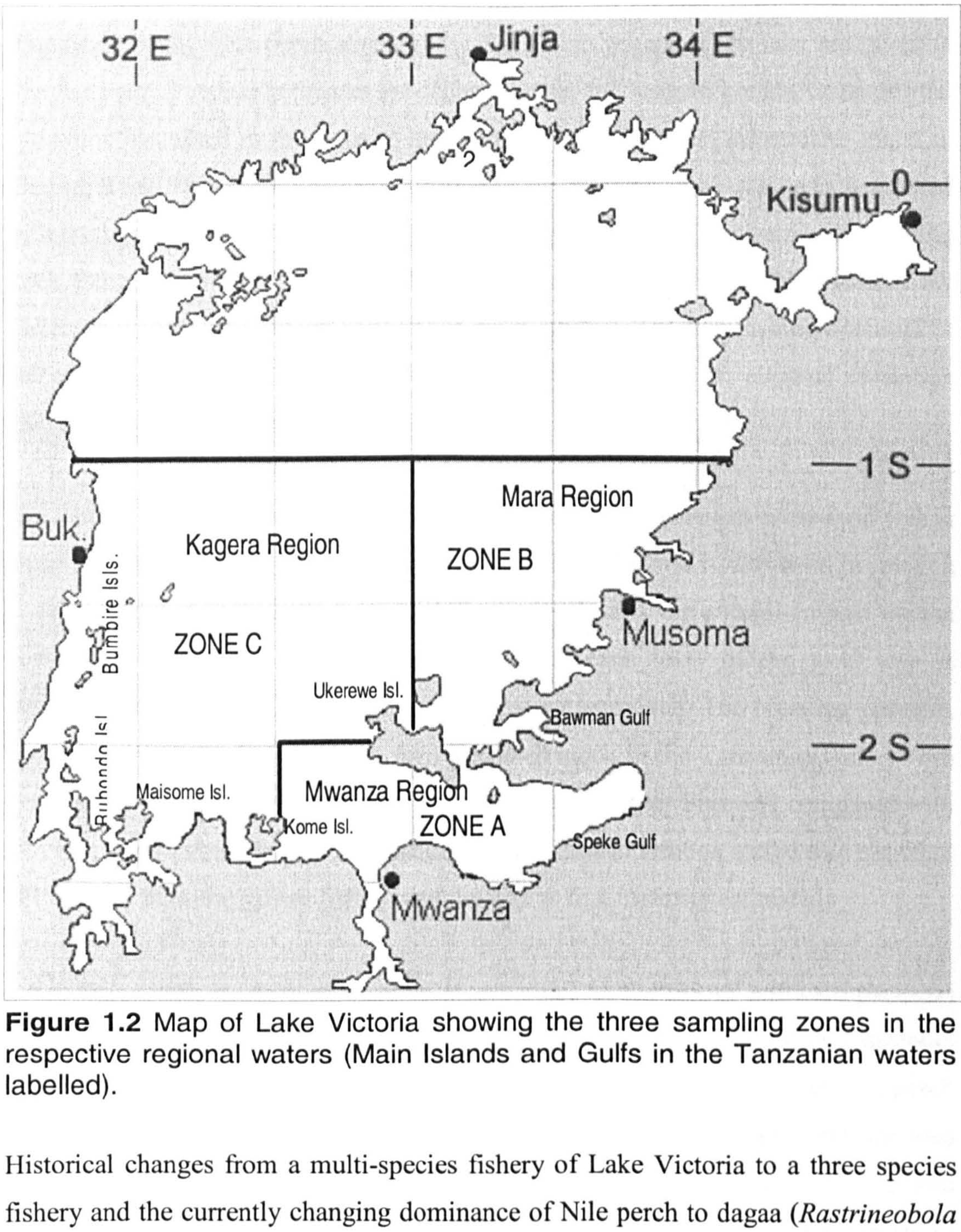


Figure 1.2 Map of Lake Victoria showing the three sampling zones in the respective regional waters (Main Islands and Gulfs in the Tanzanian waters labelled).

Historical changes from a multi-species fishery of Lake Victoria to a three species fishery and the currently changing dominance of Nile perch to dagaa (*Rastrineobola argentea*) are examined in Chapter Three. The result of a regional frame survey, unique in the history of Lake Victoria fisheries is also examined in this chapter. The current effort of the fisheries and its characteristics per country sharing the resources is analysed, while the contribution of juveniles in the catches and the impact of different gears on the Nile perch stock is discussed. Estimates of the current yield from different fisheries is given and the need for immediate interventions to manage the Nile perch fishery is discussed.

The population structure, spatial and temporal distribution patterns in relative abundance of the Nile perch stock in the Tanzanian waters of the lake are given in Chapter Four. Biomass estimates for different areas and seasons are reviewed and the variations discussed in the light of some of the environmental parameters given in Chapter Two. The overall biomass estimated for the Tanzanian waters is compared with the biomass estimates for Ugandan and Kenyan waters. Changes in the standing stock estimates over different periods and probable reasons for the disparities of the current estimates from earlier predictions are discussed. The diminishing potential of the current biomass in relation to the population structure to support escalating fishing pressure is assessed.

The diet of Nile perch and its feeding rhythm in relation to changes in the food web is given in Chapter Five. The current food web in Lake Victoria is discussed in relation to the effects of fishing pressure at different levels and the overall impact on the ecosystem. The need to ensure sustainability at each level of the food web is expressed and calls for an ecosystem management approach. The breeding patterns, sex ratios and fecundity estimates for Nile perch stock in the Tanzanian waters with the changes in size at first maturity is also given in Chapter Five and compared with previous work. The effect of overfishing is discussed in relation to the size structure of the catch from the gillnet fishery and the size at first maturity estimated.

Using the models in stock assessment incorporated in the FiSAT software package, Chapter Six estimates the population parameters for Nile perch stock in Tanzanian waters of Lake Victoria. MSY is also estimated. The sustainability of the Nile perch fishery is discussed in the light of the predictions made in this Chapter and previous predictions, the current exploitation levels and practices and the limnological and biological aspects covered under the study. The chapter summarizes the threats to sustainability of Nile perch fishery and emphasizes management interventions.

A Chapter examining the options in management of the resources (Chapter Seven) conclude the study. An overview of the status of the Lake Victoria fisheries, the environmental, biological and the socio-economic changes and transformations in the Lake Victoria ecosystem and the fishing industry is done; and the key issues which calls for immediate management action highlighted. A review of the existing regulations is also carried out and the shortcomings discussed. A proposal for a different management approach and strategy for implementation is discussed. Priority areas, which need immediate intervention and the actions needed, are also outlined. The study therefore, attempted as far as the resources and time could permit to establish the knowledge required for the Nile perch stock and its fishery towards a sustainable utilisation.

1.4 Summary

Changes, which occurred over time in the limnological characteristics impacting changes in the ecology and the resouce base of the lake and the current dependency on Nile perch fishery which lead to this study, were briefly outlined in this chapter. Lake Victoria (with a surface area of 68 800 km^2), the second largest freshwater body and the first in Africa, shared by the three riparian countries Kenya, Uganda and Tanzanian is primarly influenced by its hydrological watershed of approximately 184 000km^2. The two main seasons, rain-season from October to May and dry-season from June to September are known to influence the seasonal patterns in the lake, the period of thermal stratification, and that of mixing of the water which inturn influence the abiotic and biotic characteristics of the lake.

Human activities in the basin resulted to increase in nutrient loading and pollution enhanced with increased fishing effort and fish introduction resulted to profound changes in the water quality and the fisheries of the lake. Eutrophication and deoxygenation of the deep waters characterized the lake environment in the 1990s, while, the multispecies fishery changed to three species fishery, Nile perch (*Lates niloticus*) an introduced centropomid species, dagaa (*Rastrineobola argentea*), an endemic cyprinid species and a tillapine, *Oreochromis niloticus* an introduced cichlid species. In the early 1990s Lake Victoria fish production increased five times with Nile perch becoming the backbone of the fishery, contributing more than 60% of the total landings in the three countries. Unprecedented levels of national and international capital investments in Nile perch fishery occured followed by the establishment of 27 fish processing factories in the three riparian countries. This led to a concern of the sustainability of the resources and as a result the inception of a regional project (Lake Victoria Fisheries Reseach project-LVFRP) from 1997 to 2000. The general objective of the project was to acquire the knowledge basis

required for the rational management of the fisheries of Lake Victoria. This study conducted under the project, with a goal to assess the Nile perch stock and underpin its sustainable utilization, concentrated on the Tanzanian waters of the lake with three main sampling zones, zone A in Mwanza region, zone B in Mara region and zone C in Kagera region. An overview of the organisational set-up of the whole thesis is also given in this chapter.

CHAPTER TWO

METEOROLOGICAL AND HYDROGRAPHICAL CHANGES IN LAKE VICTORIA AND ITS BASIN

2.1 INTRODUCTION

Environment, including habitat quality and its variation in time and space influence the reproduction, survival and distribution of fish and fish stocks (Laevastu, 1993; Laevastu & Hayes, 1981). Of specific interest to fisheries science is the behaviour of fish or fish stocks to the prevailing environmental conditions and their changes (Laevastu, 1993; Laevastu & Hayes, 1981). Populations are known to adjust their age-specific patterns of mortality, growth and fecundity by changes in their physiology and behaviour to mitigate the effects of environmental changes (Wootton, 1990). Such responses or behaviour include migrations, both diurnal and long term, such as aggregation, dispersal and vertical migration, spawning and feeding migrations. Meteorological characters, especially wind, rain, cloud cover and temperature change not only affect the safety and comfort of fishermen but to a large extent affect the behaviour and availability of fish via influences on the surface waters (Laevastu & Hayes, 1981). Of the weather-induced changes in aquatic environments with direct effect in fish distribution and catches is thermal stratification and the depth of the thermocline (Laevastu, 1993; Laevastu & Favorite, 1988). This in turn influences the changes in oxygen concentration with depth, as well as nutrient availability in the water column (Laevastu & Favorite, 1988). Different fish species have different ranges of oxygen concentration tolerance, especially during spawning and egg/larvae development (Wootton, 1990). Oxygen levels not only affect fish distribution but also when coupled with temperature, affects fish activity and growth, and depending on nutrient availability, phytoplankton production. These in turn have a bottom up effect at different trophic levels, affecting primary herbivores to primary carnivores and eventually top predators. The overall ecosystem productivity is strongly influenced by the stability of the abiotic environmental factors (Wootton, 1990; Lowe-McConnell, 1987; Welcomme, 1995).

The impact of environmental changes on the Lake Victoria ecosystem and thus to the fisheries has been extensively documented (Graham, 1929; Worthington, 1930; Fish, 1957; Talling, 1966; Akiyama *et al.*, 1977; Ochumba & Kibaara, 1989; Hecky &

Bugenyi, 1992; Kaufman, 1992; Witte *et al.*, 1992a; Gophen *et al.*, 1993, Hecky, 1993; Mugide, 1993; Hecky *et al.*, 1994; Kudhongania & Chitamweba, 1995; Ochumba, 1995, Seehausen *et al.*, 1997), and is briefly summarized in Chapter One. The effects of the heavy rains of 1961 to 1964 on the lake's water level, which in-turn affected the macrophyte community and eventually the distribution and spawning of some species (Beauchamp, 1961; Welcomme, 1970; Beadle, 1974), demonstrated how the amount of rains can have different impacts in Lake Victoria ecosystem. The seasonal patterns in the lake are influenced by the dry and wet seasons (Fish, 1957; Talling, 1966; Akiyama *et al.*, 1977), which in turn have a profound influence on the spawning and recruitment patterns of the fish species, as well as the abundance and distribution of fish stocks (Chapter Four & Five). Wind speed and direction both influence surface temperatures as well as the mixing of the water column (Beadle, 1974, Talling, 1966; Newell, 1960). These meteorological characters directly influence the limnological characters.

The eutrophication status of the lake, which to a large extent depends on the levels of temperature, oxygen and nutrients and how they are distributed through the water column, is directly influenced by run-off and wind effect on mixing (Talling, 1966, Ochumba, 1995). Before the fish introductions (Chapter One), the lake lacked a permanent hypolimnion layer and was characterized by two cycles of stratification and mixing that corresponded to the long and short rains and the dry seasons; The oxycline was formed at about 50 m depth during stratification (Ochumba, 1995). In the late 1980s, the lake was severely deoxygenated with the layer between 50 m and 20 m subject to year-round anoxia (Ochumba, 1990). At the same time a fourfold increase in chlorophyll concentration and decrease in transparency was also reported (Hecky, 1993; Mugide, 1993; Ochumba, 1995) with a general decrease in the efficiency of energy transfer in the system (Ribbink, 1987; Reynolds *et al.*, 1995).

The current state of the stocks is very different from the past (Chapter One; Mkumbo *et al.*, 2002; Tumwebaze *et al.*, 2002). Attempts to assess the stocks without knowledge on the variability of some of the environmental parameters is almost impossible as they have direct or indirect effects to the stock sizes and distribution while influencing the life-history patterns (Laevastu & Favorite, 1988; Wootton, 1990). The main objective of this chapter is to investigate the changes in the climatic patterns and key environmental parameters as a basis for understanding the variations and fluctuations in the fishery and the stocks presented in the following chapters. It gives the patterns of fluctuations in some key parameters that occurred both in the atmospheric and aquatic environments of Lake Victoria during the Nile perch boom and the study period when a shift in the fisheries seemed to occur (Chapter Three). Meteorological data on rainfall, temperature and wind speed being of great use to fisheries science for making prognosis (Laevastu & Hayes, 1981) are summarized with trends over the last 20 years given. Limnological parameters on temperature, dissolved oxygen, chlorophyll *a* concentrations, turbidity and transparency measured during some surveys under the current study are presented and compared with the situation in the 1990s. The information is used to elucidate the spatial and temporal patterns of variation depicted in abundance and distribution of Nile perch (Chapter Four), as well as some of the reproductive aspects investigated (Chapter Five). The need to monitor the environmental parameters in conjunction with the overall changes in the Lake Victoria fisheries for management purposes is emphasized.

2.2 MATERIAL AND METHODS

2.2.1 Hydrographical factors

2.2.1.1 *Rainfall and atmospheric temperature*

Data on rainfall, wind speed and temperature recorded by the meteorological stations in Mara, Mwanza and Kagera were accessed from their zonal office in Mwanza. Monthly mean rainfall data (mm) plus maximum and minimum atmospheric temperature (°C) records were available from January 1980 to July 2001. These data were used to show seasonal patterns in the three regions (Mara, Mwanza and Kagera). The data were grouped for 1980 to 1986 just before the Nile perch boom, then 1987 to 1990 during the peak Nile perch explosion, 1991 to 1995 just before the declining period and 1996 to 2001 the period of overexploitation for the Nile perch fishery.

2.2.1.2 *Wind speed*

Frequencies of occurrence for winds in different speed categories were available, recorded in the mornings at 06.00 hr and at noon from 1990 to 1996 (records were done by the Meteriological offices in the three regions, data from 1996 to the current period were not available). These were used to investigate seasonal variations in occurrence of different wind speeds for the three regions over the period.

2.2.2 Limnological parameters

2.2.2.1 *Water temperature, dissolved oxygen, water conductivity and chlorophyll concentrations*

Water temperature, dissolved oxygen concentrations, water conductivity and chlorophyll concentrations were recorded using a SEABIRD-profiler. Measurement was done in every 15 by 15 nautical mile square where trawling was conducted for the months of July and November 2000 (The SEABIRD profiler was not available during the other bottom trawl cruises). In all four-hydroacoustic surveys, in February & August/September for 2000 and 2001 measurements were taken in every square within the cruising track. Coverage of the sampling sites in one of the hydroacoustic surveys is presented (Fig.2.1). Comparison was made between the dry and rainy seasons for data recorded in the Tanzania waters only and some profiles drawn by the SEABIRD-profiler are presented. Bathymetric changes were also investigated at 10 m depth intervals depending on the depth of the sampled square.

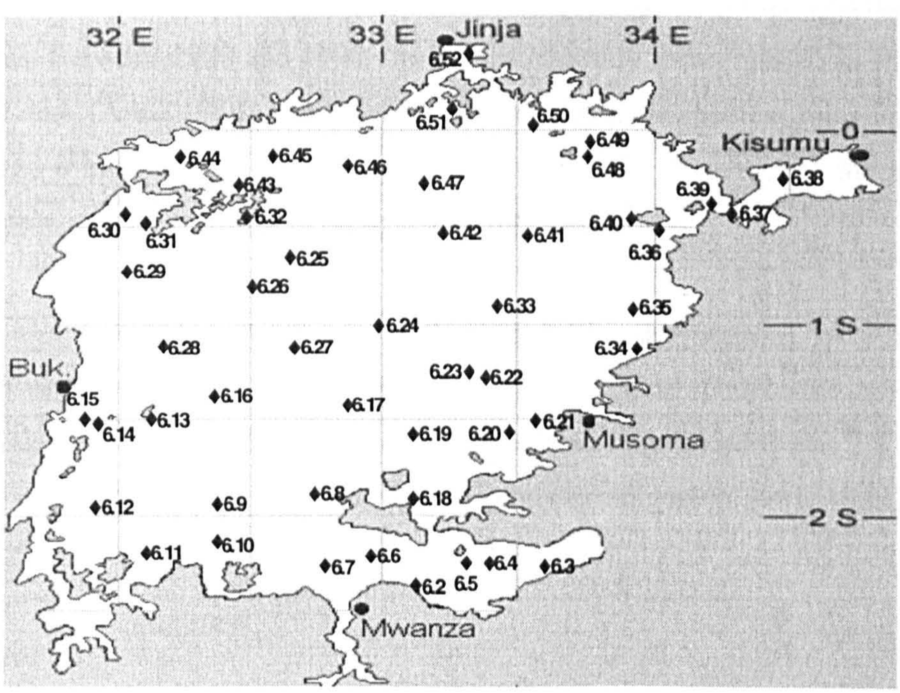


Figure 2.1 Map showing the coverage of the SEABIRD sampling sites during hydroacoustic surveys (used data is from the Tanzanian sector only)

2.2.2.2 *Water transparency*
Water transparency was recorded at every site where the SEABIRD profiler was set. It was measured to the nearest cm using a Secchi disk of 30-cm diameter. The measurements were correlated to the maximum depth of the given site.

2.3 Results

2.3.1 Rainfall patterns

2.3.1.1 *Spatial and temporal variations in mean monthly rainfall*

The same pattern of two rainy seasons (March - May and October - December) occurred for the three regions but with marked variations in the months of peak rainfall from year to year (Fig. 2.2a & b).

Generally the heavy rains were from March to May each year with the exception of 1983 and 1989 for Mwanza, 1991 for Mwanza and Mara, in 1997 for Mara and Kagera, and Mara in 2000. The Kagera region generally exhibited heavier rains and rather extended rain seasons with a more consistent pattern compared with the other two regions. Between 1980 and 1990, the highest monthly mean rainfall in Mwanza was 307.2 mm (April 1988), while Mara although with the poorest rains in some seasons, had a high rainfall of 398.8 mm in March 1981. Kagera had the highest monthly mean rainfall recorded in April 1988 of 873 mm.

Generally the months of June, July and August (the dry season) were almost completely dry for the Mwanza region and the Mara region. Unlike the other two regions, Kagera had no month without rain. The poorest rain recorded was 2.7 mm in July 1993 and it was less than 10 mm for June, July or August in 1981, 1988, 1990, 1993 and 1996 to 1999.

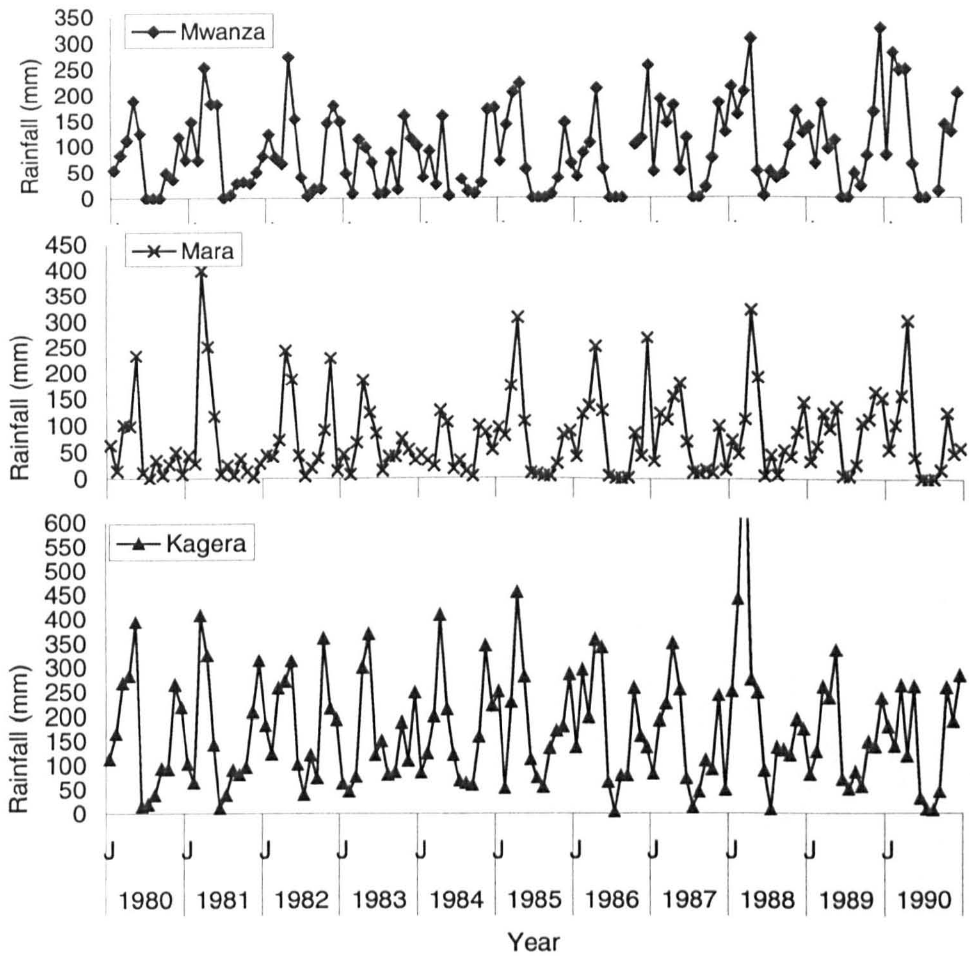


Figure 2.2a Seasonal variations in rainfall (mm per month) in the three Regions bordering Lake Victoria in Tanzania for the period 1980-1990 (data source: Mwanza Meteorological Zonal Office)

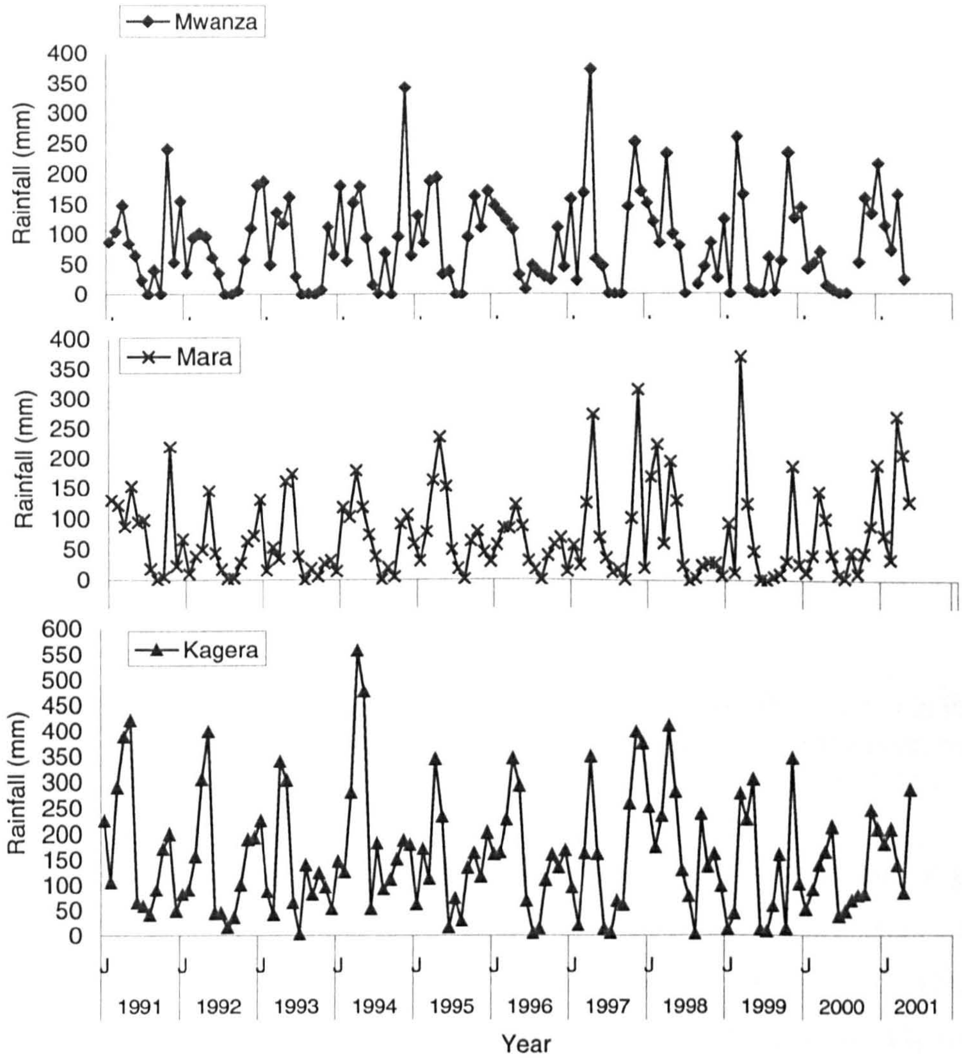


Figure 2.2b Seasonal variations in rainfall (mm per month) in the three Regions bordering Lake Victoria in Tanzania for the period 1991-2001 (data source: Mwanza Meteorological Zonal Office)

Total annual rainfall for the period 1980 to 2000 was greatest in Kagera followed by the Mwanza region while the Mara region received the lowest rainfall (Fig. 2.3). Peaks were recorded in 1988 with total annual rainfall of 2 943.7 mm for the Kagera region, 1 478.4 mm for the Mwanza region and 1 143.1 mm for the Mara region. A highly significant difference was found (two way ANOVA) in total annual rainfall between the years ($F_{0.05[20,40]} = 3.752$, $F_{crit.} = 1.838$; $P_{value} = 1.8E\text{-}4$) from 1980 to 2000, as well as between the three regions ($F_{0.05[2,40]} = 197.08$, $F_{crit.} = 3.2317$; $P_{value} = 1.94E\text{-}21$)

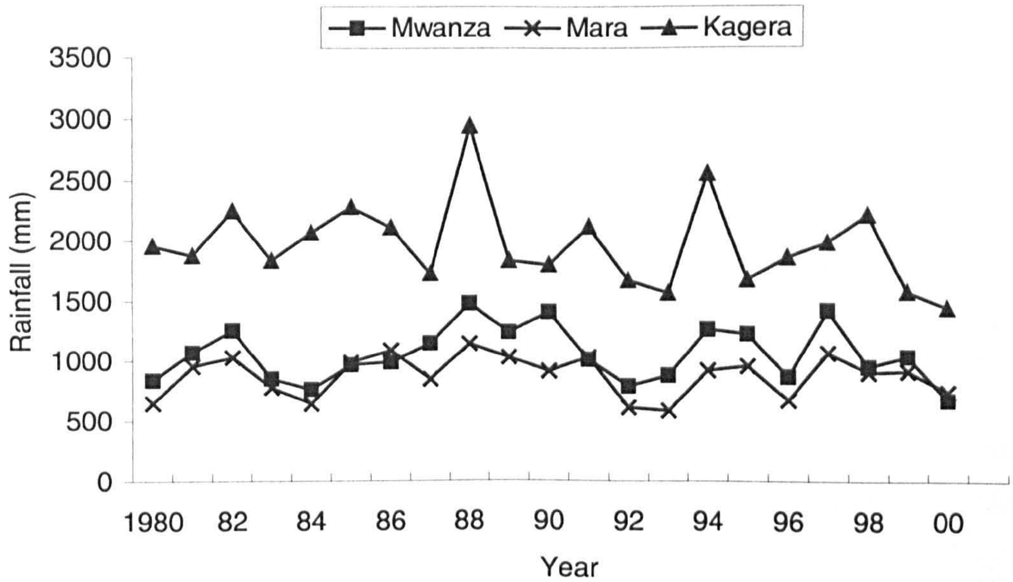


Figure 2.3 Variation in total annual rainfall for the period 1980 – 2000 in the three Regions Mwanza, Mara and Kagera, bordering Lake Victoria, Tanzanian waters.

For the period 1997 – 2001 a detailed comparison for the three regions is given (Fig. 2.4). Rainfall pattern for the three regions in March to May 1997 was similar with almost equal quantities in the Kagera and Mwanza regions and relatively low quantities in the Mara region. Unlike the other years, 1998 had relatively more rain in January & February (224.4 – 251.6 mm) in the Mara and Kagera regions while November was almost dry in the Mwanza and Mara regions (less than 100 mm). Kagera had earlier rains starting September for 1998 and 1999, but October 1999 was almost dry in all the three regions. The pattern changed in 1999 with the heaviest rains (370.9 mm) in March in the Mara region and 306.2 mm in April in the Kagera region. Mwanza had similar rainfall for March (259.7 mm) and November (232.7 mm).

The year 2000 had relatively low rainfall; with less than 150 mm for March and April and 159 mm in November in the Mwanza region while the heaviest for the Mara region was 190 mm in December and 246.3 mm in Kagera in November. Unlike the other years, January 2001 had heavier rainfall than April for Mwanza (215 mm vs. 164.5 mm) but for the Mara region it was only 74 mm. Kagera also had relatively heavy rains in January (181.4 mm) but the peak was in May (287.7 mm).

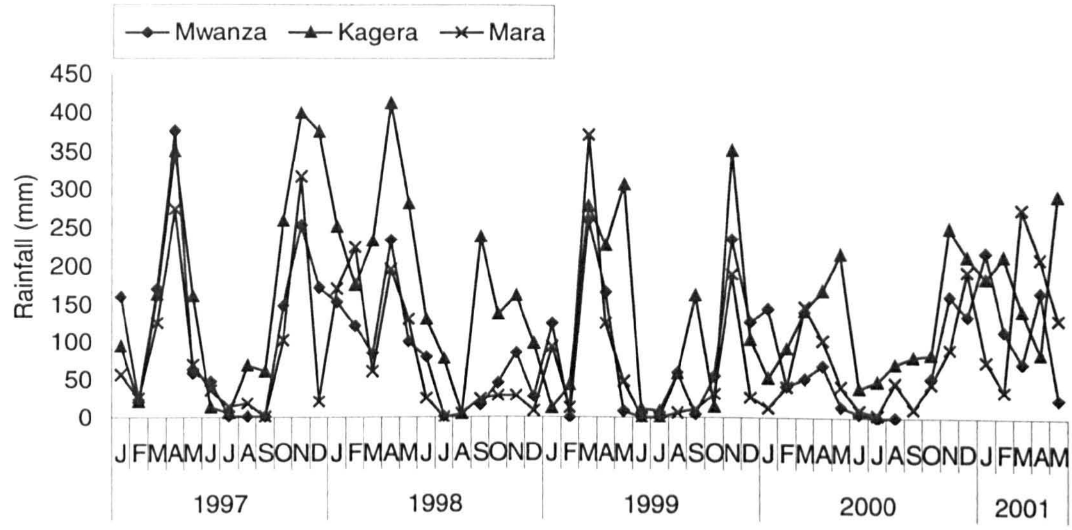


Figure 2.4 Variation in mean monthly rainfall (mm) for the three regions in the years 1997 - 2001 (data source: Mwanza Meteorological Zonal Office)

2.3.1.2 *Periodic variations in mean annual rainfall*

Annual means with 95% confidence limits of rainfall in the different years grouped above were calculated (Fig.2.5 & Appendix 1).

Highly significant variation was found (two way ANOVA) for the different periods between regions ($F_{0.05[2,6]}$ = *268.1*, F_{crit} = *5.14*; P_{value} = *1.36E-06*) but with less variation between the periods ($F_{0.05[3,6]}$ = *6.143*, F_{crit} = *4.76*; P_{value} = *0.029*). The Mara region had the lowest average annual rainfalls, ranging from 818.9±256.3 mm in 1991-1995 to a maximum mean of 1 005.3±151.2 mm in 1980-1985. Mwanza had much higher average rainfalls ranging from 962.1±190.9 mm in 1980-1985 to 1 252.9±243.8 mm in 1986-1990. The minimum mean annual rainfall for Kagera was even higher than the maximum rainfall for the other regions, ranging from 1 806.3±379.5 mm in 1996-2000 to 2 080±626.1 mm in 1986-1990.

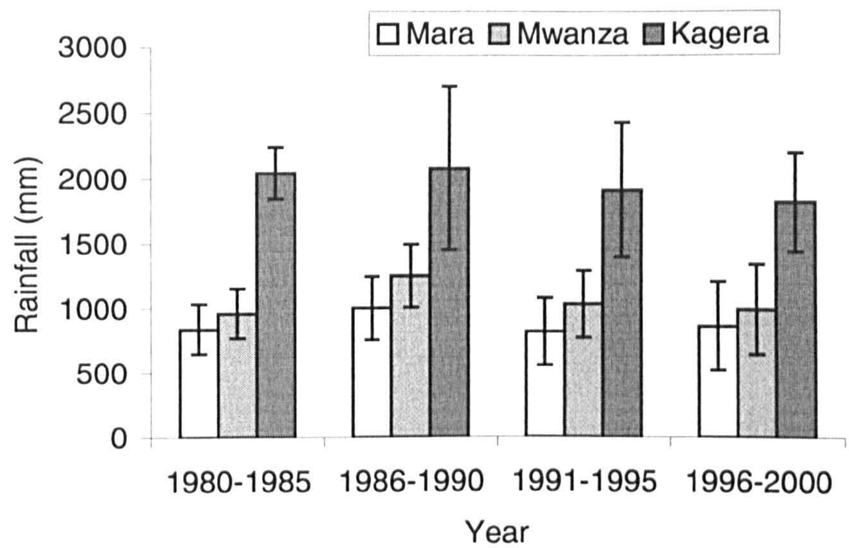


Figure 2.5 Mean annual rainfall (mm) for four different periods in Mara, Mwanza and Kagera (95% C.L. attached)

2.3.1.3 *Periodic variations in mean monthly rainfall*

Monthly means for different periods of five-year intervals illustrate the similarity in patterns of variation and the existence of the main rain season between March and May in all three regions (Fig. 2.6), which explains the increase in lake level in May and June (Chapter One; Temple, 1964). Mwanza had similar monthly rainfall for April and December and a relatively wet February for the period 1986-1990 compared with the other periods and areas. The Mwanza region had wet Januarys for the period 1996-2001 but much less rains in March compared with the Mara region.

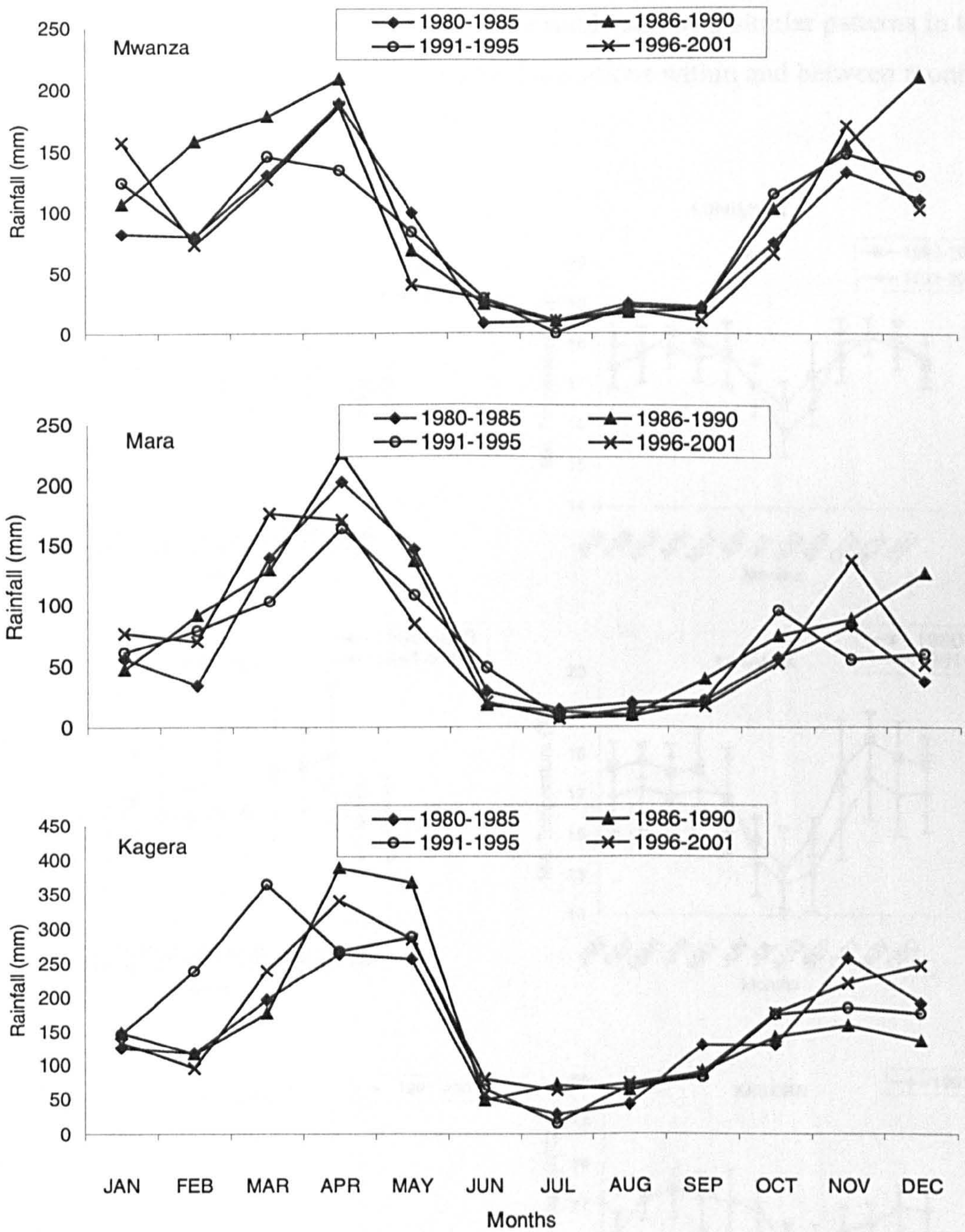


Figure 2.6 Variation in mean monthly rainfall in the three Regions for the four periods: 1980-1985, 1986-1990, 1991-1995 & 1996-2001 (data source: Mwanza Meteorological Zonal Office)

2.3.2 Fluctuations in atmospheric temperatures

Atmospheric temperatures appeared to be more stable and with similar patterns in the Mara and Kagera regions while considerable fluctuations within and between months occurred in the Mwanza region (Fig. 2.7).

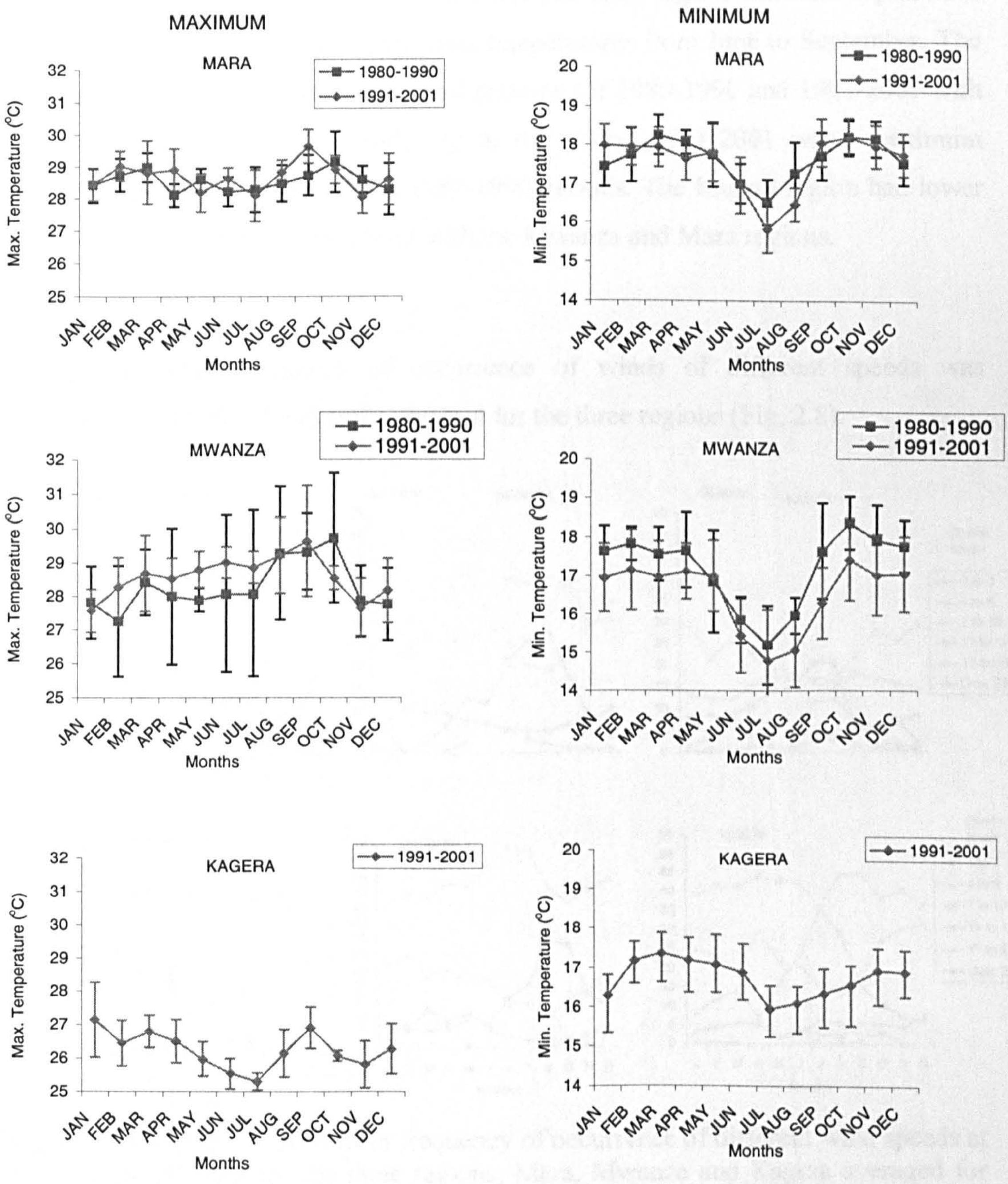


Figure 2.7 Variations in Maximum & Minimum atmospheric temperatures for Mara (1980-1990 & 1991-2001), Mwanza (1982-1990 & 1991-2001) and Kagera (1991-2001) (95% C.L. attached.).

The Mara region had minimum drop of the maximum atmospheric temperatures in May to August and a slight increase in September to October while the drop in Kagera was greater in January and September. In the Mwanza region the increase was from August to October and the drop from November to January. Minimum temperatures showed two distinctive patterns: relatively high minimum temperatures from October to May, and low minimum temperatures from June to September. The two grouping indicated similar seasonal patterns for 1980-1990 and 1991-2001 with the exception of May, June and July in the period 1991-2001 when maximum temperatures were higher than the 1980-1990 periods. The Kagera region had lower atmospheric temperatures compared with the Mwanza and Mara regions.

2.3.3 Variations in wind speed

Average monthly frequency of occurrence of winds of different speeds was calculated for 1990 to 1996 and compared for the three regions (Fig. 2.8).

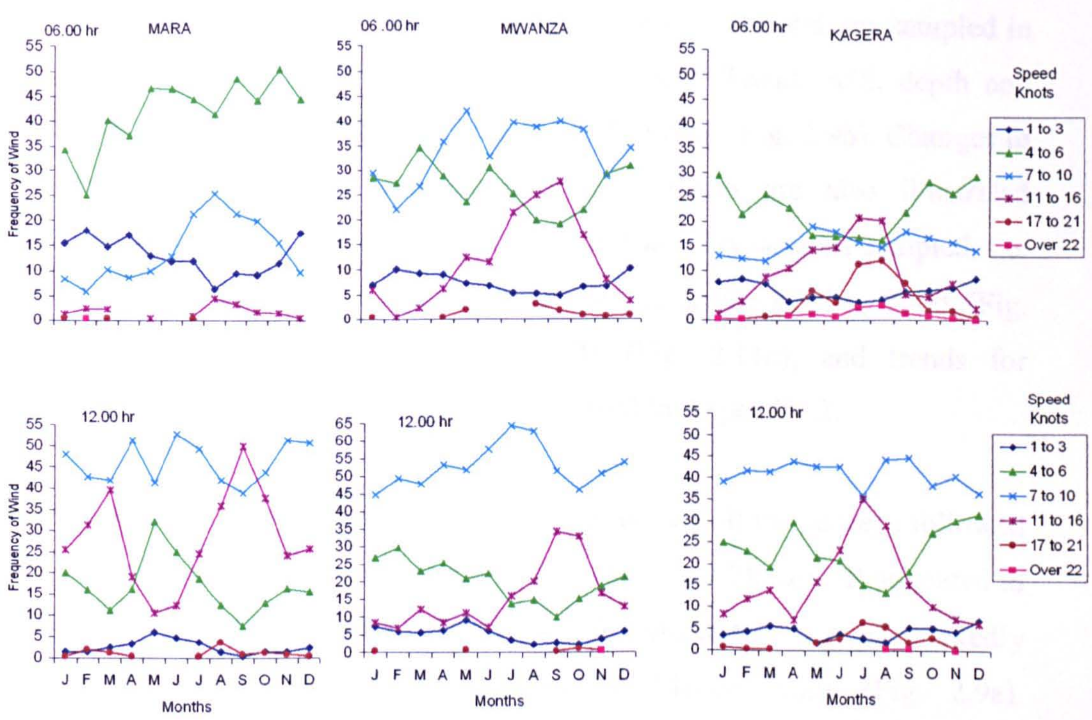


Figure 2.8 Seasonal variations in frequency of occurrence of different wind speeds at 06.00hr and 12.00hr for the three regions, Mara, Mwanza and Kagera averaged for the years 1990-1996 (data source: Mwanza Meteorological Zonal Office)

The most frequent winds in the Mara region were in the range 4-6 knots in the mornings while afternoons were in the range 7-10 knot. Strong winds became frequent in February and March, and July to November. Stronger winds occurred in the Mwanza region compared with Mara. The most frequent winds were of 7 to 10 knots except in January to March when winds of 4 to 6 knots were more frequent. During June to October winds of 11 to 16 knots became frequent in the mornings as well as afternoons. In the Kagera region, winds with the speeds of 11 to 16 knots were more frequent in the mornings in May to September while 17 to 21 knots and the >22 knots winds increased in the frequency of occurrence from June to September. Afternoons were relatively with strong winds; about 40 % of afternoon winds were in the range 7 to 10 knots through out the year.

2.3.4 Variation of limnological parameters in the Tanzanian waters of Lake Victoria

2.3.4.1 *Seasonal variations in water temperature, dissolved oxygen, water conductivity and chlorophyll with depth*

Mean water temperature (°C), mean oxygen concentrations (mg L^{-1}), mean water conductivity (µS cm^{-1}) and mean chlorophyll concentration (µg L^{-1}) with 95% confidence limits were calculated at 10 m depth intervals for the stations sampled in the three zones separately (refer Map: Fig.1.2 for zones). Trends with depth and season are illustrated for temperatures (Fig. 2.9a) and oxygen (Fig. 2.9b). Changes in mean temperature and oxygen concentrations with depth are also illustrated (Fig.2.10). Offshore profiles are compared for the wet and dry seasons sampled, i.e. November & July 2000 (Fig. 2.11a), February & August/September 2000 (Fig. 2.11b) and February & August/September 2001 (Fig. 2.11c), and trends for conductivity and chlorophyll concentration summarized in Appendix 2.

Zone A (Mwanza) had relatively higher temperatures during all the surveys followed by zone B (Mara) and then zone C (Kagera) (refer Map: Fig.1.2). Zone B appeared to have more stable temperatures while zone A and C temperatures varied markedly from station to station, as indicated by the confidence limits (Fig. 2.9a). Temperatures were almost the same from surface to bottom in shallow waters while in deep waters the difference ranged from 0.6 ^{0}C in August/September to 1.62 ^{0}C in February (Fig. 2.9a). February and November had the highest temperatures with marked differences between surface and bottom temperatures. The same trend applied for oxygen concentration. Shallow inshore waters of less than 30 m deep had high oxygen concentrations in all the sampling periods, ranging from 6.6-7.8 mg L^{-1}, while the offshore-water oxygen concentrations varied from as high as 10.3 mg L^{-1} in surface waters in August to as low as 0.28 mg L^{-1} in the bottom waters during February. The lake appeared well mixed in August/September 2000 compared with the same period the following year. Nevertheless, temperature in the Tanzanian waters of the lake varied from a mean of 24.85±0.26°C to 23.95±0.21°C for surface and bottom waters respectively (Fig. 2.10a) with an overall mean of 24.28±0.26°C.

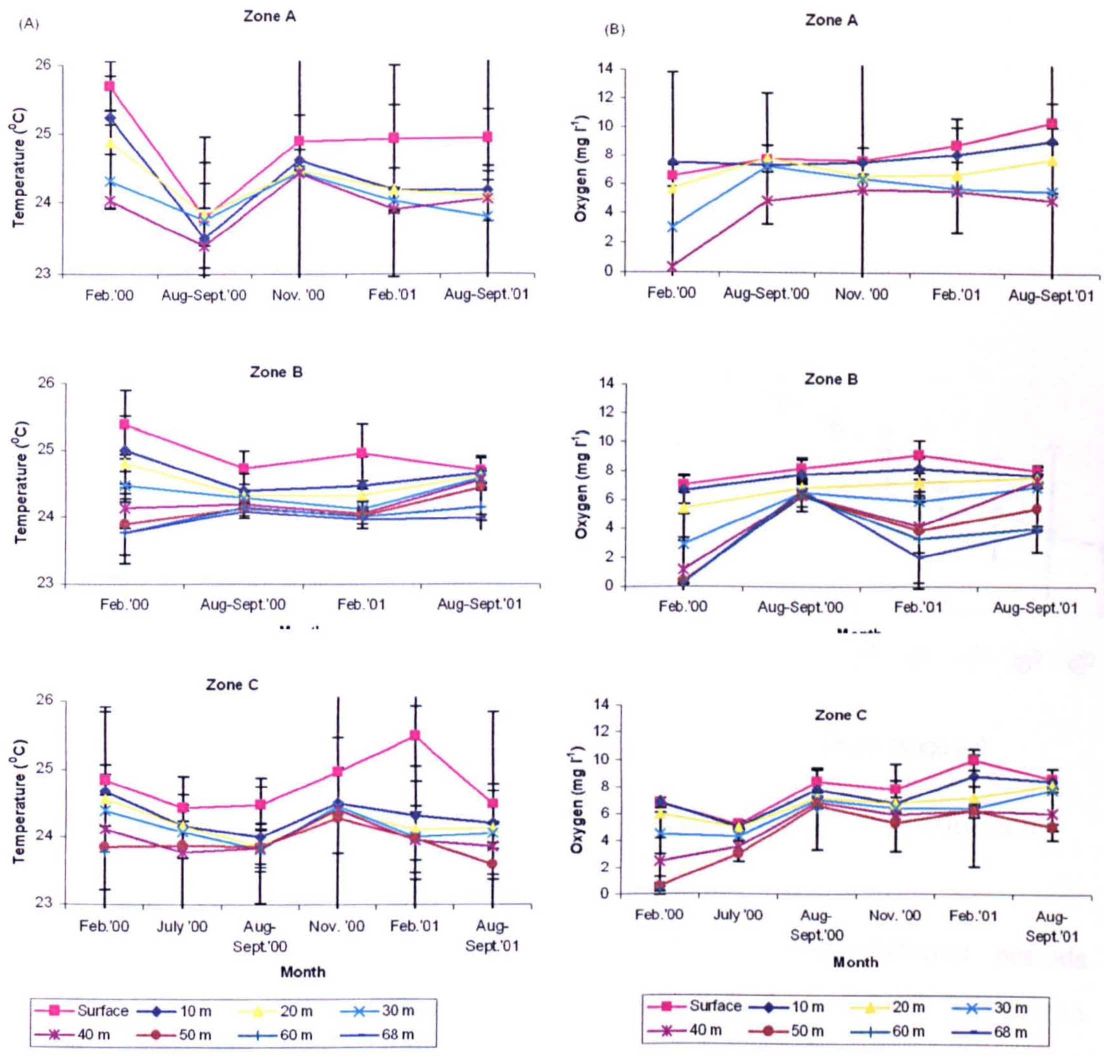


Figure 2.9 Seasonal variation in mean water temperature (a) and mean dissolved oxygen (b) at 10 m depth intervals for the sampled stations in zone A, B, & C , with 95% C.L. attached (note: zone A was not sampled in July 2000, while zone B was not sampled in both July and November 2000)

Mean oxygen concentration varied from 10.4 mg L^{-1} for the surface waters in zone A during August/September to 0.28 mg L^{-1} at 68 m deep in Zone B during February. Nevertheless oxygen concentrations as high as 6.69 mg L^{-1} were recorded at 68 m depth in August/September 2000 for zone B and 6.38 mg L^{-1} in zone C (Fig.2.9b).

With the exception of February 2000, zone A had high mean oxygen concentrations above 4.85 mg L^{-1} at 40 m deep during the sampling periods, while zone C had mean oxygen concentrations above 5 mg L^{-1} as deep as 60 m except for February and July 2000 (Fig. 2.9b).

Changes of oxygen concentrations with depth were marked in deep waters while in shallow waters minimal variation occurred. Mean concentrations in the waters sampled varied from 8.02±0.73 mg L^{-1} in the surface waters to 3.2±4.36 mg L^{-1} in the bottom waters at 68 m deep, with an overall mean of 5.49±1.57 mg L^{-1} (Fig. 2.10b).

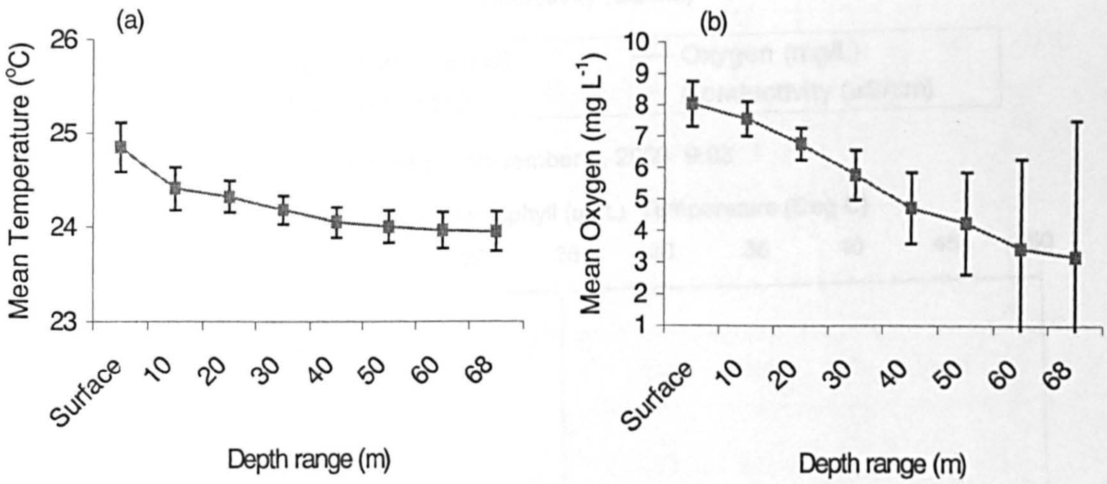
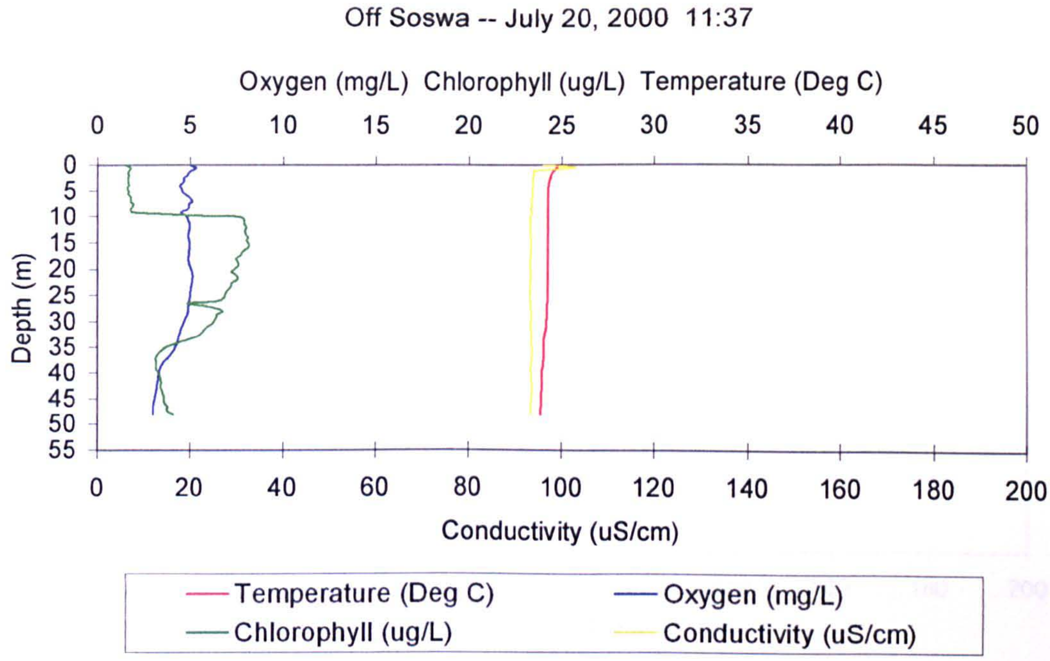


Figure 2.10 Variation of mean Temperatures (a) and mean Oxygen concentrations (b) with depth in the Tanzanian waters of Lake Victoria

Offshore oxygen-temperature profiles varied markedly in the different periods sampled (Fig. 2.11a-c). July had lower temperatures (24.3°C to 23.9°C, surface to bottom) and oxygen concentrations (4.4 mg L^{-1} to 3.8 mg L^{-1}, surface to bottom) compared with November (24.6°C to 24.3°C & 6.6 mg L^{-1} to 5.2 mg L^{-1}, temperature and oxygen concentrations respectively) (Fig. 2.11a). High evaporation and higher



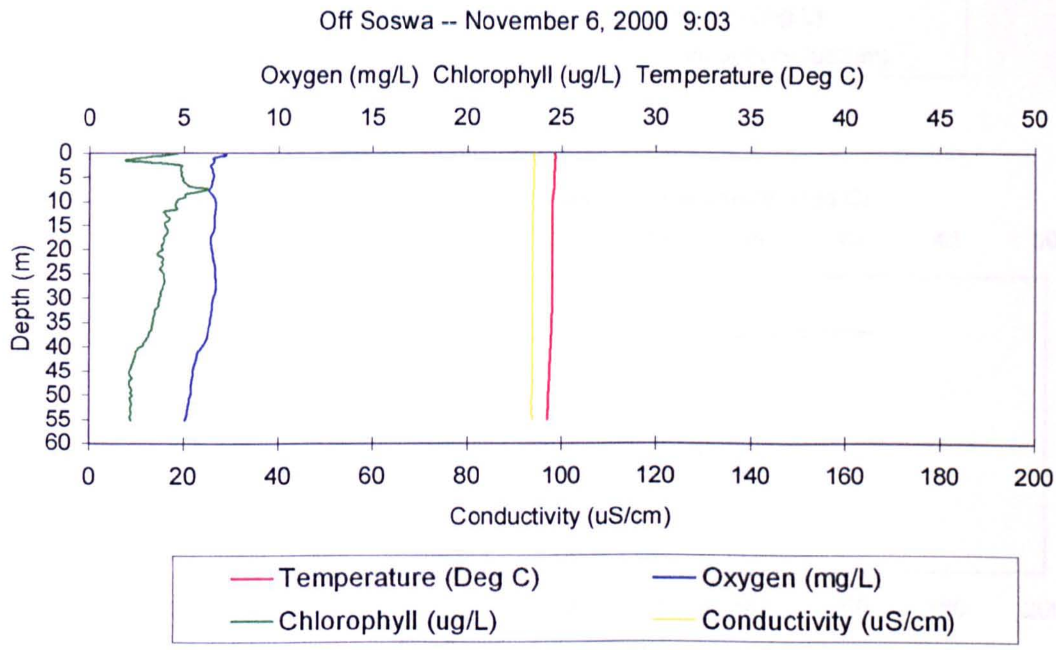
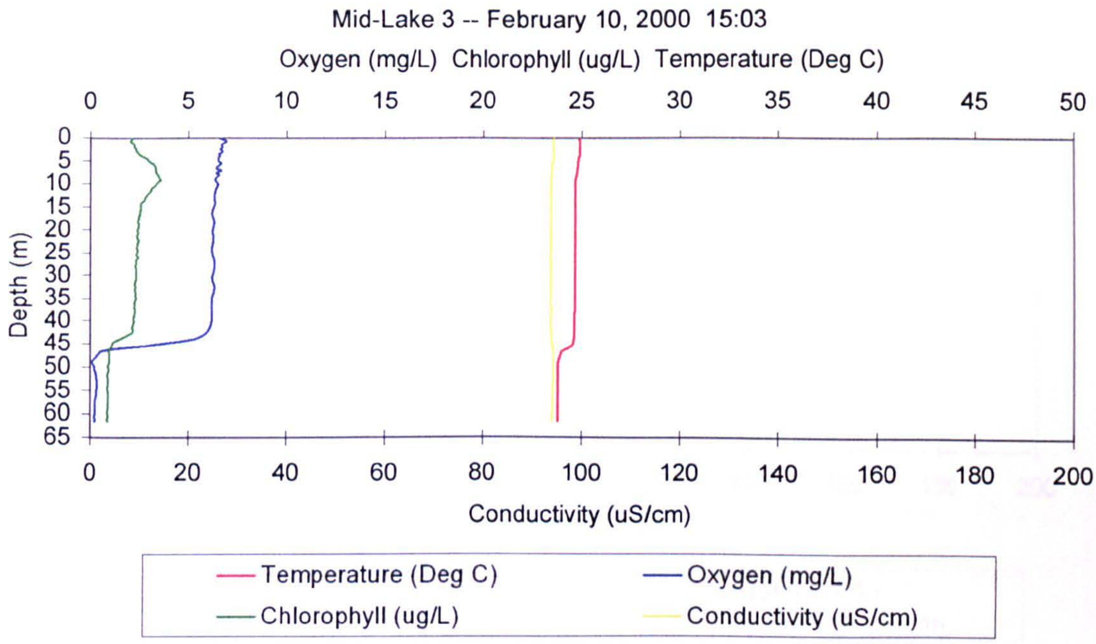


Figure 2.11a Comparison of variations in temperature, oxygen, conductivity and chlorophyll concentrations in offshore deep waters sampled in July 2000 and November 2000 (site 6.9 Map 2.1) (source: LVFRP SEABIRD profiles)

photosynthesis rate in July compared with November, probably explains the difference. In February 2000, oxygen concentrations of 6.72 mg L^{-1} found in the surface waters dropped to 0.26 mg L^{-1} in the bottom waters at 61.5 m, with an oxycline/thermocline layer formed at 45 m depth. In August high oxygen concentrations were found even in the bottom waters. There was a decrease from 11.3 mg L^{-1} in surface waters to 6.3 mg L^{-1} in the bottom waters, probably explained by the mixing of the water column, although an oxycline was observed at 12 m depth (Fig. 2.11b).



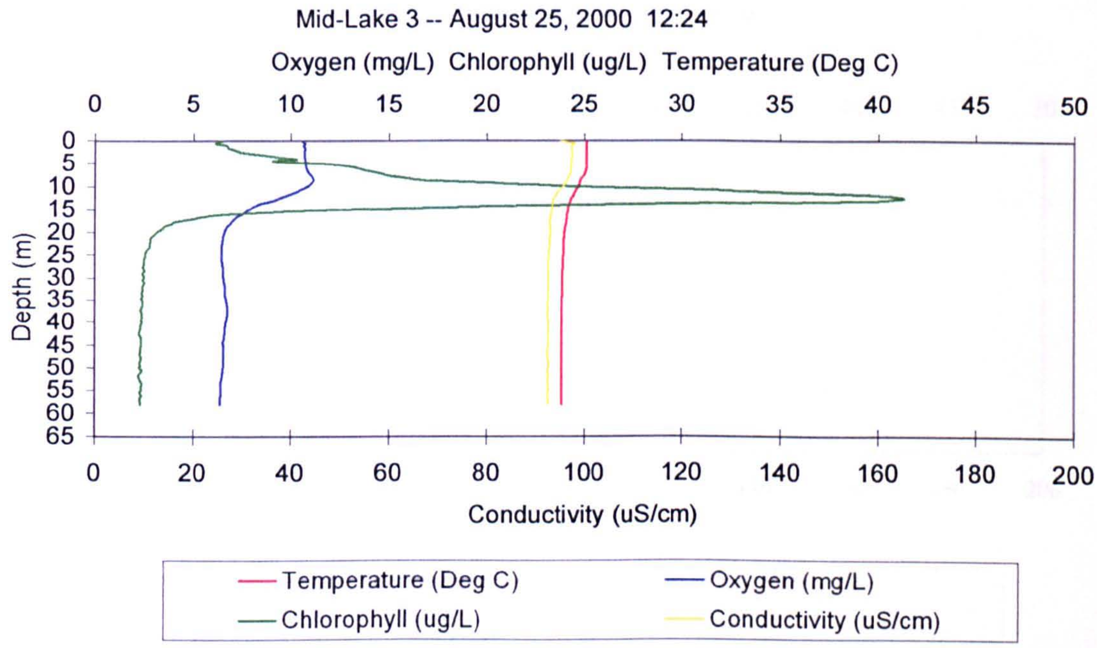
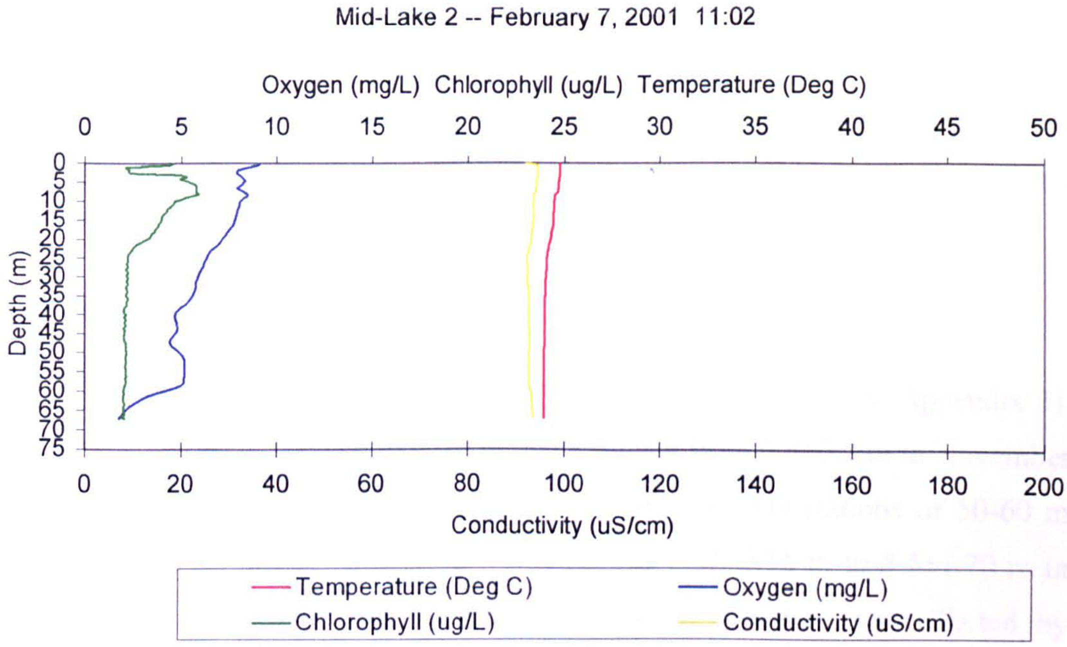


Figure 2.11b Comparison of variations in temperature, oxygen, conductivity and chlorophyll concentrations in offshore deep waters sampled in February 2000 and August/September 2000 (Map site 6.23 Fig 2.1)(source: LVFRP SEABIRD profiles)

Similar patterns were observed for February and August 2001, but with the oxycline much deeper. In February (Fig.2.11c), the oxygen concentration dropped from 7.9 mg L^{-1} in the surface waters to 2.06 mg L^{-1}, with an oxycline formed at 60 m depth.

Oxygen concentrations in August were higher in the bottom waters (3.8 mg L^{-1} at 67 m depth), and the thermocline/oxycline layer formed at 55 m depth.



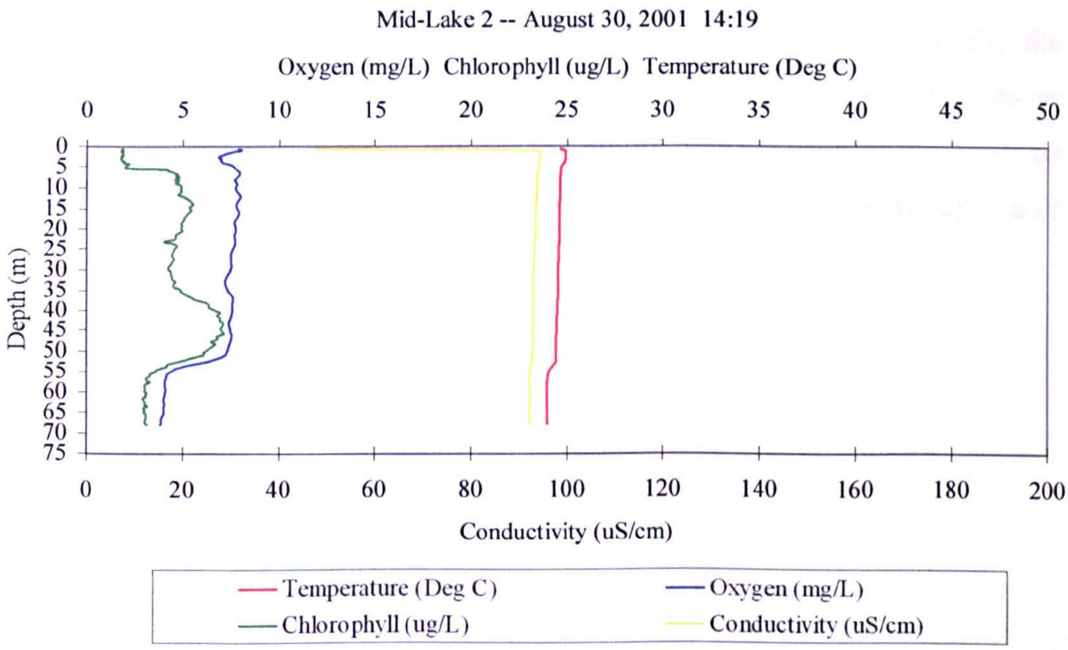


Figure 2.11C Comparison of variations in Temperature, Oxygen, Conductivity and Chlorophyll concentrations in shallow inshore waters and offshore deep waters sampled in February 2001 and August/September 2000 (Map site 6.16 Fig 2.1)(source: LVFRP SEABIRD profiles)

Mean conductivity ranged from 97.2 μS cm^{-1} for Zone B surface waters in February 2000 to 80.4 μS cm^{-1} for Zone C surface waters in February 2001, with the exception of August/September 2001 when it dropped to 53.0, 54.6 & 55.7 μS cm^{-1} for Zone C, B, and A surface waters respectively (Appendix 2).

Mean chlorophyll concentration was high at 10 to 30 m depths, with highest mean values of 26.3-μg L^{-1} at 10 m depth in Zone A during August/September 2000 (Appendix 2). This was when temperature differences from the surface to the bottom were negligible and mean oxygen concentrations highest. Phytoplankton production depends on nutrient availability, oxygen and light. Although surface waters (less than 10 m) were rich in oxygen, the intense solar radiation limits phytoplankton growth resulting to low chlorophyll concentrations. Light was probably the limiting factor for the low levels of chlorophyll concentration in waters deeper than 30 m.

2.3.4.2 *Water transparency*

Transparency increased with depth of the water column (Fig. 2.12 & Appendix 3). Secchi disk readings in stations of 5-10 m depth ranged from 0.8±0.3 m in November to 1.9±1.02 m in August/September, while in offshore waters stations of 50-60 m depth, the Secchi disk readings during February was 3.27±0.36 m to 5.5±1.70 m in August/September. Transparency in the inshore shallow waters was affected by rainfall and run-offs during November. Transparency in February of the two years had relatively low Secchi disk readings even in the offshore waters. This was also the time of thermal stratification (Fig. 2.9a & 2. 11), with low Oxygen concentrations as well. Algae blooms could possibly explain the limited transparency in the water as high abundances of blue green algae were recorded during same period (Akiyama *et al.*, 1977).

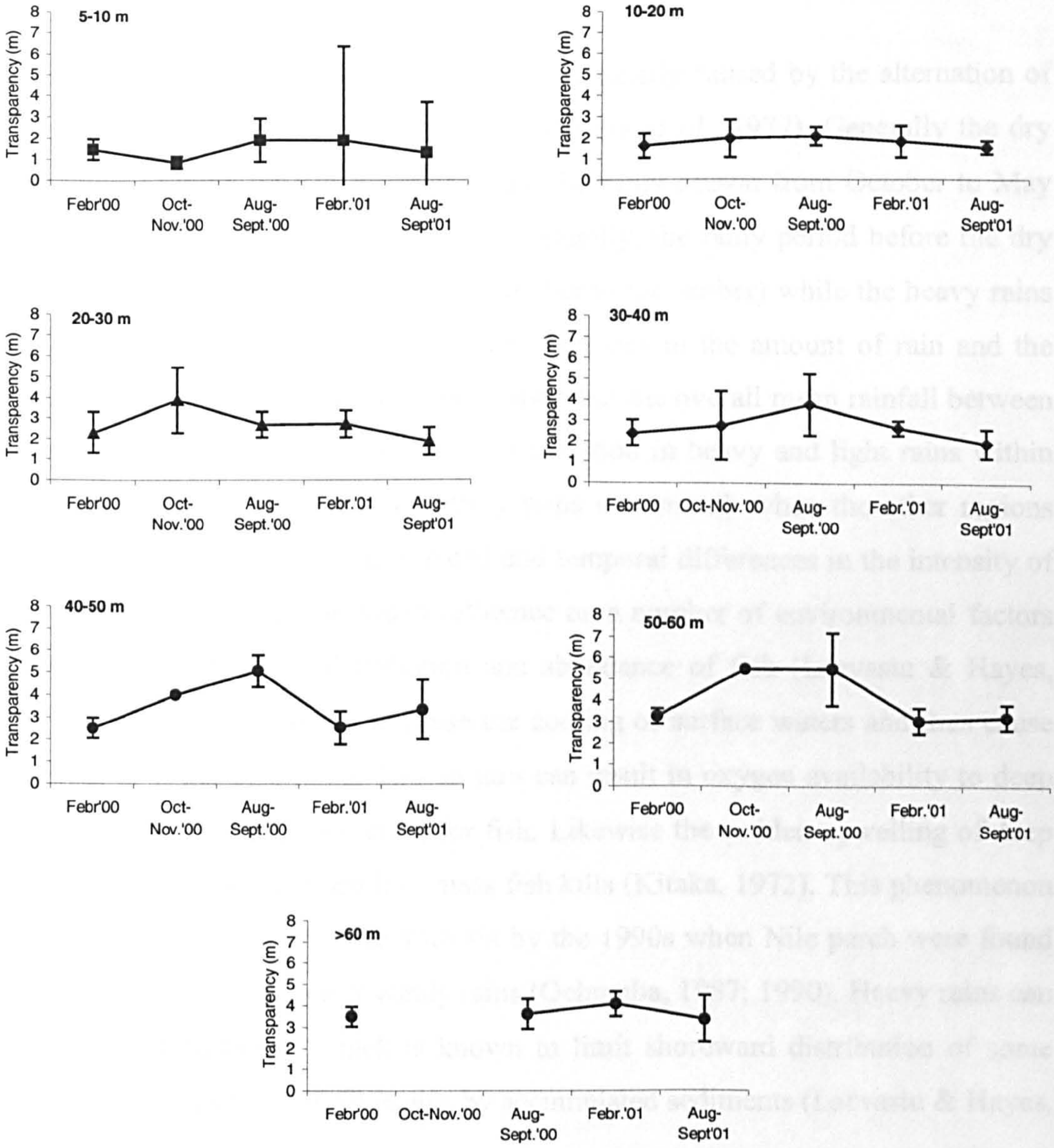


Figure 2.12 Seasonal variation in water transparency (Secchi disk depth in m) at different water column depths sampled for February, Oct.-Nov. & Aug-Sept 2000 and February & Aug-Sept. 2001 averaged for 10 m depth range from inshore to offshore waters.

2.4 DISCUSSION

Lake Victoria meteorological characteristics are mainly caused by the alternation of the dry and rainy seasons (Talling, 1966; Akiyama *et al.*, 1977). Generally the dry season extends from June to September and the rainy season from October to May but with a dry spell in January/February. Generally, the rainy period before the dry spell is characterized by light rains (i.e. October to December) while the heavy rains are from March to May. There have been variations in the amount of rain and the duration in different months of the rainy season but the overall mean rainfall between 1980 and 2001 differed little. There was a variation in heavy and light rains within the regions, a region could get the heavy rains in a month when the other regions were getting the light rains. These spatial and temporal differences in the intensity of rains are known to have a profound influence on a number of environmental factors that in turn determine the distribution and abundance of fish (Laevastu & Hayes, 1981). Heavy rains are known to cause the cooling of surface waters and thus cause movement of water or mixing. This in turn can result in oxygen availability to deep waters and thus a wider distribution for fish. Likewise the sudden upwelling of deep waters with no oxygen can result to mass fish kills (Kitaka, 1972). This phenomenon was commonly reported in Lake Victoria by the 1990s when Nile perch were found dead on the surface after heavy windy rains (Ochumba, 1987; 1990). Heavy rains can also cause high turbidity, which is known to limit shoreward distribution of some fish, avoiding erosion of gill filaments by accumulated sediments (Laevastu & Hayes, 1981).

Atmospheric temperature, and wind speed and direction have direct influence on rainfall, which in-turn both influences the hydrographical characteristics. Stratification is known to built-up during the rainy season (Fish, 1957; Talling, 1966; Akiyama *et al.*, 1977). Although the annual stratification periods were reported to last longer, and the lower part of the water column in areas of more than 50 m deep to be permanently hypoxic (Ochumba & Kibaara, 1989; Hecky & Bugenyi, 1992; Kaufman, 1992; Gophen *et al.*, 1993; Hecky, 1993; Mugide, 1993; Hecky *et al.*, 1994; Ochumba, 1995), the current study revealed mean oxygen concentrations above 3 mg L^{-1} at 60 m deep even during February and November, and as high as 6.69 mg L^{-1} at 68 m deep during June and August/September. The problem of Lake Victoria being devoid of life in waters below 50 m and an extended stratified period reported for the early 1990s (Ochumba, 1995) seems to have diminished. During the current study complete thermal stratification was recorded only in November 2000 when the thermocline and oxycline were formed at about 40 m deep. Temperatures dropped from 25.6 °C in the surface waters to 23.8 °C at 40 m and oxygen dropped to less than 1.0 mg L^{-1}, especially in zones B and C. An almost complete isotherm was noticed only for zone A in August/September 2000, when temperatures dropped from 23.8 to 23.4°C only. For the rest of the sampled times there was marked variation possibly influenced by the local winds. Fish can perceive water temperature changes as small as 0.1 °C (Laevastu & Hayes, 1981). Localised changes in water temperature and oxygen concentrations in Lake Victoria can possibly help explain the spatial distribution pattern in Nile perch abundances (see Chapter Four for details).

The effects of general global climate warming in East Africa (Hastenrath & Kruss, 1992) reported to influence the hypolimnion water temperatures (Ochumba, 1995) was also observed in this study. Water temperatures as low as 23.5 °C observed for deep waters (Graham, 1927; Worthington, 1930; Fish, 1957; Talling, 1966) were recorded only during thermal stratification of the water column.

The impact of nutrient loading in Lake Victoria and the effects of eutrophication have been of major concern (Chapter One; Ochumba & Kibaara, 1989; Hecky & Bugenyi, 1992; Kaufman, 1992; Gophen *et al.*, 1993; Hecky, 1993; Mugide, 1993; Hecky *et al.*, 1994; Ochumba, 1995). Blooming of phytoplankton (*Anabaena* and *Microcystis*) occurred in inshore waters in November/December and January/February just after the rains (Akiyama *et al.*, 1977; Talling, 1966). This could explain the low transparency recorded in the shallow waters during that time but wind-induced suspension of bottom deposit into the water column also cause low transparency (Wanink, 1998; Wanink & Kashindye, 1998). Transparency is known to fluctuate temporally and spatially due to differences in plankton density and can be significantly reduced during algal blooms (Ochumba & Kibaara, 1989). The euphotic zone (the depth at which photosynthesis takes place) as observed by Secchi disk readings, decreased from 7-8 m in 1928 (Worthington, 1930) to 1.3-3 m in the 1990s (Mugidde, 1993). Akiyama *et al.* (1977) reported Secchi disk readings of 1.1-1.9 m at a depth of 8 m in Mwanza Gulf, while van Oijen *et al.* (1981) recorded 1.8-2.5 m readings at almost the same station. The current Secchi disk reading of 0.8-1.9 at a water column depth of 5-10 m was not significantly different from the above records.

Nevertheless offshore readings of 1.9-5.5 m at 60 m water column depth differed from Worthington's (1930) readings of 7.3-7.9 of 1927 for the same open waters. However, the current readings were much higher than recorded by Mugidde (1993) of 1.3-3 m in open waters and the average transparency of 0.54 m recorded in 1987 & 1988 in shallow waters of Mwanza Gulf (Wanink & Kashindye, 1998). It is possible the 1990s eutrophic state of the lake is slowly shifting back. However since Secchi disk reading is very subjective and varies largely over the year and time of sampling while influenced by local winds and rainfall, phytoplankton production or cloud cover (Wanink & Kashindye, 1998), the reported changes needs further work for confirmation of the changes. Water transparency is reported to be temporary high during the dry season (Witte *et al.*, 1999). Standardization of sampling time, sites and duration is recommended for future monitoring to make data comparable with previous studies.

The current ecosystem of Lake Victoria is considered unstable as changes in the flora and fauna are still taking place (Witte *et al.*, 1995a). The three main commercial species; Nile perch, *Rastrineobola argentea*, and *Oreochromis niloticus* have changed in abundance over the years after the Nile perch boom (Ogutu-Ohwayo, 1995; Pitcher & Bundy, 1995; Villanueva & Moreau, 2002; Mkumbo *et al.*, 2002; Chapter Four). Current catch statistics reveal the zooplankton feeder *Rastrineobola argentea* becoming most abundant in the fisheries of the lake (Chapter Three). The inter-linking of different species through the food web (Chapter Five) very much depends on the abundance and success of each species and every trophic level in the food web. The potential yield of a fishery in any area depends largely on the level of primary productivity and the efficiency with which the primary productivity is converted to fish production through the food chains (Cushing, 1975; King, 1995; Turner, 1996). The success of the introduced species in Lake Victoria, particularly the Nile perch, must have largely depended on the previous productivity efficiency in the ecosystem. With the diverse trophic specialities in the ecosystem, and especially with the haplochromines, energy transfer from primary production to higher trophic level was complete through long food chains. Nile perch being the top predator benefited by preying at different levels in the food web. The algae blooms and the eutrophication with decreased water transparency and hypolimnetic deoxygenation, which characterized the hydrographical environment of Lake Victoria during the Nile perch boom, indicated a serious inefficiency in the ecosystem productivity. Energy generated at phytoplankton level was no longer transferred to the higher levels in the food chain due to reduced abundances of phytoplantivores and detritivores through predation by Nile perch. The current hydrographical characteristics in the lake slightly differ to those observed during the Nile perch boom. Concurrently a decrease in Nile perch with increase in *Rastrineobola*, and haplochromines as well as some of the endemic species, such as *Brycinus*, *Clarias* and *Synodontis* (Chapter Three), were observed. Is over-fishing of Nile perch the only cause of the recovery of the other species? How far will the recovery go and how far will it affect the hydrographical characteristics, and vice-versa, and thus the productivity and stability in the ecosystem?

However, studies on palaeolimnological record preserved in offshore sediments of Lake Victoria (Verschuren *et al.*, 2002) showed that increases in phytoplankton production developed from the 1930s and parallels human population growth and agricultural activity in the Lake Victoria drainage basin. The eutrophication problem in the lake was therefore a consequence of excess nutrient loading resulting from deforestation and intensified agriculture (Hecky & Bugenyi, 1992; Scheren *et al.*, 2000), which coincided with the increase of Nile perch and the declining of haplochromines. The current decline in the Nile perch stock may have caused to the present increase of haplochromines (Witte *et al.*, 2000), the two being causally related in prey-predator relationship. However, the eutrophication-induced loss of deep-water oxygen, which started in the early 1960s, could have also contributed to the collapse of the haplochromines in the 1980s (Verschuren *et al.*, 2002) although predation by Nile perch is believed to have been the key factor (Witte *et al.*, 1992b). Reduction in water transparency is also considered as a possible explanation for the disappearance of some haplochromines which vision is important for reproductive behaviour (Seehausen *et al.*, 1997; Witte *et al.*, 2000).

Continuous monitoring of hydrographical parameters concurrently with the fish stocks is crucial for understanding the dynamics of the ecosystem. This will also help isolate the effect of fishing on the stocks and thus formulation of any management regulation. (Sometimes fishing effort is blamed for changes in the fishing stocks, which are heavily influenced by environmental factors, e.g. the collapse of the herring stocks in the NW Atlantic in the 1967 due to recruitment failure influenced by environment (Laevastu, 1993; Laevastu & Favorite, 1988)).

2.5 Summary

The meteorological characteristics of the lake basin exemplified by the dry and wet seasons, which in-turn influences the period of thermal stratification and the mixing of the lake, determines the variations in any seasonal patterns observed in the productivity of the lake as well as abundances and distribution of fish stocks. Data recorded by the Meteriological offices in the three regions surrounding Lake Victoria in the Tanzanian side were accessed from the Zonal office at Mwanza city. Rainfall data from January 1980 to June 2001 gave a simillar pattern of a wet season from October to May but with a dry spell in December/January or February. Spatial differences were observed on the amount of rain received in different months. Kagera region received the highest rains (1964.11±160.90 mm $year^{-1}$) followed by Mwanza (1053±105.25 mm $year^{-1}$) and then Mara (879.96±78.11 mm $year^{-1}$).

Similar seasonal patterns in atmospheric temperatures were also depicted over the years (1980-2001). Kagera and Mara region appeared to have more stable atmospheric temperatures with slight drops during the dry season, June to September. In Mwanza region, marked fluctuations in atmospheric temperatures were depicted with an observed drop for the minimal atmospheric temparature during the same period. However Mwanza and Mara had higher atmospheric temperatures (28.62 ± 0.25°C and 28.62 ± 0.15°C respectively) compared with Kagera (26.17 ± 0.25°C). Generally, wind speed was high in afternoons compared to mornings and wind activity increased during the dry season although some spatial and temporal variation in wind speed was depicted for the three regions.

Limnological parameters recorded by a SEABIRD-profiler during the bottom trawl surveys in July and November 2000 and during hydroacoustic surveys in February/September 2000 and 2001 were investigated. Temperature variations from surface to bottom waters was minimal in shallow waters but in deep waters the difference ranged from 0.6°C in August/September the period of thermal de-stratification to 1.62°C in February and November, the period of thermal stratification in Lake Victoria. During thermal stratification, the thermocline and oxycline was formed at 40 m deep. The same trend was found in dissolved oxygen concentration. In shallow waters of less than 30 m, oxygen concentration ranged from a mean value of 6.6 – 7.8 mg L^{-1} while in deep waters the concentrations varied from 0.28 mg L^{-1} in February to as high as 6.38 mg L^{-1} in August/September at 68 m depth. The previous claim of a permanent anoxic layer in the bottom deep waters of Lake Victoria was not encountered. Mean temperature of 24.85±0.26°C to 23.95±0.21°C was recorded for surface and bottom waters respectively with an overall mean of 24.28±0.26°C, while mean oxygen concentrations varied from 8.02±0.73 mg L^{-1} in surface waters to 3.2±4.36 mg L^{-1} in the bottom waters at 68 m deep. Overall mean oxygen concentration was 5.49±1.57 mg L^{-1}.

Secchi disk (of 30-cm diameter) mean readings at the sites where SEABIRD-profiler was used ranged from 0.84±0.3 m in November to 1.9±1.02 m in August/September at stations of 5-10 m depth and in offshore waters of 50-60m depth the readings were 3.08±0.62 m in February to 5.52±1.7 m in August/September. Such readings gave an indication of a possible recovery from eutrophication when compared to previous reports, although the sampling sites and the daily and seasonal variations were not thoroughly covered under the current study. However, there was also an indication of reduced anoxic problems in the deep waters of Lake Victoria and the reported extended thermal stratification was not encountered. These changes could greatly influence the ecosystem dynamics and the productivity of the lake in general. The potential yield of a fishery in any area depends largely on the level of primary productivity which is inturn largely influenced by such limnological dynamics and the efficiency with which primary productivity is converted to fish production through the food chains.

More work is needed before concluding on the limnological changes recorded although the current decline in the Nile perch stock and the increase in the haplochromines could have some influence on such changes.

CHAPTER THREE

LAKE VICTORIA FISHERIES: TRENDS AND EVALUATION OF EXPLOITATION PATTERNS

3.1 INTRODUCTION

An understanding of the historical patterns of exploitation of any fishery is a prerequisite in any attempt to perform stock assessment. What is known about abundance of fish populations and how the stocks respond to exploitation comes primarily from the analysis of catch records (Hilborn & Walters, 1992; King, 1995). Consequently, management of fisheries relies on the outputs of stock assessment for which a well-organised data collection system is required (Cowx, 1996). Fisheries are not static systems; they develop through dynamic processes, which involve several stages that can be monitored through the collection of information on catch and fishing effort either from what is being landed, i.e. fisheries dependent data collection, or from research surveys, i.e. fisheries independent data collection. As early as 1928 the need to monitor the status of Lake Victoria's fisheries was expressed when gill net CPUE started to decline (Lowe-McConnell, 1997). With the establishment of the East African Freshwater Fisheries Research Organization in 1947, a fisheries dependent monitoring system for data collection was established (Wanjala & Martens, 1974). With the collapse of East African Community in 1977, under the assistant of FAO Committee for Inland Fisheries of Africa (CIFA), each country operated independent systems for data collection in the late 1970s following the procedure designed under FAO with catch per boat per day as a sampling unit and a boat as a unit of effort (Bazigos, 1974; Lyimo *et al.*, 1990; Rabuor, 1991; Orach-Meza, 1991). With lack of funds, equipment, and committed personnel the system has operated with problems and the reliability of the data is questionable (Bernacsek, 1986; CIFA, 1988; Reynolds *et al.*, 1989; Ssentongo, 1990).

In Tanzania, a fishery statistical collection system operated under the Fisheries Department, with fisheries staff stationed on the selected beaches. The daily catch per species and per canoe for as many days as possible was recorded. The data were then compiled at district and regional level, and sent to the Statistics Department of the Fisheries Department under the Ministry of Natural Resources and Tourism to produce annual statistical records (Ligtvoet & Mkumbo, 1991; Mous *et al.*, 1991; Budeba & Mous, 1995). With decentralization in the early 1990s, the regional and district fishery staff came directly under the local governments, who were more interested in revenue collection than statistics and with retrenchments in the late 1990s further deterioration of the system occurred. As a result the annual statistics were not consistent and the frame surveys supposed to be conducted biannually were not done. The last frame survey was in 1994 but due to limited resources the coverage was not complete. The 1998 frame survey was conducted under funds from the LVEMP project but due to rainfall problems some landings were inaccessible (Personal communication with E. Lyimo)

The system of statistical data collection in Uganda has been under the Fisheries Department, as in Tanzania, and has faced similar problems of decentralization and retrenchment. It was even worse in the 1970s and 1980s due to civil wars, when the system almost collapsed. In Kenya, the data collection system has been more consistent, operating under the supervision of the Kenya Marine and Freshwater Research Institute (KMFRI), although lack of funds and equipment equally applies.

Following intensive investment in the Nile perch fishery in the early 1990s the need to assess the stocks was demanded by all sectors of the fishing industry; especially after falls in catch rates became prevalent (CIFA, 1992). It was on these grounds the Lake Victoria Fisheries Organization (LVFO) with funds from LVFRP and LVEMP organized a Lake wide frame survey in March 2000 to provide information on the current effort operating in the fishery. The survey was conducted on the same day with each country covering their national waters. With the shortcomings of the existing catch statistical system; the LVFRP under the overall objective of assessing the stocks of the lake included in the project activities a catch assessment survey to acquire data for fishery dependent stock assessment methods. This chapter provides details of this study. With an overall objective to gain a clear understanding of the dynamics of the fishery and estimate total catch for management purposes, catch and effort data are reviewed and the current effort to the fishery assessed. In particular, changes in species composition and effort characteristic are analysed in an attempt to portray the trend and stages of exploitation; Allocation of effort to the different species and for the three countries sharing the resource is investigated. The impact of the different gears used for Nile perch fishery is analysed based on length composition of the catch. The CPUE is estimated and the changes in CPUE over time are discussed. Using fisheries dependent data from the catch survey conducted under the study and the effort from the 2000 frame survey (LVFO, 2000), an estimate of the current catches for Tanzanian waters was undertaken. The threat posed by excessive harvesting of juveniles is also assessed. The shift in species composition of the catch is discussed in the light of ecosystem stability and sustainability of the fisheries. The importance of monitoring the fisheries for reliable catch per unit effort data is expressed. Attention is given to Tanzanian fisheries of the lake but the other two countries are cross-referenced for comparison, ascertain whether the resources need to be managed by a common approach.

3.2 MATERIALS AND METHODS

3.2.1 Catch statistics

To assess the characteristics and changes in the fishery, fisheries dependent data collected by Fisheries Department were used. Annual catch records (t yr^{-1}) together with the numbers, type and sizes of gears used and the number of fishing canoes deployed from 1970 to 1995 were transcribed from the Fisheries Department statistical reports. Catch statistics from 1995 to date were not complied due to inconsistency in the beach recording as a result of lack of manpower due to retrenchment and/or change of priorities of the local governments as well as lack of frame survey data. Financial constraints and lack of committed beach recorders as mentioned earlier render the statistics unreliable and thus these were only used to provide trends.

The data were broken down to the three administrative regions bordering the lake and also according to the sampling zones for the bottom trawl surveys (Chapter Four), Mwanza in the south (bordering Zone A), Mara in the east (bordering Zone B) and Kagera in the west (bordering Zone C) (refer Map: Fig.1.2). Changes in effort, boat numbers and gillnet numbers and sizes from 1986 to 1995, and effort data from the last frame surveys 1998 & 2000 organised under the projects (LVEMP & LVFRP) were also examined.

Total annual landings and catch by species from the Kenya and Uganda annual fisheries reports were also gathered for comparison and to portray the overall trends in the lake fishery. Annual catch records for Kenya were available from 1968 to 1998 and for Uganda from 1965 to 1996. Changes in species composition were compared from 1970 when Nile perch started to be noticeable in the catches.

3.2.2 Frame survey

To assess the current effort in the fishery both in type and quantity, and to estimate the current total landings, the results of the frame survey conducted in March 2000 were used. The main objectives of the survey were to gather data on the current fishing effort and to provide accurate raising factors for estimating the total catch in the lake. It is therefore the basis for any management intervention.

The survey was conducted from 22 to 25 March 2000 concurrently in all three countries. In Tanzania, 596 landing sites were covered, while in Uganda and Kenya 597 and 297 respectively were monitored. Complete enumeration of all the landing sites, fishermen, fishing vessels and fishing gears by type and size was done. The survey proceeded with a one-day training session for the enumerators, fishermen and fisheries staffs involved in the exercise by a team of supervisors. The approach was both on land and water depending on accessibility to the landing site. One enumerator for Tanzania and Uganda covered one landing site on the mainland and the islands, except where few boats were present and then the enumerator would cover 2-3 sites. In Kenya each beach already had enumerators, and they were allocated to their usual recording beaches and adjacent minor beaches.

Information provided from the frame survey (2000) facilitated an assessment of the current fishing effort and how it is distributed per country and in relation to water area. Although it is only a canoe or boat which is considered as a unit of effort in CAS (Bazigos, 1974), both the canoes and the fishing gears (type and size) are assessed to find the actual magnitude of effort and its characteristics. A comparison on the means of propulsion was also made as this affects fishing efficiency and the fishing grounds. The proportion of fishing crafts targeting different species or using different gears was also enumerated, and used in conjunction with information from the catch assessment survey to estimate yield.

Of the different gears recorded during the frame survey, only data from the main gears were used to estimate the total yield. Gillnets is the main gear for Nile perch fishery while mesh sizes of 5" and below also target *O.niloticus*. Longlines were mainly for *Clarias*, *Bagrus* and *Protopterus* before the dominancy of Nile perch, but it has now become an important gear for Nile perch next to gillnets. Beach seines were also targeting Nile perch although it is an illegal gear. Cast nets and handlines target *O.niloticus* and common in minor landing sites in the small bays. Due to accessibility problems such landing sites were not covered under the catch surveys. The same applied to traps, which mainly target other species like *Clarias* and *Protopterus*. Scoopnets, dagaa seines, mosquito seines and lift nets all target dagaa, and the later uses paired canoes and referred to as catamaran. Under the study, the first three were grouped as dagaa seines.

3.2.3 Catch assessment survey

A catch assessment survey was conducted on six selected beaches in each of the three regions bordering Lake Victoria in Tanzanian waters on a monthly rotational basis (Fig. 3.1). Thus each region was covered once in a quarter from February 1999 to December 2000.

Of the six beaches, two were allocated for each of the main commercial species, i.e. *Lates niloticus*, *Rastrineobola argentea* and *Oreochromis niloticus*. In Mwanza region (Zone A), Chole (1a) & Kibaara (5a) were sampled for *Orechromis niloticus*; Igombe (2a) & Suzi (6a) were for *Rastrineobola argentea* and Kayenze (3a) & Nyamikoma (4a) were for Nile perch. In Mara region (Zone B) Burugu (1b) & Kinesi (3b) were sampled for *Oreochromis niloticus,* Bwai (2b) & Kibuyu (4b) for *Rastrineobola argentea* and Kome (5b) & Nyangombe (6b) for Nile perch. In Kagera region (Zone C) Nyamikazi (1c) & Ruhanga (3c) & Kijiweni (6c) were for Nile perch, Kemondo (2c) & Ikumbi Itale (5c) were for *O. niloticus* and Nyaburo Island (4c) were for *R. argentea.*

At each beach, the number of boats on the beach, number fishing and the number that was not operational on the day were recorded. Depending on the number of boats that were fishing and the size of the catch, as many as possible were sampled to determine the means of propulsion, type of gear, mesh size and number of nets per boat. The catch of each boat was sorted into species and weighed (kg). Lengths and weights of individual fish were recorded accordingly to the principal gear used. Depending on the size of the catch, a sub sample or the whole catch was measured.

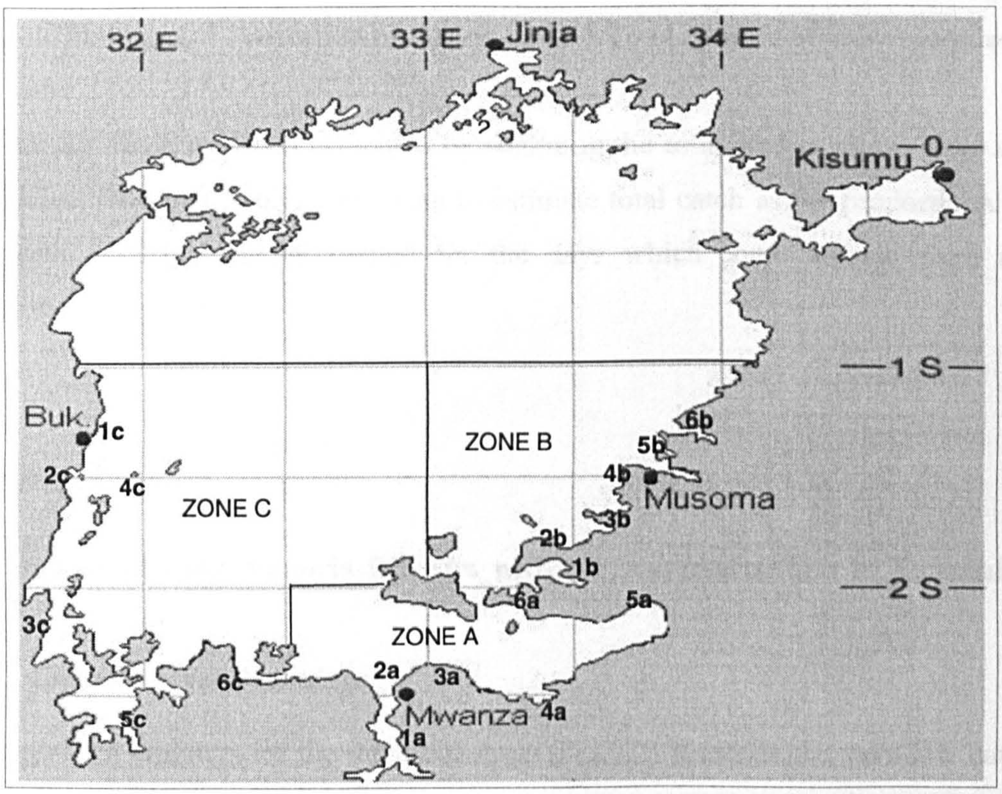


Figure 3.1 Map of Lake Victoria showing the three regional waters and the location of landing sites (by numbers, see text for names) sampled during the catch survey conducted in 1999 & 2000.

3.2.4 Estimation of total catch

The annual catch for 1999 and 2000 was estimated using the information generated from the catch survey and the 2000 frame survey. Instead of using the unit of effort of a canoe generally used (Bazigos, 1974), type of gear was taken into consideration. Catch per boat per gear type was calculated from the mean catch per boat per day for each specific gear type as:

$$CPUE_{per\ gear} = \sum_{SB_1}^{SB_n} C_{SB}/n;$$

where, SB is the sampled boat and C_{SB} is the total catch landed by the boat, n is the total number of boats of a specific gear sampled on that day.

The proportion of operational fishing boats was determined from the number fishing on a day divided by the total number of fishing boats on a landing site. This was used with the $CPUE_{per\ gear}$ and the total number of boats recorded in the frame survey to calculate the total catch landed per day. The annual catch was estimated as:

Catch = $CPUE_{per\ gear}$ * Proportion of fishing boats * Total number of boats recorded * 365 days.

Total annual catch was then estimated by summing the estimated catch per gear and per species. (Note: 365 days were used to estimate total catch as the proportional of operational fishing boats accounted for the days which some vessels were not operational in a year).

3.3 RESULTS

3.3.1 History of Lake Victoria fisheries with particular attention to Tanzanian waters

3.3.1.1 *Changes in total landings*

Trends in total landings for the three countries (Fig.3.2) illustrate the very low catch levels prior late 1970s before an increase was recorded. In Tanzania, relatively higher catches were recorded compared to the other two countries. The increase in catches was first noticed from 1982 to a peak in 1990, which was maintained until 1995. Signs of decline in catches were observed in all the three countries in 1995; Tanzania has experienced a reduction of 55% from the peak production, Uganda 34% and Kenya 40%. However, Kenya was landing the equivalent of 80% of the Tanzania catch and 1.7 times the Ugandan catch in the mid 1990s. The changes in yield were predominantly attributed to the increase of Nile perch.

3.3.1.2 *Changes in species composition*

The three main commercial species Nile perch, *Rastrineobola* (dagaa) and *Oreochromis niloticus*, plus haplochromines, which were once dominant, were examined separately (Fig. 3.3A-C). All other species (such as: *Protopterus aethiopicus*, *Bagrus docmak*, *Clarias gariepinus*, *Barbus*, *Synodontis*, *Brycinus*, *Mormyrus*, *Labeo* and *Schilbe* were combined as "others". The pattern of changes in species composition was different for the three countries.

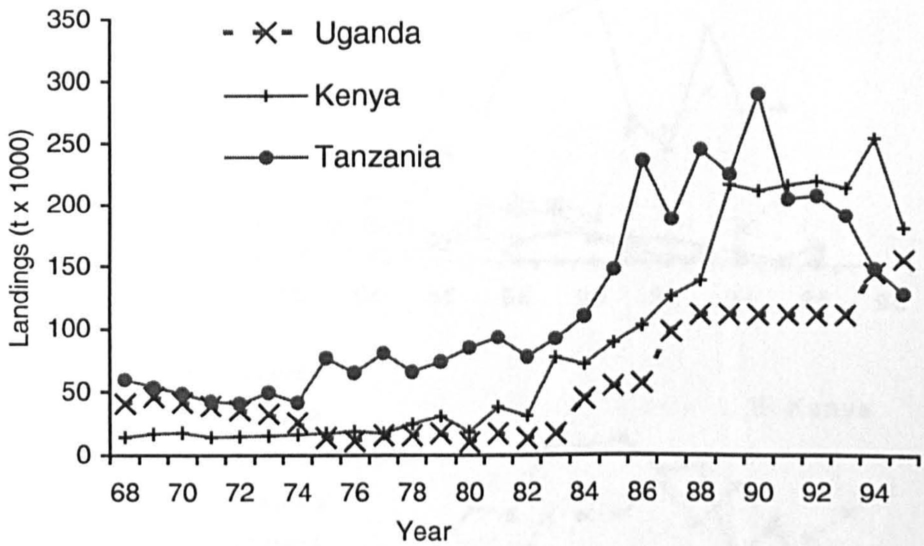


Figure 3.2 Total landings from the three riparian countries, Uganda, Kenya and Tanzania

Nile perch increased in the catches much earlier in Kenya (1982), followed by Uganda (1984) and eventually Tanzania (1986). The increase in Nile perch was concomitant with an increase in dagaa (*Rastrineobola argentae)* in the Kenyan waters but in the other two countries dagaa catches have fluctuated and usually at lower levels. With the decline of Nile perch in mid 1990s, a decline in all the other species, with an exception of *O. niloticus* was found in Tanzania. In Kenya, dagaa and *O. niloticus* increased in the catches while in Uganda all the other species increased as Nile perch catches fell off.

A comparison of the contribution of the different species to the total landings during three well-differentiated periods in the history of Lake Victoria fisheries; (1970-1980, when Nile perch started to appear in catches; 1986-1991 the period of Nile perch boom; 1992-1998 the period of decline in Nile perch catches) was done for the three countries (Fig. 3.4).

The importance of haplochromines and 'other' species before the mid 1980s and the abrupt shift to a dominance of Nile perch after the mid 1980s is illustrated. After the period 1986 to 1991, referred to as the Nile perch boom, dagaa peaked and even became the most abundant species in the Kenyan landings. Dagaa catches in Kenya was regular and increased as Nile perch was increasing. When Nile perch catches fell

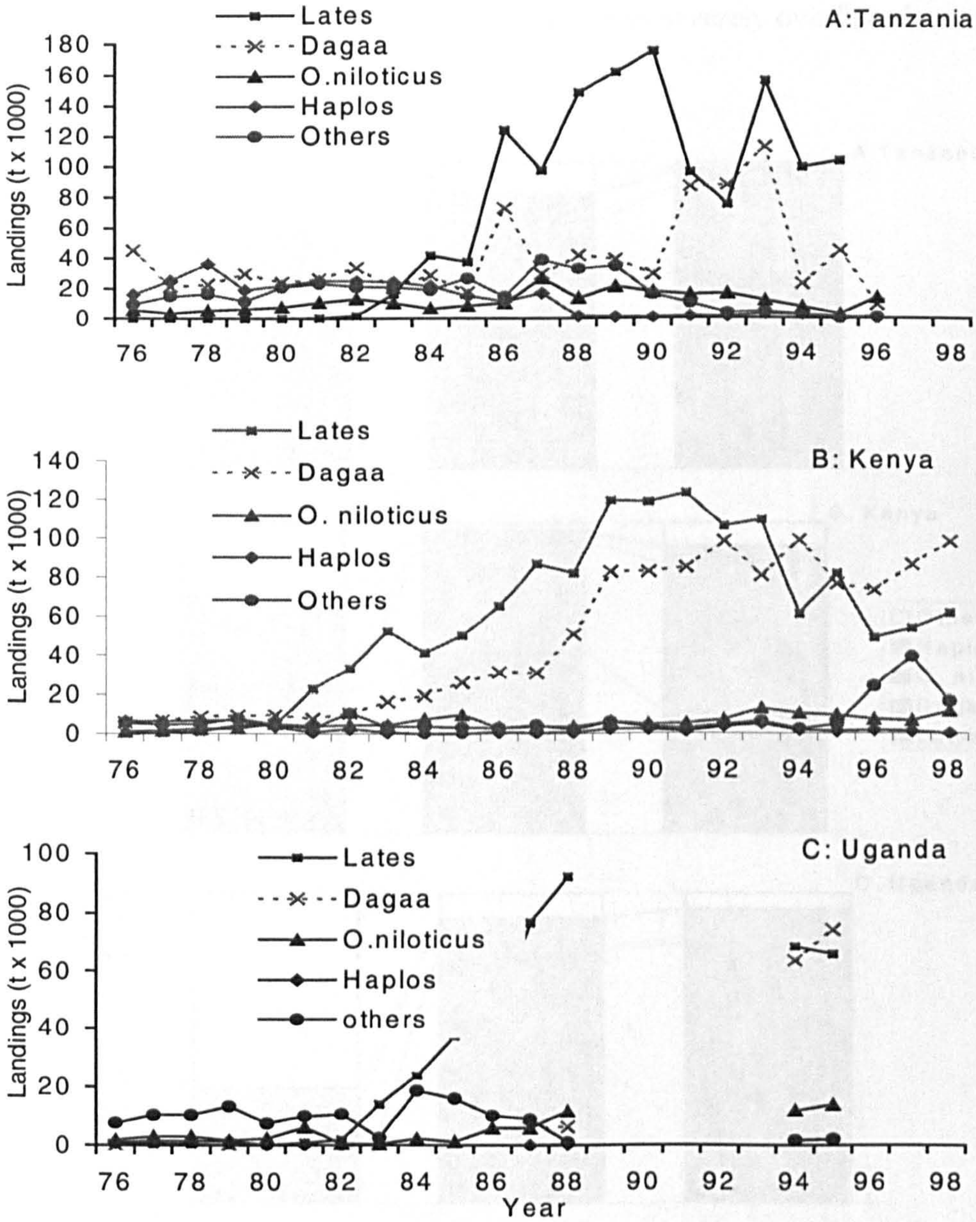


Figure 3.3 Landings by species (t * 1000) in Tanzanian (A), Kenyan (B) and Ugandan waters (C)

in 1992, the increasing dagaa catches were not affected. This may have been the trend for the other two countries Tanzania and Uganda, but poor catch records prevented such an analysis being carried out. Haplochromines and other species further decreased during 1992-1998 for all the three countries, but *O. niloticus* increased in Kenya and Uganda but decreased in Tanzania. Such inconsistencies have more to do with unreliable records (Reynolds *et al.*, 1989; Ssentongo, 1990) due to limited facilities than with the actual state of the fishery. The decrease in the Nile perch after 1992 was not depicted for Tanzanian and Uganda mostly due to the same reason of inconsistency in records but the increased use of small mesh size nets may also have contributed. The use of small mesh sizes in Kenya seems to have had no positive effect in CPUE suggesting the stocks are more severely overfished compared with the other two countries.

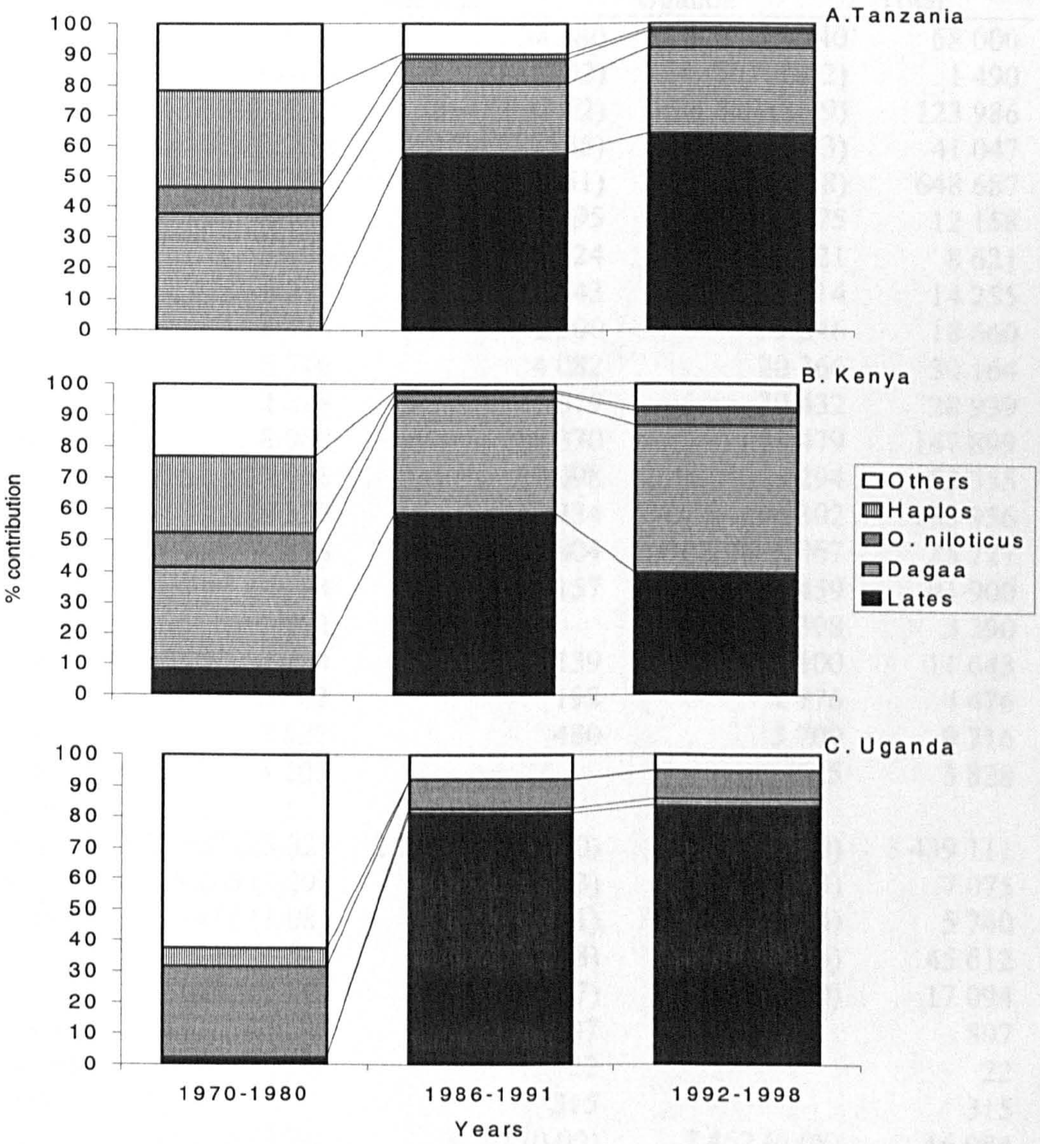


Figure 3.4 Changes in percentage contribution of species in total catch for the three countries over the three historical periods in the fisheries of Lake Victoria, 1970-1980, 1986-1991 & 1992-1998

3.3.1.2 *Changes in fishing effort with CPUE*

Effort data (number of canoes/boats) from Tanzania was used to assess the trend in fishing effort over the years. The same data for Kenya and Uganda were missing and thus comparison could not be made. Nevertheless, the results of the 2000 frame survey are used for comparison of the current effort (Table 3.1).

Table 3.1 Summary of Frame Survey 2000 showing distribution of landing sites, crafts and gears between countries (values in brackets are density by country per km^2)

Item	Kenya	Tanzania	Uganda	Total
Area km^2	4 080	34 680	29 240	68 000
Landing sites	297 (0.07)	596 (0.02)	597 (0.02)	1 490
Fishers	33 037 (8.1)	56 060 (1.62)	34 889 (1.19)	123 986
Canoes	10 014 (2.45)	15 489 (0.45)	15 544 (0.53)	41 047
Gillnets total	125 221 (33.69)	225 803 (6.51)	297 663 (10.18)	648 687
<2.5 cm	4 388	7 095	675	12 158
2.5 cm	5 176	3 124	321	8 621
3.0 cm	8 298	2 943	3 014	14 255
3.5 cm	6 714	2 300	9 646	18 660
4.0 cm	5 716	4 082	20 366	30 164
4.5 cm	2 828	5 679	20 432	28 939
5.0 cm	8 050	88 370	51 479	147 899
5.5 cm	9 963	27 098	16 294	53 355
6.0 cm	29 320	59 334	95 302	183 956
6.5 cm	8 856	8 804	8 067	25 727
7.0 cm	22 284	15 157	54 459	91 900
7.5 cm	1 992		1 398	3 390
8.0 cm	2 404	1 139	8 100	11 643
9.0 cm	2 502	198	1 776	4 476
10.0 cm	3 527	480	5 709	9 716
>10 cm	3 203		625	3 828
long lines (hooks)	972 087 (23.82)	2 212 571 (63.80)	254 453 (8.70)	3 439 111
Beach seines	5 245 (1.29)	1 019 (0.03)	811 (0.03)	7 075
Cast nets	4 418 (1.08)	46 (0.001)	1 276 (0.04)	5 740
Hand lines	27 789 (6.81)	13 238 (0.38)	4 585 (0.16)	45 612
Traps	3 192 (0.78)	2 553 (0.07)	11 349 (0.39)	17 094
Scoop nets		807		807
Dagaa seines		22		22
Lift nets		315		315
Mosquito seines	11 265 (2.76)	3 267 (0.09)	2 452 (0.08)	16 984
Engines	494 (0.12)	1 530 (0.04)	2 031 (0.07)	4 055
Other gears	1 706	15	71	1792

Number of boats seems to have been static from 1976 to 1985 followed by almost 80% increase in 1986 and it remained at the same level to 1990 when a decrease was observed to 1994 then followed an increase of almost the same magnitude in 1995 to the same level as 1990. That was the period when the Nile perch fishery was expanding and effort would be expected to increase but it was not reflected in the records clearly revealing the unreliability of the catch statistics. The 2000 frame survey data indicated more than doubling of effort from 1995 to 2000 (Fig. 3.5). Catch per Unit of effort (CPUE, catch per boat) increased from the early 1980s to 1994 when a sharp decline was noted. As effort doubled up from 1995 to 2000 the CPUE almost decreased by half.

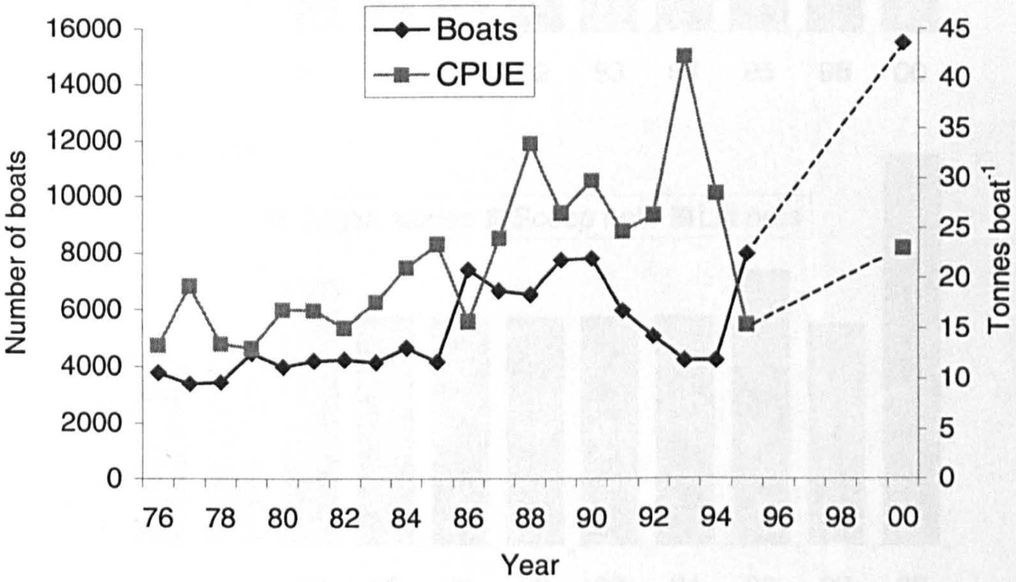


Figure 3.5 Changes in effort (number of boats) compared to CPUE in Tanzanian waters from 1976 to 1995 and 2000. (Data for 2000 was from estimates of the present study using the effort recorded during 2000 frame survey).

The marked increase in the number of boats in 2000 was accompanied by an increase in almost all the gears used (Fig. 3.6). The increase in gillnets was mainly for 5 and 6 inches mesh nets whilst nets above 6 inches were almost non existent and the sizes below 5 inches reappeared despite being illegal (Fig. 3.6a). Although there was little change in the overall number of gears used for dagaa, the composition changed with dagaa seines dominating, while the lift nets which use a pair of boats referred to as catamaran were introduced from Lake Tanganyika in the mid 1990s (Mous *et al.*, 1991) (Fig. 3.6b). Drastic increase in the use of hooks was also recorded in the 2000 frame survey. Due to differences in the type of gear and numbers per boat, theuse of boat as a unit of effort and catch per boat per day as a sampling unit is no longer applicable to Lake Victoria fisheries. Unit of effort needs to take gear type into consideration.

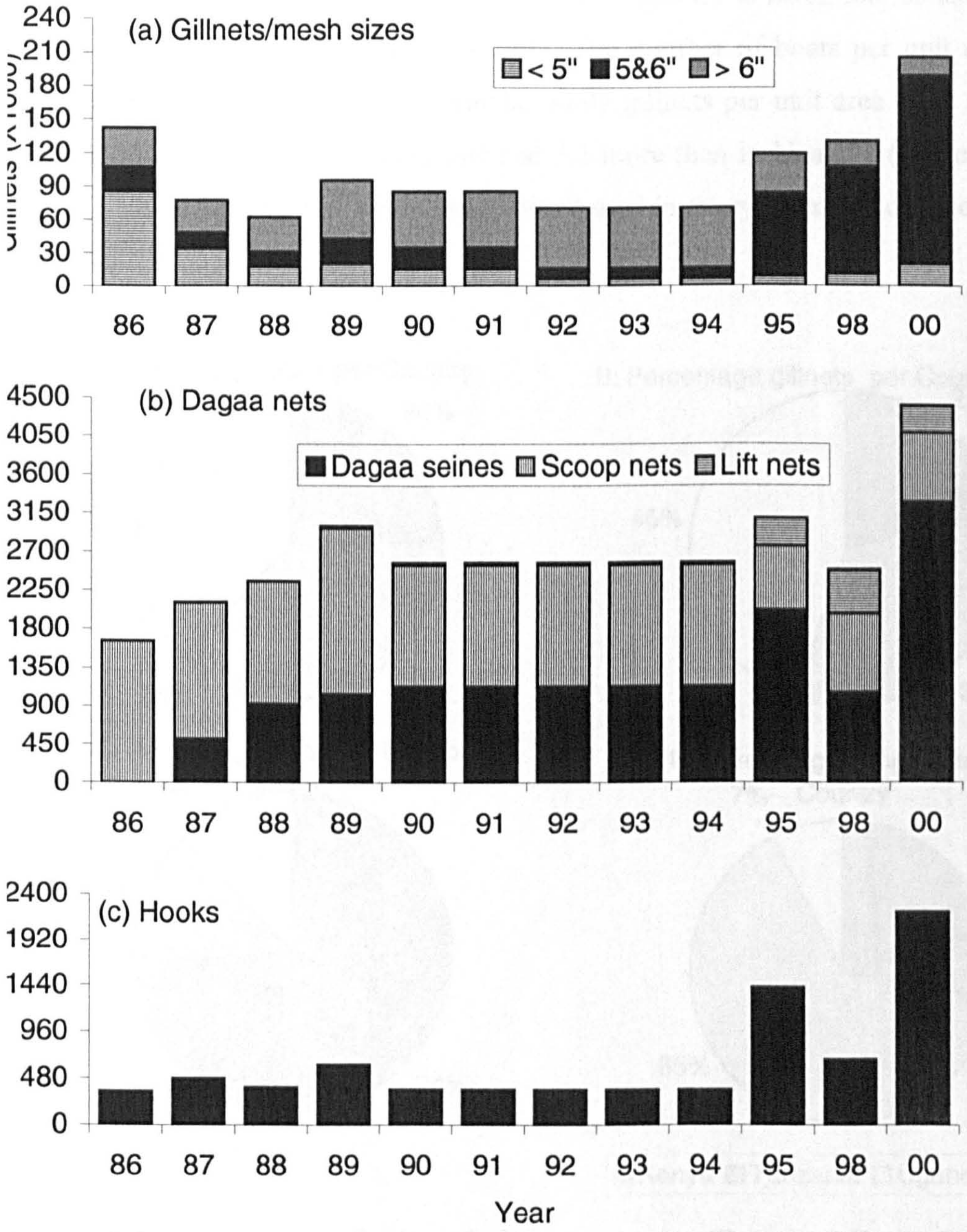


Figure 3.6 Changes in gears used, (a) gillnets of different mesh sizes (d) dagaa nets and (c) hooks from 1986 to 2000 in Tanzanian waters.

3.3.2 Current exploitation patterns

3.3.2.1 *Effort: size and distribution*

A wide difference was noted in the number and proportion of gears used between countries (Fig. 3.7). The number of boats was similar for Tanzania and Uganda

(38%) but much less for Kenya (24%) (Fig.3.7a). For the main gears used, Uganda had the highest proportional of gillnets (45%, Fig.3.7b), Kenya more beach seines (74%, Fig.3 7c) while Tanzania had the highest numbers of hooks (long lining) (65%, Fig.3.7d). Nevertheless, when water area of each country is taken into consideration, Kenya had the highest effort per unit area. The number of boats per unit area was three times that in Tanzania and Uganda, while gillnets per unit area were almost 6 times more common than in Tanzania and 3.5 more than in Uganda. (Table 3.2) On average, about 10 nets and 2 canoes are distributed in every square kilometre in Lake Victoria.

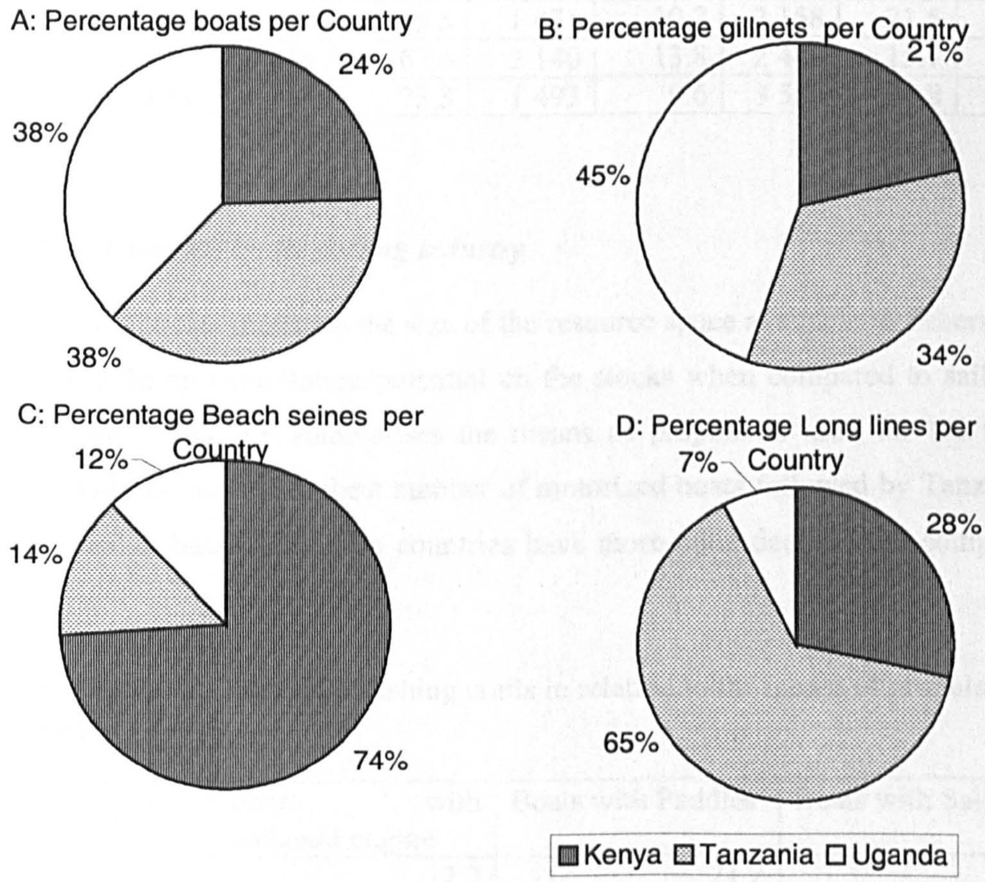


Figure 3.7 Percentage distribution of effort per country (Data from Frame Survey 2000)

Table 3.2 Density of fishing effort per country

Country	**Water Area (km^2)**	**Number of boats**	**Boats km^{-2}**	**Number of Gillnets**	**Gillnets km^{-2}**
Kenya	4 128	10 014	2.4	143 221	34.7
Uganda	29 584	15 544	0.6	297 663	10.0
Tanzania	35 088	15 489	0.5	225 803	6.4
Average	68 800	41 047	1.7	666 687	9.7

The distribution of effort to the different species was similar for Tanzania and Kenya while more boats were allocated to Nile perch, tilapia and 'other species' and less effort to dagaa fishery in Uganda compared with the other two countries (Table 3.3). This implies the dagaa fishery is less well developed or the species is targeted to a lesser extent in Uganda.

Table 3.3 Distribution of effort to different species targeted in Lake Victoria fishery for the three countries

Country	**No. of boats**	**N/perch boats**	**% N/perch boats**	**Tilapia boats**	**% Tilapia boats**	**Dagaa boats**	**% Dagaa boats**	**Other species boats**	**%**
Kenya	10 014	6 958	69.5	1 071	10.7	2 158	21.5	146	1.5
Uganda	15 544	10 439	67.4	2 140	13.8	2 446	15.7	557	3.6
Tanzania	15 489	11 393	73.3	1 493	9.6	3 558	20.8	183	1.2

3.3.2.2 *Developments in the fishing industry*

Motorization of boats increases the size of the resource space available to fishers and thus has a different exploitation potential on the stocks when compared to sail and paddled boats. Table 3.4 summarises the means of propulsion used for the three countries. Uganda has the highest number of motorized boats followed by Tanzania. This is probably because the two countries have more open deep waters compared with Kenya.

Table 3.4 Percentage number of fishing crafts in relation to the means of propulsion per country

Country	Boats with outboard engine	Boats with Paddles	Boats with Sails
Kenya	12.2	21.2	49.5
Uganda	50.1	41.4	11.2
Tanzania	37.7	37.4	39.3

3.3.2.3 *Composition of the gillnet fleet*

The current fleet composition over the whole lake and per country was assessed (Fig. 3.8a&b). Currently, more than 50% of gillnets used were of 5″ to 6″ mesh sizes. About 15% of gillnets were of mesh sizes 7" and above which represented the dominant mesh size in the early & mid 1990s (Fig.3.6a). Kenya appears to have relatively more of the larger mesh sizes (above 6 inches) (43.8%) compared with Tanzania (11.4%) and Uganda (26.9%) (Fig.3.8b). Tanzania has more than 70% of gillnets within 5 & 6 inches. Kenya appears to have comparatively smaller meshed nets (23.1%) below 5 inches.

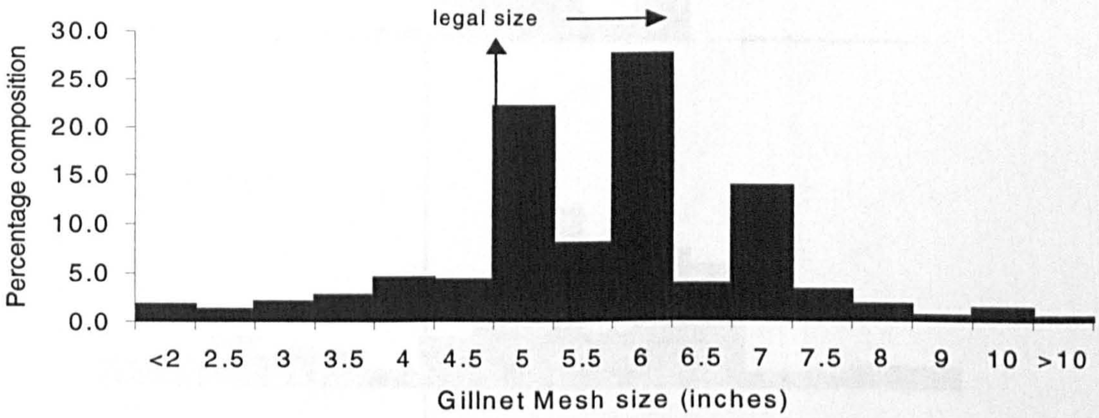


Figure 3.8a Percentage composition of gillnets by mesh sizes used in Lake Victoria. (Data from 2000 frame survey report).

3.3.2.4 *Effort variation within Tanzanian waters*

Fishing was found to be concentrated in the Mwanza region (Zone A), contributing 49% of the fishing boats recorded for Tanzania during the 2000 frame survey. The Mara (Zone B) and Kagera (Zone C) regions had 24% and 27% of the boats respectively (Fig.3.9a). The same trend applied for all the gears used (Fig. 3.9b-d), with over 50% of gillnets and beach seines recorded operating in Zone A waters (Mwanza region). Zone C (Kagera region) followed in the number of gillnets (27%) while Zone C (Mara region) was second to Zone A in the number of long-lines (35%) and beach seines (25%).

The gillnet fleet was dominated by nets of 5 inches mesh size in all the three regions (Fig.3.10). The same proportion for the 6.5 inches were recorded for all the regions, while Mara had more of the 7 and 8 inches compared with other regions. Small mesh sizes below 5 inches were comparatively more common in the Mara region followed by Mwanza. The Mara region borders Kenya and the fishing effort in that region has similar characteristics to the effort in Kenyan waters.

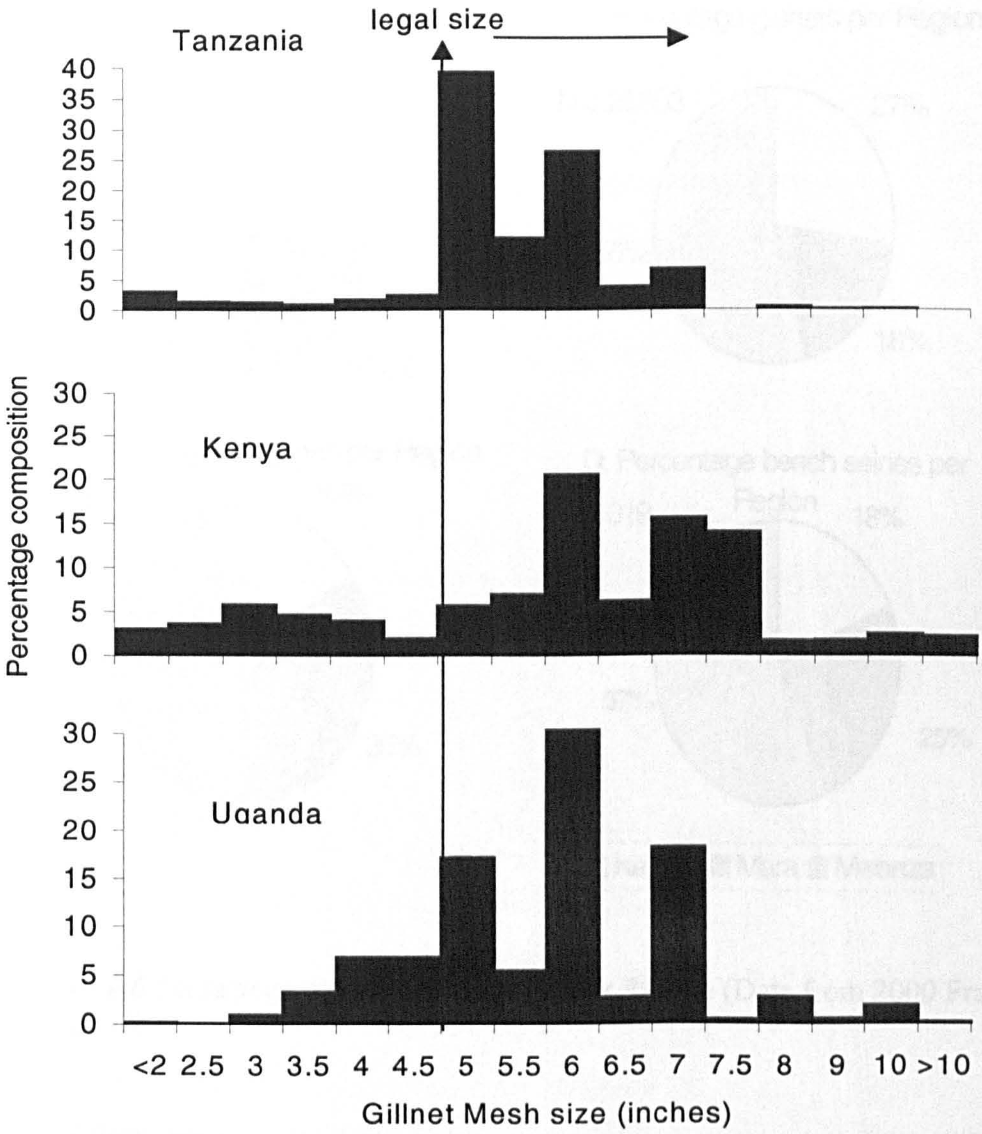


Figure 3.8b Percentage composition of gillnets with different mesh sizes used within country waters for the three riparian states. (Data from 2000 frame survey report).

3.3.3 Nile perch catch composition (in length) for different gears

All fishing gear is known to be selective to some degree on the size range of fish they catch. The size retained by gillnets and beach seines are related to the mesh sizes used. Hooks of given size are also known to catch fish within a particular size range, mostly determined by the gap between the point of a hook and the shank (King, 1995). Size composition from the three types of gear was investigated in relation to the size at first maturity for Nile perch.

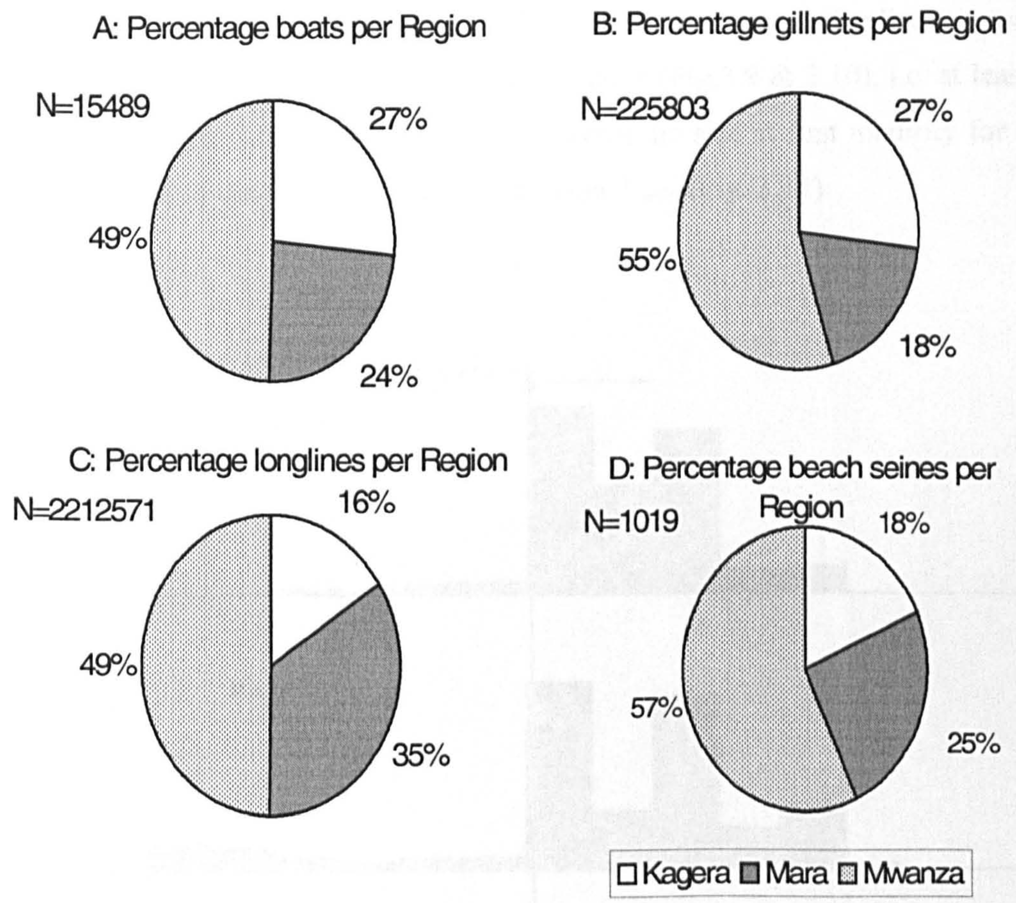


Figure 3.9a-d Percentage distribution of effort per Region (Data from 2000 Frame Survey report).

3.3.3.1 *Gillnet catch*

Length frequencies of the Nile perch catch were recorded from a range of different mesh sizes from 4 inches to 8 inches. The catch was separated to the specific gears depending on the fleet composition in a specific boat. Very few boats were found with only one mesh size of gillnets. The length frequencies were compared and the implication of the mesh sizes on the stock was assessed in relation to size at first maturity [i.e. L_{m50} of 54 cm TL for males and 76 cm TL for females (Chapter Five)].

Gillnets with mesh sizes below 5 inch caught 100% immature Nile perch while 88% of the catch from the legal mesh size of 5 inches were immature. About 79% of the catch from 6 inch gillnets was immature while a fleet with 5 inch and 6 inch nets landed about 87% of immature Nile perch. The gillnet fleet in Tanzanian waters was dominated by 5 inch (40%) and 6 inch (30%) mesh size, (Fig.3.9). About 50% of

Nile perch catch by gillnets with mesh sizes of 6" & 7" were above the size at first maturity of 54 cm TL for males (Fig. 3.11). This size range of gillnets constitutes about 50% of the gillnet fleet in Tanzanian waters (Fig.3.9 & 3.10), i.e. at least 50% of the Nile perch catch from gillnets were above the size at first maturity for males, although 97% of the females caught were below L_{m50} (Fig. 3.11)

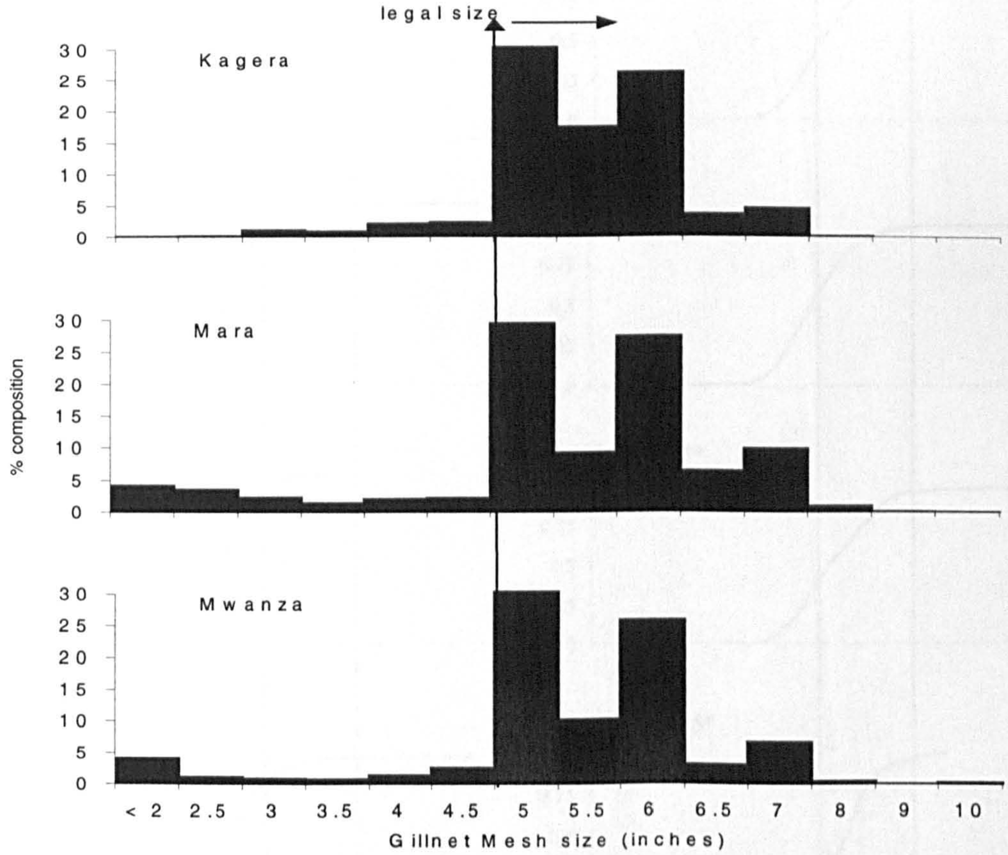


Figure 3.10 Percentage composition of gillnets with different mesh sizes used within regional/zone waters in the Tanzanian waters. (Data from 2000 frame survey report)

The combined data from gillnets indicated 50% of the catch was below 43 cm TL, while 83% and 99% were below size at first maturity for males and females respectively (Fig. 3.12). From the size composition of the catch population, it appears more small gillnet mesh sizes were in operation compared with the figures recorded during the frame survey. The frame survey relied on what the fishermen reported as gillnets smaller than 5" mesh size are illegal, it is possible the fishermen not to report the truth.

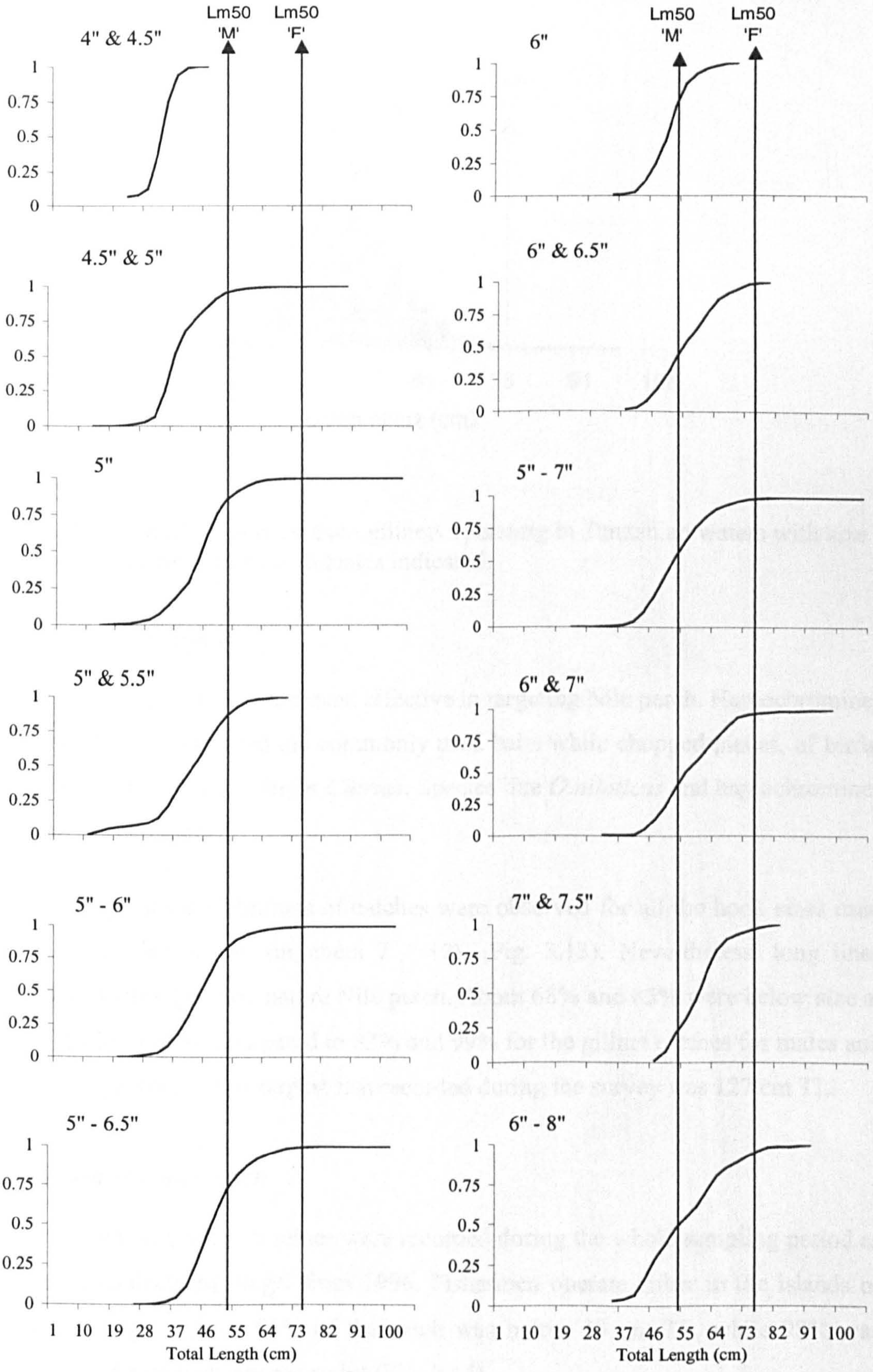


Figure 3.11 Catch selection ogives for gillnets of different mesh sizes in Tanzanian waters. (Y-axis = Fraction caught; M&F, refer to Males and Females)

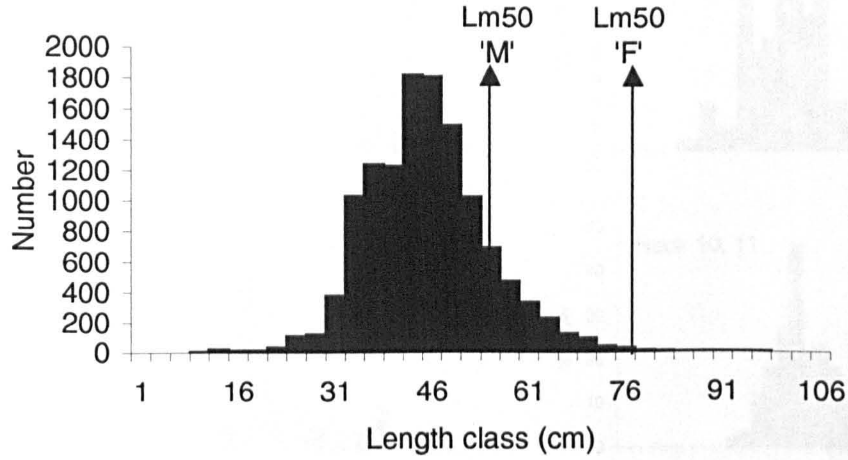


Figure 3.12 Length frequency from gillnets operating in Tanzanian waters with size at first maturity for males and females indicated.

3.3.3.2 *Long lines catch*

Long lines using live baits are most effective in targeting Nile perch. Haplochromines and *Clarias gariepinus* are the commonly used baits while chopped pieces, of birds, soaps and fish are used to target *Clarias*. Species like *O.niloticus* and haplochromines are targeted using worms.

Similar frequency distributions of catches were observed for all the hook sizes used in the Tanzanian waters (numbers 7 – 12), (Fig. 3.13). Nevertheless, long lines harvested relatively more mature Nile perch. About 68% and 85% were below size at first maturity (Lm50) compared to 83% and 99% for the gillnet catches for males and females respectively. The largest fish recorded during the survey was 127 cm TL.

3.3.3.3 *Beach seines catch*

Catches from only 5 beach seines were recorded during the whole sampling period as the gear was declared illegal from 1996. Fishermen operate either in the islands or during the night. About 50% of the catch was below 19 cm TL, while 98% was below size at first maturity for males (Fig. 3.14)

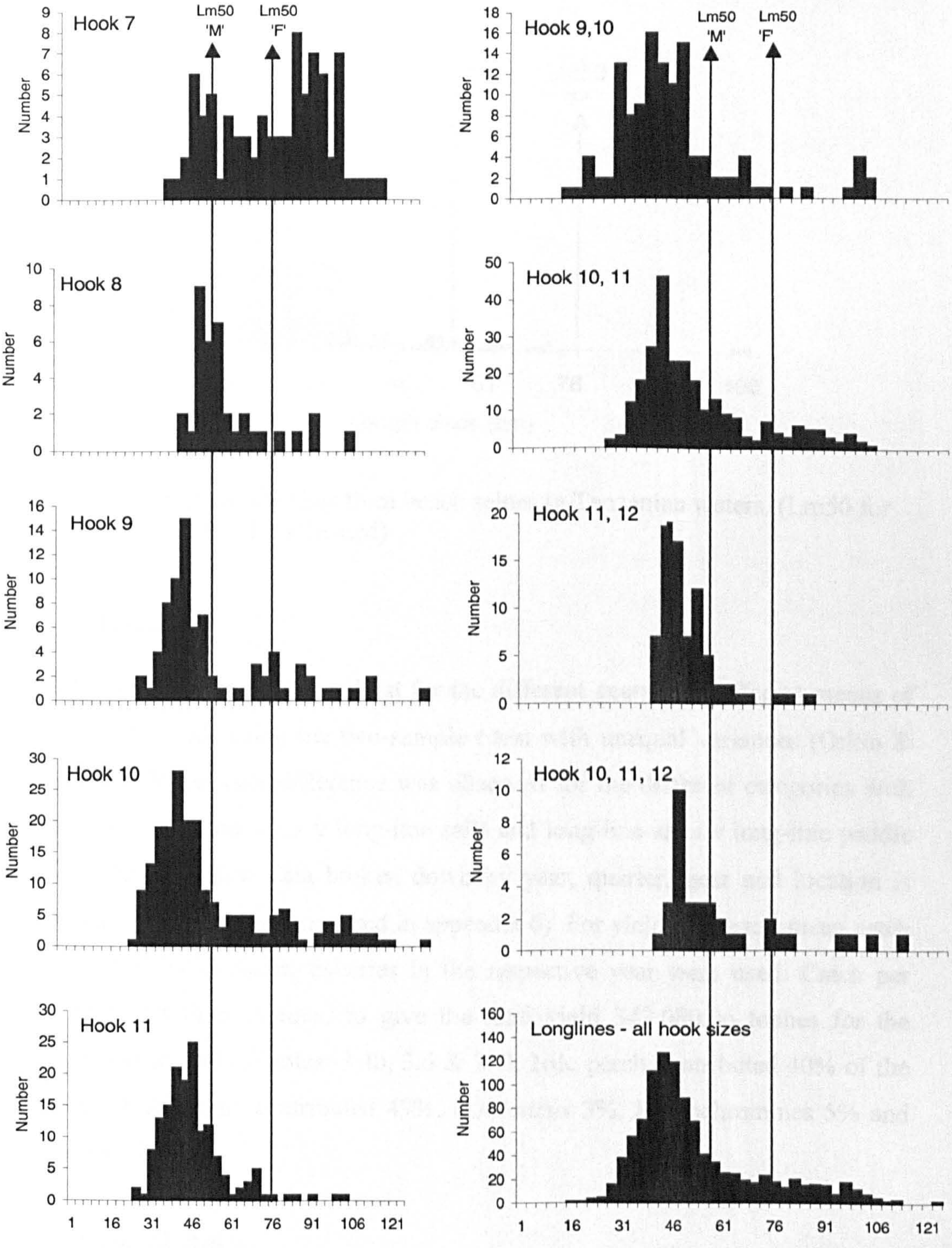


Figure 3.13 Length frequencies from long lines of different hook sizes in Tanzanian waters. (Lm50 for males 'M' and females 'F' indicated)

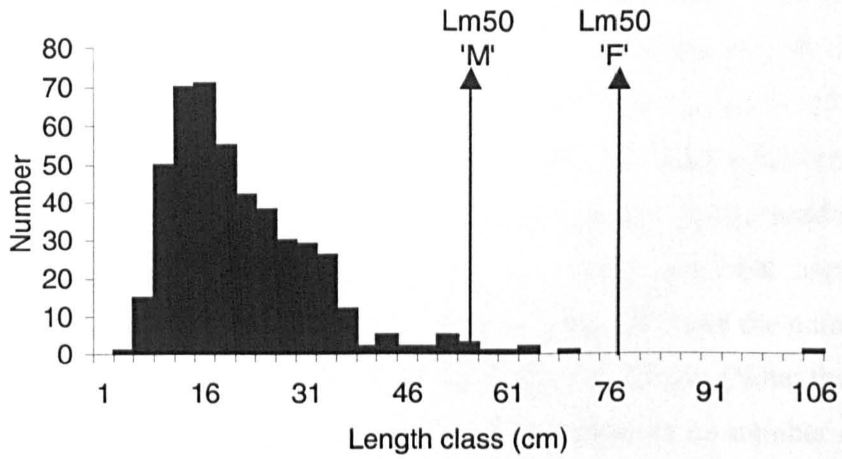


Figure. 3.14 Length frequencies from beach seines in Tanzanian waters. (Lm50 for males 'M' and females 'F' indicated)

3.3.4 Yield estimates

A comparison of mean catch per boat for the different gears and different means of propulsion was made using the two-sample t test with unequal variances (Orkin & Drogin, 1975) Significant difference was observed for the different categories with the exception of 'gillnet sails v long-line sails and long-line sails v long-line paddle (Appendix 4A-D), (Raw data broken down by year, quarter, gear and location is given in appendix 5, and summarized in appendix 6). For yield estimates, mean catch rates or CPUE for different fisheries in the respective year were used. Catch per fishery type was then summed to give the total yield 342 080.06 tonnes for the Tanzanian part in 2000 (Tables: 3.4b, 3.6 & 3.7). Nile perch contributed 40% of the total catch while Dagaa contributed 49%, *O.niloticus* 3%, Haplochromines 5% and the other species 3%.

3.3.4.1 *Nile perch fishery*

The estimated catch for Nile perch in relation to gear type indicated an increase of almost 20% from a total of 116 462.25 ± 6 712.54 tonnes in 1999 to 138 323.85 ± 6 229.14 tonnes in 2000 (Table 3.4, the calculated confidence limits are based on standard error of the catch rates per boat). The by catch of Nile perch from the dagaa and tilapiine fisheries was calculated from a mean value of the two years due to very few records, thus identical values are presented for 1999 and 2000. Motorized boats with gillnets had the highest CPUE of 69.26 & 73.19 kg day^{-1} followed by long line paddled boats 65.80 & 51.5 kg day^{-1} and then long line sails 44.10 & 46.4 kg day^{-1} for 1999 and 2000 respectively. There was a marked difference in CPUE between motorized gillnet boats and gillnet boats with sails, 69.26 kg day^{-1} v. 31.10 kg day^{-1} in 1999 and 73.09 kg day^{-1} v. 39.26 kg day^{-1} in 2000. This lead to further assessment of CPUE for motorized gillnet boats which had information on the number of nets from October 1997 to December 2000 (Table 3.5). Catch per boat appeared to have increased by 13.8% from October 1997 to December 2000 and the number of nets per boat increased by 100% indicating marked decline in CPUE. (Note: the CPUE values differ from Table 3.4, as only the boats with information on number of gillnet were used). Catch per net declined by almost 60%. The fishermen vary the fishing techniques from active gillnetting to triple mounting of nets, two to three nets are joined vertically so as to cover the whole water column. Such mounted nets are also tied on canoes with outboard engine and towed slowly over a large distance. All are attempts to increase CPUE.

Beach seines had a catch rates of 29.94 kg net^{-1} and 100% fishing rate and thus their contribution was quite substantial; almost to the magnitude of gillnet sails and gillnet paddle catch combined. Beach seines contributed 14% of the annual estimates for Nile perch.

Table 3.4 Estimated catch for Nile perch from different fisheries in relation to gear types operated in the Tanzanian waters for the year 1999 (a) and 2000 (b)

(a)

Type of Fishery	**Number of Boats**	**1999**			
		Prop. Fishing	**CPUE (kg boat^{-1})**	**Estimated Catch (t)**	**95% CL**
Gillnet/Motorized	1 217	0.82	69.26	25 227.82	8 486.98
Gillnet/Sails	2 682	0.75	31.10	22 833.54	8 142.25
Gillnet/Paddle	2 682	0.76	22.34	16 769.46	6 666.12
Longline/Sails	1 790	0.61	44.10	17 575.77	2 929.29
Longline/paddle	1 074	0.81	65.80	20 893.35	6 712.54
Beach Seines	994	1	29.94	10 863.98	14 857.63
Tilapiine fishery (by catch)	1 493	0.93	4.12	2 088.00	2 473.20
Dagaa Fishery (by catch)	3 245	0.75	0.40	211.77	93.83
TOTAL				116 463.69	3 762.72

(b)

Type of Fishery	Number of Boats	2000			
		Prop. Fishing	CPUE (kg $boat^{-1}$)	Estimated Catch (t)	95% CL
Gillnet/Motorized	1 217	0.78	73.19	25 358.86	8 869.89
Gillnet/Sails	2 682	0.8	39.26	30 746.23	7 095.28
Gillnet/Paddle	2 682	0.83	35.62	28 941.67	4 590.69
Longline/Sails	1 790	0.78	46.40	23 646.04	7 241.60
Longline/paddle	1 074	0.78	51.50	15 747.04	4 610.98
Beach Seines	994	1	29.94	10 863.98	14 857.63
Tilapiine fishery (by catch)	1 493	0.76	4.12	2 088.00	2 473.20
Dagaa Fishery (by catch)	3 245	0.75	.4	211.77	93.83
TOTAL				138 323.85	6 229.14

Table 3.5 Comparison of changes in CPUE with number of gillnets per boat for Nile perch fishery from 1997 to 2000.

YEAR	CATCH RATES (kg $boat^{-1}$)	NUMBER OF NETS $BOAT^{-1}$	Catch per Net (kg net^{-1})
1997	65.69 ± 21.39 (N = 17)	45.5 ± 8.53	1.45
1998	58.35 ± 13.24 (N = 49)	51.3 ± 6.54	1.14
1999	77 .0 ± 30.74 (N = 21)	99.14 ± 12.9	0.78
2000	74.79 ± 12.75 N = 37)	90.16 ± 9.1	0.83

The coverage of only 9 beaches in a period of three months during this study, out of 596 landings allocated for catch assessment surveys hinders further detailed analysis of seasonal changes in catches per gear and per region. Lack of adequate personal limited the coverage.

3.3.4.2 *Dagaa fishery*

In the interest of assessing the importance and contribution of the Nile perch fishery in the lake, total catch for dagaa was also estimated (Table 3.6). The dagaa seine net fishery had higher catch rates per boat, which also were almost ten times the catamaran boats, and with higher proportions of operational vessels in a day, this explains the wide difference in the estimated catch for the two gear types. The estimated catches show an increase of almost 23% from 1999 (136 317.4 t) to 2000 (167 789.0 t).

3.3.4.3 *Oreochromis niloticus fishery*

The catch for *O. niloticus* in 1999 and 2000 was 14 641 t and 11 811 t respectively (Table 3.7). This is similar to the estimate of 14 188 t in 1995 although earlier studies indicated a drop from 16 319 t in 1991 to 2 836 t in 1994 (Fig.3.3A). The survey did not cover the different fishing gears due to resource constraints. As a result, the catch could be under estimated, as could the annual statistics. Only gillnets and long lines were sampled, while angling rods & hand lines, beach seines and traps are known to be important in the *O.niloticus* fishery (Ligtvoet, *et al.*, 1995a).

Table 3.6 Estimated catch for Dagaa from different fisheries in relation to gear types operated in the Tanzanian waters for the years 1999 & 2000

Type of Fishery	Years	**Number of Boats**	**Prop. Fishing**	**CPUE (kg boat^{-1})**	**Estimated Catch (t)**	**95% CL**
Catamaran/ Liftnet	1999 2000	313	0.60 0.38	168.14 218.14	7 578.40 6 309.00	335.97 193.66
Mosquito-seine Net	1999 2000	3245	0.75 0.69	221.29 298.34	128 739.00 161 480.00	2 372.07 5 606.43
TOTAL 1999					136 317.40	1 354.02
TOTAL 2000					167 789.00	2 900.05

3.3.4.4 *Other species*

With the exception of *O.niloticus*, all the other species listed in Table 3.7 were encountered as by catch in the Nile perch, dagaa or *O.niloticus* fisheries. The mean catch rates were therefore calculated from a proportion of boats used to targeted the main commercial species and thus to calculate the total catch for each species respectively. Thus CPUE, proportion of boats fishing as well as 95% CL are not indicated as the total catch was summed from a number of gears and averaged for the two years.

An average of 17 160.99 t for 1999 and 2000 was estimated for haplochromines. This represents a huge recovery from virtually zero catch in the late 1980s to mid 1990s.

An increase was also noted for all the other species, (*Protopterus, Clarias, Bagrus, Synodontis, Labeo, Mormyrus, Brycinus, Schilbe and T.rendallii*) which together contributed 6 993.37 t. However, 64% of the catch (4510.5 t) was *Brycinus*.

Table 3.7 Estimated catch for *O. niloticus* and other species including haplochromines caught as by-catch of the three main fisheries for 1999 & 2000 in the Tanzanian waters of Lake Victoria

Type of species	Years	**Number of Boats**	**Prop. Fishing**	**CPUE (kg boat^{-1})**	**Estimated Catch (t)**	**95% CL**
O. niloticus	1999 2000	1493 1493	0.93 0.76	28.89 28.67	14 641.42 11 811.42	15 016.45 4 218.66
Haplochromines					17 160.99	
Protopterus eathiopicus					584.85	300.74
Clarias gariepinus					1 101.49	243.07
Bagrus docmak					94.86	45.32
Synodontis spp.					81.37	
Labeo					15.20	
Mormyrus kannume					99.66	70.86
Brycinus					4 510.50	
Schilbe					381.87	
T.rendalli					123.59	

3.4 DISCUSSION

Historical data on the Lake Victoria fisheries, although considered somewhat unreliable (Ssentongo, 1990; Reynolds *et al.*, 1995; Ligtvoet *et al.*, 1995a; Mkumbo & Cowx, 1999) provide an overview on the trends and exploitation levels in the fishery. Decline in CPUE was reported as early as 1929 (Graham, 1929) and remained in the fishery until the early 1980s despite the introductions of *Tilapia zillii, Oreochromis niloticus* and *Oreochromis leucostictus* in 1953; and Nile perch in the 1950s and 1960s (Chapter One). The use of shore seines introduced in the 1920s and nylon nets in 1950s coupled with fall in mesh sizes, despite a recommended 5-inch mesh limit in the 1930s, (Welcomme, 1966; Lowe-McConnell, 1997) contributed to the decline in CPUE before the Nile perch boom. The changes noted in the total landings in all three countries as a result of the explosion of the Nile perch in the early 1980s was followed by a declining trend in the 1990s and currently by signs of overexploitation. Historical data show the increase in effort and the shift from small mesh sizes to larger mesh sizes as the Nile perch fishery developed. Currently, however, there is a shift towards smaller mesh sizes, as a result of the excessive effort and the decrease in catch per unit of effort (CPUE), plus fishermen innovating different catching techniques as drifting or towing of gillnets and the vertical joining of gillnets to cover the whole water column.

The decreasing trend in CPUE found for Tanzania was prevalent in the other two countries. The double or triple mounting of gillnets to increase the catch rates reported in Tanzanian was also observed in Kenya and Uganda (Personal communication with A. Othina & J. Okaronon), while any increase in CPUE is fundamentally harvesting juveniles which constitute of 80% of the Nile perch catch. The slight increase in CPUE for gillnet motorised boats and gillnet paddled boats recorded in Tanzanian waters could be explaining by the changes in fishing practise. Motorised vessels explore distant fishing grounds whilst using triple stretched gillnets to cover more of the water column. The gillnet paddled boats are the ones operating relatively inshore and tend to use meshes below 5" so as to catch the tilapiines and other inshore species like *Brycinus* and *Schilbe*, but catch Nile perch juveniles coincidentally. The yield estimated for 1999 was almost 20 % less than the 2000 yield probably due to the export ban of Nile perch to the EU markets resulting to few boats fishing because of low prices. Although the same number of boats recorded in 2000 frame survey was used for the calculation as no other effort records were available, the proportion of boats fishing was slightly low than 2000. The ban was lifted at the end of 1999, which increased the demand resulting in an increase in the proportion of boats fishing in 2000.

CPUE can be a useful index of the size of a given stock, if the sources of variability are minimized through standardization of data collection (Hyvärinen & Salojärvi, 1991). Catch statistics in Lake Victoria consider a boat as the unit of effort irrespective of the fishing gear (Caddy & Bazigos, 1985). The results of the present study reflected the disparity of CPUE for the different gears and means of propulsion. The fishing practise also needs to be further investigated as passive gillnets or towed or single or triple mounted have different influences on the CPUE. The currently established catch statistical system in all the three countries needs therefore to be reviewed and include in the sampling the particulars of fishing gears and practices for management purposes. The research institutions could be running a standardized regular gillnets survey to give an independent estimate of the stocks and monitor changes in CPUE.

The gillnet fleet which was once dominated by 7-9 inches mesh size (Ligtvoet & Mkumbo, 1991) has become dominated by 5-6 inches. The number of long line hooks and beach seines have also increased. The length distributions landed by each gear reveal the heavy exploitation of juveniles with the exception of long lines with hooks of sizes 7 and 8. 83% of the catch landed by gillnet fleet was below the size at first maturity, while 88% males and 79% females of Nile perch caught by the legal minimum size of gillnets (5") were below their sizes at first maturity. For beach seines, which contributed 14% of the Nile perch annual catch for Tanzania, 100% of the catch was below size at first maturity. Kenya had the highest number of beach seines (Table 3.1). The large –scale harvesting of juveniles is believed to be a serious threat to the sustainability of the Nile perch fishery (Cowx *et al.*, 2000; Mkumbo *et al.*, 2000; Mkumbo *et al.*, 2002; Pitcher & Bundy, 1995; Reynolds *et al.*, 1995).

Among factors known to influence a collapse in an overexploited stock are market forces and uncontrolled increase of fishing effort (Hilborn & Walters, 1992, King, 1995). In Lake Victoria, the Nile perch fishery is directly under the influence of the fish processing factories, which are currently operating at under capacity (SEDAWOG, 1999a). The demand for fish is very high and with foreign markets selective for fillets from juvenile fish, there is no control of effort as long as someone can pay for a fishing and vessel licence, which is less than 15 US $ per year in Tanzania. The fish processing factories finance the successful fishermen with large fishing fleets of over 100 canoes with 80 to 120 triple joined nets in each canoe. To reduce the operational cost, one 45 Hp engine is used to tow up to 12 canoes to and from the fishing grounds, and fishing camps are formed on the nearest island. Collector boats belonging to the respective processing factory move from one camp to another to collect the catch for the factories. The set-up in the fishing industry in Lake Victoria has changed remarkably. Less successful fishermen are either turning to species other than Nile perch or are operating as labourers for the successful ones financed by or directly fishing for the Nile perch fish processing factories. Some of the less successful fishermen are now fully engaged in the beach seining, mostly at night, while others are using haplocromines from the beach seine catches or *Clarias*, as baits, to exploit Nile perch by long lines. The long lines, with the range of hook sizes used, they catch a wider range of Nile perch sizes than in the gill net fishery. The large sizes are considered the ones to replenish the stock and need to be protected from fishing for sustainability of the Nile perch fishery.

The analysis of the historical data available and the exploitation status revealed the problems in the fisheries. It is apparent, as a result of the introductions to Lake Victoria, the fisheries have gone through different phases of development. The 1960s to 1970s appear to be the growth phase followed by the fully exploited phase of 1980s to early 1990s and the overexploitation phase in mid 1990s to date. According to a generalised development model of uncontrolled fisheries, a collapse phase is expected unless fishing effort is controlled and carefully managed (Csirke & Sharp, 1984; Hilborn & Walters, 1992). From 1995, the CAS system in Tanzania broke-down due to retrenchment and decentralization. The Fisheries Department lacked the personnel and direct supervision to the district/beach level. As a result it is difficult to establish the trends in the fishery and the levels of exploitation. With a monitored fishery, it is easy to set limits in fishing effort than to reduce effort after overcapacity. There is need to restore and strengthen the CAS system to collect the fisheries dependent data. With the current fishing effort and fishing practices, a collapse in the Nile perch fishery is imminent (Chapter Six; Cowx *et al.*, 2000; Pitcher & Bundy, 1995; Pitcher *et al.*, 1996; Moreau, 1995; Villanueva & Moreau, 2002).

In the current yield estimates; dagaa contributes 46% of the total catch in the Tanzanian part. Under predator prey relationship, the release of predation pressure by Nile perch is expected to favour expansion of the dagaa stock (Moreau, 1995; Villanueva& Moreau, 1995). However, the contribution of dagaa to the Nile perch diet is minimal (Chapter Five; Hughes, 1986; Ogari & Dadzie, 1988; Mkumbo & Ligtvoet, 1992) and it may not therefore have such a direct influence on prey-predator relationships as predicted by the models. Nevertheless, the dagaa fishery is developing as the Nile perch catch rates are decreasing as it is an alternative fishery of income for the marginalized Nile perch fishermen. The Nile perch fishery currently requires a huge capital investment as the CPUE is decreasing. It appears that only the successful fishermen/gear owners subsidized by the fish processing factories that are surviving in the Nile perch fishery. The poor fishers seem to be switching to dagaa fishery, which needs less capital investment. This may explain the increase in dagaa contribution to the total landings and exemplifies the poverty level the fishermen will go to as Nile perch is collapsing and concurrently the danger of collapse of the other fisheries as they are the only alternative livelihood.

The yield estimates for *O.niloticus* were higher than 1992 catch records. It is difficult to ascertain whether it is an increase due to increase in stock size as there were no CPUE trends for comparison from the catch assessment surveys. Nonetheless, the Kenyan sector reported a decline in catch rates and high fishing mortality and exploitation rates (Getabu, 1992; Dache, 1994). The increase therefore could also be attributed to switching of the marginalized Nile perch fishermen to the use of beach seines, under-mesh nets and hooks both for hand & line and long lining, all effective in catching tilapia as well as juveniles of Nile perch. Piracy and theft of gillnets in Nile perch fishery is encouraging the continued use of these gears which are accelerating the collapse of the Nile perch fishery.

The haplochromine catch, which fell to 22 t in 1995 was estimated at 17 161 t for 2000, almost to the same level of 16 966 t in 1986 before the Nile perch boom. A recovery was also noted for the other species. Fishing effort now targets these species especially, haplochromines both for sale and as bait for the long line fishery, *Protopterus, Bagrus, Brycinus* and *Schilbe* for subsistence and *Clarias* for subsistence and as bait for the long line Nile perch fishery (Cowx, *et al.,* 2002; Njiru *et al.,* 2002). This may limit any recovery and impede any ecological re-stability in the lake (Moreau *et al.,* 1993).

Unlike a well-monitored fishery, it is difficult to assign the Lake Victoria fishery to any of the generalized dynamic processes in fisheries systems (Caddy & Gulland, 1983; Hilborn & Walters, 1992), which makes any predictions for the stocks difficult. Being a shared resource amongst the three riparian states of Kenya, Uganda and Tanzania, common management approach is crucial. Kenya has the highest effort compared with her water area, and also has the highest proportion of under-sized gears. The stock is therefore subjected to different intensity of fishing effort from the three national waters. Nevertheless, a general decline characterises the Nile perch fishery as a result of the alarming increase in effort both in term of fishing canoes and the gears. The exploitation pattern described is a cause for concern and calls for immediate interventions. A collapse was once predicted with the increasing effort (Pitcher & Bundy, 1995). Further, more than 80% of the catch is immature and the size of the spawning stock needed to sustain recruitment is unknown.

The estimated catches from the catch survey illustrate the current shift in the fisheries of the lake. The dagaa (*Rastrineobola argentea)* is currently the most dominant in the total landings, although biomass estimates by hydroacoustic survey (Tumwebaze *et al.*, 2002; Getabu *et al.*, 2002) still rank it second in abundance. Signs of a fall in CPUE were also recorded (Othina & Tweddle, 1999; Nsinda, 1999). However, the impact of fishing on dagaa is different to Nile perch, having a higher production turnover due to relatively high fecundity, high growth rate and high natural mortality (Wanink, 1991). Effort is also restricted to some extent by the difficulties in using light attraction in strong moonlight. The sustainability of the fishery is therefore relatively higher. With recovery of haplochromines, presence of high abundances of the fresh water shrimp (*Caridina niloticus*) (Goldschmidt & Wanink, 1993; Budeba & Cowx, 2000) and the present level of dagaa, all primary prey to Nile perch (Chapter Five), provide some support for the predator population not to be limited by food resources. However, what is threatening the sustainability of the Nile perch is far from food availability.

Excessive fishing effort as a result of open access to the fishery, high investment from the fish processing factories and high market demand resulting to fishing for juveniles are the driving forces which could lead to a collapse of the Nile perch fishery. The socio economic set-up in the industry supports this concern. The successful fishermen supported or subsidized by the processing factories have the means to increase effort and cover almost every corner of the lake. The marginalized less successful fishermen concentrate fishing inshore using illegal gears which increases the harvest of juveniles that are equally in high demand for local markets. Lack of effective control, monitoring and surveillance system (CMS) leaves the situation to take its own course and eventual collapse seems inevitable, unless immediate management actions are implemented. Some initiatives of community involvement in management of the resources are taking place though beach management units (BMU) in Tanzania (SEDAWOG, 1999b) but with the current socio-economic set-up in the industry, sense of ownership and thus accountability is eroded. There is need therefore to define roles and involve all the stakeholders in the management of the Nile perch fishery for sustainability.

Any attempt to control or limit effort in the Nile perch fishery has to specify number and sizes of gears used as well as the fishing practise. Catch surveys need regular, well structured monitoring programme with equipped and trained personnel in order to have reliable catch statistics for management of the fisheries. The stakeholders, especially fishermen and processors, could be trained in the process of co-management (Chapter Seven) to participate in collecting catch statistics and the Fisheries Department staff could advise and supervise in a situation of limited personnel as currently in Tanzania. Without reliable time series trends in CPUE it is impossible to track changes in the abundance of the stocks supporting a fishery at levels where sustainable yield can be regulated.

For any management regulations to be equally applicable for the three countries sharing the fisheries resource the effort deployed by each should be evaluated and the characteristics of each country's fishery well documented. The 2000 frame survey was unique to Lake Victoria, being conducted on the same days over the three countries and with enough funds and trained personnel to facilitate such information. This needs to be repeated on a regular basis. The need for consistency in statistical data recording and availability of funds and committed/trained personnel cannot be overemphasized. The system of catch survey conducted during the present study is recommended with an increase of days in a quarter for a wide coverage especially in the islands. To estimate total catches reliably in Lake Victoria more commitment is needed from the sector planners and managers to direct resources to monitoring of the fishery. The research institutions of the three riparian countries could be charged with this responsibility. They should have trained personnel to conduct the quarterly surveys while the communities could also keep daily records of catches landed. Availability of reliable historical CPUE and total catch and total effort data over a prolonged time series is the basis for any future predictions on the resource and is the only way to assess the state of the fishery and the need to alter management measures.

3.5 Summary

Fishey dependent data from existing catch assessment surveys for Kenya, Tanzania and Uganda and project supported frame survey and CAS surveys were used to assess the changes both in catches and effort over time in Lake Victoria. The trend was of low catches in all the species before mid 1980s and a sudden increase in the late 1980s with Nile perch dominating the later. The Kenyan fish landings from 1994 to 1998 showed a fall off in the landings of Nile perch. A declining trend in CPUE from the peak of 1994 as number of boats (effort) increased, was found along with an increase in number of the gears and the reduction in mesh sizes used over the period. Kenya had the highest effort (about 2.4 boats km^{-2} & 35 gillnets km^{-2}) followed by Uganda (about 0.6 boats km^{-2} & 10 gillnets km^{-2}) and Tanzania (about 0.5 boats km^{-2} & 6 gillnets km^{-2}). According to the frame survey, Kenya had 23% of gillnets below the legal mesh size of 5 inches, while for Uganda it was 18% and 11% in Tanzania.

Composition of the catches from different gears targeting Nile perch was also investigated. Gillnet fleets landed 83% and 99% immature males and females respectively, while the legal size of gillnets (5 inches) landed 88% immature fish (below 54 cm TL for males and 77 cm TL for females, the size at first maturity - L_{m50}). About 68% and 85% of the catch from hooks was below L_{m50} for males and females, respectively, while beach seines landed 98% immature Nile perch.

Catch per unit of effort (CPUE) varied significantly with the means of propulsion and the type of gear. Catch per boat increased by 13.8% from October 1997 to December 2000 but number of nets per boat increased by 100% resulting in a decrease of catch per net by almost 60%. The need to include type of gear in CAS and also standardizing the number of nets per boat was expressed for proper indices of relative abundance.

Using the effort recorded in the frame survey and the CPUE estimated during the catch surveys under this study, yields for the Tanzanian sector were estimated as: Nile perch - 138 323.8 ± 6 229.14 t, Dagaa - 167 789.00 ± 2 900.05 t, *O.niloticus* 11 811.4 ± 4 218.7 t, haplochromines - 17 161.00 t and the other species (*Protopterus, Clarias, Bagrus, Synodontis, Labeo, Mormyrus, Brycinus, Schilbe* and *T. rendalli*) - 6 993.4 t. Total yield of 342 080.06 t was estimated for the Tanzania waters, with Nile perch contributing 40%, Dagaa 49%, *O.niloticus* 3%, haplochromines 5% and the other species 3%. Due to a limited sample size of landing sites (9 out of 596) and gear especially for the lesser species, catches of some species could have been inaccurate.

Dagaa appears to becoming the most dominat fish species in the landings of Lake Victoria coupled with signs of recovery of haplochromines. The need to have a functional CAS system in Tanzania to monitor changes and have reliable indices of relative abundance for the management of fisheries resources is emphasized. Reduction of effort and fishing for juveniles needs a collaborative effort from all the stakeholders to sustain the Nile perch fishery.

CHAPTER FOUR

STOCK DISTRIBUTION AND ABUNDANCE

4.1 INTRODUCTION

Information on abundance and distribution of commercially important fish stocks is vital to estimate yield, which forms the basis for developing management strategies (Pitcher & Hart, 1982; Laevastu & Favorite, 1988). Estimates of the magnitude of the fisheries resources, the fluctuations and factors affecting the changes and the response of the stocks to fishing are all-important inputs to management. This information is used to decide how to exploit the resources without harming the production capacity of the ecosystem. Abundance of fish species is not a fixed quantity and it varies both spatially and temporally and such variations may not be reflected clearly in aggregated catch and effort statistics. Thus, although the fisheries dependent data collection can give an estimate of CPUE, which is commonly used as an index of relative abundance, fishermen usually improve their search techniques and concentrate in the rich fishing grounds. As a result CPUE can remain high to the point of collapse of the fishery (Hiborn & Walters, 1992). In Lake Victoria, fishermen have tended to move further offshore while concurrently reducing mesh sizes to catch juveniles or even changing fishing practices by vertically joining gillnets or towing them (Chapter Three). As a result, fisheries independent surveys were also conducted during this study.

Fisheries independent data collection surveys give better abundance indices which are proportional to stock size and reflect stock trends and responses to changing management regimes than fishery dependent surveys (Hilborn & Walters, 1992). It is also possible to get relative abundance patterns of distribution over the entire water area and over time. In Lake Victoria, the first fisheries independent survey was conducted in 1927-28 to assess the tilapiine stocks after a fall in gill net catches (Graham, 1929). The second survey was not until 1967 to 1971 when a lake-wide survey was done conducted under a UNDP/FAO project in collaboration with the then EAFFRO (Bergstrand & Cordone, 1971; Kudhongania & Cordone, 1974). Results from this survey on abundance and distribution were considered the only reliable reference on the stock sizes of Lake Victoria fishery. However, that survey was carried out before the Nile perch boom and the shift in the fishery in which the haplochromines, which were then the most abundant, had almost disappeared, and Nile perch, dagaa and *Oreochromis niloticus* became the most important commercial species (Bwathondi, 1985). Localized research efforts have been going on under FIRRI (Uganda), KMFRI (Kenya) and TAFIRI/HEST (Tanzania) but mostly on general biological aspects for particular fish species and some attempts on stock abundances covered only limited areas and short periods (Arunga, 1981; Acere, 1985 Bwathondi, 1985; Asila & Ogari, 1988; Katunzi, 1985; Ogutu-Ohwayo, 1990; Okaronon *et al.* 1985; Ligtvoet & Mkumbo, 1990; Witte & van Densen, 1995). Such localized information was used in an attempt to estimate the Nile perch stock size in Lake Victoria and predictions of a collapse with increase in fishing effort were cautioned (Pitcher & Bundy, 1995).

Sustainability of the Nile perch stock is at present a concern to all the stakeholders in the sector. The investment and present fishing effort are based on inadequate knowledge of the resource base. However, there is a general belief that there are non-exploited off shore and deep-water stocks of Nile perch, which will support intensive fishing. Within the overall objective of LVFRP project to estimate the abundance and establish the distribution patterns of the Nile perch stock in Lake Victoria, this chapter assesses the changes in species composition and determines the spatial and temporal distribution patterns of Nile perch in the Tanzanian waters with comparison of total biomass indices from Kenya and Ugandan waters. Catch rates from fisheries independent trawl surveys are examined and related to fluctuations and their probable causes. Estimates of biomass and abundance using the 'swept area method' are provided and mapped in geographical areas over different seasons. Understanding the fluctuations in abundance and distribution of the Nile perch resource over time and locality is fundamental for addressing the concerns about the sustainability of the fishery and is a basis for the management of the resource.

4.2 MATERIALS AND METHODS

4.2.1 Bottom trawl surveys

The Tanzanian part of Lake Victoria was divided into three zones (Fig. 4.1). Zone A stretches from Kome and Buhiru islands in the south west, north eastwards to the south west of Ukerewe island, including Speke Gulf and Mwanza Gulf. Zone B is from the Tanzania-Kenya border southwards to the north west of Ukerewe islands. Zone C covers the Kagera waters from the Tanzania-Uganda border southwards to Kome Island, including Emin Pasha Gulf.

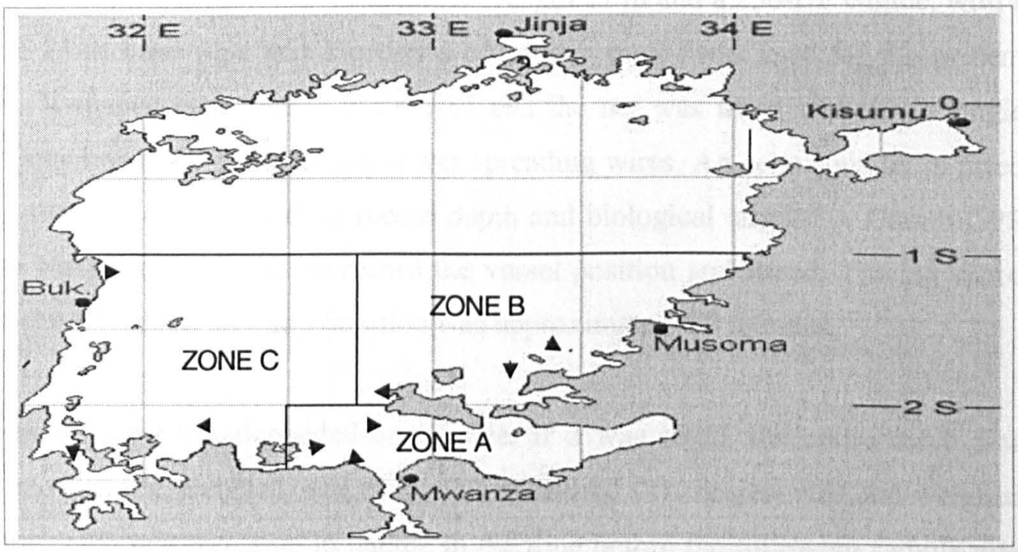


Figure 4.1 Lake Victoria showing the three zones sampled (A, B, & C) of the Tanzanian waters (arrows indicate the non-trawlable rocky bottom areas)

The sampling stations were allocated within each zone using gridlines of five nautical mile-squares based on degrees and minutes of latitude and longitude on hydrographical charts. In each square, one sampling station was allocated, except in very deep waters, where squares of ten to fifteen nautical miles were sampled. Sampling started in November 1997 but due to vessel problems it was suspended in February 1998 until March 1999 and continued monthly to July 2000 except when the vessel was used for six monthly hydro-acoustic surveys in August/September and January/February 1999 & 2000. Harmonized surveys with standardized gears were conducted at the same period in the Kenyan (Getabu & Nyaundi, 1999) and Ugandan (Okaronon *et.al*, 1999) waters of Lake Victoria. A total of 530 hauls, covering the entire depth range (deeper than 5-m due to the vessel draught) were conducted, of which 196 were in zone A, 158 in zone B and 176 in zone C. A total of 18 monthly cruises were conducted. Areas with rough, rocky substratum were not sampled. Each consecutive zone was sampled on a three-monthly rotational basis because of resource constraints, but it was deemed possible to determine seasonal changes in fish population structure. Two quarterly surveys covering the whole of the Tanzanian waters were also conducted in November 2000 and April 2001. The sampling stations were located in fifteen by fifteen, nautical square-miles. A total of 69 hauls was made. Some squares were not sampled during some quarters due to very rough weather.

The research vessel, *R.V. Victoria Explorer*, length 17 m and a 250-HP engine, with a net with 24-m head rope and a cod-end of 25-mm mesh, was used for the present surveys. V-shaped otter-boards were used and the net was fitted with 15-m single sweeps attached to 20-m upper and lower spreading wires. An echo sounder is fitted beneath the keel of the vessel to record depth and biological targets. A Gamin GPS Satellite Navigator was used to record the vessel position and speed. Towing speed was 3.4-3.6 knots and trawling duration was approximately 30 minutes.

Treatment of the catch depended on its size. If it was small, the entire catch was sorted into species, weighed, and every fish measured (TL nearest cm) and weighed (g). If the catch was too large to handle in the time before the following sample was landed, fish above about 35 cm TL were sorted from the catch and measured individually. The remaining small fish, <35 cm TL, were sub-sampled by taking three shovels full of fish from a thoroughly-mixed heap on deck. Depending on the average size of fish in the sample, the number of shovels could be increased to have a minimum of 200 fish. The weights of the sub-sample and complete sample from which the sub-sample was taken were used to obtain a raising factor. Changes in species composition was determined using the mean catch rates of the different species separately for the three zones, and this was compared with historical data from *IBIS*, *R.V. KIBOKO* & *R.V. TAFIRI II*, to assess the change in fish diversity in the lake. Species dominance in the catches was also assessed by comparing the percentage composition of different species in the catches of *R.V. Explorer* operated in waters of more than 5m deep and those of *TAFIRI* II operated in the same period but in the inshore waters of less than 10 m deep. Changes in fish stock abundance were assessed using the mean catch rates of the different research vessels. Monthly catch rates (kg hr^{-1}) from the three sampled zones, A, B & C, were treated separately to assess the temporal distribution of the fish stocks. Mean catch rates from different depth ranges were used to determine the batho-spatial distribution of the stocks. These were then compared to historical data (Kudhoghania & Cordone 1974; HEST/TAFIRI unpublished data). It is recognized that the capture efficiency and selectivity of the vessel used may vary but it was assumed that the output would illustrate trends in stock abundance.

For standing stock biomass (t km^{-2}) and abundance (t) estimates, mean catch rates per 15 by 15 nautical mile squares were used. Each square was allocated a reference number (Fig. 4.2) and using GPS positioning hauls were allocated to the specific squares.

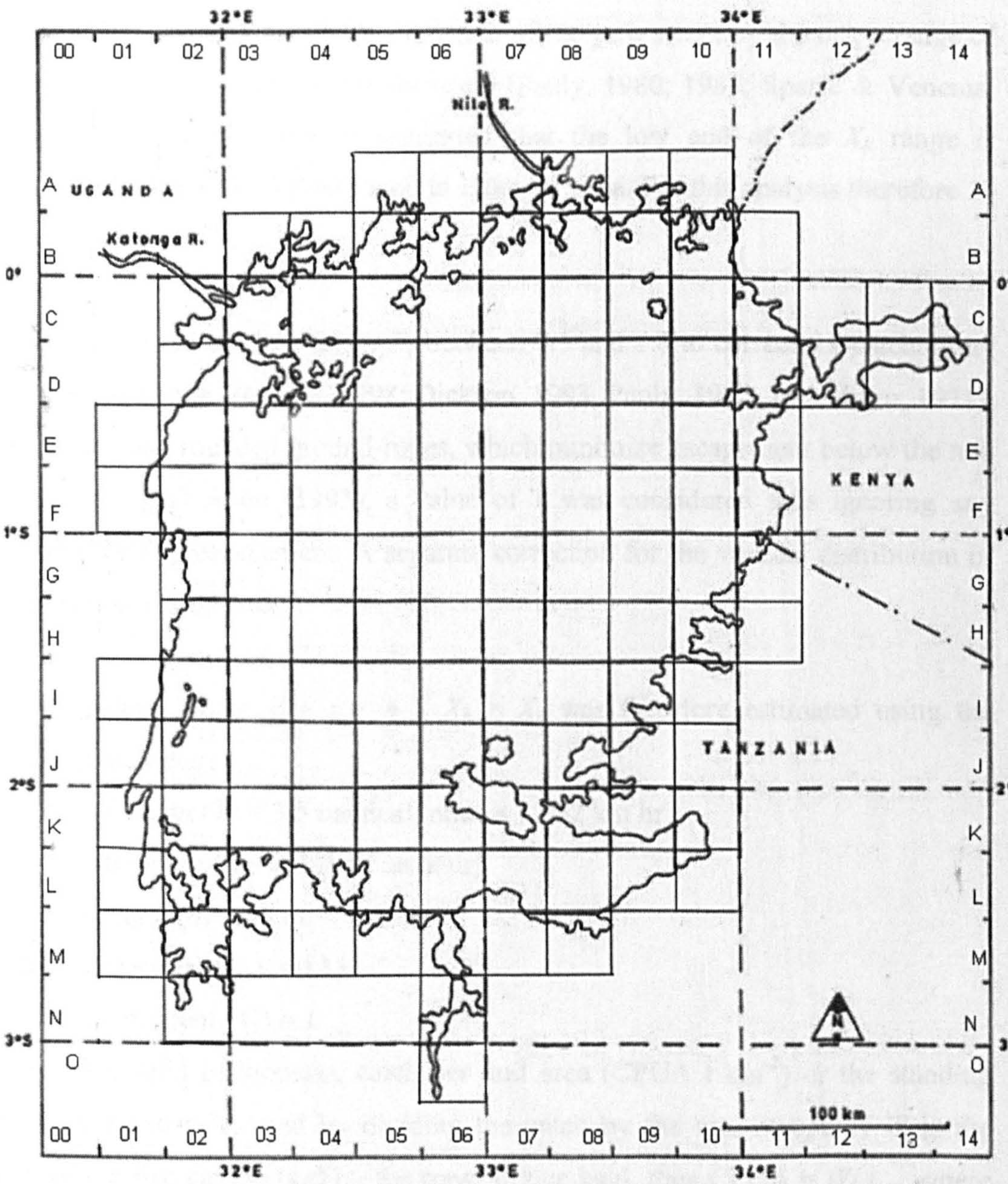


Figure 4.2 Lake Victoria map showing 15 by 15 nautical mile sampling squares with the reference letters and numbers along the sides

The swept area method (Sparre & Venema, 1992; 1998) was used to estimate the biomass of the demersal stocks. The effective path swept, *A*, or the area within which fish are susceptible to capture was estimated as:

$A_{sw} = D * h * X_h$

$D = V * t$,

where V is the velocity of the trawl over the ground, t the time spent trawling, h the length of the head-rope, and X_h the fraction of the head-rope which is equal to the width of the path swept by the trawl.

The wingspread is therefore given as $h * X_h$.

As it is difficult to measure X_h, or the width of the path swept by the net, a range of values 0.33 to 0.7 is given in the literature (Pauly, 1980; 1983; Sparre & Venema, 1998) Ligtvoet *et al.*, (1995a) suggested that the low end of the X_h range is appropriate for the soft lakebed found in Lake Victoria. For this analysis therefore $X_h = 0.33$ is adopted.

It is also suggested to use a factor X_e between 0.5 and 1.0 to correct for catchability efficiency (Sparre & Venema, 1998; Dickson, 1993, Pauly, 1980, Isarankuru, 1971). The net used had rounded ground-ropes, which minimize escapement below the net. Thus following Dickson (1993), a value of 1 was considered thus ignoring any correction for fish escapement. A separate correction for the vertical distribution of the fish is considered later.

The area swept, $A_{sw} = V \times t \times h \times X_h \times X_e$ was therefore estimated using the following parameters

Speed of the vessel (V) = 3.5 nautical miles × 1.852 km hr^{-1}

Time spent trawling (t) = 0.5 (half an hour)

Head rope length (h) = 24 m

Width of path swept (X_h) = 0.33

Catchability efficient (X_e) = 1

For the estimation of biomass, catch per unit area (CPUA t km^{-2}) or the standing crop is used and calculated by dividing the catch by the area swept. If W is the weight of the fish caught (kg) by the trawl in one haul, then CPUA = W/A_{sw}, where A_{sw} is the area swept.

Each haul gives an estimate of the CPUA, and is expected to be a representative of a larger area within which it is assumed that the fish biomass and its distribution are statistically uniform. The area could be established on the basis of bathymetric and/or geographical limits (Gunderson, 1993). For this study, it was based on location; the sampling squares of 15 by 15 nautical miles or 15-minute interval in the latitude and longitude lines. Being close to the equator, the area of each square, A_{sq} is nearly the same, i.e. 771.7 km^2. The proportion of a given square occupied by water, F_i was estimated from measurements on a map, and the sampled area in that square is $F_i \times A_{sq}$, and the biomass estimate for the square is CPUA × $F_i \times A_{sq}$.

If N_i hauls were made in a given square, the mean CPUA and the biomass within that square or fish abundances was estimated as:

$$CPUA_i = \sum_{j=1}^{N_i} W_{ij} / (N_i \times A_{sw})$$

As Nile perch is not a totally demersal species but is distributed throughout the entire water column, the catch rate needs adjusting for this dispersal pattern. The proportion of the population estimated by the swept area method was considered only approximately 50% of the total biomass based on vertical gill net experiments (Asila, 2001). To account for this distribution a correction factor $P_i = 0.5$ was used.

The standing stock for the given square (Sc_i) was therefore estimated as:

$SC_i = CPUA_i / P_i$

Total biomass or abundance estimates (Q_i) in the water column was given by the formula:

$Q_i = F_i \times A_{sq} \times SC_i$

Abundance indices (B_i) were calculated for each zone as the standing stock (SC) multiplied by the total area of squares visited during each survey. These were calculated for the three zones and each quarter separately. Comparison was also made with estimates from Kenya and Uganda waters, and eventually the whole lake.

4.2.2 Historical bottom trawl surveys

Historical data collected by three different research vessels were used for comparison and assessment of trends.

The research vessel *IBIS*, length 17-m and a 180-HP engine, was used in the 1969/1970 bottom trawl surveys with two standard nets of 24-m and 19-m head rope, and cod-ends of varied mesh sizes but mainly 64, 38 and 19-mm mesh sizes. Average towing speed was 3 knots and fishing duration was 60 minutes. The survey was lake-wide from January 1969 to May 1971 inclusive, but data from hauls made in the Tanzanian waters only are considered for the present study. A total of 318 hauls were conducted in the Tanzanian waters.

The research vessel *R.V. KIBOKO,* length 15 m and a 150-HP engine, was used in the 1985/1989 bottom trawl surveys with a net of 18-m head rope and a cod-end of 25-mm mesh. Towing speed was 3 knots and fishing duration was 30 minutes. The surveys were more localized, and only data from zone A, which had a wide coverage, were used for comparison. A total of 417 hauls was made for the period from 1984 to 1993 in zone A.

The research vessel *R.V. TAFIRI II,* length 16m and a 175-HP engine, was used in the 1995/1996 bottom trawls in zone A with a net of 13.5-m head rope and a cod-end of 38 mm. Trawling speed was 2.5 knots and duration of the hauls was 60 minutes. Sampling was random (not stratified) and monthly, with a total of 1219 hauls from 1995 to 1996.

4.3 RESULTS

4.3.1 Changes in species composition and stock abundance

Nile perch dominated experimental trawl catches from 1989 to 2000; but haplochromines predominated before this time (Table 4.1). In 1969/1970, the haplochromine catch was 450.2-kg hr^{-1} and constituted 71% of the total catch. Twenty-four other species were caught; Nile perch catch was negligible (1.0 kg hr^{-1}). The contribution of the other species, e.g. *Oreochromis esculentus, Bagrus docmak, Clarias gariepinus, Protopterus aethiopicus* and *Synodontis victoriae,* was more than 10 kg hr^{-1} of the catches.

In the 1985 surveys in the Mwanza Gulf, haplochromine catch rates was 219.1 - kg hr^{-1}, representing 69% of the total, and Nile perch catches increased to 75.3 kg hr^{-1} (24%). Only four other species were recorded, *Protopterus aethiopicus, Bagrus docmak, Clarias gariepinus* and *Oreochromis niloticus* (Table 4.1). Catches by the same vessel in the same area in 1989 comprised 94.6% Nile perch, while haplochromines were not found. All other species recorded earlier contributed less than 2% of the catches.

In 1995/1996, Nile perch catch rate increased from 191 kg hr^{-1} (almost 100% of the catch), to 279.9 kg hr^{-1} (91%). Other species in the catch included haplochromines, *Schilbe intermedius* and *O. niloticus,* but their contribution was minor (Table 4.1). Nile perch contributed 91.6% of the catches (249.11 kg hr^{-1}) in 1999/2000, while haplochromines had reappeared and become an important component of the catch (18.8 kg hr^{-1} representing 5.7% of the total catch). Thirteen other species were recorded, i.e. *O. niloticus*, *Rastrineobola argentea*, *P. aethiopicus*, *Schilbe intermedius*, *C. gariepinus*, *Barbus profoundus*, *Barbus altianalis*, *B. docmak*, *Brycinus* spp., *Synodontis* spp. and *Labeo victorianus*. The percentage contribution of the species differs with habitat. Catches from *R.V.TAFIRI II* from inshore waters had relatively higher contributions of *O.niloticus* (11.2%) and *P.aethiopicus* (13.6%) in the total catch than the off shore catches of *R.V.Victoria Explorer* (Table 4.2). Nile perch was less dominant in the inshore waters (69.9% by weight) as well as haplochromines (1.5% by weight).

Table 4.1 Species composition by mean catch (kg hr^{-1}) sampled by the four research vessels; *IBIS, R.V. KIBOKO, R.V.TAFIRI II & R.V. Victoria Explorer*

Species	*IBIS*	*R.V.KIBOKO*		*R.V.TAFIRI II*		*R.V.Vic/Expl.*
	1969/1970	**1985**	**1989**	**1995**	**1996**	**1999/2000**
Haplochromines	450.15	219.10	0	0	10.44	32.71
O.esculentus	17.46	0	0	0	0	0
O.variabilis	0.68	0	0	0	0	0
O.niloticus	2.73	0.10	0.80	0	3.37	4.86
O.leucostictus	0	0	0	0	0	0
Tilapia zillii	0.13	0	0	0	0	0
Bagrus docmak	29.38	3.70	0.20	0	0	0.18
C. gariepinus	20.95	1.80	0.90	0	0	0.73
X. eupogon	0.26	0	0	0	0	0
P. aethiopicus	11.88	16.80	1.50	0	0	2.71
L. niloticus	1.00	75.30	94.60	191.20	279.90	249.11
S. victoriae	12.51	0	0	0	0	0.18
S. afrofischeri	0.10	0	0	0	0	0.04
B. profundus	0	0	0	0	0	0.31
B. altianalis	0.32	0	0	0	0	0.23
L.victorianus	0.17	0	0	0	0	0.02
Mormyrus kannume	0.31	0	0	0	0	0
Schilbe intermedius	0.63	0	0	0	0.89	1.67
Brycinus spp.	0	0	0	0	11.92	0.54
A. frenatus	0	0	0	0	0	0
G. longibarbus	0	0	0	0	0	0
Rasrineobola argentea	0	0	0	0	0	2.80
Caridina niloticus	0	0	0	0	0	0.01
Total	548.66	316.8	98.0	191.2	306.53	296.1

The percentage contribution of all other species by weight was higher in inshore waters compared with offshore waters, except for *Barbus profundus*. *Rastrineobola argentea* was not represented although it is currently most abundant species in the catches from Lake Victoria (Chapter Three), because the type of gear and method used was selective against the species.

Stocks abundances fluctuated over the years (Fig. 4.3). The mean catch rates (548.66 kg hr^{-1}) in 1969/70 were high but fell dramatically to very low catch rates (96.67 kg hr^{-1}) in the 1980s. A recovery was observed in the 1990s to a peak of 306.53 kg hr^{-1} in 1996. Stock abundance remained at a relatively high level to 1999/2000 (296.1 kg hr^{-1}), but drop abruptly (129.57 kg hr^{-1}) in the last bottom trawl surveys in April 2001.

Table 4.2 Species composition by percentage mean catch rates sampled by the two research vessels*; R.V.TAFIRI II* (inshore waters only) & *R.V. Victoria Explorer* (more offshore waters) in 1999/2000

Species	*R.V. Victoria Explorer*	*R.V.TAFIRI II*
Lates niloticus	91.6000	69.8885
Oreochromis niloticus	0.8141	11.2244
Protopterus aethiopicus	0.5412	13.6477
Haplochromine	5.7334	1.4834
Schilbe intermedius	0.2446	0.9995
Rastrineobola argentea	0.5654	0.0000
Clarias gariepinus	0.1605	0.8924
Barbus profundus	0.0646	0.0079
Brycinus jacksonii	0.0975	1.3049
Synodontis victoriae	0.0466	0.0952
Synodontis afrofischeri	0.0011	0.0595
Bagrus docmack	0.0422	0.3808
Labeo victorianus	0.0046	0.0159
Momyrus kannume	0.0001	
Afromastercembelus	0.0001	
Caridina nilotica	0.0005	
Snails	0.0481	
Barbus altinalis	0.0009	

Considering the Nile perch stock separately, a general increasing trend is depicted irrespective of the different vessels used (Fig. 4.4). The relatively low mean catch rate in 1992 is explained by the localised surveys of *R.V. KIBOKO* in zone A, which by then was heavily overfished by commercial trawlers. The minimal variation in catch rates in 1995 and 1996 (indicated by the 95% C.L.) is also due to concentrated

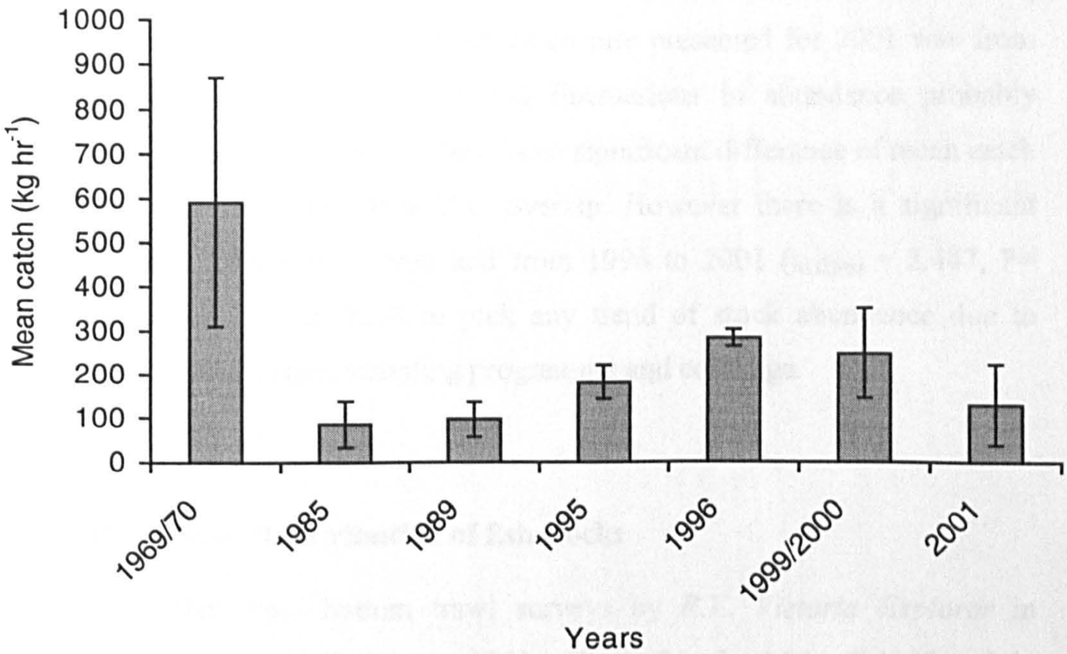


Figure 4.3 Mean catch rates of the different research vessels at different periods in Lake Victoria: 1969/70 *R.V. IBIS*, 1985&1989 *R.V. KIBOKO*, 1995&1996 *R.V. TAFIRI II* and 1999/2000 & 2001 *R.V. Victoria Explorer*.

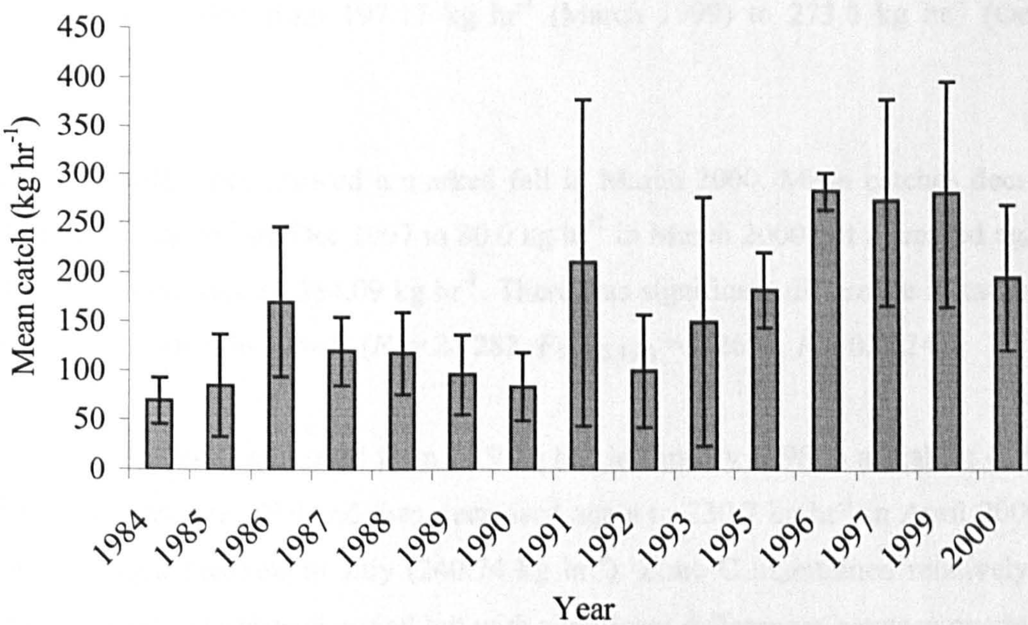


Figure 4.4 Change in Nile perch mean catch rates in different periods by different research vessels (*R.V. KIBOKO*, 1984-1993; *R.V. TAFIRI II*, 1995&1996; *R.V. Victoria Explorer*, 1997-2000) in the Tanzanian waters of Lake Victoria

surveys by *R.V. TAFIRI* II in Speke Gulf, which was by then a very rich fishing ground (Mkumbo *et al.*, 1996). The mean catch rate presented for 2001 was from surveys done in one quarter and seasonal fluctuations in abundance probably explains the drop illustrated, however there is no significant difference of mean catch rates over the years as all the 95% C.L. overlap. However there is a significant difference of catch rates before 1996 and from 1996 to 2001 ($t_{0.05(6)} = 2.447$, P= 0.002). Nevertheless, it is difficult to pick any trend of stock abundance due to differences in the vessels used, sampling programme and coverage.

4.3.2 Spatial - Temporal distribution of fish stocks

Catch rates recorded from bottom trawl surveys by *R.V. Victoria Explorer* in November and December 1997, January 1998 and monthly from March 1999 to July 2000 indicated varying temporal patterns within zones B and C (Fig. 4.5). Zone A had more stable catches over the period compared with the other two zones. ANOVA analysis showed there was no significant difference of catch rates for the different quarters in zone A ($F_s = 1.232$, $F_{0.05(5,172)} = 2.2667$, and $P = 0.296$). The mean catch varied from 197.17 kg hr^{-1} (March 1999) to 273.0 kg hr^{-1} (October 1999).

Zone B catch rates showed a marked fall in March 2000. Mean catches decreased from 287.7 kg hr^{-1} in. Dec 1997 to 80.0 kg hr^{-1} in March 2000 but increased again in June the same year to 354.09 kg hr^{-1}. There was significant difference in catch rates between quarters in zone B ($F_s = 2.7283$, $F_{0.05(5,163)} = 2.2696$, $P = 0.0214$).

Catches in zone C increased from 74.9 kg hr^{-1} in January 1998 to a peak of 415.9 kg hr^{-1} in September 1999 and then decreased again to 230.7 kg hr^{-1} in April 2000 and with a slight increase in July (240.74 kg hr^{-1}). Zone C maintained relatively high catches over the sampled period but with significant differences between quarters ($F_s = 5.4044$, $F_{0.05\,(5,176)} = 2.2654$, and $P = 0.000119$). Using the two way ANOVA, there was no significant difference between zones ($F_s = 0.164$, $F_{0.05\,(2,17)} = 4.103$, and $P = 0.8509$) and between the different sampled time ($F_s = 0.5229$, $F_{0.05\,(5,17)} = 3.3258$, and $P = 0.7542$). Likewise, no significant interactive effect was found between the sampled months and zones ($F_{interaction} = 1.51$)

4.3.3 Batho-spatial distribution of fish stocks

The pattern of variation in catch rates with depth did not differ between zones (Fig. 4.6). Catch rates exhibited a slight increase with depth but no significant difference between the different depth ranges (F_s =2.56, $F_{0.05\ (4,14)}$ = 3.84, P = 0.12) or between zones (F_s = 0.2084, $F_{0.05\ (2,14)}$ = 4.46, P = 0.82). There was also no significant interactive effect between zones and the depths sampled ($F_{interaction}$ = -0.89). The ranges of 50-60 m (5 samples), and above 60 m (2 samples), were not included in the analysis because of too few samples.

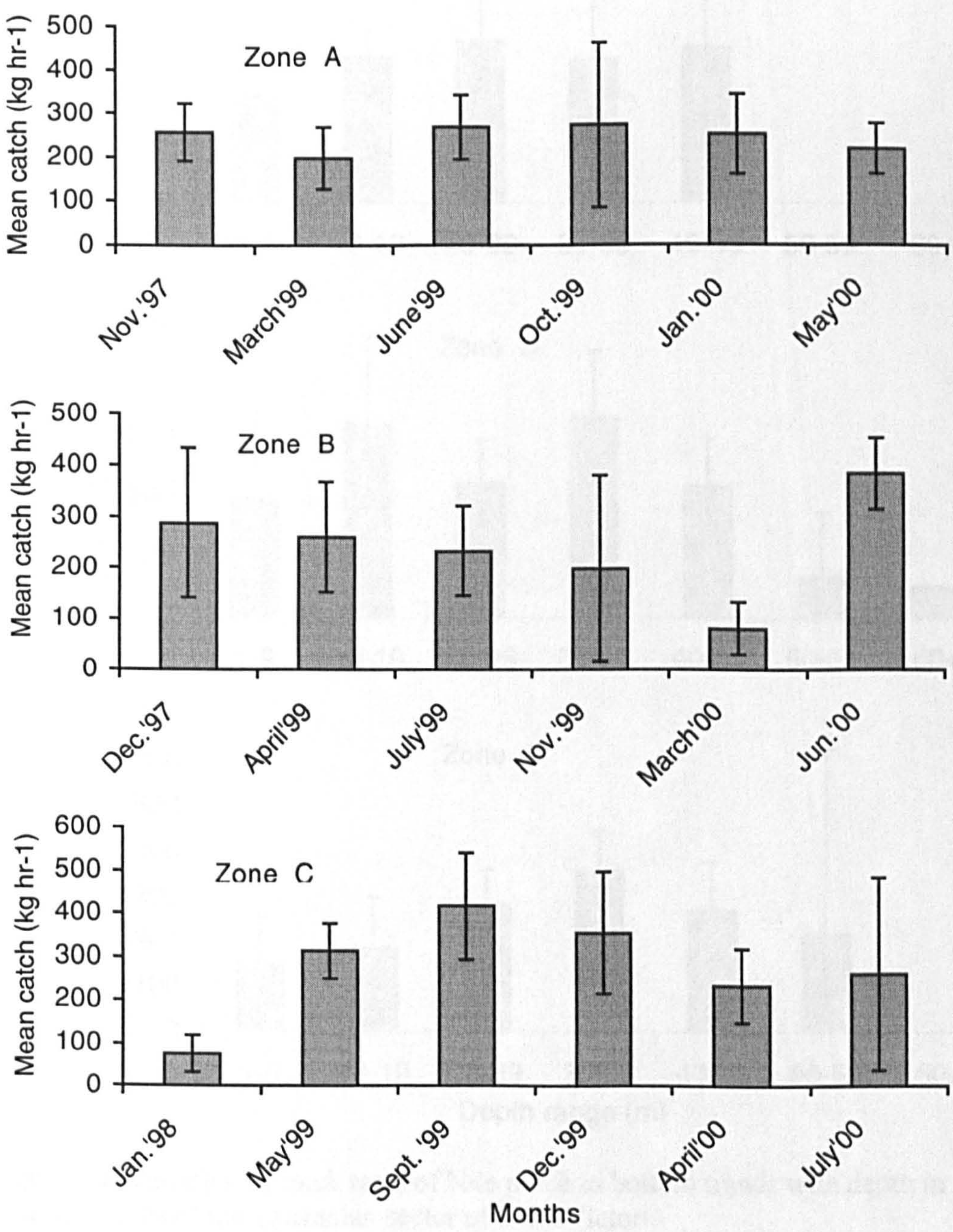


Figure 4.5 Monthly mean catch rates from the three zones (A, B & C) sampled quarterly from Nov. 1997 to July 2000.

There was a difference in catch rates for the different species in the three zones (Fig. 4.7). Haplochromines were more abundant in zone A, while Bawman Gulf, Musoma and Shirati Bay (Zone B) had relatively high catches of *O. niloticus* followed by the Emin Pasha Gulf and Kemondo Bay and Kagera Bay (Zone C) because *O. niloticus* occurred in shallow waters of less than 20m deep. The group of 'others' included the species listed in Table 4.2 above.

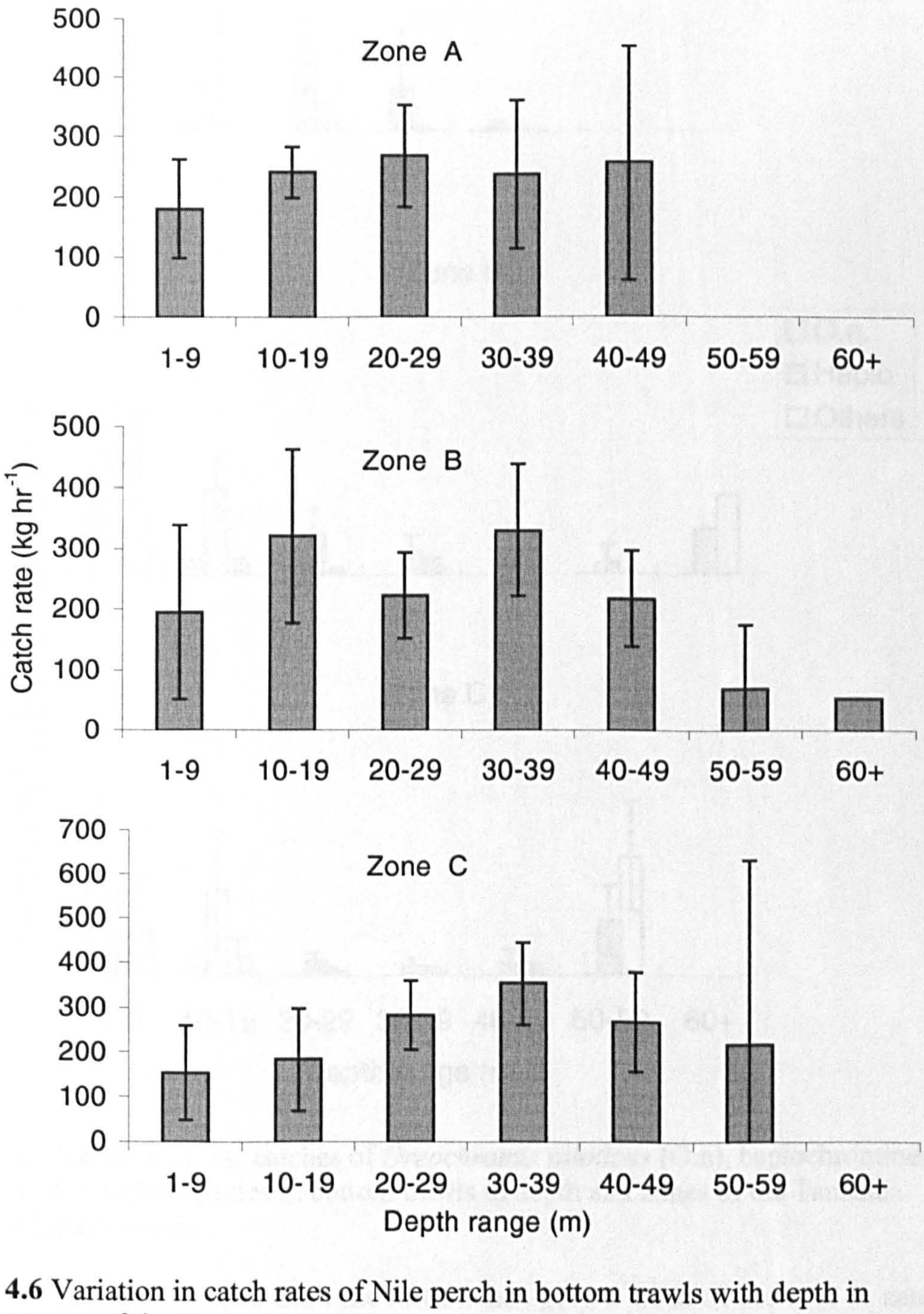


Figure 4.6 Variation in catch rates of Nile perch in bottom trawls with depth in different zones of the Tanzanian sector of Lake Victoria

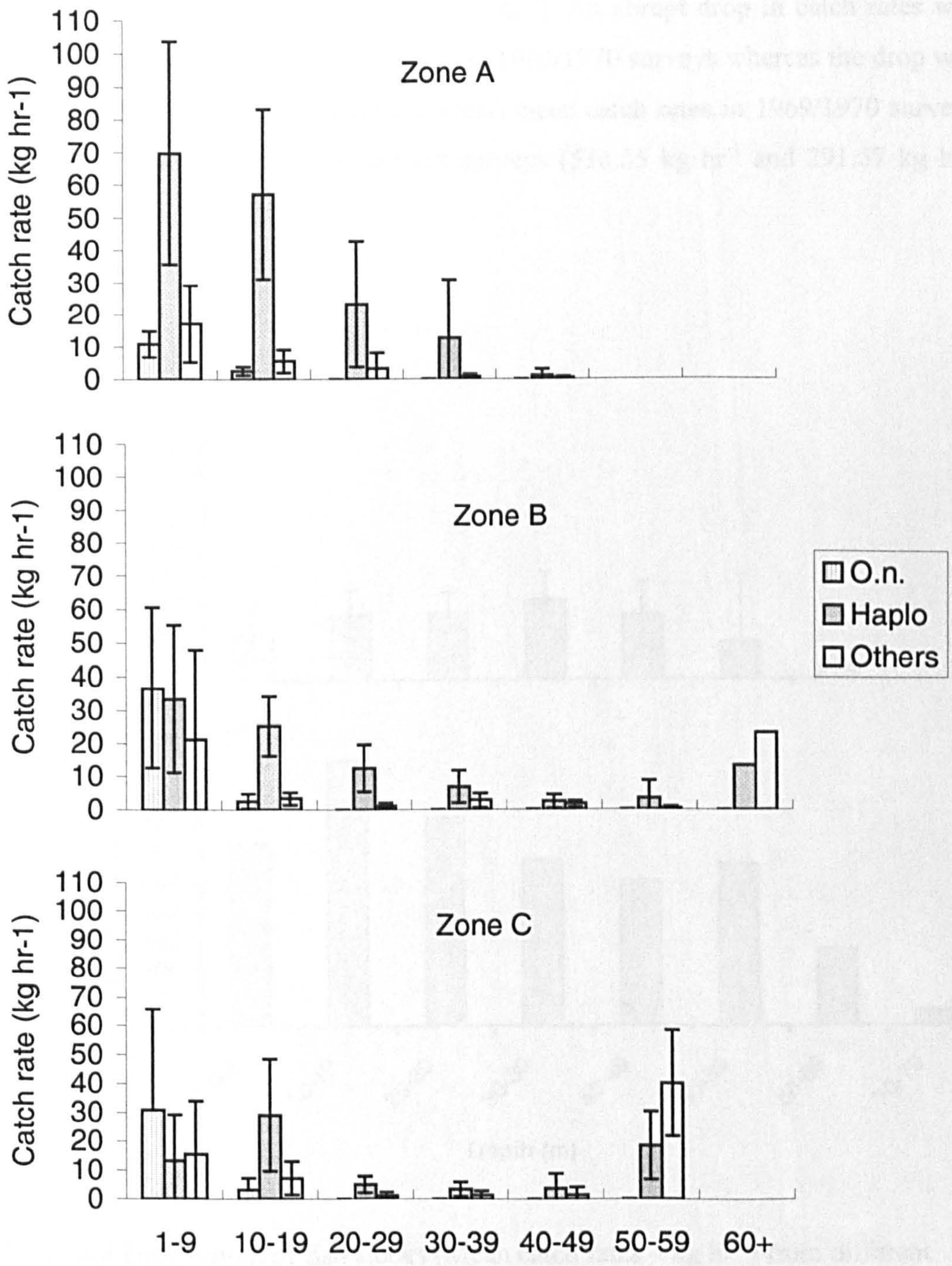


Figure 4.7 Variation in the catches of *Oreochromis niloticus* (O.n), haplochromines (Haplo) and the other species in bottom trawls in depth and zones of the Tanzania sector of Lake Victoria

Combined catches by depth from the three zones gave a trend of increase in catch rates with depth to 40 m depth followed by a decrease (Fig. 4.8a). ANOVA showed significant differences in catches between depth ranges (F_s = 3.3631, $F_{0.05\ (4,525)}$ = 2.3889, P = 0.0099). Highest catch rates (320.19 kg hr^{-1}) were in the depth range of

30-39m. In the 1969/1970 surveys (Fig. 4.8b), catches in the inshore waters of 10-19 m depth range were the highest (935.3 kg hr^{-1}). An abrupt drop in catch rates was found for the depth range of 60-69 m in the 1969/1970 surveys whereas the drop was at 50-59m-depth for recent surveys. Overall mean catch rates in 1969/1970 surveys were almost twice those of the current surveys (536.55 kg hr^{-1} and 291.57 kg hr^{-1} respectively).

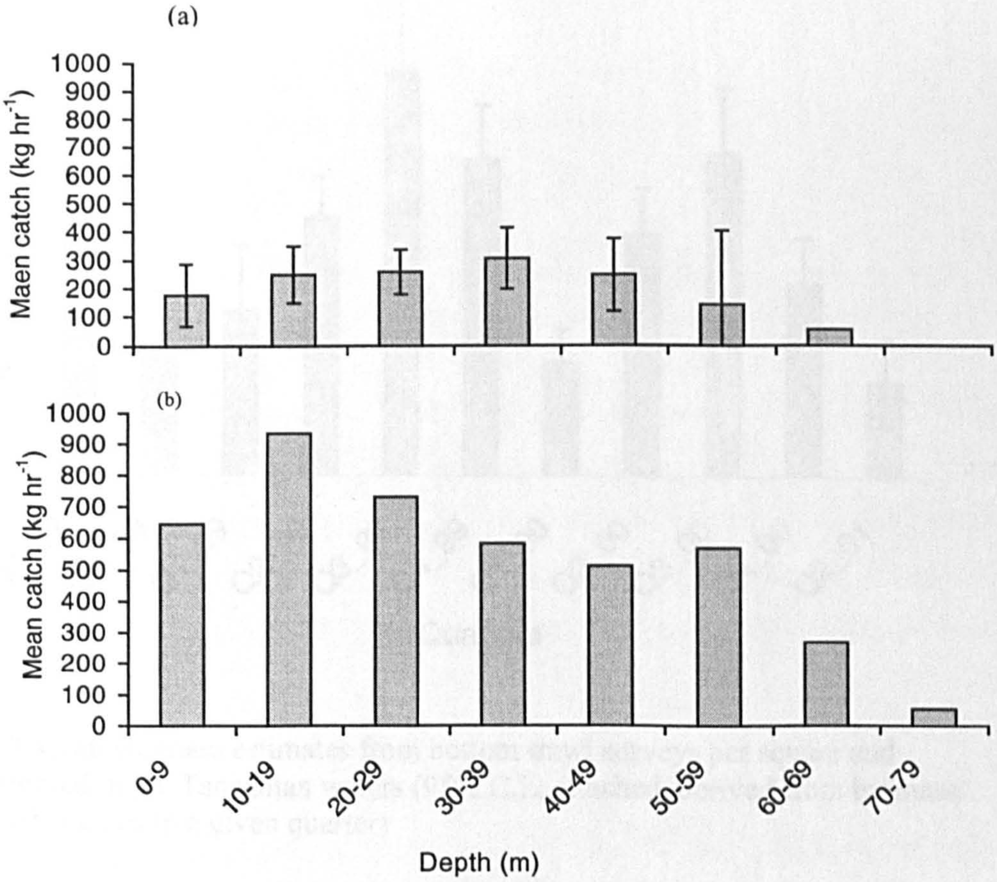


Figure 4.8 Distribution of fish stocks (Mean catch rates – kg hr^{-1}) from different depths of the Tanzanian waters during different periods: a, 1999/2000 surveys & b, 1969/1970 surveys

4.3.4 Biomass estimates by swept area method

Mean biomass indices per sample square (15 × 15 km) fluctuated from 1 802.94 t in the second quarter of 2001 to 7 711.78 t in the third quarter of 1999 (Fig. 4.9). Biomass estimates for the different zones in the different quarters varied (Fig. 4.10). Zone C had the highest biomass indices except for the first quarter. Mean biomass indices (Fig. 4.10) varied from 2 622.6 t in the first quarter to 7 466.1 t in the fourth quarter while for zone B it was 1 516.8 t in the first quarter to 6 810.6 t in the third quarter. Zone A had a narrow range of variation from 3 494.4 t in the first quarter to 4 303.2 t in the fourth quarter. A general pattern of low biomass indices in the first quarter with increase to a peak in the third quarter followed by a decline to the fouth quarter was observed (Fig. 4.9).

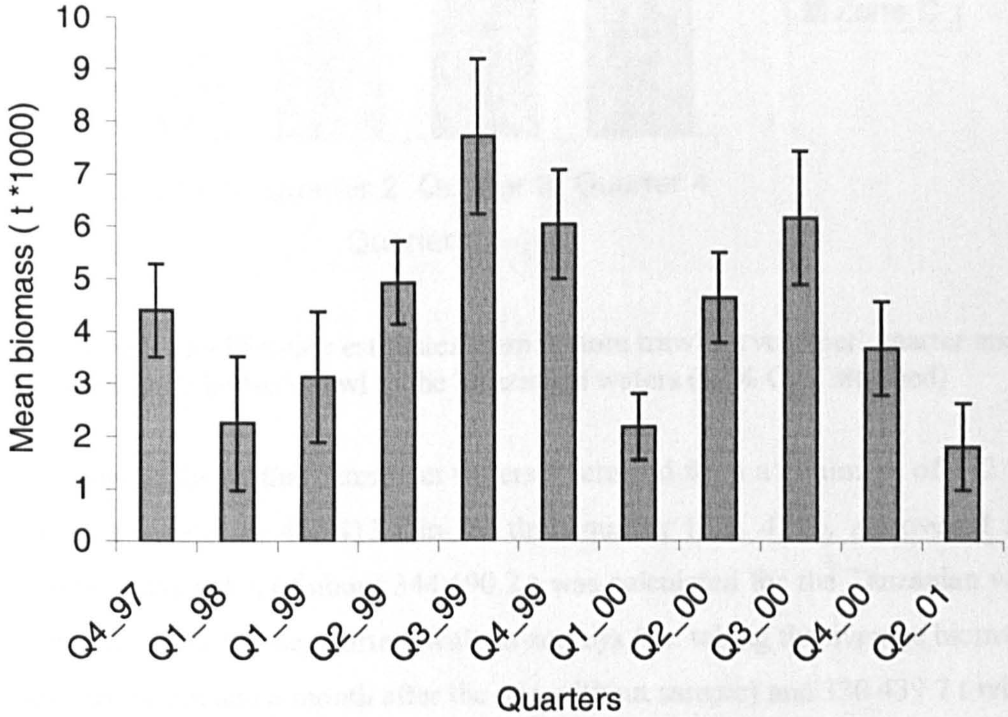


Figure 4.9 Mean Biomass estimates from bottom trawl surveys per square and quarter sampled in the Tanzanian waters (95% C.L. attached, derived from biomass per sampled squares in a given quarter)

The pattern was repeated over the two years sampled, and the first quarter had the lowest biomass estimates for all the three zones (Fig. 4.10). Zone A appeared to have relatively stable biomass index over the year while in zones B and C biomass increased to the third quarter and decreased for zone B in the fourth quarter but was maintained at a higher level in zone C. However, a non-significant difference was found by two way ANOVA (between zones, $F_s = 2.97$, $F_{0.05(2,11)} = 5.14$, $P = 0.13$ & between quarters, $F_s = 4.32$, $F_{0.05(3,11)} = 4.76$, $P = 0.06$). Due to unequal sample sizes/ hauls per quarter, the mean biomass estimates per quarter was used in the ANOVA test. This limited further analysis to test for interaction.

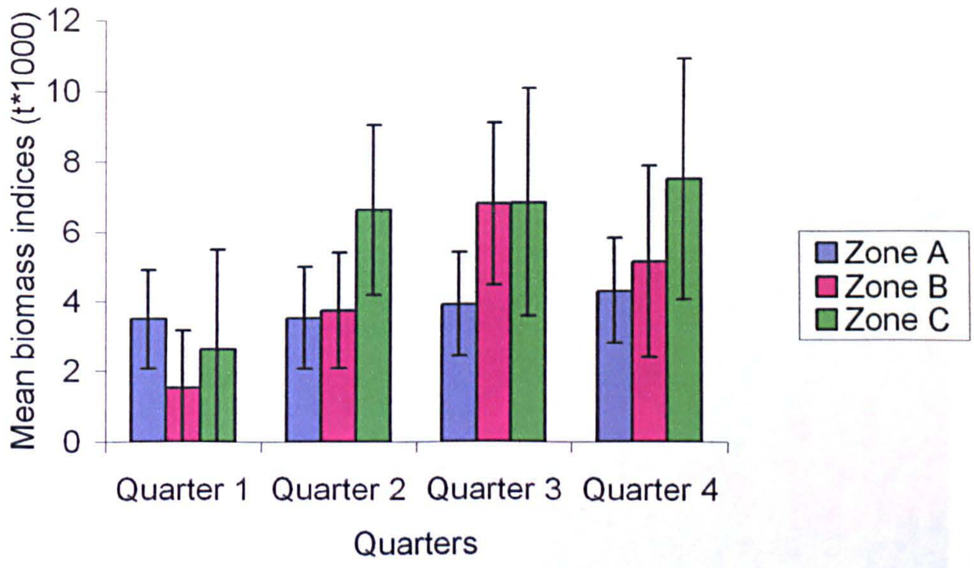


Figure 4.10 Mean Biomass estimates from bottom trawl surveys per, quarter and zone sampled by bottom trawl in the Tanzanian waters (95% C.L. attached)

Total biomass for all the Tanzanian waters fluctuated from a minimum of 172 705 t in the first quarter to 439 413 t in the third quarter (Fig. 4.11). An overall mean annual biomass index of about 344 690.2 t was calculated for the Tanzanian waters with interpolation for the quarters with no surveys (i.e. taking the average biomass of a previous month and a month after the one without sample) and 330 439.7 t without interpolations.

Zone C appeared to have higher abundance indices when compared with other zones, but this is because the proportions for water area in the different zones varied, with zone C having the highest surface area (Zone A = 16%, B = 33.9% and C = 50.1% of 34 921 km^{-2}, the total water area for the Tanzanian part of Lake Victoria).

Catch per unit area for the different zones and different quarters (Fig. 4.12) indicated almost similar standing crop densities within zones in different quarters. With the exception of first quarter for zone B and C, standing crop densities were above 8 t km^{-2}.

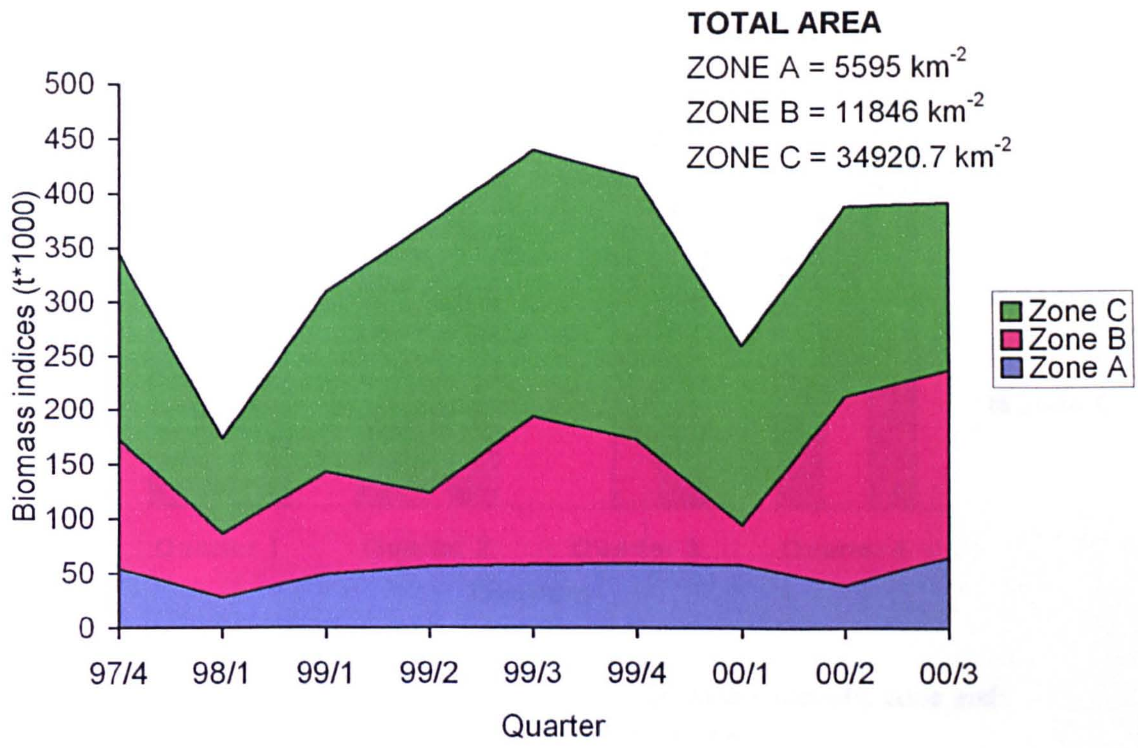


Figure 4.11 Quarterly biomass indices (t*1000) for Nile perch scaled to the total area of the respective zones

The mean values of CPUA over the whole period by quarters sampled (Fig. 4.13) illustrate the variations in the distribution of the Nile perch stock over the lake area sampled and the slight declining trend indicated by the regression line ($CPUA = -0.119 \times Time + 9.6996$, $R^2 = 0.031$). The decline in the first quarter of 2001 was marked compared with the same quarters in 1999 and 2000; excluding this quarter in the analysis, a slight increasing trend in abundance was observed ($CPUA = 0.1142 \times Time + 8.3307$ $R^2 = 0.034$) .The 95% confidence limits indicate the degree of variation within a quarter in a given zone. The intra-annual variation in the relative abundance of the stock is also depicted. An overall mean density of 9.87 t km^{-2} was calculated. The mean values of CPUA were mapped to give the distribution of the relative abundance over the whole area sampled (Fig. 4.14)

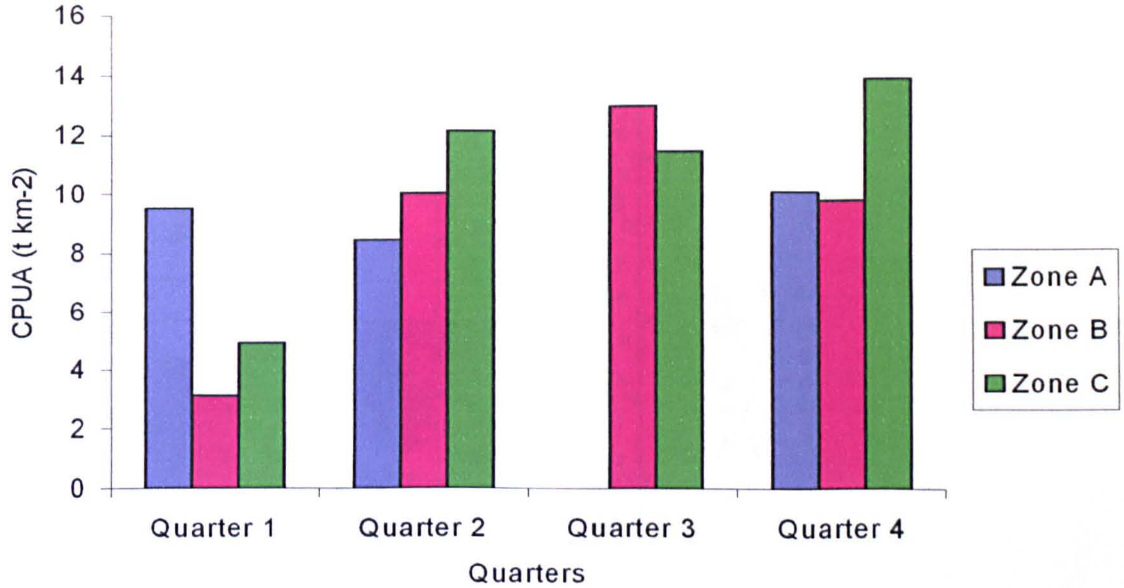


Figure 4.12 Catch per unit area for Nile perch in Tanzania waters by zone and quarter from bottom trawl surveys in the period 1997-2000

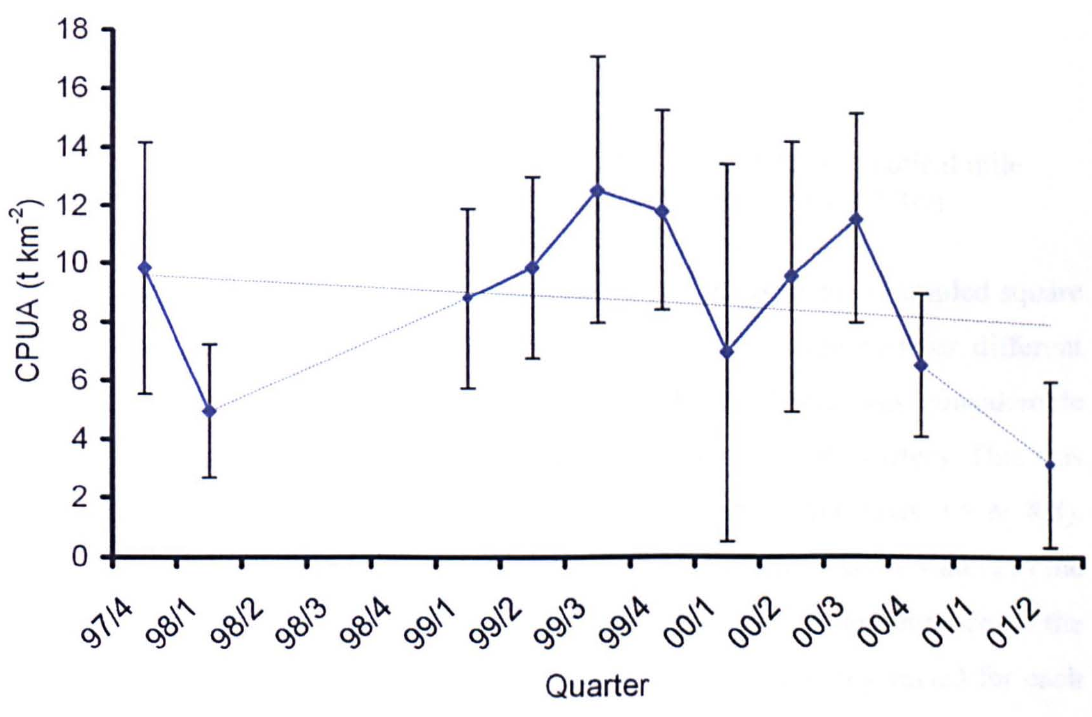


Figure 4.13 Catch per unit area by quarter from bottom trawl surveys in Tanzanian waters. Dashed lines indicate quarters with no survey (95% C.L. attached). Horizontal dashed line gives the trend from linear regression.

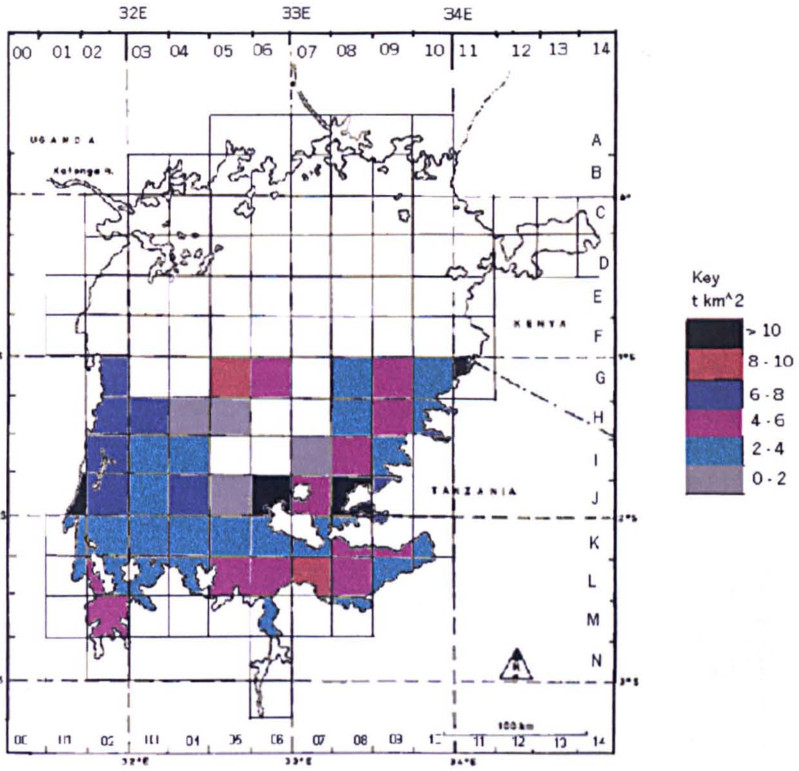


Figure 4.14 Nile perch standing crop biomass (t km^2) per 15 by 15 nautical mile squares surveyed for the Tanzanian waters of Lake Victoria (1997 – 2000)

The standing crop calculated for Nile perch and *O. niloticus* in each sampled square is summarized (Appendix 7) and the CPUA for Nile perch mapped for different quarters and zones respectively (Appendix 8.1 – 8.11). There was considerable variation in abundance between the sampled squares in different quarters. This was particularly prevalent in the 2nd quarters of 1999 and 2000 (Appendix 8.4 & 8.8). High densities (above 10 t km^{-2}) were found along the inshore shallow waters in the north - east and west, and around Ukerewe Island but also in the entrance to the gulfs, Emin Pasha Gulf, Speke Gulf and Bawman Gulf, though they varied for each survey.

Abundance index estimates for different depth ranges is given in Table 4.3 with the catch rates, biomass indices and CPUA per zone and depth range in the different quarters summarized in Appendix 9. Highest stock densities for Nile perch were at the depth range of 30-39 m. Other species have higher abundances in the shallow waters of less than 20 m deep. These were mostly *O. niloticus* and *Protopterus aethiopicus*. Relative high abundances for the other species were also observed at depths below 50 m. These were mainly *Barbus profundus* Greenwood, 1972, *Synodontis victoriae* Boulenger, 1906 and some piscivorous haplochromine species.

Table 4.3 Standing crop and biomass indices from different depth ranges for Nile perch and other species from bottom trawl surveys in the Tanzanian waters

			Nile perch		Other species	
Depth range(m)	No. of hauls	Water Area by Depth (km $^{-2}$ *1000)	Standing crop (t km^{-2})	Biomass (t*1000)	Standing crop (t km^{-2})	Biomass (t*1000)
1-9	85	5.303	7.0388 ±0.65	37.327 ±3.43	1.6491 ±0.38	8.7451 ±2.0
10-19	160	3.284	9.8932 ±0.31	32.489± 1.03	0.8992 ±0.07	2.9529 ±0.25
20-29	120	3.841	10.258 ±0.32	39.401 ±1.24	0.3073 ±0.05	1.1804 ±0.19
30-39	103	4.221	12.211 ±0.52	51.544 ±2.21	0.1843 ±0.04	0.7781 ±0.2
40-49	53	4.256	9.8496 ±1.02	41.920 ±4.34	0.071 ±0.09	0.3022 ±0.4
50-59	15	5.467	5.7194 ±2.5	31.268± 13.65	0.6206 ±1.3	3.3929 ±7.13
60+	1	13.006	2.1446	27.892	0.7379	9.5971

Abundance index estimates for the three riparian countries (Figure 4.15, Appendix 10) illustrates the proportion contribution from each of the three national waters. Tanzanian waters supported the highest proportion followed by Uganda and Kenya. Almost the same pattern of seasonal variation in abundance was found in Uganda and Tanzania. The total lake wide Nile perch biomass estimates varied from 461 032 t for the fourth quarter in 1998 to a maximum of 912 279 t in the third quarter 1999. An average abundance index of Nile perch for the whole lake between the fourth quarter in 1997 and the third quarter in 2000 was 619 639.3 t. Excluding the 1997 and 1998 estimates (gears and methodology were not standardized), this average abundance index was adjusted to 693 674.3 t. The estimates are only for Nile perch, which contributed 91.6% of the total catch and thus implying a total abundance of 757 286.3 t for the stocks in Lake Victoria. Dagaa is not included, as the method used for sampling is not applicable for the species. However, hydroacoustic results gave a mean biomass index of 2.17×10^6 t corresponding to standing stock biomass of 31.0 t km^{-2}, of which *L. niloticus* constituted 59.3%, *R. argentea* (dagaa) 22.4%, haplochromines 15.0%, *Caridina nilotica* 1.1% and other species 2.2% (Getabu *et al.*, 2002).

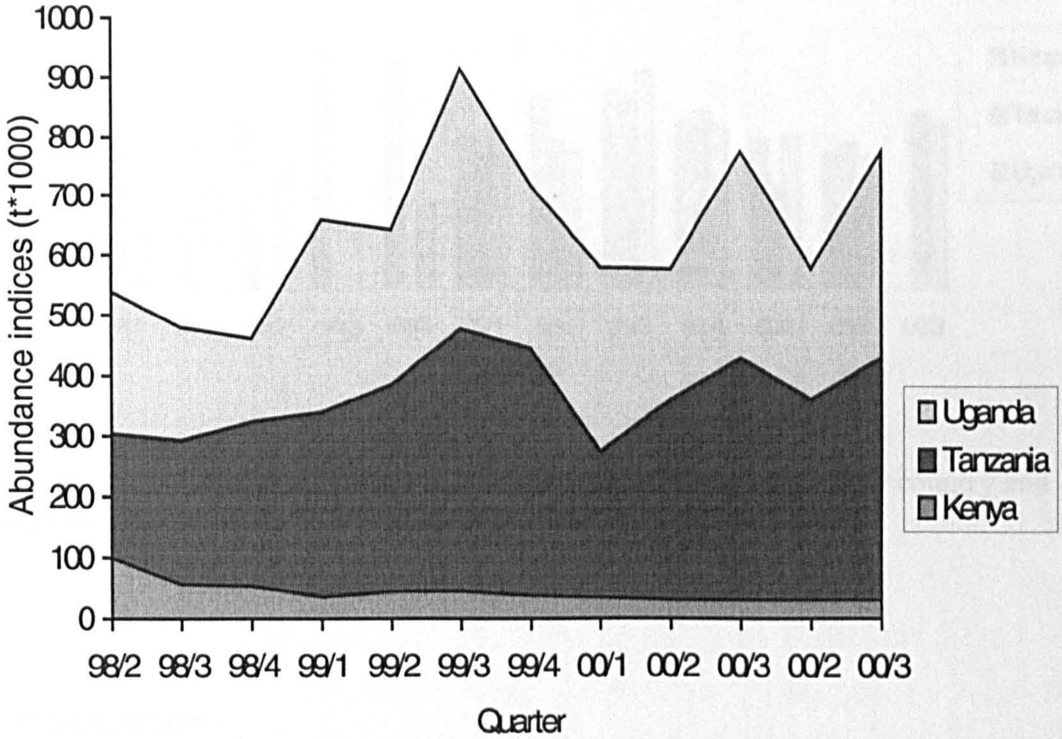


Fig. 4.15 Abundance indices for Nile perch in Lake Victoria by country and quarter from bottom trawl surveys in the period 1987 - 2000

Standing stock biomass (CPUA) was calculated to establish the relative productivity of the respective National waters (Figure 4.16). Kenyan waters exhibited very high catch rates in 1998 while Ugandan waters were very low. The differences were probably due to differences in gears. With standardized gears from 1999, using the two way ANOVA, there was no significant difference between national waters (F_s = 0.279, $F_{0.05\ (2,20)}$ = 3.885, P = 0.761) but there was a significant difference between the quarters (F_s = 3.829, $F_{0.05\ (6,20)}$ = 2.996, and P = 0.023). The Nile perch average standing stock estimate for the whole lake was 10.56 t km^{-2} for the period 1999 to 2000.

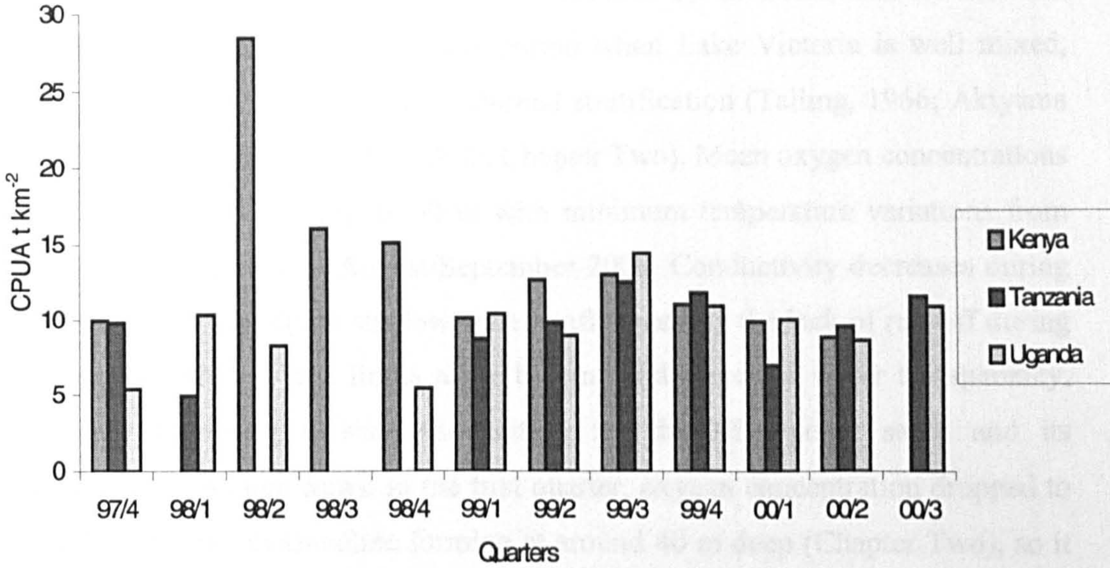


Fig. 4.16 Catch per unit area (t km^{-2}) for Nile perch in Lake Victoria by country and quarter from bottom trawl surveys in the period 1987 - 2000

4.4 DISCUSSION

4.4.1 The distribution and abundance of fish stocks of Lake Victoria.

The distribution of fish stocks in Lake Victoria varies between quarters within regions in Tanzanian waters except for Zone A. Being relatively shallow with many vegetation fringed bays, zone A has the most stable catches over the different seasons This is because thermal stratification and deoxygenating of the lower parts of the water column seems to persist only for very short periods due to relatively strong winds in that region (Chapter Two). With the exception of February when oxygen concentration was less than 3 mg L^{-1} below 40 m deep, the rest of the monitored months had more than 4.85 mg L^{-1} and minimal temperature difference from surface to bottom (Chapter Two). The high oxygen concentrations favoured the relatively stable distribution of Nile perch in this zone. Nile perch being very sensitive to oxygen concentrations is limited to waters with more than 2 mg L^{-1} (Fish, 1956; Ochumba, 1987).

The relatively low abundances in the first quarters and high abundances in the third quarters of the years sampled was mainly influenced by environmental factors. The third quarter in a year is generally the period when Lake Victoria is well mixed, while the first quarter is the period of thermal stratification (Talling, 1966; Akiyama *et al.*, 1977, Wanink & Kashindye, 1998, Chapter Two). Mean oxygen concentrations were above 5 mg L^{-1} as deep as 60 m with minimum temperature variations from surface to bottom waters in August/September 2000. Conductivity decreases during the third quarter especially in shallow waters influenced by the lack of run-off during the dry season. This in turn limits algae blooms and increases water transparency, consequently favouring a wide distribution for the Nile perch stock and its availability to the bottom trawl. In the first quarter, oxygen concentration dropped to 0.28 mg L^{-1} with the thermocline forming at around 40 m deep (Chapter Two), so it was unlikely for Nile perch to be distributed in the bottom waters.

Heavy rains are frequently associated with strong winds, which favour mixing of the water column, influencing nutrient and oxygen availability. These in turn favour phytoplankton production and zooplankton availability, which draw the herbivores and eventually the piscivores. For example, the region surrounding Zone B had the highest rainfalls in March 1999 (376.1 mm), which favoured high catches in April 1999, while the very low rainfall in March 2000 (145.8 mm) probably affected the catches.

Wind driven currents as well as the intensity of turbulence are known to affect the behaviour of fish and availability to fishing (Laevastu & Favorite, 1988). Zone C has considerably stronger waves compared with the other zones, and this may be one of the factors explaining the higher abundances especially in the second and fourth quarters.

There is also considerable variation in abundance of Nile perch between the sampling squares in different months. Localized wind effects can result into localized mixing of the water column during thermal stratification resulting in variation in fish abundances. There is also a seasonal difference in rainfall patterns and wind speed and direction (Chapter Two), which can influence the environmental factors and further influence the distribution of fish. For example, in February 2000 the lake was well stratified compared with February 2001 or the mixing of the water column was complete in August/September 2000 compared with the same period in 2001. Rainfall in February 2001 was greater than for the same month in 2000, while February 1999 was almost dry (Chapter Two). Such annual seasonal variations influence the distribution and availability of fish. Nile perch seem to aggregate in behaviour, as very high densities up to 33 t km^{-2} can be found in one square while the following square can be with less than 2 t km^{-2}. Such behaviour poses another serious threat for severe stock collapse (Hilborn & Walters, 1992), as the fish are more vulnerable to capture if the distribution patterns are known.

The batho-spatial distribution pattern exhibited a decline in stock abundance with depth, similar to that observed in 1969/1970 (Kudhoghania & Cordone, 1974) but with differences in the depth ranges of high abundances. Below 50-m depth, an abrupt drop in mean catch rates was observed unlike the 1969/70 surveys where the drop was below 70 m deep. This could probably be linked to the presence of a hypoxic layer below 50 m (Hecky *et al.* 1994; Ochumba, 1995), but this is no longer a permanent layer (Chapter Two). Limnological findings show oxygen concentrations as high as 6.67 mg L^{-1} at 67-m depth in August 2000, 5.7 mg L^{-1} at a depth of 55 m in September 2000 and 5.8 mg L^{-1} at 50 m deep in February 2001 (Chapter Two). However oxygen concentrations decreased with depth from a mean of 8.02±0.73 to 3.2±4.36 mg L^{-1} in surface waters to deep waters (68 m) respectively (Chapter Two). Haplochromines, the dominant stock in 1969/70 are relatively more tolerant to low oxygen levels than Nile perch (Fish, 1956; Oijen, 1982; Ochumba, 1987) and this may also contribute to the difference in depth distribution in relative abundance for the two surveys. Generally, Nile perch is a bottom dwelling species (Hopson, 1972), but in deeper waters it stays and forages in water layers 10-20 m below the surface (Ligtvoet *et al.*, 1995b). However, the detritivorous/phytoplanktivorous haplochromines constituted 40% of the demersal biomass (Witte & Oijen, 1990) that also explains the high catch rates in deep waters during 1969/70 surveys.

The 1969/1970 surveys had the highest catch rates at 10-19 m depth while in the recent surveys it was at the depth range of 30-39 m. This is probably explained by the differences in the dominant species during the two surveys and the current decrease in water transparency (Chapter Two) due to algae blooms as well as siltation. Before the disappearance of the dominant haplochromines, the mean catch rates of Nile perch and haplochromines by depth showed inverse patterns (Witte *et.al*, 1995a; Goudswaard & Ligtvoet, 1988). In 1979, catch rates of Nile perch were lowest in waters of 15-25 m deep, while haplochromines catches were highest in these depths. However, by 1986 the pattern was reversed, Nile perch catches were highest at the depth range of 15-25 m and haplochromines catches lowest (Witte *et.al.* op.cit.). This is probably explained by the effect of predation by Nile perch coupled by intensive fishing pressure in the shallow areas by beach seines and by trawlers in Mwanza Gulf (Hughes, 1986; Ogari & Dadzie, 1988, Chapter One). Relatively high catch rates of haplochromines were found in waters of less than 20 m depth during the recent surveys. These seem to be recovering from the reduced fishing pressure and predation (Witte *et al.*, 1995a; Mkumbo & Ligtvoet, 1992), although currently Nile perch has switched to prey predominantly on the haplochromines (Chapter Five), which can also influence their distribution to the shallow inshore waters, other environmental factors remaining favourable.

The batho-spatial distribution of Nile perch in the lake has been changing over the years probably following the abundances of their dominant prey in the respective periods. In 1979, when Nile perch upsurge started in Nyanza Gulf, the highest catch rates were in waters less than 10 m deep. After 1982, the highest catch rates were at depths of 10-25m (Witte *et al.*, op.cit.), while in Tanzanian waters in 1985 highest catch rates were obtained from waters of 16-35 m deep (Ligtvoet & Mkumbo, 1990), almost overlapping with the findings of the present surveys. The dominant prey item has also changed from haplochromines to *Caridina niloticus* (Hughes 1986, Ogari & Dabzie, 1988, Mkumbo & Ligtvoet, 1992, Chapter Five). The ecological interactions in the predator/prey relationships as well as the oxygen levels in the water column probably influence the depth preference. The depth range with high catch rates was that with the highest chlorophyll concentrations (Chapter Two). With phytoplankton concentrations, zooplankton are expected to be more abundant which in turn would attract the higher trophic levels in the food chain. As a result, the Nile perch following its prey probably became more abundant in that depth range. Oxygen concentrations in the 30-35 m depth range were generally acceptable with an average of 4 mg L^{-1}.

Temporal distribution of the Nile perch stock appears to have a cyclic pattern in relative abundances, following the period of complete mixing of the water column, i.e. June to August, the third quarter exhibited highest abundances. Mixing of water column favours relatively even distribution of oxygen as well as other food items in the water column and in turn the distribution of Nile perch and its availability to the bottom trawl. Some periods of heavy rains are also characterized by high turbulence, which favours mixing and favourable oxygen concentrations even during the periods of thermal stratification in November to December, and thus contributing to relatively high abundances. The first quarter had the lowest abundances, and is associated with the time of complete thermal stratification (Chapter Two) and thus Nile perch is unlikely to be distributed in the bottom waters.

Catch rates in the present study were low compared with the pre Nile perch period, despite a five-fold increase in catches of Nile perch in the early 1990s (Bwathondi 1990, Ogari & Asila 1990, Ssentongo, 1992; Orach-Meza, 1992). Changes in species composition in the catches make comparison difficult, although the sampling gears are more or less comparable. The present low catch rate is possibly due to differences in catchability and vertical distribution of Nile perch compared with the haplochromines; the latter being more available to the gear and more frequenting the bottom layers as 40-50% of the haplochromines population were detritus feeders (Witte & van Oijen, 1990; Witte *et al.*, 1995b). Other species, like *Rastrineobola* and *Oreochromis niloticus*, were more prevalent in the recent surveys, but these are pelagic and inshore species, respectively, and not fully represented in bottom trawl catches. *Rastrineobola* increased considerably in the fishery catches in the 1980s and early 1990s (Ligtvoet *et al.* 1995b), and is now the most important species in the fishery (Chapter Three). *Oreochromis niloticus* is equally under-represented due to its habitat preference for shallow, non-trawlable areas, but it is third in importance in the fishery (Ogutu-Ohwayo 1995, Ligtvoet *et al.* 1995b; Chapter Three).

The present estimate of 685 083.3 t for Nile perch is still within the range of 500 000 to 700 000 t estimated in 1987 (Pitcher & Bundy, 1995), just before peak catches in Lake Victoria (Chapter Three; CIFA, 1988; Ssentongo & Welcomme, 1985). Pitcher and Bundy (1995), using biomass estimates of 321 540 t for Nile perch in waters shallower than 40 m estimated by Ligtvoet and Mkumbo (1990) from trawl surveys in Tanzania during 1987 raised the estimates to about 578 000 t for the whole lake. Assuming a 20% error to the estimates they arrived at the given range of 500 000 to 700 000 t. Using a 'Surplus-production model' with constrained optimisation using the 'solver' algorithm in the 'Excel' spreadsheet the maximum biomass (B_∞) was estimated at 697 186 to 773 834 t while without constraints a maximum biomass of 1 049 266 to 1 870 895 t was estimated (Pitcher & Bundy, 1995). The first estimates with constraints conform with the present range of biomass estimates from bottom trawls surveys, while the second without constraints comply with the hydro-acoustic surveys estimate of 802 530 to 1 936 677 t (Getabu, *et al.* 2002). Using the ECOPATH model, Moreau (1995) estimated the Nile perch biomass in the lake to be 17.2 t km^{-2} in 1985/1986. This implies a decline in Nile perch biomass in the lake when compared with the present bottom trawl biomass estimates (10.56 t km^{-2}), but if compared with the hydro-acoustic estimates (18.38 t km^{-2}), a slight increase is observed.

What is the actual state of the Nile perch fishery if stock densities seem to be around the Maximum Biomass (B_∞)? Pitcher and Bundy (1995) projected stock biomass using surplus-production model for different effort scenarios from 1990. With an increase of effort at 7% p.a. from the 1990 effort level a collapse in the Nile perch biomass and destruction of the fishery was predicted by 1997. Effort has increased since 1990 (Chapter Three) but the biomass remains within the B_∞ range. The size composition of the present population (Chapter Six) and the increase in effort (boats) as well as nets per boat (Chapter Three) suggests that with a continuation of the current heavy exploitation and unsustainable fishing practices in the Nile perch fishery, the predicted collapse is only deferred if serious management interventions are not forecoming.

The current biomass estimates indicated a slight declining trend over the study period, which was also observed in the hydroacoustic results (Tumwebaze *et al.*, 2001; Getabu *et al.*, 2002). The distribution patterns under the current study gives an indication of seasonal dependence influenced by the hydrographic conditions. Monitoring of the environmental parameters is therefore of equal importance to that of the fish stocks. The coverage in the limnological data collection during this study was limited due to lack of equipment to start, and later, expertise in calibrating the SEABIRD profiler during the bottom trawl surveys. Most of the information on limnology was collected during the hydroacoustic surveys. This hindered detailed correlation of fish abundances with the limnological parameters as the two were collected at different sampling times.

Long-term stock estimates of abundance, densities and CPUE are all important parameters in understanding how the stock behaves to fishing and other seasonal environmental parameters. The present estimates on Nile perch are the first of their kind in Lake Victoria but long-term estimates would assist in establishing the actual state of the stocks for sustainable harvesting. The need to have reliable research vessels, which can be used for a long period with standardized methodology and gears within the three countries sharing the lake resources, is crucial. The comparison of catches from four different research vessels that have operated in the Tanzanian waters confirms this need. Fisheries independent surveys for measuring relative abundance patterns should be central to the fisheries management of Lake Victoria so as to reflect the stock trends and responses to any management strategies implemented. Nile perch needs close and continuous monitoring as management actions are implemented so as to track any changes before it becomes too late and the predicted collapse observed.

4.4 Summary

Bottom trawl surveys were conducted in Lake Victoria from November 1997 to February 1998 when it was suspended due to vessel problems until March 1999 but continued monthly to July 2000 except in January/February and August/September of 1999 and 2000, when the vessel was used for hydroacoustic survey. A total of 530 hauls covering the entire depth range and wide coverage of Tanzanian waters were conducted. Two quarterly surveys covering the entire national waters were also conducted in November 2000 and April 2001. The research vessel *R.V. Victoria Explorer* (17-m length and 250-HP engine) was used with 24-m head rope and a cod-end of 25-mm mesh trawl net. Towing speed was 3.4-3.6 knots and trawling duration was approximately 30 minutes. Historical data from *RV IBIS,* a vessel operated during the 1967/1971 lake wide bottom trawl surveys; *R.V. KIBOKO* operated during 1984/1993 HEST/TAFIRI surveys, which concentrated in Mwanza Gulf and the *R.V. TAFIRI II* operated by TAFIRI in Mwanza Gulf and Speke Gulf in 1995-1996 were used to assess trends in the fishery.

Stock abundance fluctuated over the years, but due to changes in species composition and data collected by different research vessels of differing efficiency under varying sampling programmes, it was not possible to established trends. However, when haplochromines dominated in the early 1970s catch rates were as high as 591-kg hr^{-1}, but fell dramatically as haplochromines declined and Nile perch increased in the early 1980s. Despite differences in the vessel used, Nile perch catch rates followed an increasing trend throughout the 1980s and 1990s.

Seasonality in environmental factors greatly influenced the distribution and abundance of Nile perch stocks. Temporal distribution of the Nile perch stock appeared to have a cyclic pattern in relative abundances, following the period of complete mixing of the water column, i.e. June to August, the third quarter exhibited highest abundances. Mixing causes relatively even distribution of oxygen as well as food items in the water column and in turn the distribution of Nile perch and its availability to the bottom trawl, while the first quarter with lowest abundances is the period of thermal stratification.

The batho-spatial distribution pattern exhibited a decline in stock abundance with depth. High catch rates were recorded at the depth range of 30-39 m, different from 1995 (Witte *et al.,* 1995a) observations when highest catch rates were at 15-25 m depth. Changes in prey species and their distribution and abundances together with the variations in environmental parameters were probably the influencing factors.

An overall mean annual biomass index ranging from 330 439.7 t to 344 690.2 t, was determined for the Nile perch stocks in Tanzanian waters, with an overall mean density of 9.87 t km^{-2}, and for the whole lake was 693 674.3 t with a mean density of 10.56 t km^{-2} (using data from the same work under the LVFRP project in Ugandan and Kenyan waters). Nile perch contributed 91.6% of the total catch equivalent to total abundance of 757 286.3 t for the fish standing crop excluding dagaa in Lake Victoria. However, hydroacoustic results gave a mean biomass index of 2.17×10^{6} t corresponding to standing stock biomass of 31.0 t km^{-2}, of which *L. niloticus* constituted 59.3%, *R. argentea* (dagaa) 22.4%, haplochromines 15.0%, *Caridina nilotica* 1.1% and other species 2.2% (Getabu *et al.*, 2002).

Nile perch seem to aggregate, as very high densities up to 33 t km^{-2} were found in one area while the adjacent area could be with less than 2 t km^{-2}. Such behaviour contributes to the threat of severe stock collapse, as the fish are more vulnerable to capture if the distribution patterns are known.

Although the current biomass estimates seem to be comparable to previous estimates and predictions, (Pitcher & Bundy, 1995; Moreau, 1995) and thus the effect of the excessive effort to stock biomass is not evident, the present size composition of the stocks and of the catch (Chapter Three & Six), and the aggregating behaviour of Nile perch calls for management interventions for the sustainability of the fishery.

CHAPTER FIVE

BIOLOGICAL ASPECTS OF THE NILE PERCH STOCK

5.1 INTRODUCTION

The Lake Victoria ecosystem has undergone a series of faunal and limnological changes and alteration of the trophic dynamics by the exotic species is thought to be one of the major influences (Kaufman, 1992; Reinthal & Kling, 1994). Introduced predators generally reduce the overall ecological production in an ecosystem (Marshall, 1995), although may increase the amount of commercially harvestable fish, as is the case in Lake Victoria. The situation in the lake is still dynamic and changes in the stocks are still continuing. Nile perch is at the top of the food web in Lake Victoria and is known to have the capability of adjusting its feeding habits to take advantage of the most abundant food source (Ogari, 1988). Predator–prey interactions are known to be important determinants of yield to fisheries, thus to understand the dynamics in the Nile perch fishery, diet studies are fundamental. Seasonal fluctuations in breeding seasons, which can be triggered by environmental factors as well as food availability, the mean length at sexual maturity (L_m) and the reproductive potential or fecundity of a stock are also very important input parameters for any strategy in fishery management. These parameters vary with environmental factors as well as fishing pressure on the stocks (Pitcher & Hart, 1982).

There is considerable information on the diet of Nile perch in Lake Victoria (Hamblyn, 1966; Gee, 1969; Okedi, 1971; Hopson, 1982; Acere, 1985; Hughes, 1983; 1986; Ogari, 1985; Ogari & Dadzie, 1988; Ogutu-Ohwayo, 1990; Mkumbo & Ligtvoet, 1992). It is a more efficient predator than any endemic species in the lake. Since its introduction, marked changes have occurred in its feeding habits, reflecting changes in the abundance of its prey. Nile perch has shifted from feeding on haplochromine cichlids to *Caridina nilotica*, *Rastrineobola argentea*, various invertebrates and juveniles of Nile perch. More recently, *Caridina* has become the major prey and when absent, the species has shifted to juvenile Nile perch followed by *Rastrineobola* (Ogutu-Ohwayo, 1990; Mkumbo & Ligtvoet, 1992).

The reproductive biology of Nile perch, however, is poorly documented. Information on its reproductive potential are based on observation of Worthington (1929) and

Holden (1963) in Lake Albert, Kenchington (1939) in the Blue Nile, Hopson (1972, 1982) in Lake Chad and Lake Turkana, Okedi (1971) for Lakes Victoria and Kyoga and Acere (1985) for Lake Victoria and Kyoga. The last two were based on very few females. More recently Ogutu-Ohwayo (1988), examined the reproductive aspects of Nile perch, but did not consider seasonality and concentrated more on material from Lake Kyoga.

In view of the major changes that have occurred in lake Victoria in the latter part of the 20th century, it is important to update changes in the reproductive tactics and feeding habits of Nile perch, to support formulation of management policy. This chapter therefore, examines in detail these biological aspects in the Nile perch stock in the Tanzanian waters of Lake Victoria and compares them with the previous findings. This information will then be used in conjunction with the yield predictions (Chapter Six) to formulate management strategies for sustainable Nile perch fishery (Chapter Seven).

5.2 MATERIAL AND METHODS

Samples for biological studies were obtained from the monthly bottom trawl surveys conducted using *R.V. Victoria Explorer* in the three zones A, B, C, from November 1997, January & February 1998, January 1999 to June 2000, November 2000 and April 2001 (Chapter Four). Subsequent bottom trawl sampling for diurnal feeding patterns were conducted on 26-27 March 2001, during the full moon; 9-10 April 2001, during the half moon and on 13-14 June 2001, during the dark moon. Bottom trawl hauls of half an hour were made after every two hours.

During trial operations of a mid-water trawl in August 2001, some stomachs were also collected for diet analysis. A mid-water trawl net was also operated using *R.V. Victoria Explorer* in Zone A for 24-h on 26-27 August and 8-9 September. Trawls were half an hour and the data were treated separately to assess any differences in diet with water depth. Depth of sampling in the water column varied depending on echo-concentrations.

Additional samples for maturity stages and fecundity estimates were collected from one of the filleting factories (Tanzania Fish processors Ltd) on the 16 and 17 June 2001, as the number of mature females in the experimental catches was considered too few for the analysis.

Specimens of Nile perch from one or two hauls in a day (depending on size of the catch) were dissected for sex/maturity and dietary analysis. Identification of stomach contents was done on board the vessel (*R.V. Victoria Explorer*). The dominant food items were identified to generic level. The point method (Hyslop, 1980) was used to determine the contribution of each prey item to the diet. Stomach fullness was noted before opening the gut. Each stomach was awarded an index of fullness ranging from 0 (empty) to 1 (full). Contribution of each prey items was estimated as a fraction of the fullness in decimal points. To determine change in diet with size, the points awarded to each prey type was summed within each 10 cm length category, and percentage contribution calculated for shifts in the diet of Nile perch with increasing size. Spatial and temporal variations in the diet were similarly assessed from monthly and zoned data separately.

The twenty-four feeding data were treated separately in 2-h interval to identify the peak feeding times. Data collected during the different phases of the moon were also analysed separately to examine the effect of moonlight on feeding behaviour of Nile perch.

To determine patterns in maturity with length and season and the age at maturity (L_{m50}), the gonads of each fish were removed, the fish sex and maturity status determined, based on the classification of Hopson (1972), summarized in Table 5.1. Sex ratios were calculated for samples within zones and for the combined samples from the three zones. Seasonality in maturity and thus peak breeding periods were determined by calculating the percentage of mature fish in different months and zone separately.

Table 5.1 Coding of maturity stages of male and female Nile perch according to Hopson (1972)

Males	Females
I. Immature: Testes a pair of thin transparent strands running longitudinally along the dorsal wall of the body cavity; sexes indistinguishable macroscopically.	I. Immature: Appearance alike testes; sexes indistinguishable macroscopically.
II. Early developing: Testes transparent greyish-white, occasionally pinkish; narrow and flattened.	II. Resting: Ovary grayish-white, or pinkish, transparent, smooth and cylindrical, circular in transverse section; eggs not visible macroscopically; only slightly vascularized.
III. Late developing: Testes semi-transparent, greyish-white or pinkish; often well vascularized; more or less flattened in transverse section; no milt.	III. Early maturing: Ovary pinkish or reddish, semi-transparent; pear-shaped in section; eggs not visible macroscopically, tissue well vascularized.
IV. Mature/resting: Testes opaque, whitish or pinkish; often well vascularized; firm, triangular in section; slight milt exudes from lumen when cut.	IV. Late maturing: Ovary pinkish or reddish with small opaque yolky ova, clearly visible; pear-shaped in section.
V. Mature/ripe: Testes opaque, ivory white or pinkish; soft; triangular in section; lying in the longitudinal groove on ventral surface; copious milt when cut.	V. Ripe: Ovary yellowish-buff, opaque due to presence of large yolky ova clearly visible through superficial membrane; pear-shaped in section; large blood vessels on surface.
VI. Ripe/running: Similar in appearance to stage V but milt running freely from vent when slight external pressure applied to fish.	VI. Running: Ova yellow-brown in colour, oil globule present; slight external pressure causes ripe ova to be extruded from the vent.
	VII. Spent: Ovaries loose and flabby, containing torn follicular tissue rich in blood with a few residual stage V ova.

The length at sexual maturity (L_{m50}), which is defined as the length at which 50 per cent of all individuals are sexually mature (King, 1995), was estimated from the proportion of mature fish in 5-cm length groups separately for males and females in the different zones. A logistic maturity ogive was fitted to the data, using Solver under Excel software. The equation used was:

$$P = 1/(1 + exp(-r(L - L_m)))$$

where r is the slope of the curve and L_m is the mean length at sexual maturity or the length that corresponds to a proportion of 0.5 (or 50%). A separate curve based on samples from processing factory was determined. Samples from the processing factory included more mature females than recorded from the trawl samples and was thus considered being reliable estimate of L_m.

Ripe ovaries from mature females dissected for dietary studies were preserved in 10% formaline solution for determination of fecundity in the laboratory. Fecundity being the number of ripening eggs in the ovary prior to the next spawning season (Bagenal, 1978), was only determined from ovaries at stage V and VI. In the laboratory, the ovary was weighed, and three sub-sample of about 0.04 g each were taken from the sides and the centre of the ovary. The number of eggs in each sub-sample was counted under a binocular dissecting microscope. Each ovary was treated separately and the mean number of ova from the sub-samples was used to estimate the total number of ova in each pair of ovaries. This was then related to the fish size (total length in cm).

5.3 RESULTS

5.3.1 Spatial and temporal changes in diet

A total of 2 896 stomachs were analysed for variations in the type of prey ingested by Nile perch in the three zones sampled. Only 1 511 guts had food, 285 were empty and 1 105 extruded.

The overall contribution of the different prey items is given in Figure 5.1. *Caridina* contributed 42.7% followed by Haplochromines (41.3%), then dagaa (10.8%) and Nile perch juveniles (3.3%) and. All other prey items contributed less than 2% in the diet of Nile perch, these included Odonata (0.6%), *Barbus* (0.5%), *Schilbe* (0.3), Snails (0.2), *O.niloticus* (0.1),*Clarias* (0.1), *Synodontis* (0.1), Fish remains (0.2) and Crabs (0.1).

The contribution of the different prey items differed much for zone A, compared with the other two zones (Fig. 5.2). Almost the same contributions of *Caridina* were found in the samples from zone B and C (38.33% & 38.99% respectively) while in zone A haplochromines dominate in the diet (67.59%). Nile perch seem to have a substantial contribution in the diet for zone B (20.45%) and zone C (15.39%). Dagaa (*Rastrineobola argentea*) contributed <10% in each of the three zones. Other fish species that were found in the diet contributed <1% except *Oreochromis niloticus*

(1.34%) in zone A, *Barbus profundus* (1.62%) and *Synodontis* (1.81%) in zone B; and Odonata (1.25%) in zone C.

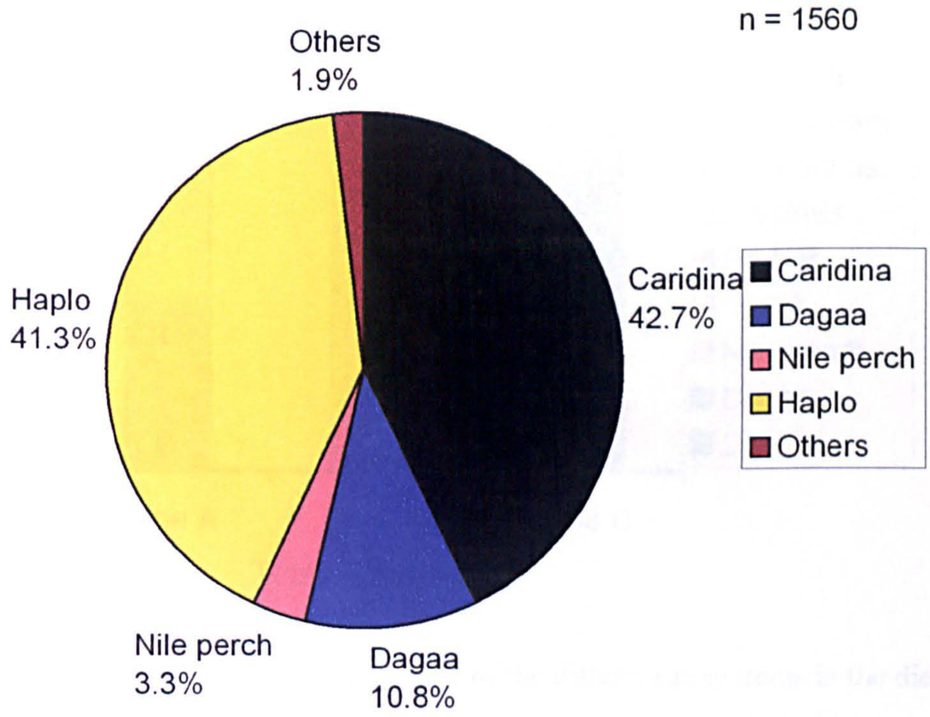


Figure 5.1 Contribution of the different prey items to the diet of Nile perch over March 1999 to April 2001 for bottom trawl samples in the Tanzanian waters

The dominance of *Caridina niloticus* in the diet of Nile perch was more prominent in the 24-h mid water trawl samples collected from zone A. Figure 5.3 summarises the results from 613 specimens of Nile perch gutted. *Caridina* contributed 83.6% in the diet while haplocromines were only 9.3%. Dagaa and Nile perch contribution was also very low (2.7% and 0.8% respectively). Unlike the bottom trawl samples the different prey items were few. Fish remains, *Brycinus* and *Barbus* were included in the group of 'others', which together contributed 3.7% to the diet.

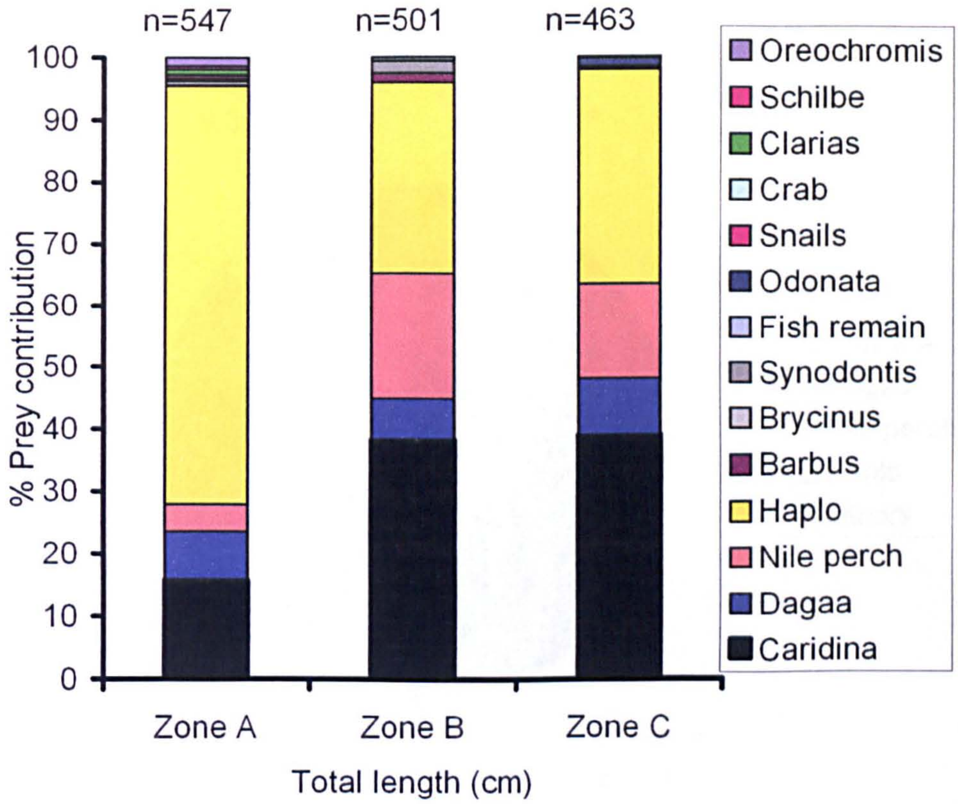


Figure 5.2 Percentage contribution by zone of the different prey items in the diet of Nile perch, Tanzanian waters

The diet of Nile perch exhibits considerable seasonality in the dominance of different prey items consumed (Fig. 5.4). The dominant prey item for the months April to September was *Caridina*, contributing 54.1% to 71.2% of the stomach contents. In the other months, October to March the contribution of *Caridina* ranged from 6.2% to 37.8%. During the periods when *Caridina* contribution was low; haplochromines were the dominant prey item in the diet. The exceptionally high contribution of haplochromine in March and October 1999, January and May 2000, were when the surveys were conducted in zone A, reflecting the importance of this food item in the diet of Nile perch from this zone. Samples from the same zone (A) in November and June did not show the dominance of haplochromines. March 2000 had high contribution of haplochromines although sampling was in zone B probably reflecting scarcity of the *Caridina* and an increase in haplochromines in the habitat. The dominance of *Caridina* in the diet in June 1999 when the survey was in zone A probably reflects seasonal fluctuations in abundance of the prey species.

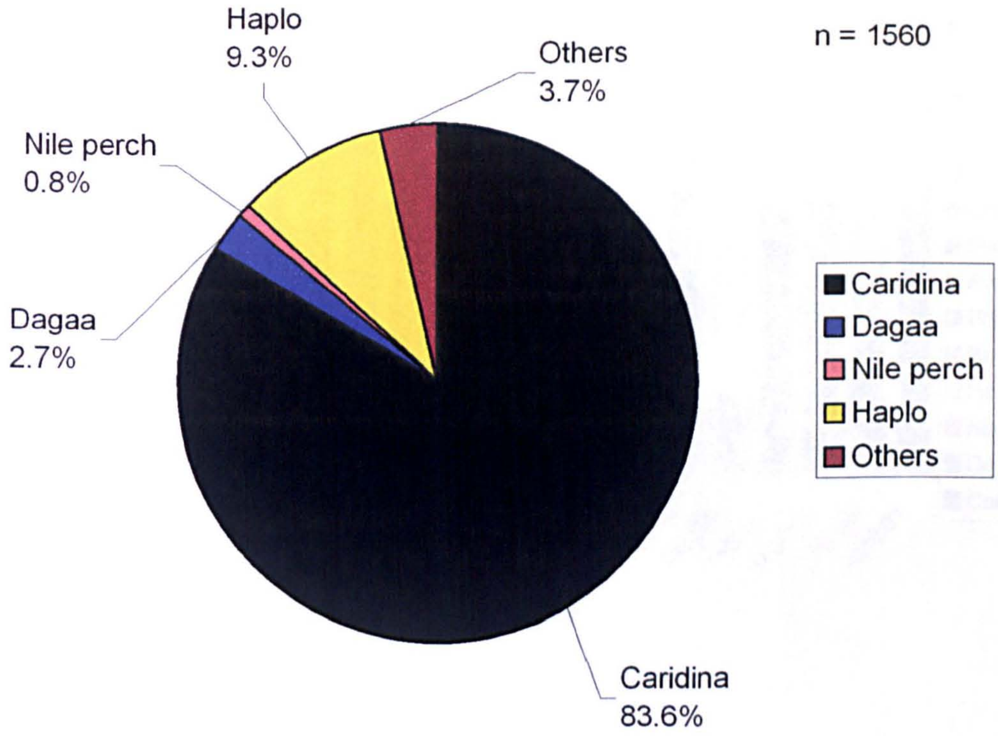


Figure 5.3 Contribution of the different prey items to the diet of Nile perch from mid-water trawl samples of August & September 2001 in Tanzanian waters

Changes in the diet over the three years of study were investigated for the three zones (Fig. 5.5). The dominance of haplochromines in the diet of Nile perch in zone A is further elaborated. An increase in the contribution of *Caridina* in the diet for zones B and C from 1999 to 2000 was noted. A decrease in dagaa and Nile perch in the diet in 2000 was found but with an increase in year 2001 for zone A. Data for zone B and C were not collected in year 2001 due to financial limitations and thus it is impossible to verify the changes.

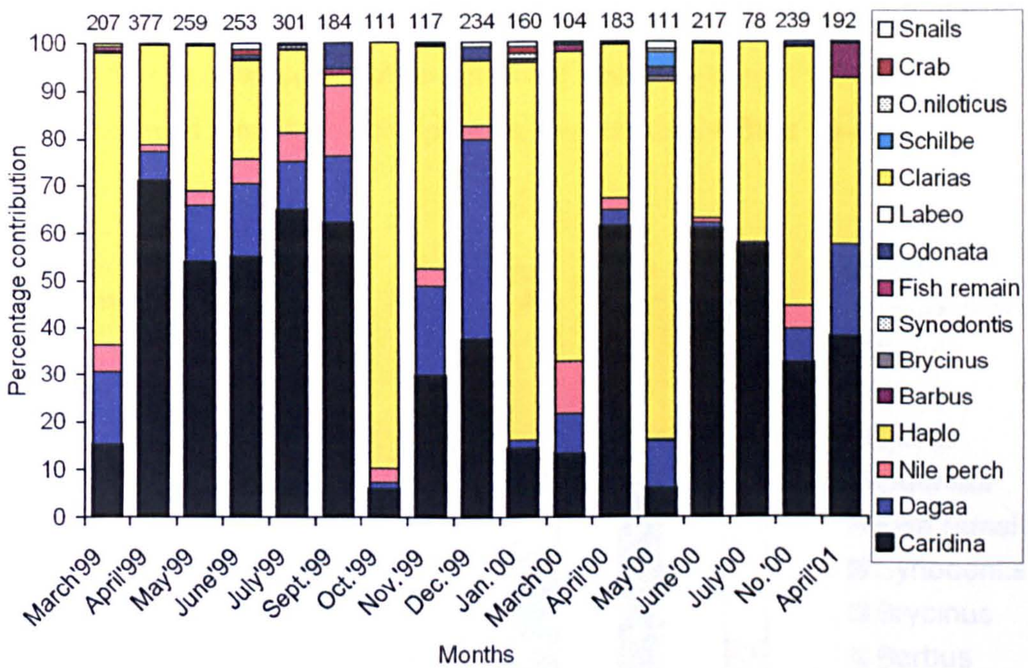


Figure 5.4 Monthly variations in the percentage contribution of prey items in the diet of Nile perch over the period of March 1999 to April 2001 in Tanzanian waters, Lake Victoria (sample size indicate at the top of bars)

5.3.2 Ontogenic shifts in diet

The diet of Nile perch <20 cm TL was predominated by *Caridina*, contributing more than 70% (Fig. 5.6). Between 20 cm and 60 cm TL, *Caridina* predominance decreased from 48% to about 30%, as Nile perch switched to feeding on haplocromines, which contributed more than 70% of the diet. In large fish (>90 cm TL) Nile perch became cannibalistic with its own juveniles contributing about 30% of the diet. Other fish prey such as *Clarias* (7%), *Oreochromis* (8%) and *Barbus profundus* (7%), also became important and the contribution of haplochromines declined to about 50%. The contribution of dagaa was low (<16%) in all sizes of Nile perch <100 cm TL, and absent in the stomachs of larger fish.

Almost the same percentages of prey contribution to different sizes of Nile perch was found for the mid water pelagic trawl samples for sizes <60 cm TL, while dagaa replaced Nile perch as prey in sizes >60 cm TL, but the contribution of haplochromine was almost the same (Fig. 5.7). Despite of the low overall contribution of other prey items compared with *Caridina* (Fig. 5.3), the decrease in dominance of *Caridina* in the diet of Nile perch larger than 30 cm TL was evident. Nevertheless, the *Caridina* contribution remained above 50% up to 80-90 cm TL, while for bottom trawl samples the contribution was less than 40% at 30-40 cm TL.

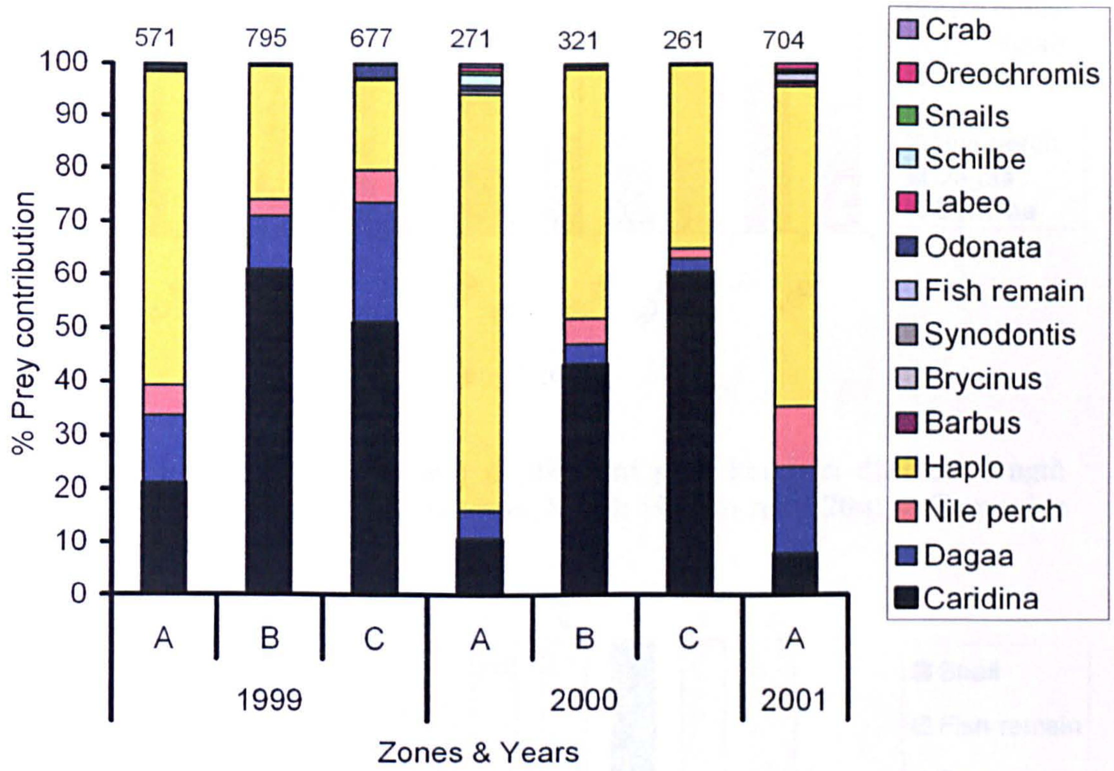


Figure 5.5 Changes in the percentage contribution of prey items in the diet of Nile perch over the three years for the three zones in Tanzanian waters, Lake Victoria (sample size indicated).

The ontogenic changes in diet of Nile perch differed between zones (Fig. 5.8). In zone A *Caridina* contributed 82% of the diet in Nile perch of less than 10 cm TL but it dropped to less than 50% in the sizes 10-20 cm TL. The contribution of haplochomines was more than 60% for sizes above 20 cm TL to 100 cm TL. Above that size, Nile perch contributed over 80% in the diet. In zone B the shift occurred at 60 cm TL; *Caridina* contribution was 100% in the 1-10 cm TL length class and was maintained above 50% to 60 cm TL fishes. Unlike zone A, the haplochromine contribution in this zone was below 50% except for 60-70 & 80-90 cm TL length classes. In zone C the shift was at 50 cm TL. The contribution of *Caridina* was 67% in fish of less than 30 cm TL but haplochromines contributed over 60% of the diet in fish larger than 50 cm TL. Similar to other zones, Nile perch became cannibalistic above 100 cm TL.

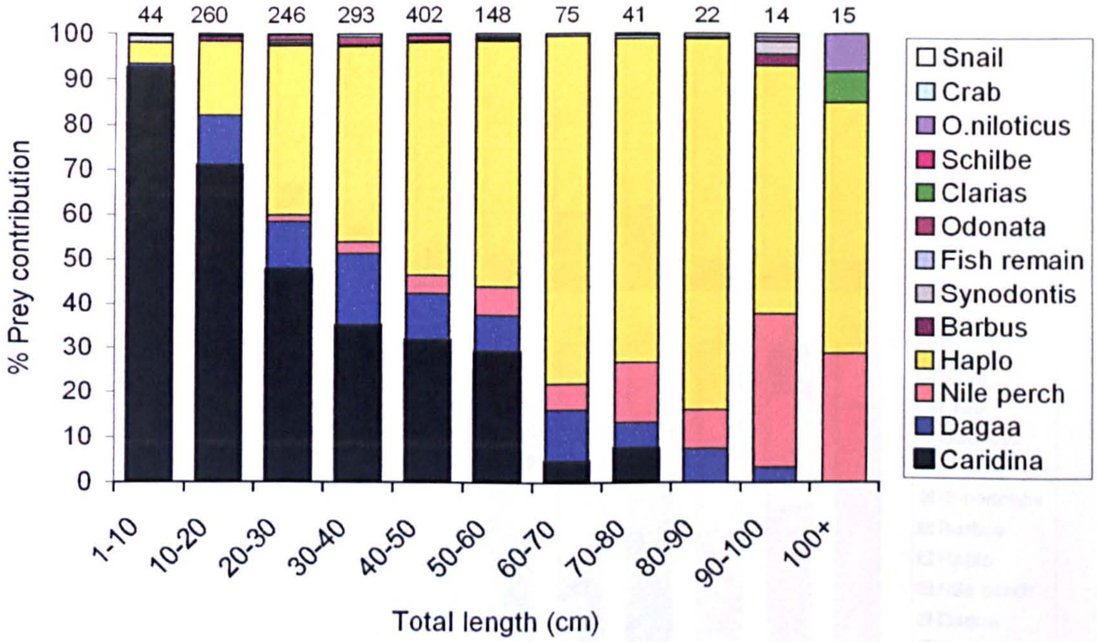


Figure 5.6 Contribution (percentage) of different prey items in different length groups (cm TL) of Nile perch sampled from March 1999 to April 2001 in Tanzanian waters (sample size indicated)

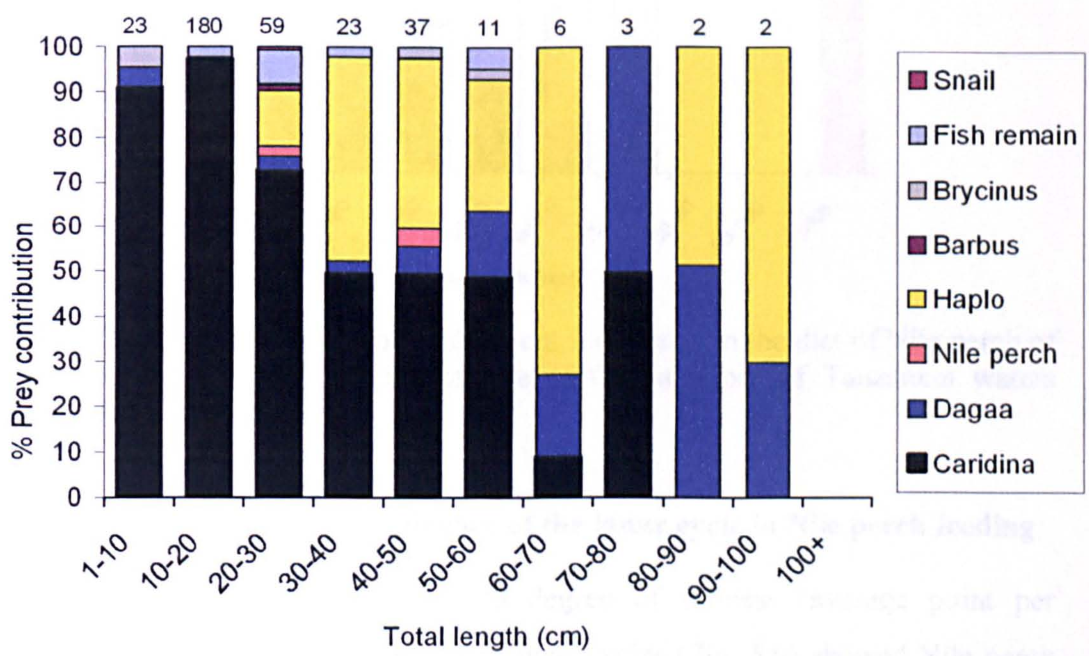


Figure 5.7 Contribution (percentage) of different prey items in different length groups (cm TL) of Nile perch sampled by mid water pelagic trawl in August & September 2001 in Tanzanian waters (sample size indicated)

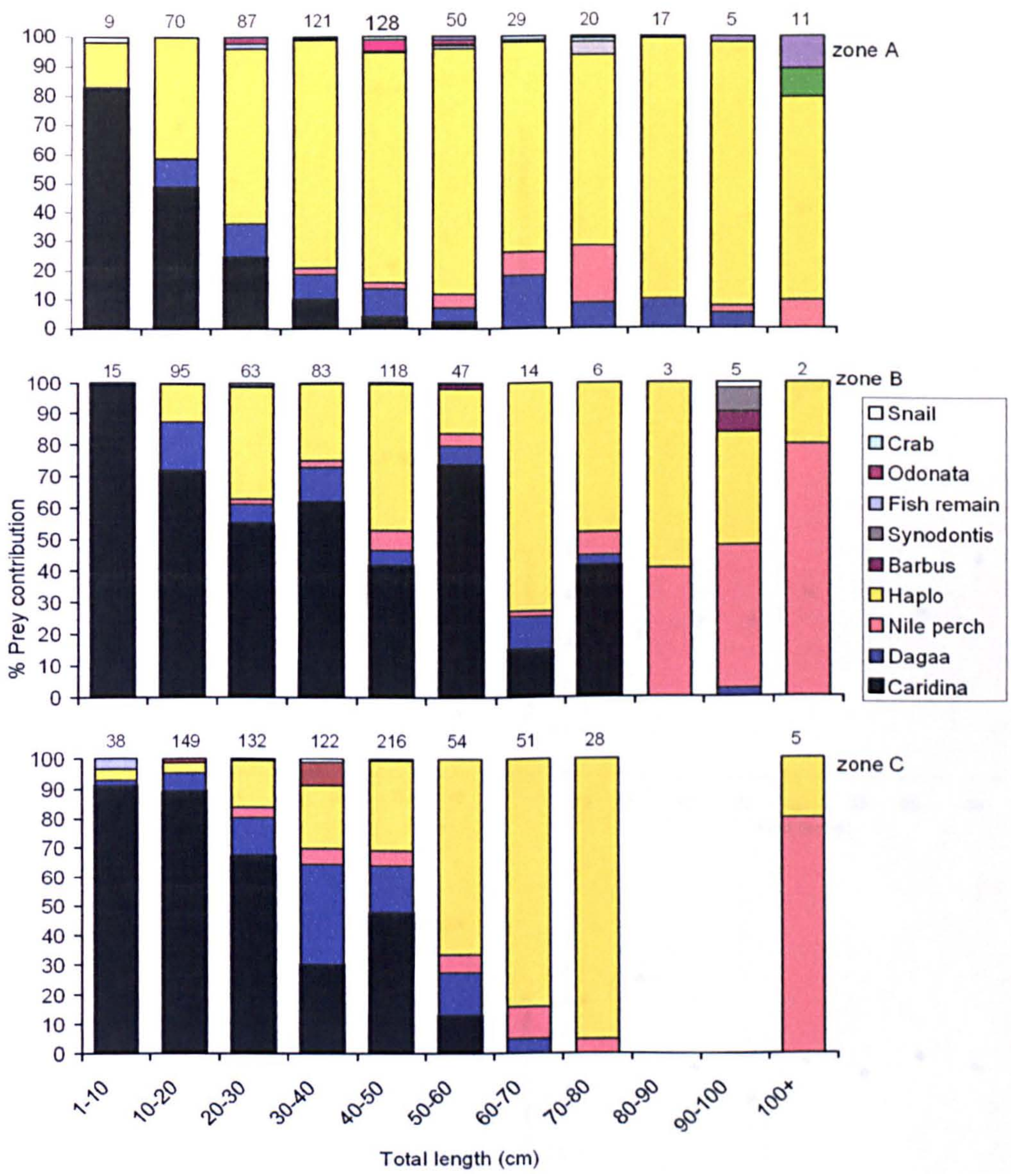


Figure 5.8 Percentage contribution of different food items in the diet of Nile perch of different 10 cm length groups in the three different zones of Tanzanian waters (sample size indicated)

5.3.3 Diurnal rhythms and the influence of the lunar cycle in Nile perch feeding

The percentage of empty stomachs and degree of fullness (average point per stomach) over 24-h cycle and in the three lunar cycles (Fig. 5.9) showed Nile perch to feed more actively during the morning hours. During full and half-moon, the percentage of empty stomach decreased from midnight. Average stomach fullness during the full moon was high through out the twenty-four hours with an indication of peaks just before dusk and dawn. During half-moon, there was an increased feeding activity at mid night being the time of moonrise while during dark-moon fish seem not to feed during the night hours and start feeding late in the morning

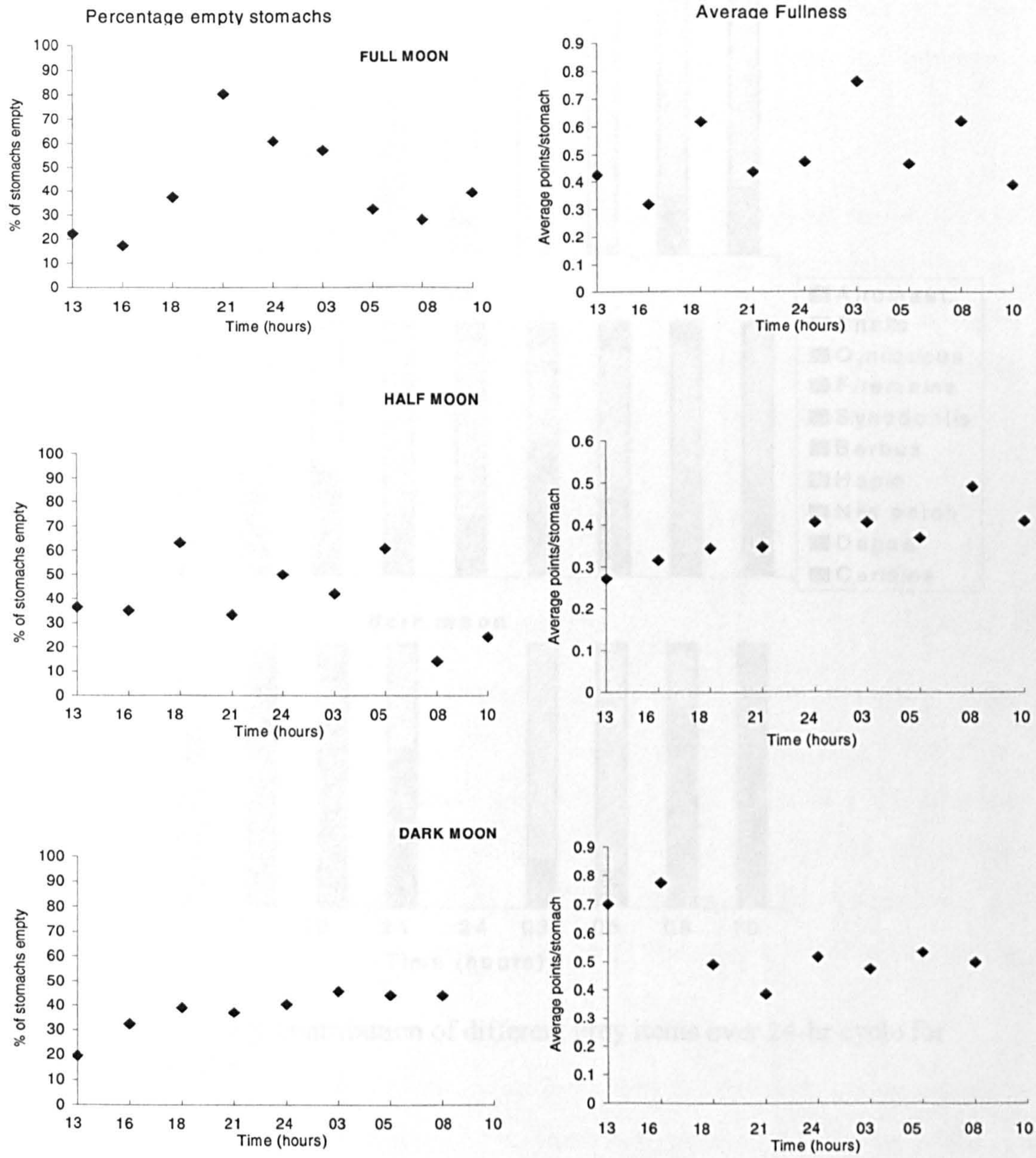


Figure 5.9 Diurnal feeding rhythms during different lunar cycles for Nile perch in Tanzanian waters, Lake Victoria

There was also a difference in the type of food eaten during night and daylight hours as well as during the different cycles of the moon (Fig. 5.10). *Caridina* was the main prey during evenings and the dark-moon phase, contributing 57%, followed by haplochromines (33%) and dagaa (5%). In the full moon and half-moon phases, haplochromines became the most important prey with a contribution of 64% and 57% respectively, followed by dagaa (14% &17%), Nile perch (6% & 16%) and *Caridina* (11% & 4%).

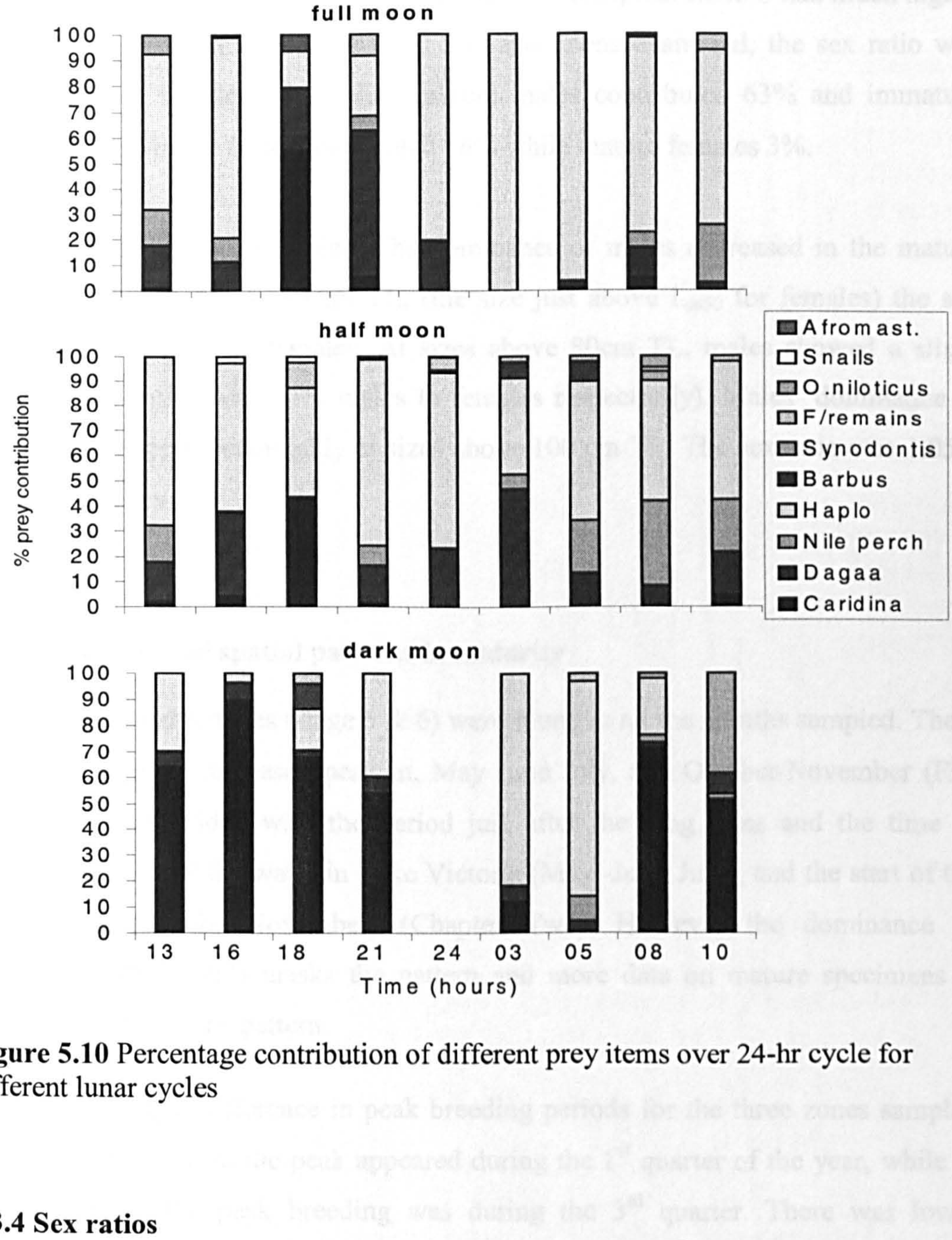


Figure 5.10 Percentage contribution of different prey items over 24-hr cycle for different lunar cycles

5.3.4 Sex ratios

The sex ratio of 3 899 Nile perch examined from the three zones was 2.4:1 males to females, which was significantly different from the expected 1:1 ratio. The proportion of immature males and females were 56% and 25% respectively, while the mature males were 15% and mature females 4%. Similar sex ratios were found for zone A and B. Of the 1 213 specimens examined in zone A, the sex ratio was 1.9:1 males to females. The proportions of immature males were 52% and immature females 31%, while mature males and females were 13% and 4% respectively. In zone B, 1 380 Nile perch specimens were examined a sex ratio of 2.1:1 males to females was found. Immature males represented 52 % and females 28% while mature males were 16% and females 4% of the population sampled. Zone C had much higher numbers of immature males. Of the 1 306 specimens examined, the sex ratio was 3.8:1 males to females of which immature males contributed 63% and immature females 18%. Mature males contributed 16% while mature females 3%.

The sex ratio differed with size. The dominance of males decreased in the mature population. Fishes below 80 cm TL, (the size just above L_{m50} for females) the sex ratio was 2.6:1 male to females. At sizes above 80cm TL, males showed a slight increase (sex ratios was 2.8:1 males to females respectfully). Males' dominance in the catches dropped remarkably at sizes above 100 cm TL. The sex ratio was 1.05:1 males to females

5.3.5 Temporal and spatial patterns in maturity

Mature males and females (stage 5 & 6) were found in all the months sampled. There is an indication of increased peak in, May June July, and October/November (Fig. 5.11). These coincided with the period just after the long rains and the time of complete mixing of the water in Lake Victoria (May -July, July), and the start of the rain season (October/November) (Chapter Two). However the dominance of immatures (stage 2&3) masks the pattern and more data on mature specimens is needed to establish the pattern.

There was a slight difference in peak breeding periods for the three zones sampled (Fig. 5.12). In zone A, the peak appeared during the 1st quarter of the year, while in zone B and C the peak breeding was during the 3rd quarter. There was lower spawning activity in the 4th quarter for zone B, but for zone C this applied to the 1st quarter. Due to limited number of females, the changes in maturity are based on the male data, which is also biased by the dominance of immature specimens.

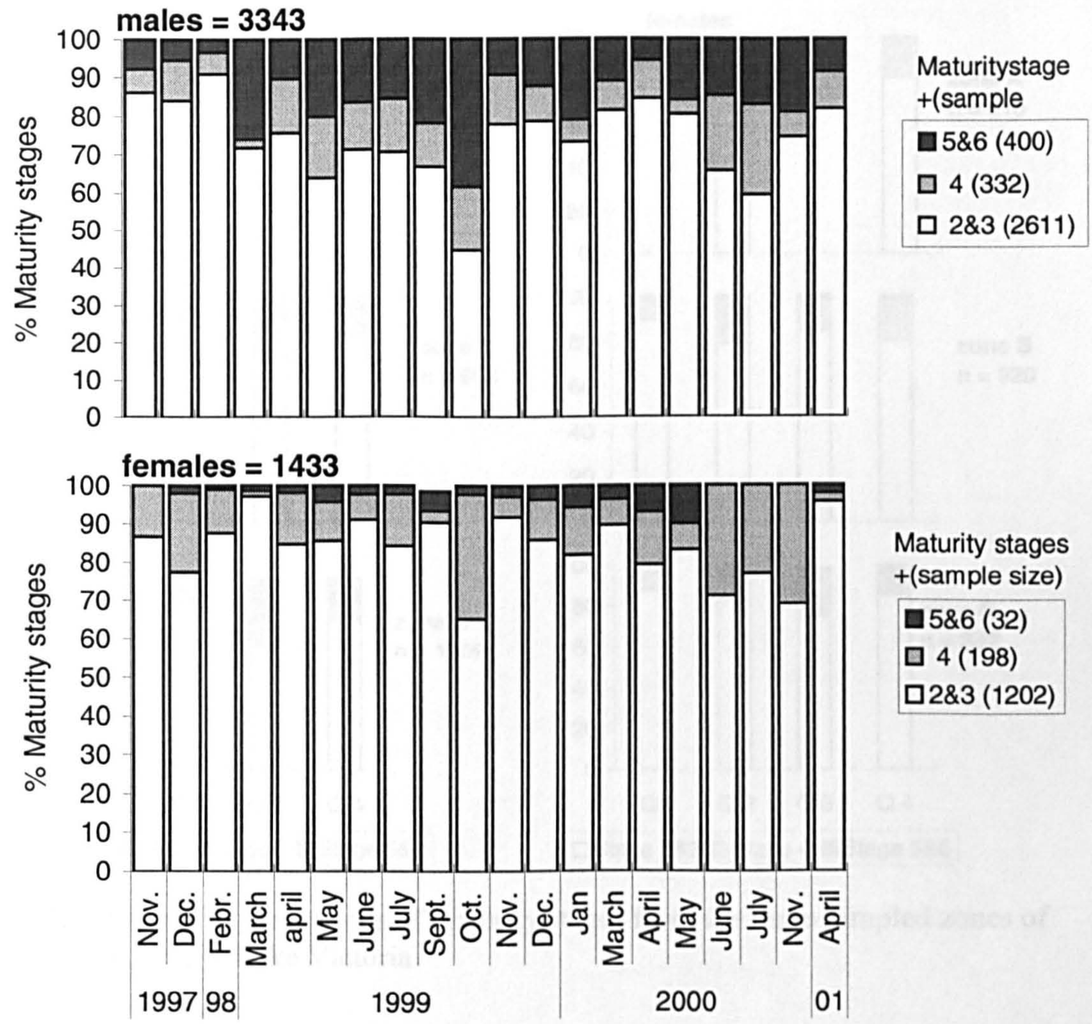


Figure 5.11 Percentage of maturity stages for the months sampled from November 1997 to April 2001 in the Tanzanian waters of Lake Victoria

5.3.6 Length at sexual maturity (L_m)

The mean length at which 50 per cent of all individuals of Nile perch in Tanzanian waters become sexually mature was 54.34 cm TL for males and 76.71 cm TL for females. That included samples from a fish-processing factory (Fig. 5.13). Using samples from the bottom trawl surveys only, little difference of length at sexual maturity was found for males between zones (Fig. 5.14a-c). Differences were found for females but this could be due to small number of mature females encountered in the bottom trawl catches. The sizes at sexual maturity excluding data from fish processing factory were 54.88 cm TL and 83.14 cm TL for males and females respectively (Fig. 5.14d). The smallest mature male (stage 5) encountered was 35.3 cm TL and weighed 0.7 kg while for females it was 47.9 cm TL and 1.4 kg

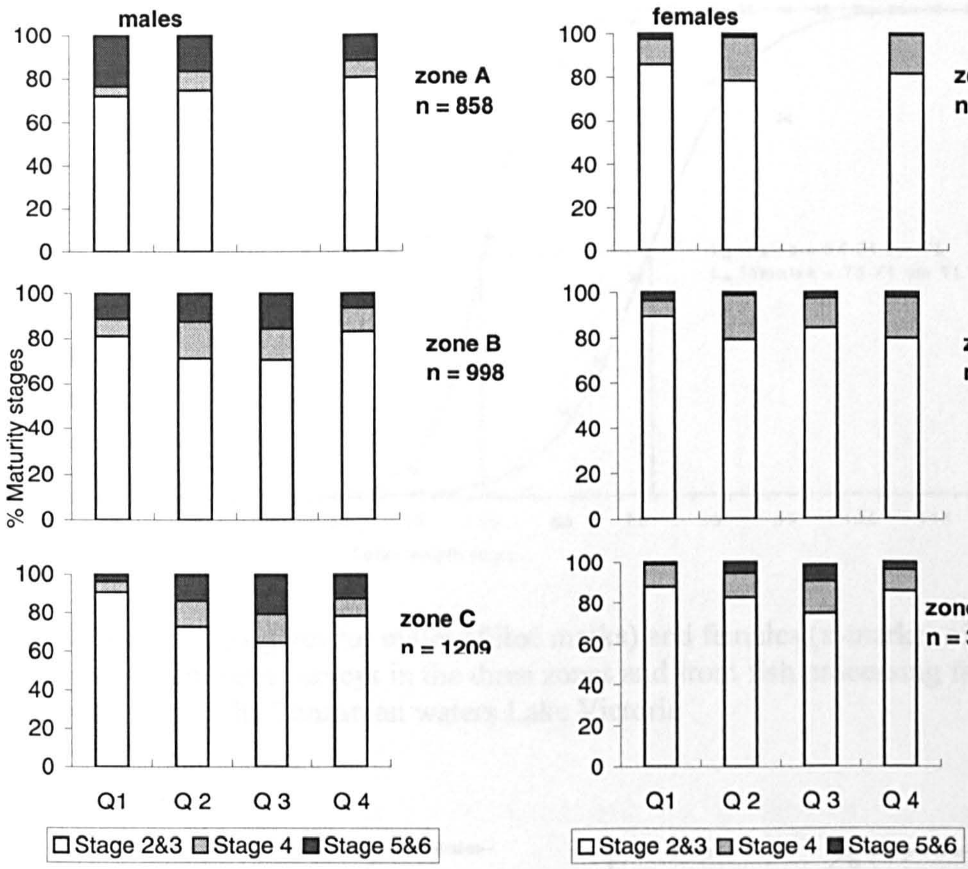


Figure 5.12 Quarterly proportions of maturity stages from the three sampled zones of the Tanzanian waters, Lake Victoria

5.3.7 Fecundity

A total of 45 ovaries at stage 5 and 6 were assessed for fecundity (Fig. 5.15).

For the specimens examined, number of eggs per fish ranged from about 556 000 for a female of 66 cm TL to 13 847 640 for 84 cm TL female. A weak relationship ($F = 4.6L^{2.89}$; $r^2 = 0.34$) was found between fecundity (F) and length (TL cm), probably because of the small sample size or possibly prior release of some ova due to pressure during hauling. Hopson (1969) reported of large number of eggs shed at the time of capture as some of the ova lay loosely in the lumen of each overy. One female of 200 cm TL was encountered and the fecundity was 8 758 724 eggs while a smaller fish of 84 cm TL had a fecundity of 13 847 640 eggs. Such discrepancies could also explain the weak relationship.

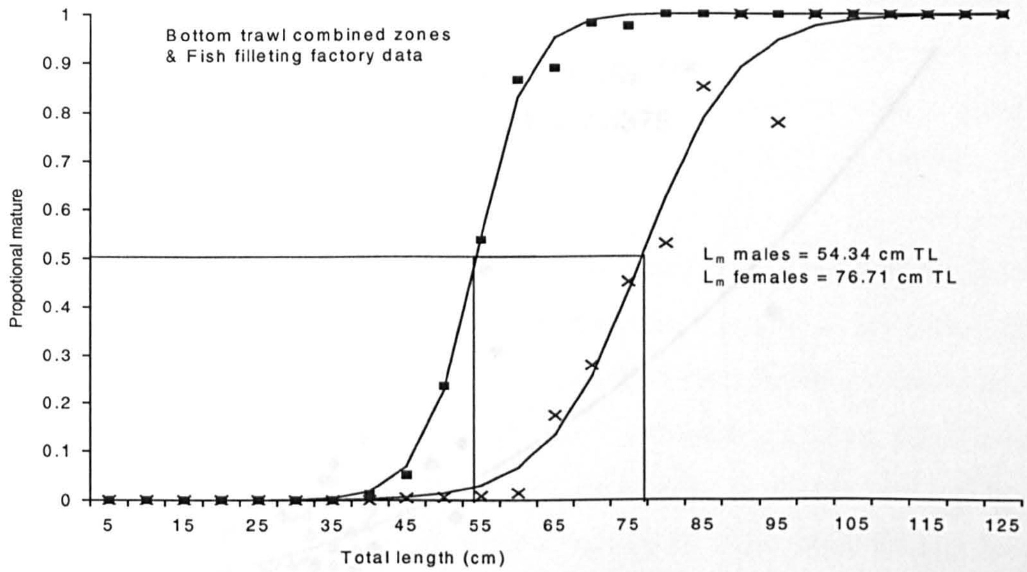


Figure 5.13 Maturity ogives for males (filled marks) and females (x-marks) of Nile perch from bottom trawl surveys in the three zones and from fish processing factory (gill net catches); in the Tanzanian waters Lake Victoria

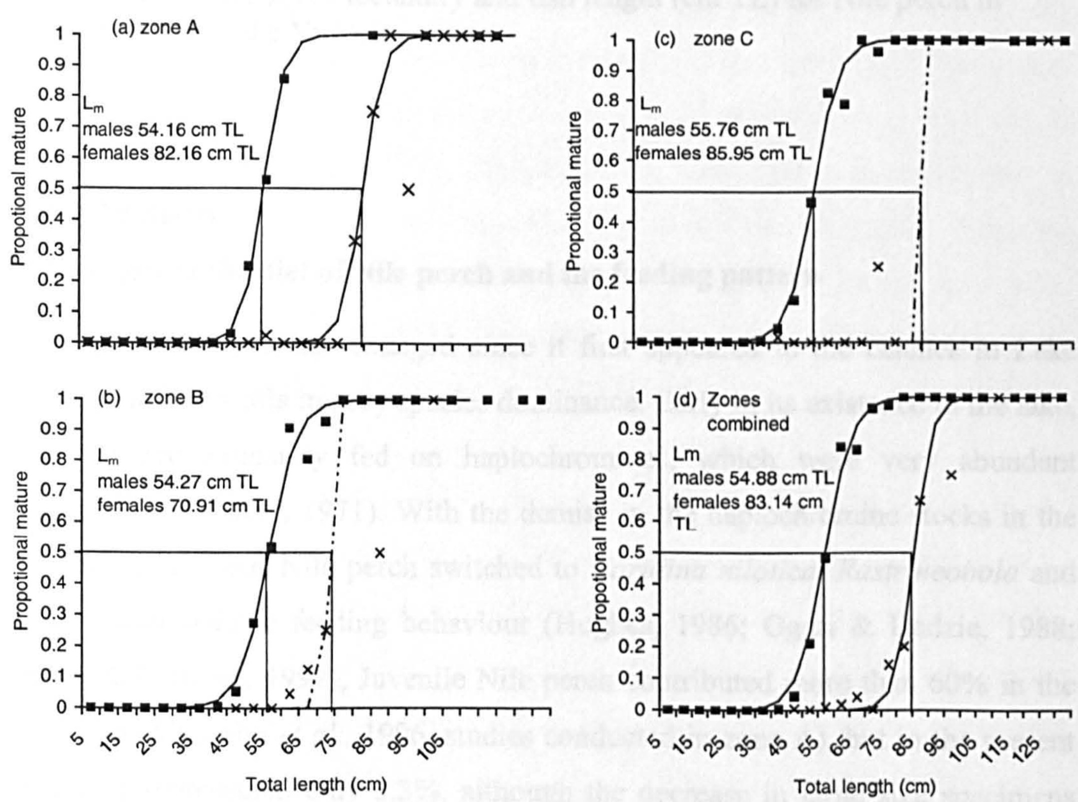


Figure 5.14 Maturity ogives for males (filled marks) and females (x-marks) of Nile perch from bottom trawl catches in the three zones (a-c) and (d) combined

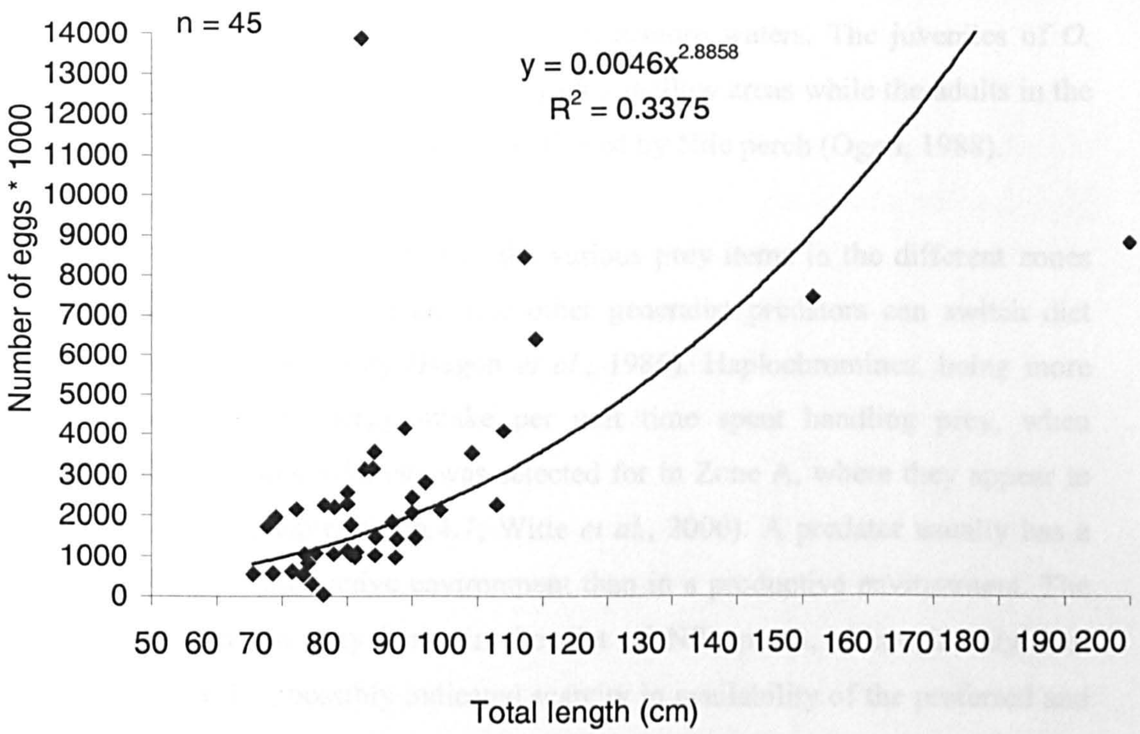


Figure 5.15 Relationship of fecundity and fish length (cm TL) for Nile perch in Tanzanian waters, Lake Victoria

5.4 DISCUSSION

5.4.1 Changes in the diet of Nile perch and the feeding pattern

The diet of Nile perch has changed since it first appeared in the catches in Lake Victoria, to follow shifts in prey species dominance. Early in its existence in the lake, Nile perch predominantly fed on haplochromines, which were very abundant (Hamblyn, 1966; Okedi, 1971). With the demise in the haplochromine stocks in the 1970s and early 1980s Nile perch switched to *Caridina nilotica, Rastrineobola* and adopted a cannibalistic feeding behaviour (Hughes, 1986; Ogari & Dadzie, 1988; Mkumbo & Ligtvoet, 1992), Juvenile Nile perch contributed more than 60% in the diet in 1996 (Mkumbo *et al.*, 1996, studies conducted in zone A), but in the present survey, they represented only 3.3%, although the decrease in large size specimens and dominance of juveniles relative to previous studies could have contributed to the observed changes in diet . Despite the abundance of *Rastrineobola,* its contribution of only 7.8% to the diet possibly reflects its schooling behaviour and diurnal migration patterns because more *Rastrineobola* were consumed during full and half moon compared with the dark moon. *Oreochromis niloticus* was virtually absent from the diet of Nile perch, although it is prevalent in inshore waters. The juveniles of *O. niloticus* are found in the muddy grassy/papyrus shallow areas while the adults in the open inshore waters are too large to be swallowed by Nile perch (Ogari, 1988).

The differences in the contribution of the various prey items in the different zones sampled, verified how Nile perch, like other generalist predators can switch diet depending on prey availability (Begon *et al.,* 1986). Haplochromines, being more profitable in terms of energy intake per unit time spent handling prey, when compared with *Caridina niloticus* was selected for in Zone A, where they appear to be more abundant (Chapter 4 Fig.4.7; Witte *et al.*, 2000). A predator usually has a broader diet in an unproductive environment than in a productive environment. The occurrence of fourteen prey items in the diet of Nile perch, although only four contributed above 1%, possibly indicated scarcity in availability of the preferred and profitable prey to the Nile perch. The presence of cannibalism, more commonly in zone B and C, indicated scarcity of alternative food source. Hopson (1972) established that the switching of Nile perch to cannibalism in Lake Chad was caused by a dearth of other food sources, although a degree of cannibalism is wide spread amongst fish (Smith & Reay, 1991; Pitcher, 1995). Cannibalism is also known to have a density dependant regulatory effect (Laevastu & Favorite, 1988). When the biomass of adults is high, predation of the juvenile biomass can be expected to be high. Decreases in cannibalism in the Nile perch stock probably indicate a decrease in the biomass of the adults possibly as a result of fishing.

The seasonal variation of prey contribution in the diet can also be explained by the seasonality in abundance of the shrimp *Caridina* in the water column. During thermal stratification, *Caridina* are found just below the thermocline (Cowx & Tweddle, 1999; Ochumba, 1995). Nile perch being very sensitive to oxygen levels cannot forage in this layer and thus explain the low contributions of *Caridina* in the diet during October to January. The high contributions in March and April differ in the two years, as they were probably associated with water mixing due to strong waves during heavy rains. Previous studies in the same area (Mkumbo & Ligtvoet, 1992) found the same pattern of fluctuations in the contribution of *Caridina*. The dynamics of *Caridina* in Lake Victoria are still unknown (Ssentongo & Welcomme, 1985) although they are currently under investigation (Budeba & Cowx, 2000).

Nile perch showed a size related shift in its feeding behaviour as was also documented in previous studies (Hughes, 1986; Ogari, 1985; Ogari & Dadzie, 1988; Mkumbo & Ligtvoet, 1992; Mkumbo *et al.*, 1996). Specimens below 20 cm TL feed predominantly on *Caridina*, but switched to piscivory predominantly on haplochromines at 60 cm TL. In the previous studies, the shift occurred in slightly bigger sizes, at 70 cm TL (Hughes, 1986) and at 80 cm TL (Ogari, 1988). This is possibly explained by the reduction in size at first maturity. The protein requirement during reproductive activities is three or four times higher than normal (Begon *et al.*, 1986) and possibly explains the shift to fish at 60 cm TL.

Increase in the abundance of *Caridina* and the planktonic cyclopoid and calanoid copepods, and insect larvae chironomid larvae in Lake Victoria have been documented (Witte *et al.*, 1995a). All were recorded as prey of juveniles of Nile perch of <10 cm TL (Ogari & Dadzie, 1988; Wanink, 1988; Witte *et al.*, 1995b). The Nile perch population therefore is not threatened by food shortage in the juvenile stages, but the relatively high contributions of *Caridina* in sizes above 60cm TL, especially in zone B, probably indicate shortage of profitable and preferred prey options.

Although Nile perch feeds throughout the day, there was an indication of two feeding peaks during dawn and dusk, and this probably corresponds to the active feeding time of the prey species. *Bagrus docmac*, another predator in the lake was reported to have the same peak feeding periods (Ogari, 1988). The type of food eaten during the day and night differs in quantity per type and for different lunar cycles. This is linked to the amount of light required by the predator to locate the prey as well as the behaviour of the prey. The predominance of *Caridina* during the dark moon suggests that they are more inactive and less scattered during this period. *Caridina* is attracted by light like *Rastrineobola argentea*, dagaa and during half moon and dark moon it is not only an important component to the diet of Nile perch but contributes more in the commercial catch of dagaa fishery. The extensive light fishing on dagaa can have some negative effects to the Nile perch stock, as *Caridina* is also harvested and this could potentially lead to scarcity of food for Nile perch below 60 cm TL. This eventually can affect the growth, survival and recruitment of the Nile perch stock.

The food web for Lake Victoria has shifted considerably since the Nile perch explosion (Witte & de Winter, 1995). *Caridina* now occupies a very important link between almost all the commercially important species of the lake's fishery. It is an important food to dagaa, and juvenile as well as adult Nile perch. It is also an important prey (the juveniles) for haplochromines (Greenwood, 1981; Witte *et al.*, 1995b) and *Oreochromis niloticus* (Njiru, 1999). The simplified food web which currently exists in the lake (Fig. 5.16) shows this position.

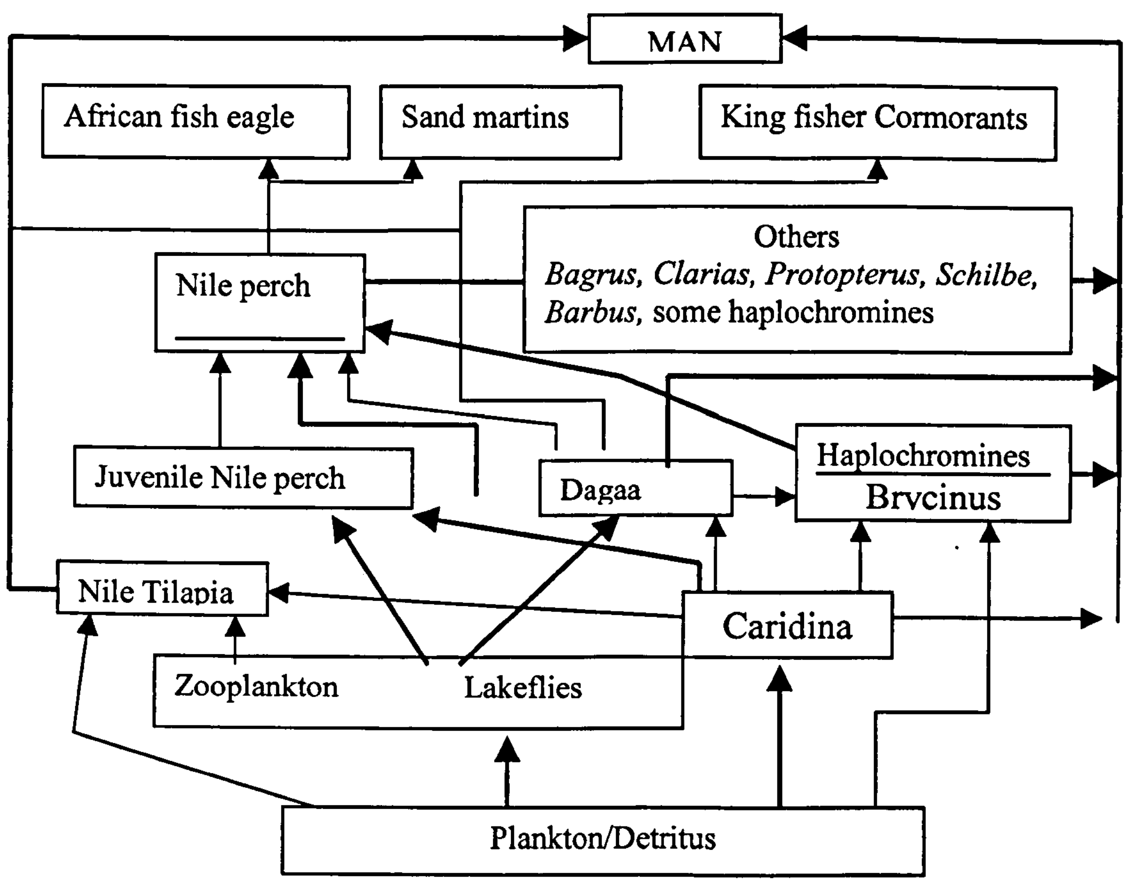


Figure 5.16 A simplified current Food web in Lake Victoria

Nile perch, currently the most important fishery, is the top predator, feeding on a number of trophic levels; at primary level, juveniles feeding on planktons, cladocera and cyclopoids, then insect larvae and *Caridina*. At the secondary level it feeds on haplochromines and *Rastrineobola*, while the bigger fish are tertiary consumers. Thus the main food links from phytoplankton and detritus are: (1) via *Caridina* to juvenile Nile perch to adults; or (2) directly via *Caridina* and haplochromines to adult Nile perch; (3) via insects to juvenile Nile perch and haplochromines then to adult Nile perch; (4) via zooplankton to *Rastrineobola*, haplochromines and juvenile Nile perch and then to adult Nile perch; or (5) directly culminates to *Oreochromis niloticus* (Nile Tilapia). *Caridina,* occupying the niche left by haplochromines and also released from the previous predation pressure of the many zooplanktivorous haplochromines, has built up in stock abundance and is now a major component of the diet of Nile perch. This has reduced predation pressure on haplochromines and is possibly the reason for the latter recent resurgence, although in the predictions (Moreau, 1995) it was associated with the increase in fishing pressure for Nile perch. Other fish species are also exploiting the decline in the Nile perch stock abundance, e.g. endemic predators like *Clarias* and *Bagrus*, which probably compete with Nile perch for food.

However, fishing has adapted to exploit the newly emerging haplochromines, preventing any stability in stock structure and influence on the ecosystem integrity. There is a considerable commercial fishery for haplochromines during full moon by dagaa seines (Personal observation in Speke Gulf), while at the same time they are targeted as bait for the long line fishery. Furthermore there is now considerable exploitation of the *Caridina* for animal feeds (Budeba & Cowx, 2000), which may further disrupt the trophic interactions (Hart, 1995). Fishing pressure is also heavily directed to *Rastrineobola* and *Oreochromis*, the other two important stocks for the trophic efficiency of the ecosystem as they are feeding on the lower levels in the food web (Wanink, 1998b). The 'mixed trophic impact routine' of ECOPATH II (Moreau, 1995) showed that a decrease of the biomass of *Caridina* will have a direct negative effect on the Nile perch, while at the same time a positive effect on detritus biomass, which will in turn increase the anoxia problem in the lake. The same applies for the reduction of *Rastrineobola* and *Oreochromis* biomasses, which may result to an increase in zooplankton and phytoplankton and magnify the eutrophication problem in the lake, although some phytoplanktivorous and zooplanktivorous including haplochromines can increase. These will in turn favour the increase in the higher trophic levels. The current resurgence of haplochromines is probably in accordance to the trophic cascade theory (Carpenter *et al.*, 1985), due to reduced predation pressure. However, Nile perch have switched again to feed predominantly on them as was found for Zone A where the recovery is most marked (Witte *et al.*, 2000; Tumwebaze *et al.*, 2000). However, with the fishing pressure from the dagaa fishery, coupled with the long line bait fishery, the recovery may be short lived and the stability expected in the trophic dynamics may not appear, unless they are protected from intense fishing pressure.

5.4.2 Reproductive biology of Nile perch

The sex ratio in Nile perch was found to differ from the expected 1:1 ratio with a preponderance of males (2.4:1 to 2.8:1) to about 100 cm TL. Above 100 cm TL almost the same proportions of males and females were caught. The same pattern of sex ratio was reported earlier (Ligtvoet & Mkumbo, 1990; Hughes, 1992; Witte & de Winter, 1995) but with more males (10:1 to 7:1 sex ratio). The earlier studies also reported an earlier fall in the proportions of males to a 1:1 sex ratio at 90 cm TL, and a dominance of females at 100 cm TL (1:10 male to female ratio), which was not encountered in the present study. Unequal sex ratio is not considered as one of the important life history parameters in regulating populations (Begon & Mortimer, 1986; Begon *et.al.*, 1986; King, 1995)

Nile perch in Lake Victoria, like many other tropical fishes, has a continuous breeding cycle throughout the year (Bagenal, 1978). The same was also observed for Nile perch in Lake Albert (Hamblyn, 1962) and Lake Chad (Hopson, 1972). However there was an indication of two peaks of breeding, in November/December and May/June. The two peaks coincide with the start and end of the rainfall seasons, although the later coincided also with the time of thermal de-stratification and mixing of the lake (Chapter Two) and the juveniles would coincide with the peak cyclopoids - copepod production in August/September (Witte *et al.*, 1995b). Both rainfall and lake mixing have an impact on environmental parameters such as oxygen and temperature, as well as nutrient and food availability, all known to trigger reproduction activities in fish (Pitcher & Hart, 1982). As rainfall patterns differ in the three zones of study (Chapter Two) the breeding patterns also differ slightly and suggest rainfall is the key influencing factor. The breeding patterns are therefore expected to differ for the Kenyan and Ugandan waters as the rainfall patterns also differ (Beadle, 1981).

A long spawning season as seen in Nile perch, is suggested to be of survival value. Spawning distributed over a long period reduces chances of loss in a fluctuating environment, while competition among young and newly hatched may also be reduced. With some changes in foods with size, the long reproductive season would result in use of a greater variety of foods in any given time of the year. This would contribute to a reduction of intra-specific competition for food, resulting in increased chances of survival of young.

The size at sexual maturity for males (54.34 cm TL) and females (76.71) remains within the range observed in the past for the same species in Lake Victoria and found in different habitats (Table 5.2).

Excluding the findings of Okedi (1971), which probably refers to the smallest mature individuals encountered, the size at sexual maturity for males is within a very narrow range. It is the females that seem to have a very wide range of difference. This is probably due to a small sample size of mature females dealt with in the different studies. Comparing the findings of Ogutu-Ohwayo (1988) and Ligtvoet and Mkumbo (1990) with the present findings, the size at sexual maturity for females in particular has dropped markedly from 95 cm TL to 76.7 cm TL. This is probably explained by selective fishing mortality. With large mesh sizes used during the onset of the Nile perch fishery, the large maturing genotypes were removed from the population

The fecundity estimated ($F= 4.6L^{2.86}$) was comparable to the findings of Ogutu-Ohwayo (1988) in Lake Kyoga ($F= 4.436*10^{-6}L^{2.92}$, F is number of eggs in million). The power constant approximate to 3 is common for many fishes that produce relatively many eggs (Pitcher & Hart, 1982). It is difficult to ascertain whether there has been an increase in fecundity of Nile perch in Lake Victoria, as the only documented work is that of Asila and Ogari (1988), giving a wide range of 3 million to 15 million eggs. However, it has been suggested that long-lived species with low annual mortality should have a lower reproductive effort per reproductive season as compared to a small species having a short life expectancy and high annual mortality (Williams, 1966). The protracted reproductive season and high fecundity in Nile perch is probably an adaptation to the harsh environment the eggs and larvae are exposed, i.e. being pelagic (Hopson, 1969). Nile perch *L. niloticus* is reported to spawn in relatively sheltered conditions in Lake Chad, and the pelagic eggs, averaging 0.83 mm in diameter, are characterized by a large single oil globule and a narrow perivitelline space (Hopson, 1969). However, there is no similar study conducted in Lake Victoria.

Table 5.2 Comparison of Size at sexual maturity for Nile perch (*Lates niloticus*) at different periods and habitats.

Habitat & Year of study	Males (cm TL)	Females (cm TL)	Source of information
Lake Albert (1963)	60	85	Holden (1963)
Lake Chad (1972)	50	60-65	Hopson (1972)
Lake Kyoga & Lake Victoria (1986)	50-65	60-95	Ogutu-Ohwayo (1988)
Lake Victoria & Lake Kyoga (1970)	30-33	33-35	Okedi (1971)
Lake Victoria (1984)	54	68	Acere (1984)
Lake Victoria (1989)	60	95-100	Ligtvoet & Mkumbo (1990)
Blue Nile (1939)	60	60	Kenchington (1939)
Lake Turkana (1982)	65	90	Hopson (1982)
Lake Victoria	54	77	Present study

Under stressful environments or influences as predation and overfishing which results to increased mortality, fishes tend to grow faster and reproduce earlier (Wootton, 1990; Begon *et al.*, 1986), thus leading to increased resilience in the stock. The spatial differences found in size at sexual maturity could possibly be explained by difference in fishing effort in the three zones. Zone A was heavily fished in 1995 when fishermen had to migrate to the other zones. However, catch rates during the present study were comparable with the other two zones. Size at sexual maturity for females was also higher in zone A and C (82.16 cm TL & 85.95 cm TL respectively) compared with zone B (70.91 cm TL) possibly indicating differences in fishing effort. Zone B with higher proportions of the undermesh illeagal gear have a more selective fishing for the large maturing individuals. The extent to which the population migrates and mixes in different localities has not been established. However, Nile perch is reported to move quite long distances (Ligtvoet & Mkumbo, 1990), and thus localised overfishing could rapidly be replaced by migration. As a result, fishing impact in one country or specific rich fishing grounds will have an effect to the whole stock in the lake. Temporal and spatial variations in stock density (Chapter Four) suggest the possibility of certain migratory patterns in Nile perch stock, but further work is needed to establish the migration patterns of Nile perch.

The differences in diet found in the different zones can be only a temporary phenomenon depending on where is the fish and which prey is abundant and thus may not act as an environmental factor for a predator which can easily switch preferences in the feeding behaviour (Begon *et al.*, 1986). Nevertheless the growth performance index of Nile perch is found to have decreased (Chapter Six), indicating that the fish is not fairing well in the habitats compared to the time of its introduction. Although fishing mortality could have influenced some changes in the biological parameters of Nile perch investigated in this chapter, the extent to which the ecological changes in Lake Victoria (Chapter Two) are influencing the Nile perch stock and thus inducing changes in the life history strategies need further investigations. Further work is needed to assess the prey abundances and trophic interactions, which through ECOPATH-ECOSIM simulations, yield predictions can be made and management regulations formulated targeting the expected levels of prey abundance to sustain the fishery.

5.5 Summary

A total of 2 896 stomachs from: the monthly bottom trawl surveys from November 1997 to June 2000 (Chapter Four), bottom trawl sampling for diurnal feeding patterns- Mwanza Gulf (March, April & June, 2001) and from mid water pelagic trawl operations-Speke Gulf August/September 2001), were analysed for prey contribution and feeding patterns using the point method (Hyslop, 1980). Sex and maturity status was also detrmined from 3 899 specimens using Hopson's (1972) classification. Ripe ovaries (stage 5 & 6) were also collected for determination of fecundity in the laboratory.

An overall dominancy of *Caridina niloticus* in the diet of Nile perch was elaborated and found to contribute 42.7% & 83.6% in bottom trawl and 24-h mid water pelagic trawl samples respectively, but with considerable spatial, temporal and diurnal variations. Haplochromines contributed 41.3%, dagaa 10.8% Nile perch 3.3% and the other prey encountered (Odonata, *Barbus, Schilbe, O.niloticus, Clarias, Synodontis* and Snails) contributed 1.9% in the Nile perch diet from bottom trawl samples. This indicated marked reduction in cannibalism found in previous studies when Nile perch were contributing over 60% of the diet (Mkumbo & Ligtvoet, 1992; Mkumbo *et al.*, 1996).

Caridina was more dominant in April and September and in Zone C, while haplochromines were dominant in March, October, January and May, when surveys were conducted in Zone A. Differences in sampling months in the different zones hinders any conclusion on spatial and temporal differences in the feeding pattern of Nile perch.

Nile perch showed a size-related shift in its feeding behaviour. *Caridina* contributing more than 70% of the diet of <20 cm TL Nile perch, decreasing in dominance to 30% contribution at 60 cm TL when haplochromines contributed over 70%. Nile perch became cannibalistic at above 90 cm TL when its own juveniles contributed about 30% of the diet.

There was an indication of peak feeding time just before dusk and dawn, and also variation in prey type during day and night or full moon and dark moon but more data over extended period are need as the present observation was obscured probably by limited sample size.

There was a dominance of males in the Nile perch (2.4:1), but the sex ratio decreased with increase in size to almost equal proportions (1.05:1 males to females) at sizes above 100 cm TL. This differed from previous findings where the proportions of males were much higher (from 7:1 to 10:1) and a dominance of females was found at sizes above 100 cm TL (Ligtvoet & Mkumbo, 1990). However, it is difficult to ascertain changes in sex ratio as very few large specimens were sampled compared with previous studies.

Breeding was found to be continous throughout the year, although an indication of increased proportion of mature specimens were encountered in November/December and May/June. Size at first maturity (Lm50) was 54.34 cm TL and 76.71 cm TL for males and females respectively. A marked drop of size at first maturity was found compared with 1988 when males matured at 60 cm TL and females at 95-100 cm TL (Ligtvoet & Mkumbo, 1990). The relationship between fecundity and total length for

Nile perch $F = 4.6L^{2.89}$; ($r^2 = 0.34$). The weak relationship is explained by the small sample size or possibilities of prior release of eggs from some ovaries due to pressure at capture (Hopson, 1969).

The feeding behaviour of Nile perch (being a generalistic predator) switching diet depending on prey availability, the ontogenic shifts and cannibalism together with high fecundity are all addaptations of the population towards sustainability. However, the current food web in Lake Victoria is much, which implies reduction in transfer efficiency in the system with *Caridina* forming a direct link from detritus to the top predators. Fishing for dagaa is reported to extensively harvest the *Caridina*, which can lead to even more serious reduction in transfer efficiency in Lake Victoria. However, the current increase in the contribution of haplochromines in Nile perch diet and the reduction in cannibalism, possibly indicate a reduction of the Nile perch population, which may inturn favour ecosystem stability through recovery of prey species and eventually increase in transfer efficiency in the fisheries and thus high yields again. However, it is not known whether overfishing of Nile perch can lead to an increase in the transfer efficiency of the fisheries (Turner, 1996). The trophic dynamics and how they are influenced by changes in abundance at different levels of the food chain, and inturn influencing fish yields and the ecosystem stability, needs further studies for the sustainability of the fisheries of Lake Victoria.

CHAPTER SIX

POPULATION PARAMETERS AND ASSESSMENT OF THE NILE PERCH STOCK

6.1 INTRODUCTION

Several attempts have been made to assess the status of the Nile perch stocks in Lake Victoria but none had a wide or a complete coverage. For example, Hughes (1992), and Asila and Ogari (1988) determined the population parameters in the Kenyan waters while Acere (1985), and Ligtvoet and Mkumbo (1990, 1991), Ligtvoet *et al.* (1995b) did the same for Ugandan waters and Tanzanian waters, respectively. These localized studies allowed for an assessment on Nile perch fishery in the whole lake (Pitcher & Bundy, 1995) but the authors expressed uncertainties on the reliability of the data used. Despite subsequent advice on reduction of fishing effort provided by these studies, the exploitation of Nile perch in the lake has been expanding, possibly due to lack of the capacity to limit access and lack of political and social will due to the economic benefits accruing from the fishery. As a result fishing effort on the Nile perch stock has been increasing with little control despite alarming signs of overfishing indicated by decreasing modal length of the catches, decreasing catch per unit effort, decreasing total landings with increase in effort, decreasing mesh size of nets used (Kudhongania & Coenen, 1992; Ogari & Asila, 1990; Cowx & Tweddle; 1999; LVFO, 2000; Mkumbo & Katunzi, 2000; Mkumbo *et al.*, 2002) and decrease in size at first maturity (Oguto-Ohwayo, 1988; Ligtvoet & Mkumbo, 1990; Mkumbo *et al.*, 2002; Chapter Five).

Current exploitation patterns (Chapter Three, Mkumbo *et al.*, 2002) and some predictions (Pitcher & Bundy, 1995; Pitcher *et al.*, 1996; Moreau, 1995; Villanueva & Moreau, 2002) revealed considerable reduction in Nile perch stock size and changes in the population structure. The dominance of juveniles characterises the landings from all the different gears used with a decrease in catch per unit of effort despite of increasing in number of gillnets per canoe (Chapter Three). Nevertheless, the frame survey conducted in 2000 revealed an enormous increase in effort (Chapter Three).

Due to the signs of overfishing and the heavy investment done on the industry especially with the 27 fish filleting factories; 9 in the Tanzania sector (SEDAWOG, 1999b), there has always been a continuous pressure to estimate the 'size' and the potential of the fishery, and answer questions relating to maximum sustainable yield and the corresponding fishing effort that can be exerted (LVFO, 1999). The sustainable yield from a fish stock depends on complex interactions between many biological and environmental parameters, and any attempt at its estimation from just a few parameters, which in any case may be variable, is hazardous. Nevertheless, such estimators may provide an indication of the magnitude of a potential resource against which management decisions can be made. It was on this basis that the Lake Victoria Fisheries Research Project (LVFRP), among other objectives launched the stock assessment programme to evaluate the status of the stocks to aid sustainable management of the Nile perch fishery.

Proper assessment and management of a fishery requires an understanding of the population parameters of the species on which it is based, namely stock abundance, growth, recruitment and mortality (Sparre *et al.*, 1989; Hilborn & Walters, 1992; King, 1995), as these are the processes controlling the production. The number of fish is increased by reproduction of the adult stock, which results in juveniles being added into the stock or recruitment occurs. Likewise, the weight or biomass of the fish stock is increased by the growth of individual fish while the stock is being reduced in numbers and biomass by natural mortality and fishing mortality. The changes in population parameters are indicators of the adjustment in the life history strategy of the species in response to stress either from natural causes or fishing (Laevastu & Favorite, 1988; Wootton, 1990; King, 1995). Estimates of parameters such as growth rates, mortality and recruitment are necessary to determine fish production (Ricker, 1975; Allen, 1971; Pitcher & Hart, 1982; Gulland, 1988). These parameters of a fish stock can be estimated either by using data on number of fish at different lengths, i.e. length-frequency data or CPUE - catch per unit effort data (Sparre *et al.*, 1989; King, 1995). These data can be collected directly from the landings of fishing vessels i.e. fishery-dependent data or from fisheries research vessel i.e. fisheries-independent data. To use CPUE data under surplus production models (Ricker, 1975) it must be accurately reflecting changes in abundance of fish in the stock and a long time-series of catch-and effort data must be available (Gayanilo & Pauly, 1997). The conditions are not fulfilled for the landings in Lake Victoria (Chapter Three) and thus only length- frequency data both from fisheries-dependent and fisheries-independent sources collected during the current study period were used for the purposes of the current estimates.

This chapter aims to establish the status of the Nile perch stock in the Tanzanian waters and determine the levels at which it may be sustainably exploited. Using the different assessment routines provided in FiSAT package, the chapter attempts to determine the population parameters of Nile perch and estimate the yield and the current exploitation levels. Linked to abundances and distribution patterns of the stocks (Chapter Four) and the biological information (Chapter Five) and exploitation patterns (Chapter Three), and compared to historical values, the current status of the Nile perch fishery is discussed and provide recommendations on the exploitation levels for sustainability of the fishery. Areas of research priority for management purposes are also pointed out.

6.2 MATERIALS AND METHODS

6.2.1 Sampling programme

Fisheries independent data were collected during the monthly bottom trawl surveys (Chapter Four) while fisheries dependent data were collected during a beach sampling programme, which was conducted monthly in nine selected beaches, three from each zone (Chapter Three). A total of 283 323 fish were measured for the fisheries independent data from March 1999 to July 2000 and 13 507 fish for the fisheries dependent data from February 1999 to December 2000. During both programmes, total length was measured to the nearest 0.1 cm and weight to the nearest 0.1 kg.

6.2.2 Selectivity of the gears

Generally fishing gears are selective, catching fish only within a certain range sizes, and to know the true size structure of a population, it is necessary to account for the effect of gear selection (Gayanilo & Pauly, 1997). This is achieved by estimating, for each size class of fish sampled, the probability of capture (i.e. fraction retained) and then dividing, for each length class, the numbers actually caught by the calculated probability of capture of the specific gear.

Trawl net selection is generally one sided, referred to as knife-edge selection, of which the smaller fish have a reduced probability of capture (Gayanilo & Pauly 1997). Data from the bottom trawl net was not corrected for selectivity as a very small codend mesh size of 20 mm was used.

Gillnets tend to select against both small and large fish, and were corrected for selectivity using the Baranov/Holt model (Sparre & Venema (1998), with the assumptions of selection curves of all mesh sizes to be presented by normal distribution with the same standard deviations. The following equations were used.

Based on a pair of gill net mesh sizes m_A and m_B, the optimum length corresponding to mesh size A (L_A) and to mesh size B (L_B) is estimated from the catch by length class of each mesh (C_A & C_B), through a linear regression equation of the form:

$$\ln(C_B/C_A) = a + b * L_i \qquad C_B/C_A \text{ - referred to as catch ratio.}$$

The intercept and slope of the regression is used to estimate the optimum length as:

$$L_A = (-2a * m_A)/[b * (m_A + m_B)] \quad \text{and}$$

$$L_B = (-2a * m_B)/[b * (m_A + m_B)].$$

The standard deviation of both the selection curves is estimated from:

$$\text{s.d.} = \sqrt{2a(m_A - m_B)/b^2(m_A + m_B)} \quad \text{and the selection factor by:}$$

$$\text{SF} = -2a/[b * (m_A + m_B)].$$

The optimum length for the meshes is also given by:

$$L_A = \text{SF} * m_A \text{ and } L_B = \text{SF} * m_B$$

With L_A, L_B, and standard deviation (s.d.) estimated, the probability of capture at any given length (L_i) is given for mesh m_A by:

$$P_{A.Li} = e^{-[(Li - LA)^2/(2(\text{s.d.})^2)]}, \text{ and for mesh } m_B \text{ by:}$$

$$P_{B.Li} = e^{-[(Li - LB)^2/(2(\text{s.d.})^2)]}.$$

With multiple mesh sizes (n), there are n-1 estimates of the intercept (a) and slope (b),

i.e. $[a_1, b_1]$, $[a_2, b_2]$, …… $[a_{n-1}, b_{n-1}]$, corresponding to the mesh sizes:

$[m_1, m_2]$, $[m_2, m_3]$, …… $[m_{n-1}, m_n]$

A common selection factor can be estimated by performing a regression analysis, whereby, $-2*a_i/b_i$ is the independent variable y_i, and $m_i + m_{i+1}$ is the independent variable x_i, i.e. $-2*a_i/b_i = SF(m_i + m_{i+1})$, $i = 1,2, \ldots, n-1$, then a common selection factor is given by:

$$SF = -2\sum_{\square=1}^{n-1}(m_i + m_{i+1}) * (a_i/b_i)/ \sum_{\square=1}^{n-1}(m_i + m_{i+1})^2$$, and standard deviation for

each consecutive pair of mesh sizes as:

$$s.d = \sqrt{(1/n-1)\sum_{\square=1}^{n-1}[-2a_i(m_{i+1} - m_i)/b_i^2(m_i + m_{i+1})]}$$

The optimum length for mesh size i is obtained by: $L_i = SF * m_i$ and then probability of capture for each mesh size calculated for correction of selectivity.

For the Nile perch gill net fishery, mesh sizes of 4.5" to 8" in varying combination for different boats were used, and thus selectivity was worked out separately for each combination of mesh sizes.

6.2.2 Length frequency and Length-Weight relationships

Monthly length frequency distributions from the bottom trawl surveys and gillnet beach sampling surveys were pooled into 3-cm length classes, the later after being corrected for selectivity and afterwards saved as Lotus 1-2-3 (version. 2.01) files and exported to FISAT package for analysis.

The length frequency distributions were also grouped by quarter and zones sampled to assess any spatial or temporal differences in size distribution of the population.

The parameters a and b of the functional relationship between total length and weight were calculated for the different zones and then combined for the whole area sampled after being tested for statistical difference. The following equation was used to calculate the length-weight parameters:

$$W = a * L^b$$

The regression parameters were estimated by log transformation (Sparre *et.al*, 1989)

$$\ln W = \ln a + b * \ln L$$

using the Microsoft EXCEL linear regression routine. The regression coefficient of the logarithmic function r^2 was calculated through the EXCEL routine. Under the same routine, 95% confidence limits of the slope were estimated as:

$b \pm t^* S_b$, where S_b is the standard deviation of the slope, and similarity with the expected value of 3 for b was tested using χ^2 test (Fowler & Cohen, 1990).

The condition factor (CF), being an index used to quantify the state of well being of fish, defined as:

$CF = W^*100/L^b$, (Weatherley, 1972)

was also calculated for the different zones to quantify the state of the well-being of the stocks in the three zones sampled.

6.2.3 Estimation of growth parameters

Data analysis was based on length frequency distributions using the Electronic Length Frequency Analysis (ELEFAN 1) routine of the FiSAT (Gayanilo *et al.*, 1996) and FiSAT II for Windows (Gayanilo & Pauly, 2001) programs. Estimation of the growth parameters was based on the von Bertalanffy growth model expressed in the form:

$$L_t = L_\infty (1 - \exp(-K * (t - t_0)))$$

Where L_t is the predicted length at age t; L_∞ is the asymptotic length or the maximum length the fish of a given stock would reach if they were to grow indefinitely; K is the growth coefficient and t_0 the age the fish would have been at zero length.

The asymptotic length (L_∞) was estimated using the Powell-Wetherall plot (Wetherall, 1986) and the 'Response surface routine' under ELEFAN I and growth coefficient (K) was computed following the von Bertalanffy generalised model in the ELEFAN 1 routine of the FISAT (Pauly *et al.*, 1980; Pauly, 1987; Gayanilo *et al.*, 1996) and FISAT II for Windows (Gayanilo & Pauly, 2001) programs. ELEFAN 1 was used to identify the growth curve that best fitted the length-frequency data, using the best-fit value of Rn as criterion (Rn is 'goodness of fit' index of the ELEFAN 1 routine which = $10^{ESP/ASP}/10$; where, ESP is 'explained sum of peaks' and ASP is 'available sum of peaks' in a growth curve).

Estimation of the theoretical length at zero (t_0) for the species was computed using Pauly's empirical equation:

$$t_0 = -0.392 - 0.275 \log L_\infty - 1.038 \log K$$

Age at time zero is a parameter useful in locating the starting point of the growth curve.

The life span (t_{max}) is the approximate maximum age that a fish in the population could achieve and is calculated as the age at 95% of L_∞ using the parameters of the von Bertalanffy growth function as: $t_{max} = t_0 + 3/K$. (Taylor, 1958).

The age at first maturity (t_m) was also calculated. It is the age at which fishes of a given population mature for the first time, calculated from the length at first maturity using the parameters of the von Bertalanffy growth function (Froese *et.al.*, 2000) as:

$$t_m = t_0 - \ln(1 - L_m/L_\infty)/K$$

The growth performance index (ø') is used to compare different populations of the same species. The growth performance index was computed according to Pauly and Munro (1984), and Pauly *et.al.* (1998) as:

$$ø' = \log(K) + 2\log(L_\infty)$$

where K is expressed on an annual basis and L_∞ is in cm.

6.2.4 Estimation of mortality and probability of capture

The total mortality rate (Z) was estimated using the linearised length –converted catch curve (Pauly, 1980; 1984), with the growth parameters from the von Bertalanffy as input data.

The catch curve was obtained by plotting the natural logarithms of the numbers of fish surviving by length:

$$\ln(N_{(L1-L2)}/dt) = \text{constant} - Z_{t(L1+L2)}/2 \quad \text{or} \quad \ln(F/dt) = \text{constant} - Z_t$$

where, F is the number of individuals in each age and, t is relative age. The value of dt is the time taken for the species to grow through a particular length class.

Natural mortality (M) was estimated with Pauly's (1980) empirical formula linking natural mortality with the von Bertalanffy parameters; K (yr^{-1}), L_∞ (cm) and mean annual water temperature T (°C):

$$\ln(M) = -0.4851 - 0.0824 \ln(L_\infty) + 0.6543 \ln(K) + 0.463 \ln(T)$$

An average water temperature of 24°C (Chapter 4) was used for the estimate of M.

Fishing mortality (F) was computed from the relation $Z = F + M$, while the exploitation rate was calculated from $E = F/Z = F/(F + M)$.

6.2.4.1 *Estimation of probability of capture*

The probability of capture was obtained from the backward projection of the right descending arm of the length converted catch curve and calculating the number of fish that would have been caught had it not been for selection and incomplete recruitment.

6.2.4.2 *Recruitment patterns*

The recruitment pattern was obtained by using FISAT, from a time series of length frequency data, to determine the number of pulses per year and the relative strength of each pulse. This method (Pauly, 1984) involves:

1. backward projection onto the time axis of a set of length frequency data;
2. summation of each month of the frequencies projected onto each month;
3. subtraction, from each monthly, sum of the lowest monthly sum to obtain a zero value where apparent recruitment is lowest; and
4. expressing monthly recruitment in percentage of annual recruitment.

6.2.4.3 *Maximum yield (L_{opt})*

The size at maximum yield is the length class a fishery would obtain the maximum possible catch by weight per recruit (Beverton, 1992) computed as:

$$L_{opt} = L_\infty * (3/(3 + M / K)$$

6.2.5 Separation of length frequency distribution

The Bhattacharya method was used to separate length-frequency distribution into its component normal distributions or pseudo-cohorts (Bhattacharya, 1967). The plot was based on approximating the assumed normal (bell-shaped) curve of a length-frequency distribution as a parabola, which was then converted to a straight line. The Bhattacharya plot has a straight line of the form:

$$dt(\ln N) = a + b\,(L)$$

where $dt(\ln N)$ is the difference between the natural logarithms of the number in one length class and the number in the preceding length class; L is the upper limit of the preceding length class. The straight line crossed the length axis at a point which was the mean (and mode) of the length-frequency distribution, i.e. the normal distribution had a mean of $(-a/b)$, and a standard deviation of $\sqrt{(-dLb)}$, where dL is the length class interval.

6.2.5.1 *Estimation of stock size and fishing mortality from length-structured VPA*

The monthly length frequency data from catch surveys was used as it represented CPUE. Linearly interpolation of size-frequency distribution was done where gaps occurred in the original data (Gayanilo & Pauly, 1997). The months of February, September and November had no data, length frequencies in each length class from a previous months and the month after were added and divided by two to fill the gap. The frequencies were then raised to represent the total annual catch for the year 2000. This was done using the total number of boats sampled and the total number of fishing boats from the frame survey report (LVFO, 2000). An averaged proportion of operational vessels was derived from the 9 beaches sampled monthly and this was used to calculate the proportion of operational boats for the year. This was used to determine the raising factor for total annual catch. The formula used was:

$$P_{FB} = \sum_{L_1}^{L_n}(B_{FL}/B_{TL})$$

where, B_{TL} is the total number of fishing boats at a Landing beach (L); B_{FL} is the number of boats fishing in a sampling day; L_n is the total number of landing beaches sampled over the period and P_{FB} is the proportion of fishing boats operational. The total number of operational fishing boats (B_{TF}) was calculated as:

$$B_{TF} = B_T * P_{FB},$$

where B_T was the total fishing boats from Frame survey record. The raising factor (f) was estimated by:

$f = (B_{TF}/B_S) * (365/\text{Sampled days})$

where B_S is the total number of boats sampled over the year 2000 and it represented the population structure of the total landings. Assuming that each of the boats fishing was landing a catch of the same length distribution as in the sample, multiplying the sampled frequencies by the factor (f) gives the annual length frequencies from all the boats fishing.

The total sample weights were estimated by FiSAT using the Length-Weight relationship coefficients of *a* and *b*.

The Jones' length- based cohort analysis was used to estimate stock size and fishing mortality. The input parameters for the FiSAT programme were, terminal fishing mortality (*F*), natural mortality (*M*), growth constant (*K*), asymptotic length ($L\infty$) and *a* and *b* constants from length –weight relationship. Essentially the steps in using the equation for cohort analysis involved working backward from the most recent year. The parameters required were fed in to a re-arranged catch equation to obtain N_t for the oldest group or the terminal population given the inputs from:

$$N_t = C_t\,(M + F_t)/F_t)$$

C_t is the terminal catch or the catch from the largest length class

N_t is fish present at the start of the time, *t*, and the remaining fish at the end of the year is N_{t+}□, which was calculated from:

$$N_t = N_{t+1} \exp\,((M/2) + C_t) \exp\,(M/2)$$

Then starting from N_t, successive values of *F* were estimated by iteratively solving:

$$F_t = -\ln\,(N_{t-1}/N_{t+1}) - M$$

6.2.6 Yield per recruit analysis

Recruits are young fish entering the exploited phase of their life, or become vulnerable to the fishing gears. Relative yield per recruit (*Y/R*) analysis is used to assess the trade-off between capturing a larger number of fish early in their life span before they die off naturally and capturing a smaller number of larger fish later in their life span. It aims to describe changes in the stock and the yield from one year to another as a result of changing the fishing pattern i.e. the effort exerted on age/length group (Sparre & Venema, 1998; King, 1995). Management advice is most often based on relative yield as this suggests the changes in yield, which would result from changing fishing effort, and delaying the age at first capture. Of the two FiSAT options (knife-edge selection and ogive selection), knife-edge selection was used.

6.2.6.1 *Relative yield- per- recruit model with knife – edge selection*

The relative yield-per-recruit (*Y'/R*) model with knife –edged selection is based on Beverton and Holt (1966) modified by Pauly and Soriano (1986). The inputs for the model are the L_c/L_∞ ratio and *M/K* ratio. No probability of capture data is required. The relative yield- per-recruit (*Y/R*) was computed from:

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

Where: $U = 1 - (L_c/L_\infty)$ = the fraction of the growth to be completed after entry into the exploited phase; $m = (1\text{-E})/(\text{M/K}) = (K/Z)$ and $E = F/Z$ (is the exploitation rate or the fraction of deaths caused by fishing), *M*, the natural mortality and *K*, the von Bertalanffy parameter.

The different exploitation rates *E*, $E_{0.1}$, $E_{0.5}$ and E_{max} were estimated using FiSAT based on the first derivatives of the above function ($E_{0.1}$ being the level of exploitation at which the marginal increase in yield per recruit reaches 1/10th of the marginal increase computed at a very low value of *E*, and $E_{0.5}$ is the exploitation level which results in reduction of the unexploited biomass by 50 percent, E_{max} is the exploitation level which maximizes *Y'/R)* (Gayanilo & Pauly, 1997).

6.2.6.2 *Relative biomass-per-recruit (B'/R)*

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

$$B'/R = (Y'/R)/F$$

which was inverted from:

$B/R = (Y/R)/F$ where $\overline{Y} = F*\overline{B}$, and $\overline{B} = N*\overline{W}$; where $\overline{B}$ is the mean annual biomass, $\overline{W}$ is the mean weight of fish in the stock and $\overline{Y}$ is the mean yield.

6.2.7 Thompson and Bell yield and stock prediction

Yield (catch in weight), stock biomass and value of catch were predicted for various levels of fishing effort, using the length converted Thompson and Bell analysis. The output from the Virtual Population Analysis, fishing mortality at length and catches at given length were used as input data. Additional inputs were parameters of a length-weight relationship and average price of fish per kilogram for the length groups.

The sum of the yields ($Y = \sum Y_i$) was computed from

$$Y_i = C_i * \overline{W_i}$$

where the mean body weight

$$\overline{W_i} = (1/L_{i+1})*(a/b+1)*(L_{i+1}^{b+1} * L_i^{b+1})$$

where a and b are the coefficients of the length-weight relationship and L_i and L_{i+1} are the lower limit and upper limit of the length class respectively.

The catch C_i was estimated from

$C_i = (N_i - N_{i+1})*(F_i/(M+F_i))$, and the predicted population (N_i) was given by

$N_{i+1} = N_i * \text{EXP}(-(M+F_i)*\Delta t_i)$, and

$$\Delta t_i = (1/K)*ln((L_\infty - L_i)/(L_\infty - L_{i+1}))$$

The biomass was computed from

$$B_i = ((N_i - N_{i+1})/(M + F_i))* \Delta t_i * \overline{W_i}$$

Fish value was computed by

$V_i = Y_i * v_i$, where v_i is the unit value for 'i' class

6.2.8 Estimation of Maximum Sustainable Yield (*MSY*) using Cadima's formula

Cadima's estimator for exploited stocks, which was based on the generalized version of Gulland's estimator of unexploited stocks, was used to determine MSY.

Gulland's estimator was: $MSY = 0.5*M*Bv$, where M was natural mortality and Bv the virgin stock biomass. Cadima's estimator has the form: $MSY = 0.5*Z*B$, where Z is total mortality and B is the biomass of exploited stock. This was rewritten by Sparre *et al.* (1989) as: $MSY = 0.5*(Y + M*B)$, where Y is the total catch in a year, M is the natural mortality and B is the average biomass in the same year.

The Yield (Y) estimated under VPA from the length frequencies was used, while parameter for M was estimated from Pauly's empirical formula. The value for biomass (B) used was calculated under the swept area method (Chapter Four). For comparison, the yield estimated from the catch rates recorded under the fishery dependent data collection (Chapter Three), was also used.

6.3 RESULTS

6.3.1 Length frequency distributions

6.3.1.1 *Fisheries independent data*

Monthly length frequency distributions for the 238 422 Nile perch sampled during bottom trawl surveys are illustrated (Fig. 6.1). The smallest and greatest mid-length class represented were 2.0 cm TL and 137 cm TL respectively. Continuous breeding and recruitment throughout the year was indicated by the occurrence of juveniles throughout the sampled period. Only two to three cohorts are well discriminated in November 1997, January 1998, July, August, October and December 1999.

The dominance of fish below 50 cm TL was highlighted by the aggregated length frequencies (Fig. 6.2a). Almost 98% of the catch was below 54 cm TL, as illustrated by the truncated length frequencies (Fig. 6.2b).

Spatial and temporal difference in the size distribution of Nile perch was also investigated (Fig. 6.3). A similar pattern was found in Zone A and C with relatively more large sizes in the latter, but newly recruited individuals dominated in Zone B. Recruitment of new cohorts of juveniles was discernible in April, May, June, July, November 1999 and March, April, May, June, July 2000. The Same scale was used

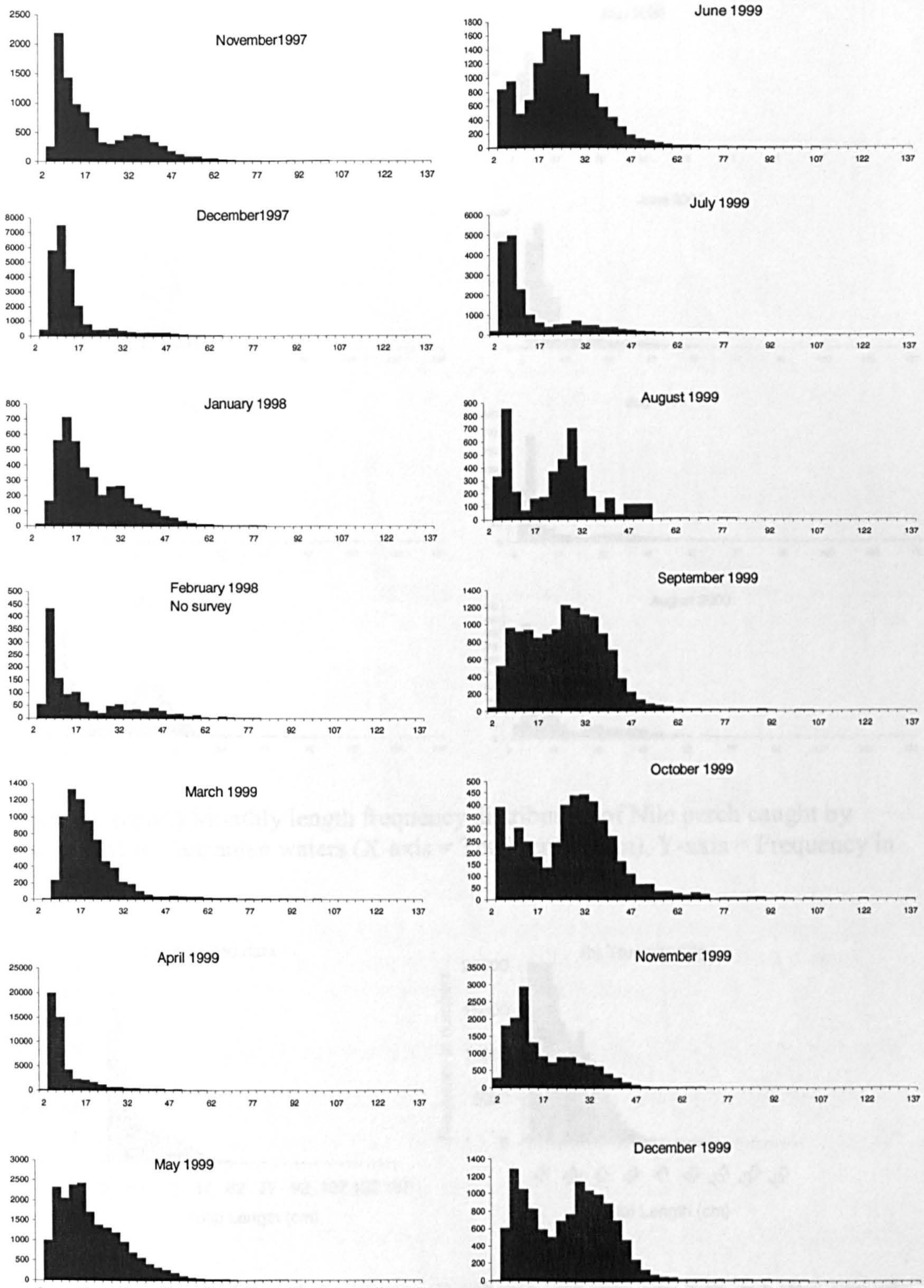


Figure 6.1 Monthly length frequency distribution of Nile perch caught by bottom trawl in Tanzanian waters (X-axis = Total length (cm), Y-axis = Frequency in numbers)

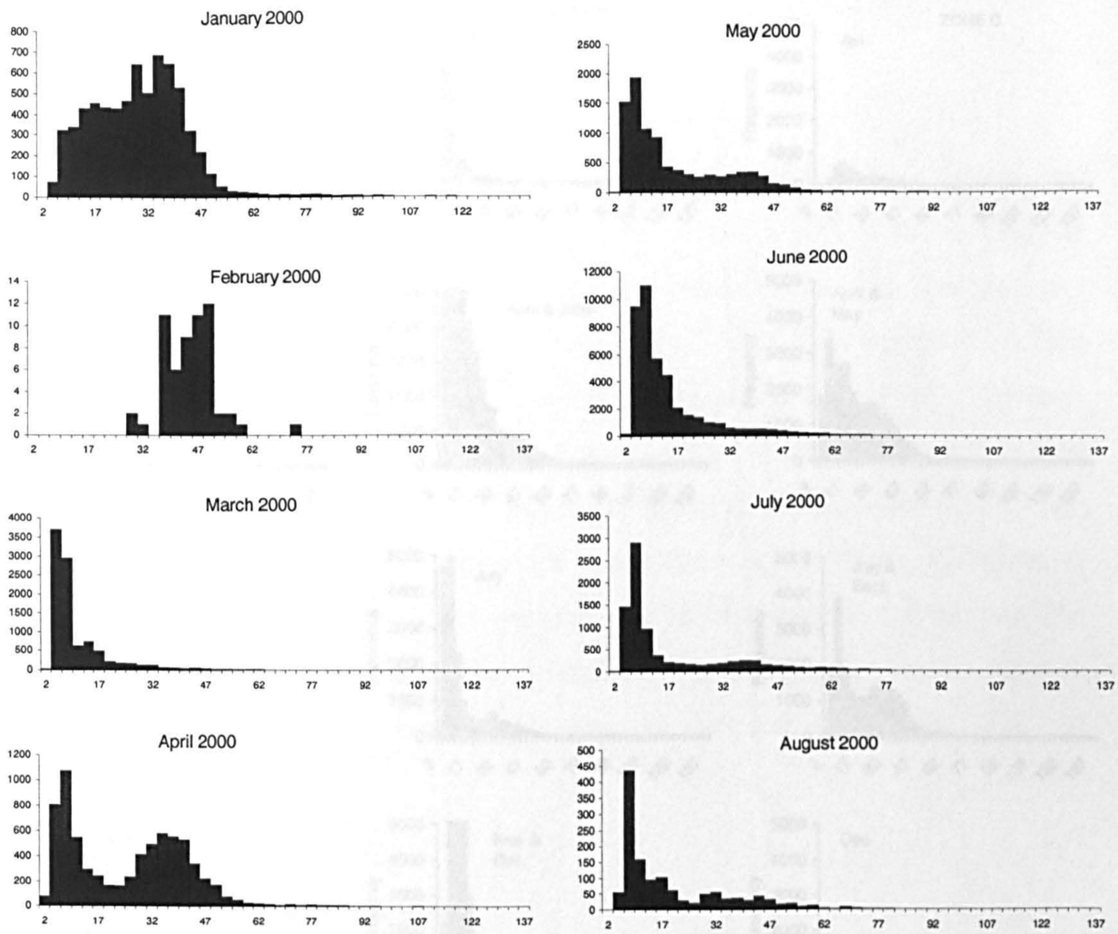


Figure 6.1 (cont.) Monthly length frequency distribution of Nile perch caught by bottom trawl in Tanzanian waters (X-axis = Total length (cm), Y-axis = Frequency in numbers)

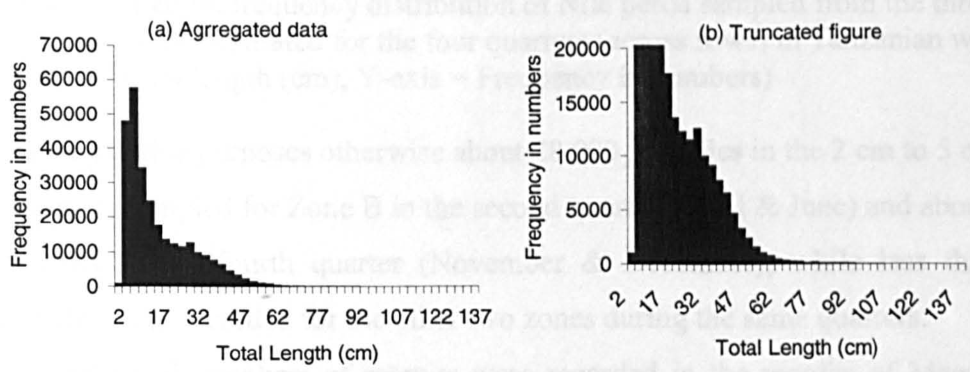


Figure 6.2 Aggregated length frequency distribution of Nile perch from bottom trawl in Tanzanian waters (a) with same figure truncated and different scale (b) to illustrate the dominance of juveniles in the catch.

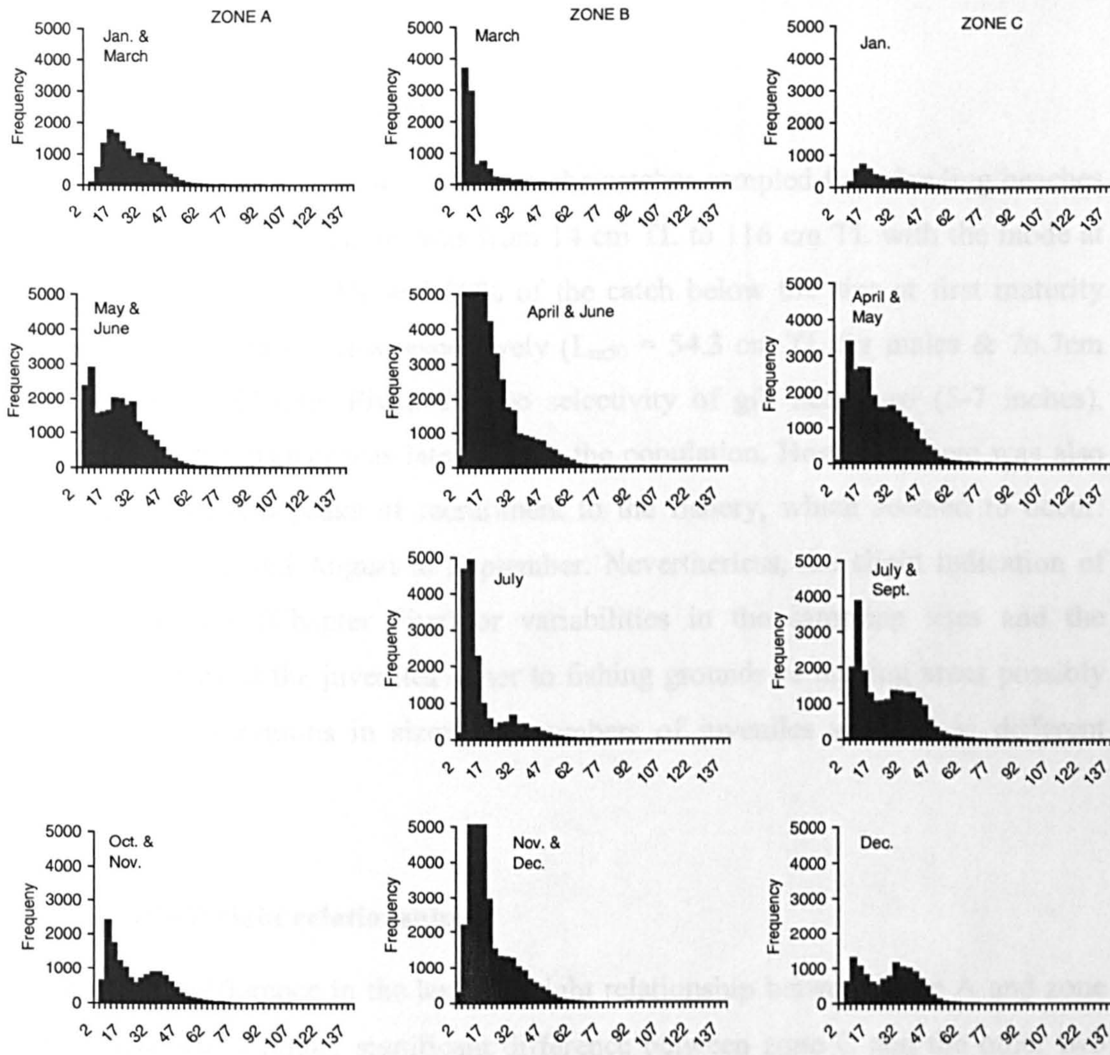


Figure 6.3 Length frequency distribution of Nile perch sampled from the three zones (along columns) separated for the four quarters (across rows) in Tanzanian waters (X-axis = Total length (cm), Y-axis = Frequency in numbers)

for comparative purposes otherwise about 28 000 juveniles in the 2 cm to 5 cm length class were sampled for Zone B in the second quarter (April & June) and about 10 000 juveniles in the fourth quarter (November & December), while less than 3 000 juveniles were recorded for the other two zones during the same quarters.

Relatively high numbers of recruits were recorded in the months of March, April, May, June, July and November, a rather prolonged recruitment period. There was an increased recruitment to the population in June & July and also October to December 1999, during the mixing of water in the lake and in the period of the short rains (Chapter Two). This could as well be influenced by sampling, possibly more shallow waters or nursery grounds were covered or shoals of juveniles were encountered migrating.

6.3.1.2 *Fisheries dependent data*

A different size distribution was found on the catches sampled from landing beaches (Fig. 6.4). The size distribution was from 14 cm TL to 116 cm TL with the mode at 48 cm TL, and almost 83% and 99% of the catch below the size at first maturity (L_{m50}) for males and females respectively (L_{m50} = 54.3 cm TL for males & 76.7cm TL for females, Chapter Five). Due to selectivity of gill nets used (5-7 inches), recruitment to the fishery was later than to the population. However, there was also an indication of two peaks of recruitment to the fishery, which seemed to occur: January to March and August to September. Nevertherless, the slight indication of seasonal breeding (Chapter Five) or variabilities in the sampling sites and the migration pattern of the juveniles either to fishing grounds or nursing areas possibly influenced the variations in sizes and numbers of juveniles sampled in different months.

6.3 2 Length-Weight relationships

There was no difference in the length-weight relationship between zone A and zone B, but there was a highly significant difference between zone C and the other two zones (Table 6.1), (two-tailed t test, $t = 2.570$, $P<0.01$). Nevertheless, the upper limit of the 95% CL of the intercept '*b*' for zone C overlaps with the lower limits of 95% CL for the other two zones.

The slopes were therefore tested for difference from the expected isometric growth of 3 in length weight relationships (King, 1995), but there was no significant difference, even for the slope for zone C ($t= -7.042$, $P>0.05$). Consequently the length/weight data were combined.

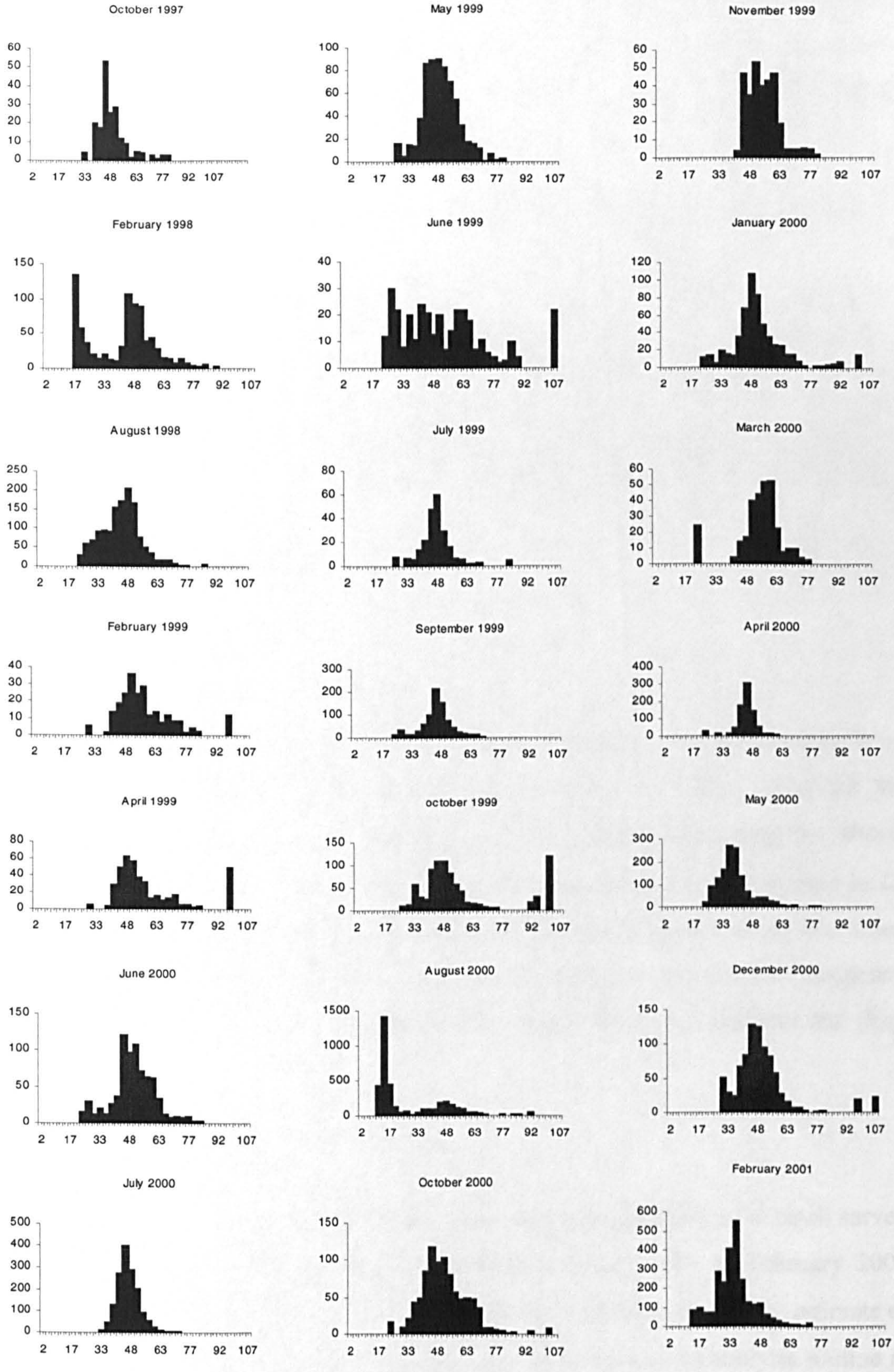


Figure 6.4 Length frequency distribution of Nile perch caught by gill nets from catch surveys in Tanzanian waters (X-axis = Total length (cm), Y-axis = Frequency in numbers)

The condition factor for zone C was also slightly higher compared with other two zones but the 95% CL indicated no significant difference (Table 6.1). The parameters for the combined length/weight data (a = 0.000018 & b = 2.92) were used as inputs to the FISAT package.

Table 6.1 Length-Weight relationship parameters and values for Condition factor, with the related statistics.

Zone sampled	Numbers sampled	Intercept *(lnq)*	*a*	*b* ± (95%CL)	r^2	CF ± (95%CL)
A	839	-11.019	0.0000164	2.94±0.064	0.975	0.169±0.0129
B	672	-11.020	0.0000164	2.94±0.070	0.976	0.161±0.0127
C	679	-10.745	0.0000216	2.87±0.072	0.973	0.183±0.0141
Combined	2190	-10.850	0.0000180	2.92±0.040	0.974	0.171±.0077

6.3.3 Population parameters

6.3.3.1 *Growth parameters*

Fisheries independent data

The growth parameters for the monthly length frequency distribution data from bottom trawl were estimated by the ELEFAN 1 routine of FISAT. Through the Powell-Wetharall plot (Fig. 6.5), the 1st estimate of L_∞ was 210 cm. using the criteria of the highest Rn value in the response surface analysis of ELEFAN 1 routine an L_∞ of 216 cm, and a K of 0.16 yr^{-1} were estimated. The best-fit growth curve was fitted through the 'Direct-fit routine in ELEFAN 1 both for the normal frequency distributions (Fig. 6.6a) and the restructured length frequency distributions (Fig. 6.6b)

Fisheries dependent data

The same procedure done for the bottom trawl data was repeated for the catch survey data. The monthly length frequency data from February 1999 to February 2001 corrected for selectivity were used. The Powell-Wetharall plot gave an L_∞ estimate of 180.99 cm (Fig. 6.7), which was used under the response surface analysis routine in ELEFAN 1, and an L_∞ of 218 cm and a K of 0.16 yr^{-1} was estimated. The von Bertalanffy growth curves (Fig. 6.8a & 6.8b) were fitted by the ELEFAN 1 direct fit routine.

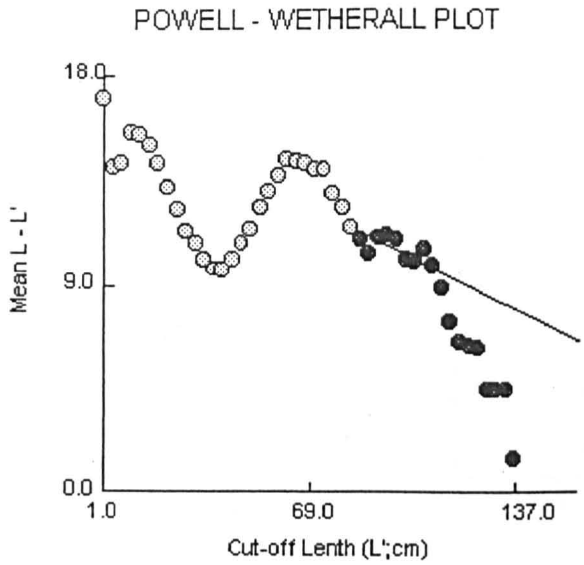


Figure 6.5 Estimation of L_∞ from the bottom trawl data using the Powell-Wetherall plot

A comparison of the growth parameters estimated from the two data sets (Table 6.2) showed the bottom trawl data had a slightly lower L_∞ that is probably explained by the more small fishes compared with the catch survey data.

Table 6.2 Growth parameters estimated using ELEFAN 1 and the von Bertalanffy growth function for Nile perch in Tanzanian waters of Lake Victoria, 1999-2000

Parameter	**Bottom trawl data**	**Catch survey data**
L_∞	216 cm	218 cm
K	0.16 yr^{-1}	0.16 yr^{-1}
t_0	-0.20785	-0.20895
t_{max}	18.541 years	18.542 years
t_m	1.60 yrs (Males) 2.53 yrs (Females)	1.58 yrs (Males) 2.50 yrs (Females)
ϕ'	3.87	3.88

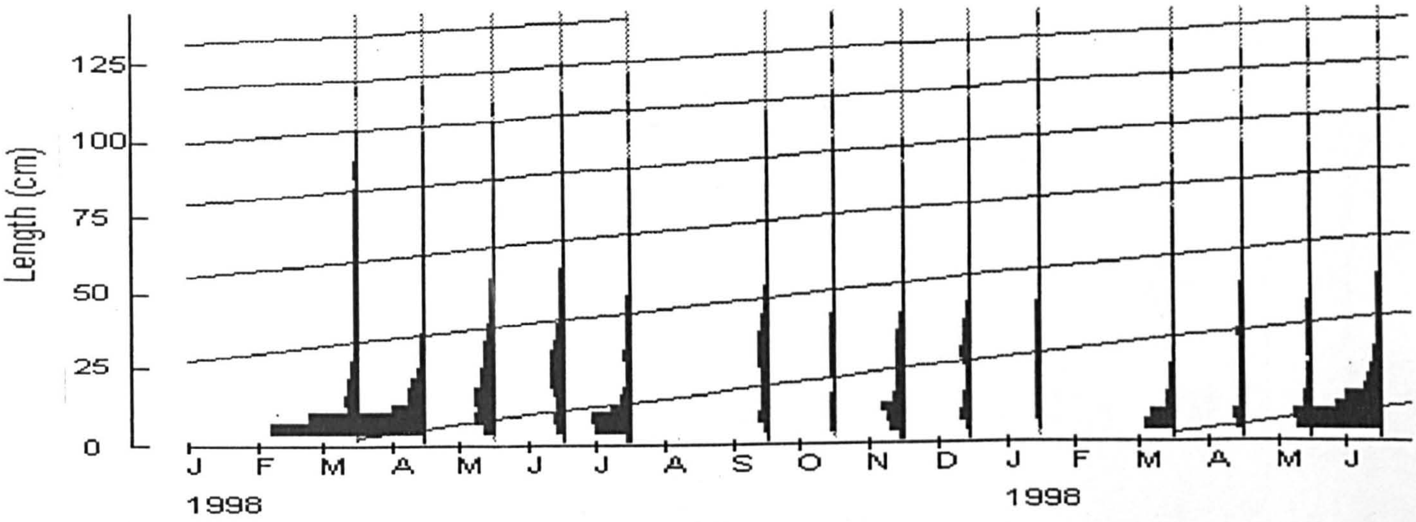


Figure 6.6a Growth curves fitted by ELEFAN 1 for the bottom trawl frequency distributions from March 1999 to June 2000

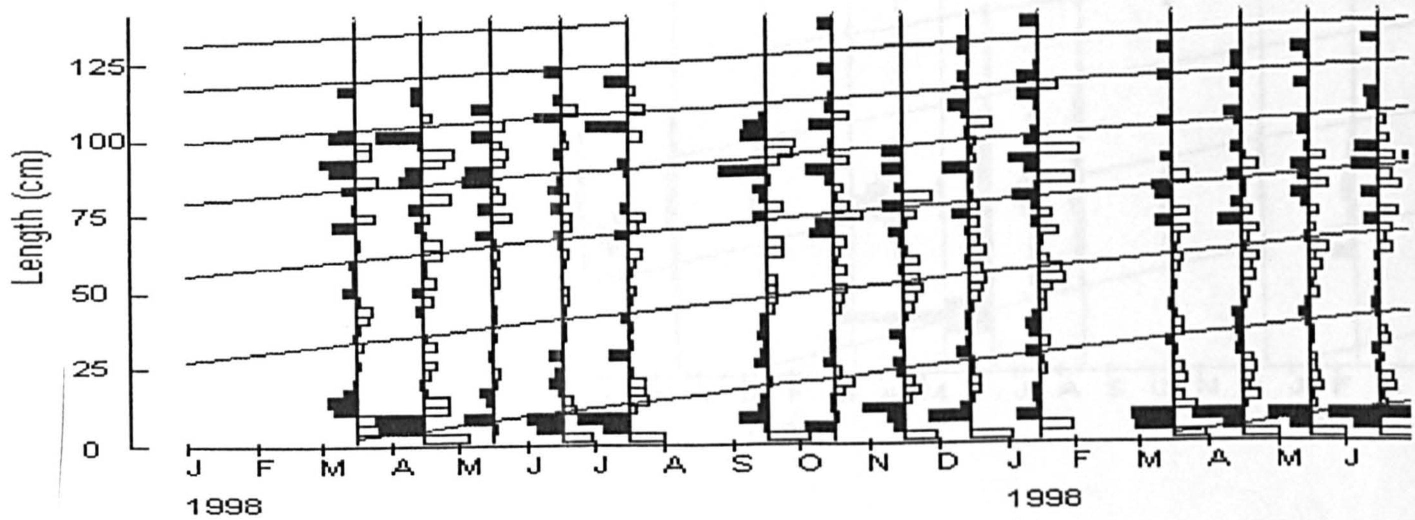


Figure 6.6b Growth curves fitted by ELEFAN 1 for the bottom trawl restructured length frequency distributions from March 1999 to June 2000

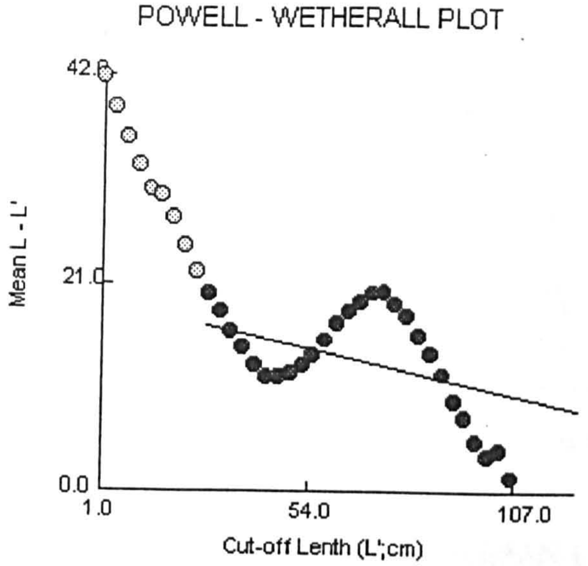


Figure 6.7 Estimation of L_∞ from the catch survey data using the Powell-Wetherall plot

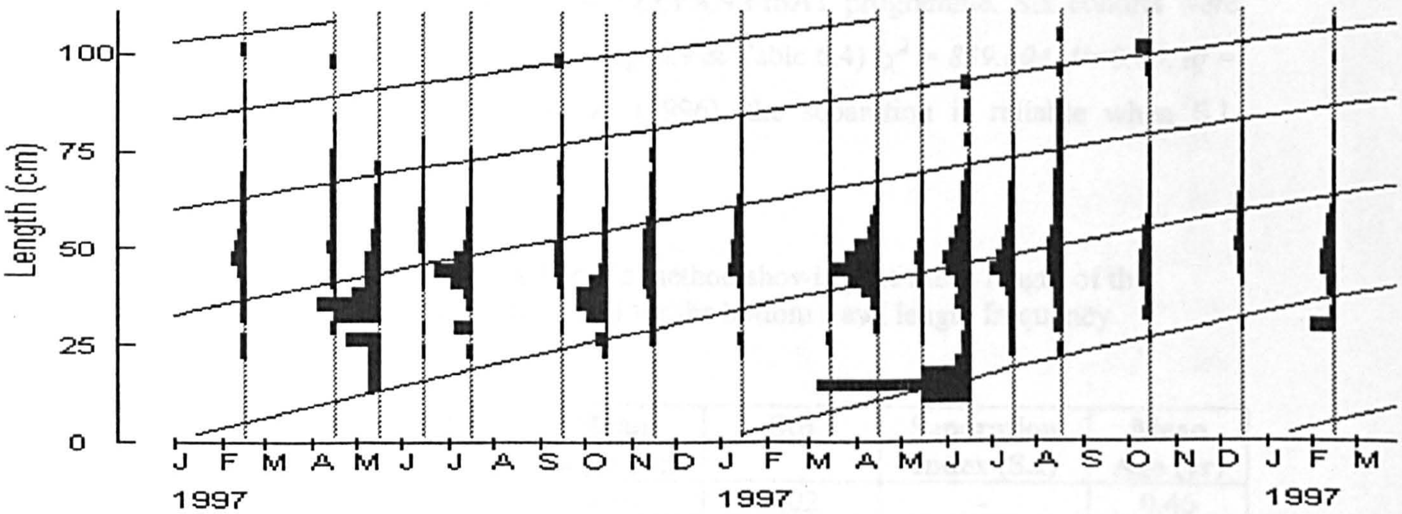


Figure 6.8a Growth curves fitted by ELEFAN 1 for the catch survey frequency distributions from February 1999 to February 2001

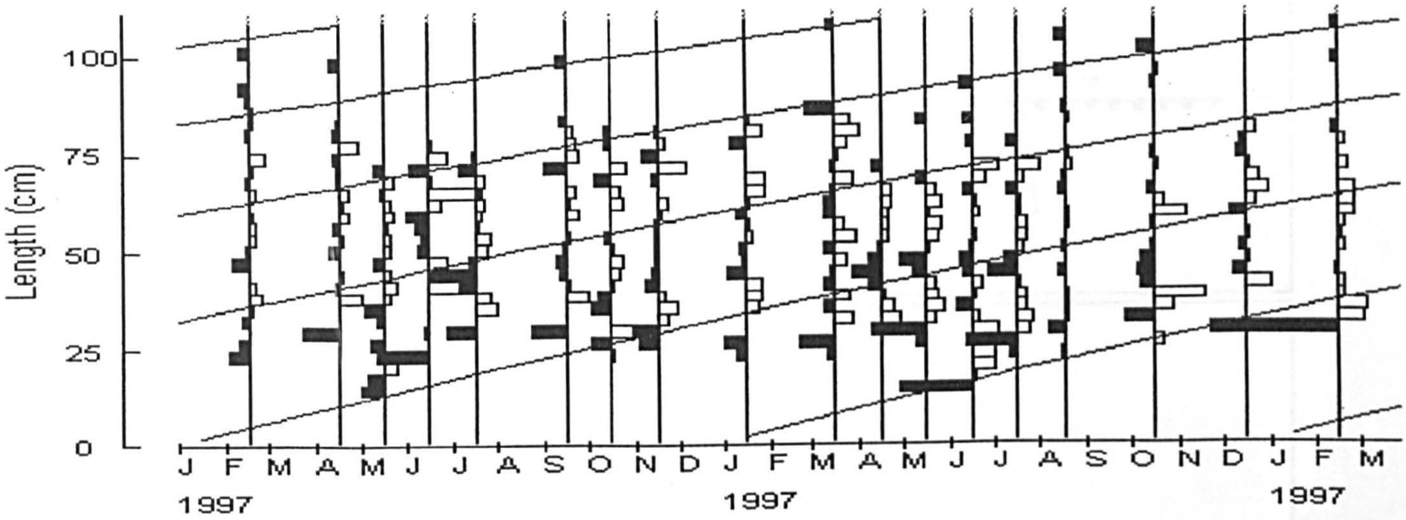


Figure 6.8b Growth curves fitted by ELEFAN 1 for the catch survey restructured length frequency distributions from February 1999 to February 2001

6.3.3.2 *Separation of the length frequency distribution*

An attempt was made to separate the cohorts using the Bhattacharya's method under Modal Progression Analysis of the ELEFAN/FISAT programme. Six cohorts were separated at 95% confidence level (Fig. 6.9 & Table 6.4) ($\chi^2 = 839.804, P<0.05, df = 18$). According to Gayanilo, *et al.* (1996), the separation is reliable when S.I. (Separation Index) is above 2.

Table 6.4 Results from Bhattacharya's method showing the mean length of the cohorts and the separation index (S.I.) for the bottom trawl length frequency distributions of Nile perch.

Group No.	Population (N)	Mean length (cm)	Std	Separation Index (S.I)	Mean Age (yr)
1	2,801.00	9.53	3.02	-	0.46
2	684.91	20.03	5.34	2.51	0.86
3	3226.27	38.00	6.61	3.01	1.59
4	229.67	57.78	6.05	3.13	2.49
5	67.2	78.16	6.66	3.21	3.53
6	9.85	98.04	9.22	2.50	4.71

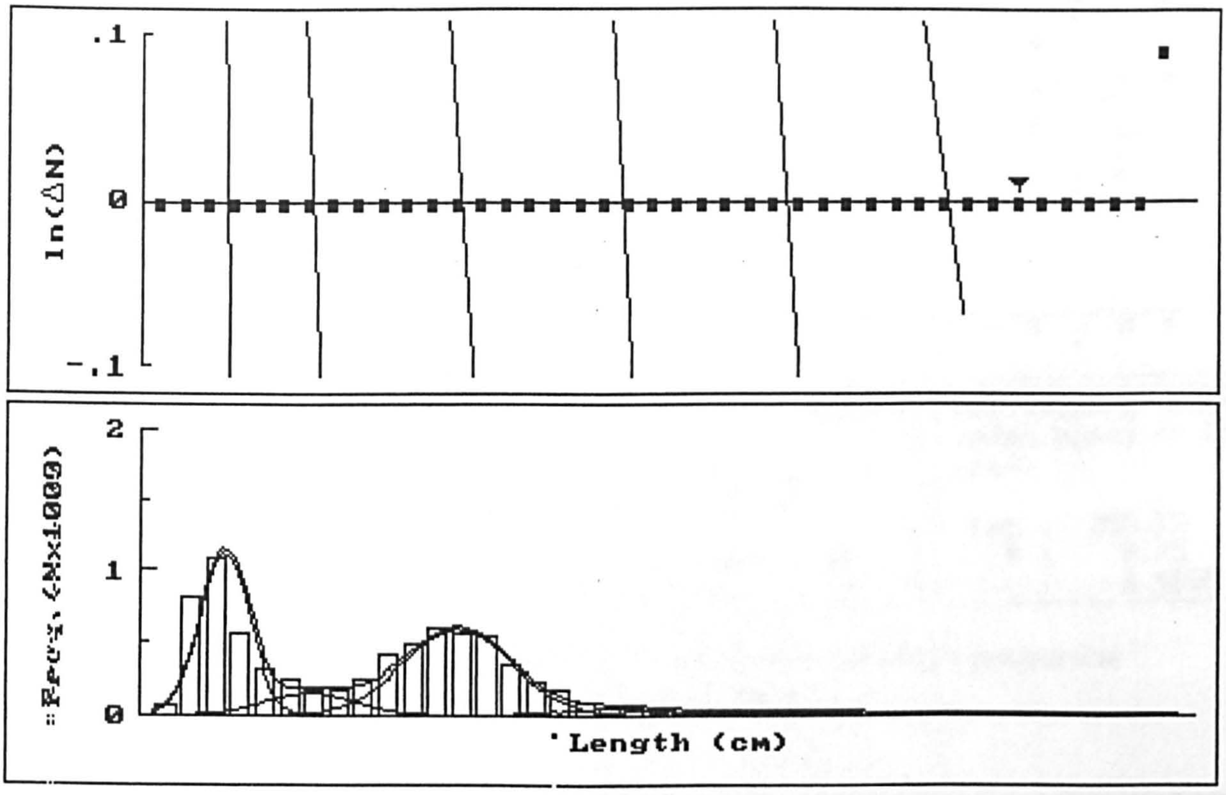


Figure 6.9 Separated length frequency distribution for the Dec. 2000 sample from bottom trawl data, using Bhattacharya method

About eight cohorts for the bottom trawl data were separated using the Linking of Means procedure (Fig. 6.10). The very low correlation coefficient values given explain the difficulties encountered in separating the cohorts. The occurrence of pseudo-cohorts resulting from continuous breeding with absence of obvious breeding peaks in a year (Chapter Five) probably underlies the problem. A possibility of a growth pattern whereby the fish attain most of their size at first maturity very early in life could as well apply. Such a growth pattern is reported to be common among long-lived tropical fishes (Williams *et al.,* 1995; Choat & Axe, 1996; Hart & Russ, 1996; Newman *et al.,* 1996; Craig *et al.*, 1997; Craig 1999).

6.3.3.3 *Analysis of growth increment*

Data from the linking of mean lengths above was used to compose the Gulland and Holt plot to estimate growth parameters based on the fact that growth rate declines linearly with length, reaching zero at L_∞ under the VBGF. The residuals of the plot are used for inferences on seasonality of growth (Gayanilo *et al.*, 1996).

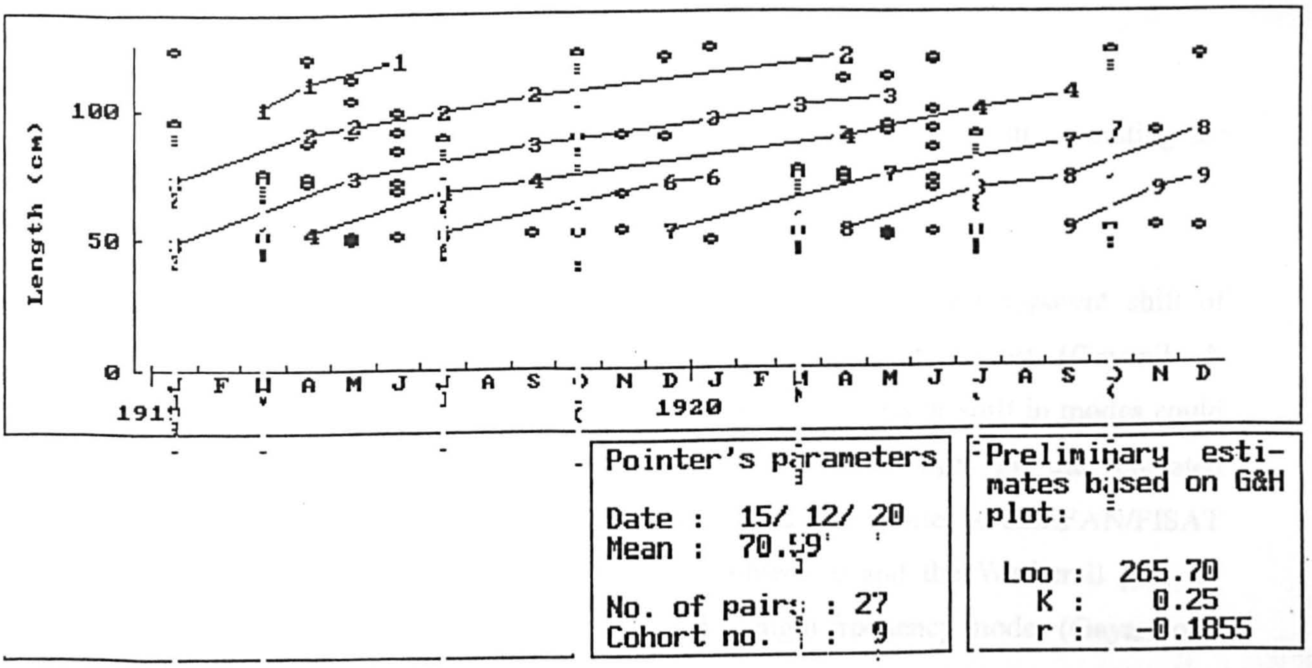


Figure 6.10 Linking of Means from Bhattacharya plots of the Modal progression analysis. Linked means believed to be of the same cohort

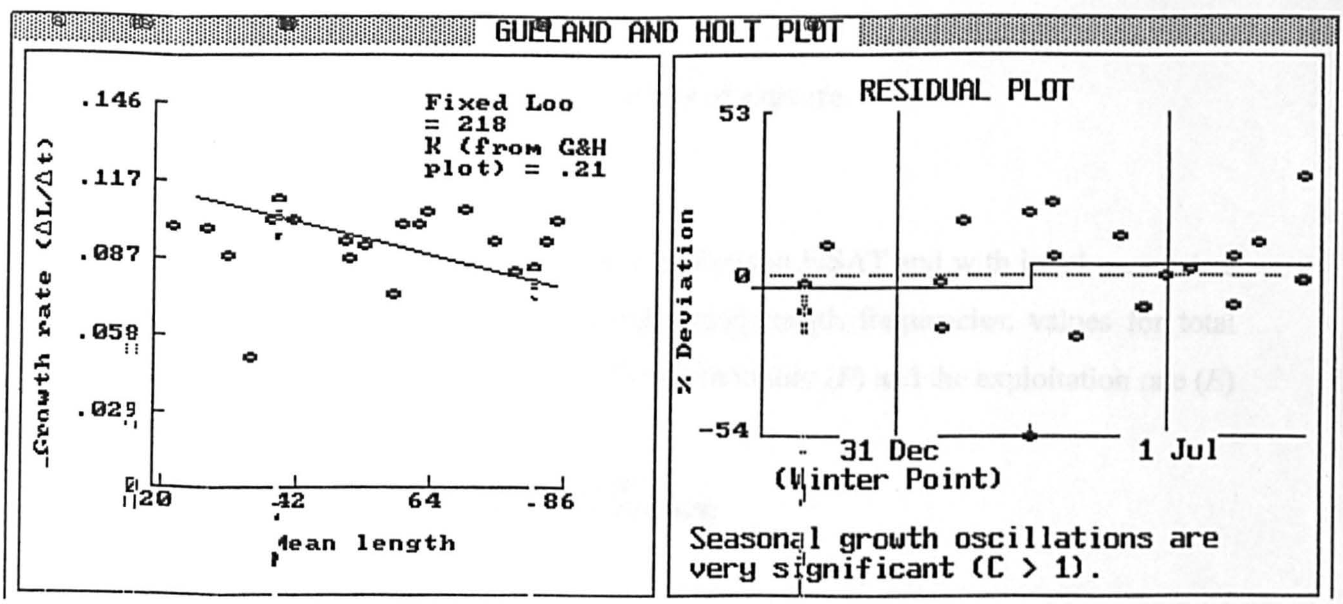


Figure 6.11 Gulland and Holt plot for the mean lengths from Bhattacharya plot with a forced L_∞ 0f 218 cm

A fixed value of 218 for L_∞ was used, as it was not possible to estimate it from the plot. A value of 0.21 was estimated for *K* (Fig. 6.11). This indicates that the fish grow to about 50 cm TL in their first year. Tagging information (Ligtvoet & Mkumbo, 1990; Asila, 1999) and the fitted curve by ELEFAN 1 (Fig. 6.6) indicated lower growth rates. The residual plot indicated a very significant seasonal growth oscillation, with a reduced growth rate during the rain season (October to March) and increased growth in the dry season (June to October). This probably explains the very low correlation values (Fig. 6.10) and the difficulty experienced in separating the cohorts.

Both the Bhattacharya method and Modal progression rely on apparent shift of modes in length-frequency samples, which represent separate cohorts (Gayanilo & Pauly, 1997). With continuous breeding, no apparent cohorts or shift in modes could be identified which explains the unrealistic and differing ages for the separated cohorts. The problems of overlapping of age groups also applies to ELEFAN/FISAT programme but it is considered to be more objective and the Wetherall plot for estimation of L_{∞} to be more independent of the length frequency modes (Gayanilo & Pauly, 1997; King, 1995). Without any other reliable technique for long lived species and with continous breeding, like tagging and recapture data, the estimates from ELEFAN/FISAT were used to derive the other estimates.

6.3.4 Mortality estimates and probability of capture

6.3.4.1 *Fisheries independent data*

Using the length-converted catch curve analysis in FiSAT and with input parameters of L_{∞} = 216, K = 0.16 for the bottom trawl length frequencies, values for total mortality (Z), natural mortality (M), fishing mortality (F) and the exploitation rate (E) were estimated (Fig. 6.12).

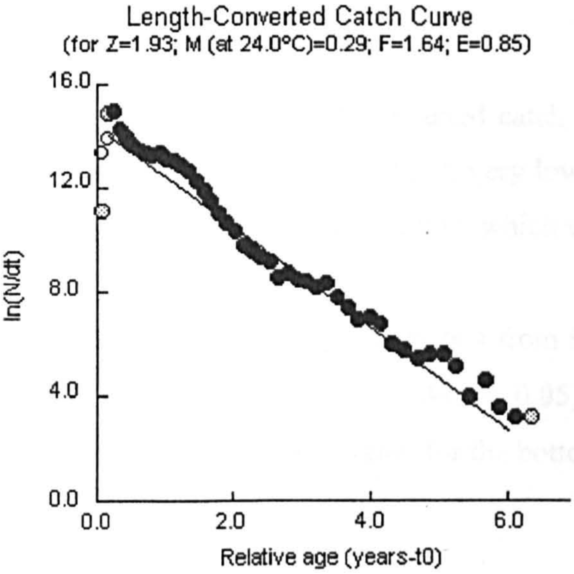


Figure 6.12 Length-converted catch curve for the bottom trawl length frequency data with the estimated mortality parameters indicated.

Using the probability of capture routine, the different lengths at first capture were estimated (Fig. 6.13). The estimated length at which 50% of the fish are retained by the gear was very low, and reflected the small mesh codend used in the trawl, proving it was non-selective.

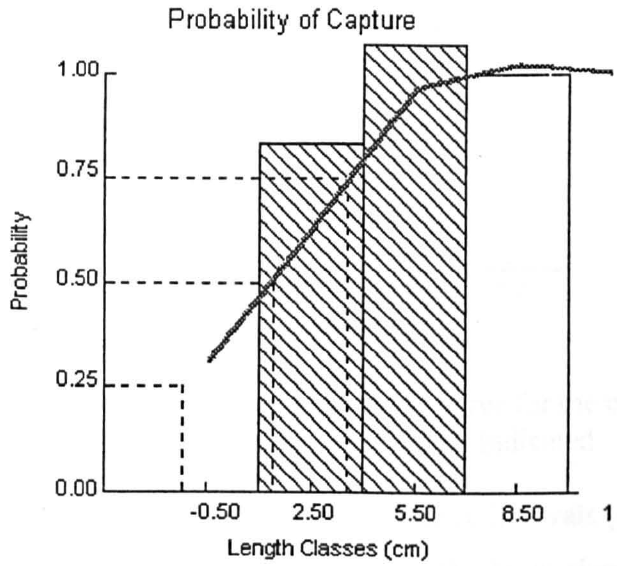


Figure 6.13 Probability of capture for the bottom trawl using the length-converted catch curve

6.3.4.2 *Fisheries dependent data*

The same routine of the length-converted catch curve analysis was repeated for the catch survey data (Fig. 6.14 & 6.15). A very low L_{50} was also estimated (10.42 cm) compared to the mode of the distribution, which was at 44.5-48.5 cm TL.

A comparison of the mortality parameters from the two data sets (Table 6. 3) found no significant difference (χ^2 = 0.0044, P>0.05), although the total mortality and fishing mortality were slightly higher for the bottom trawl data.

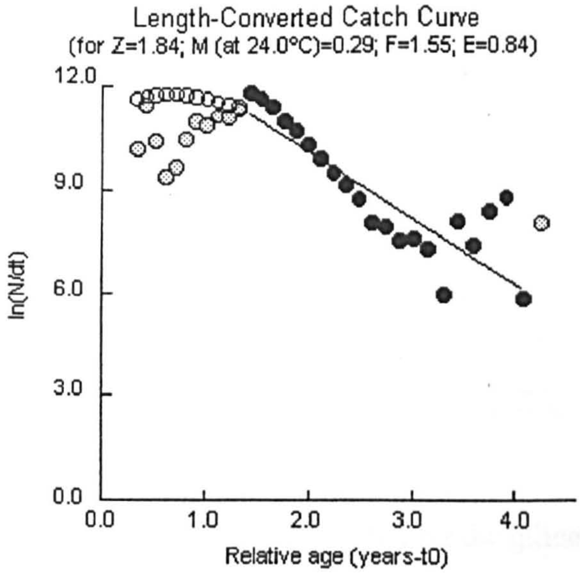


Figure 6.14 Length-converted catch curve for the catch survey length frequency data with the estimated mortality parameters indicated

The selected fit gave a lower confidence intervals (CI) to the estimated total mortality (*Z=2.34 – 1.35*), while eliminating the large sized population gave a very high *Z*-value of 2.89 yr^{-1} with CI of 3.14 - 2.65. The largest length groups are usually not used when they are close to the L_∞ because as fish approach L_∞ the relationship between age and length become uncertain (Sparre *et al.*, 1989). Nile perch lives to approximately 18 yrs, but the large samples (Fig.6.14) are given a relative age of 4 years, way below the maximum age, which justifies the fit.

Table 6.3 Parameter estimates from length-converted catch curve for bottom trawl and catch survey data sets

Parameter	Bottom trawl data Value	Catch survey data Value
Total mortality (*Z*)	1.93 yr^{-1}	1.84 yr^{-1}
Natural Mortality (*M* for 24°C)	0.29 yr^{-1}	0.29 yr^{-1}
Fishing Mortality (*F*)	1.64 yr^{-1}	1.55 yr^{-1}
Exploitation rate (*E* = *F*/*Z*)	0.85	0.84

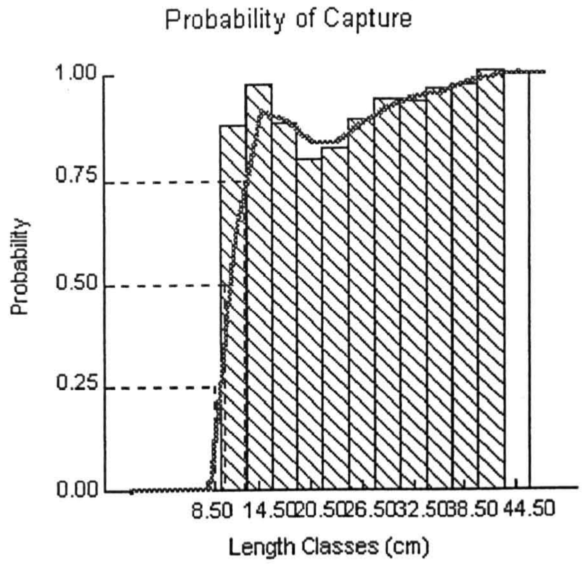


Figure 6.15 Probability of capture for the gillnets catch using the Length-converted catch curve

6.3.5 Recruitment pattern

6.3.5.1 *Fisheries independent data*

Recruitment occurred throughout the year with strong pulses from August to December and a peak in September/October (Fig. 6.16), which probably represents extensive recruitment around this latter spawning period (Chapter Five). A weak pulse extending from December to July represents the continued spawned juveniles from November of the same year to March of the following year.

6.3.5.2 *Fisheries dependent data*

Recruitment to the gillnet fishery is represented by an extended period from April to July, with a peak in June just before the complete mixing of the water column (Chapter Two). From August to March, recruitment to the fishery was relatively very low percentages (Fig. 6.17). Environmental conditions coupled with fish behaviour may explain the recruitment pattern observed for the gillnet fishery in Lake Victoria.

6.3.6 Length at maximum yield (L_{opt})

The length class with the highest biomass, computed according to the equation

$L_{opt} = L_\infty * (3/(3 + M/K)$. was 134.6 cm TL using L∞ of 216 cm from the bottom trawl data, or at 135.9 cm TL using L∞ of 218 cm from catch survey data. The pooled length frequency data from catch survey was used to fit size at first maturity (L_m) and L_{opt} for the evaluation of growth and recruitment overfishing (Fig. 6.18). The modal length of the catch was below the size at first maturity (L_m) and the size for highest biomass (L_{opt}). However, the calculated L_{opt} appears unrealistic to target the size for management of Nile perch stocks due to cannibalism, as this will increase juvenile mortality due to predation (Walters *et al.*, 1997, Villanueva & Moreau, 2002). Likewise the empirical formula (Pauly, 1980) used to calculate natural mortality was established based on marine fishes with high fecundity and continue to suffer predation pressure at all life stages. The applicability of such a relationship to species, which are free from predation as adults, is not known (Turner, 1995).

6.3.7 Estimation of stock size and fishing mortality from virtual population analysis

The monthly fishery dependent length frequency distribution data for the year 2000 raised in proportion of the number of boats and days sampled were used for the length structure VPA. Input parameters were L_∞ (218 cm), K (0.16 yr^{-1}) natural mortality M (0.29) and a terminal fishing mortality (F_t) of 0.29.

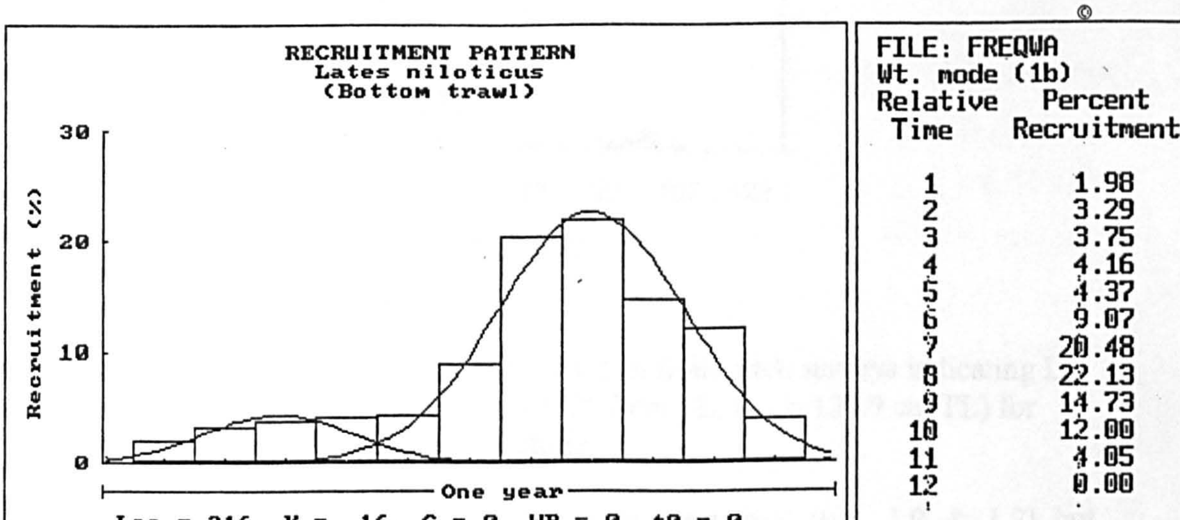


Figure 6.16 Monthly recruitment pattern (%) shown as histograms with the recruitment pulse indicated by a curve (bottom trawl data)

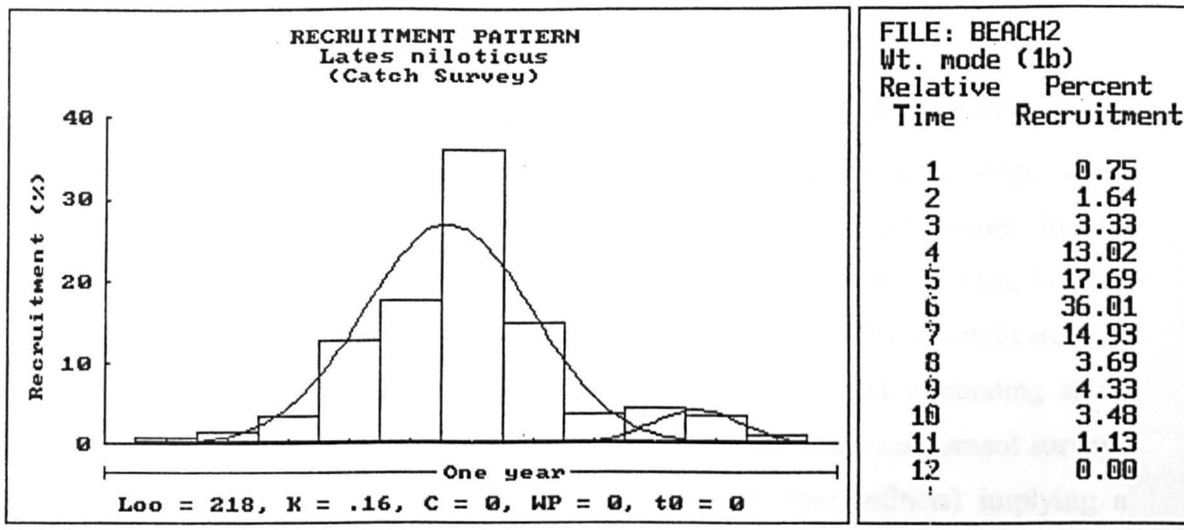


Figure 6.17 Monthly recruitment pattern (%) shown as histograms with the recruitment pulse indicated by a curve (catch survey data)

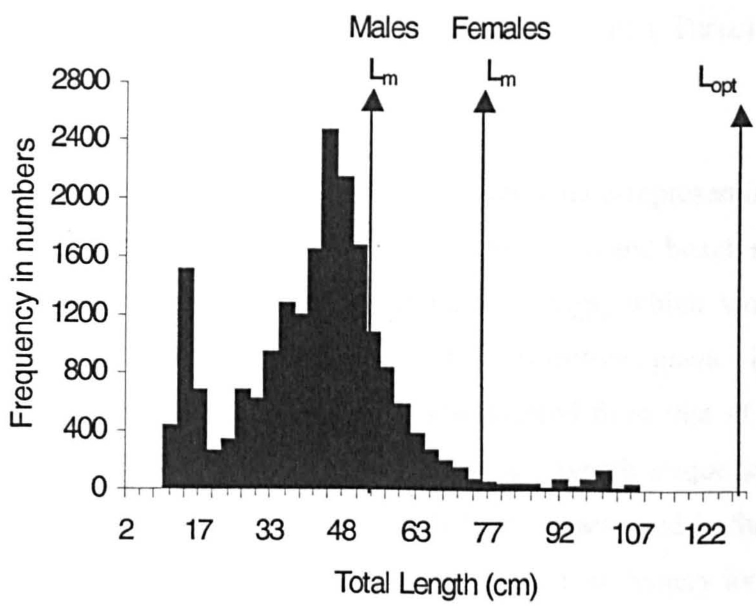


Figure 6.18 Pooled monthly length frequency data from catch surveys indicating L_m, and L_{opt} (L_{m50} for males = 54.3 & females = 76.7 cm TL; L_{opt} = 135.9 cm TL) for Nile perch in Tanzanian waters, Lake Victoria

Different values for terminal fishing mortality were used (0.6, 1.0 & 1.2) but produced very similar results, as F_t is only a guess value and the programme by iterative solving, changes the value until the population sizes and fishing mortality for all age groups are computed.

Mean exploitation rate (*E*) of 0.62 and a mean fishing mortality (*F*) of 0.47 were the outputs from the VPA (Fig. 6.19) with the fishing mortality for each length class (curve) and the corresponding population size (histograms). The highest fishing mortality (4.0 yr^{-1}) was at length classes 64 to 67 cm TL (Appendix 11a), but the highest catch in weight was at 47 cm to 50 cm TL (Appendix 11b). A total catch for Nile perch of 75 154.52 tonnes was estimated by the VPA and a standing stock biomass of 45 553.79 tonnes. The estimated catch from the catch assessment surveys for the year was 85 046.76 t (considering only catch from gillnets) implying a difference of 13%. This can be explained by a possibility of errors in sub-sampling for length measurements and thus underestimated the actual numbers landed per canoe. As length frequencies from other gears were not included (long line, beach seines and by catches from dagaa and tilapia) it is not possible to compare the yield estimated from catch survey (138 323.85 t, Chapter Three) with the VPA estimated yield (75 154.52 t).

The VPA model reguires length-frequency data-representing mean annual catch at length (Gayanilo & Pauly, 1997). The long line and beach seine data were scant and thus difficult to be raised to annual landings, which would represent the actual population structure landed by the respective gears. Bottom trawl data was experimental, and the catch-at-length differed from that of the fish landings. Future CAS should consider collecting adequate length-frequency data representative of catches and landings from all the different gears used in the fishery, to facilitate the use of VPA in yield estimates. However the main fishery for Nile perch is on gillnets, landing over 60% of the total catch and thus the VPA results although based on only gillnet data can be reasonably representing the Nile perch fishery in the Tanzanian sector of the lake.

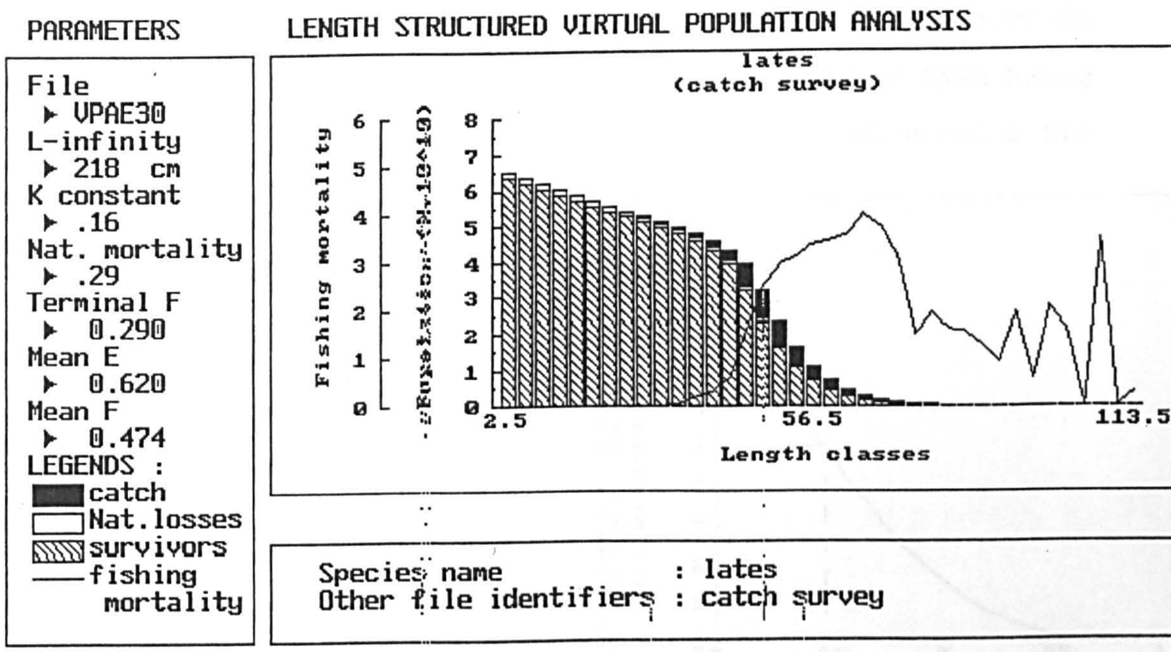


Figure 6.19 Distribution of fishing mortality (curve) and the population (histograms) by length class (in cm) using VPA for the Nile perch in Tanzanian waters of Lake Victoria.

With values of L_c/L_∞ = 0.05, and M/K = 1.8 as input parameters to the predictive knife-edge model, the relative yield-per-recruit (Y'/R) and the relative biomass-per-recruit curves were produced (Fig. 6.20a). The exploitation rates (*F/Z*) at different levels of the yield were estimated. The exploitation rate which produces maximum yield (E_{max}) was 0.37 while the exploitation rate at which the stock would have been reduced to 50% of its unexploited biomass ($E_{0.5}$) was estimated at 0.24. The exploitation rate at which the marginal increase of the relative yield-per-recruit is $1/10^{th}$ of its value at E-10 was estimated at 0.35. Changing the size at capture (L_c) to the size at modal length of the gillnet catch population (48 cm TL), an L_c/L_∞ value of 0.22 was used (Fig. 6.20b). E_{max} increased to 0.46, $E_{0.1}$ to 0.41 and $E_{0.5}$ to 0.28. The relative yield-per-recruit and biomass-per-recruit values are given (Appendix 12a & 12b respectively).

The calculated exploitation rate from the length converted catch curve (Fig. 6.11) was 0.84 much higher than the E_{max} signifying over-exploitation of the stock. From relative yield-per-recruit isopleths (Fig. 6.21) the highest yield (0.037-0.042 kg per recruit) would be at L_c/L_∞ of the range 0.6 to 0.7 with exploitation rate (E) of 0.6-0.8 implying an increase of size at first capture to the size class ranging from 130.8 cm to 152.6 cm TL. The followed range of high yield-per recruit (0.03-0.037 kg per recruit) is within the L_c/L_∞ range of 0.4-0.6 and exploitation rate of 0.4-0.6 (with fishing mortality F= 0.44). This corresponds to 87.2 cm to 130.8 cm TL as size at first capture

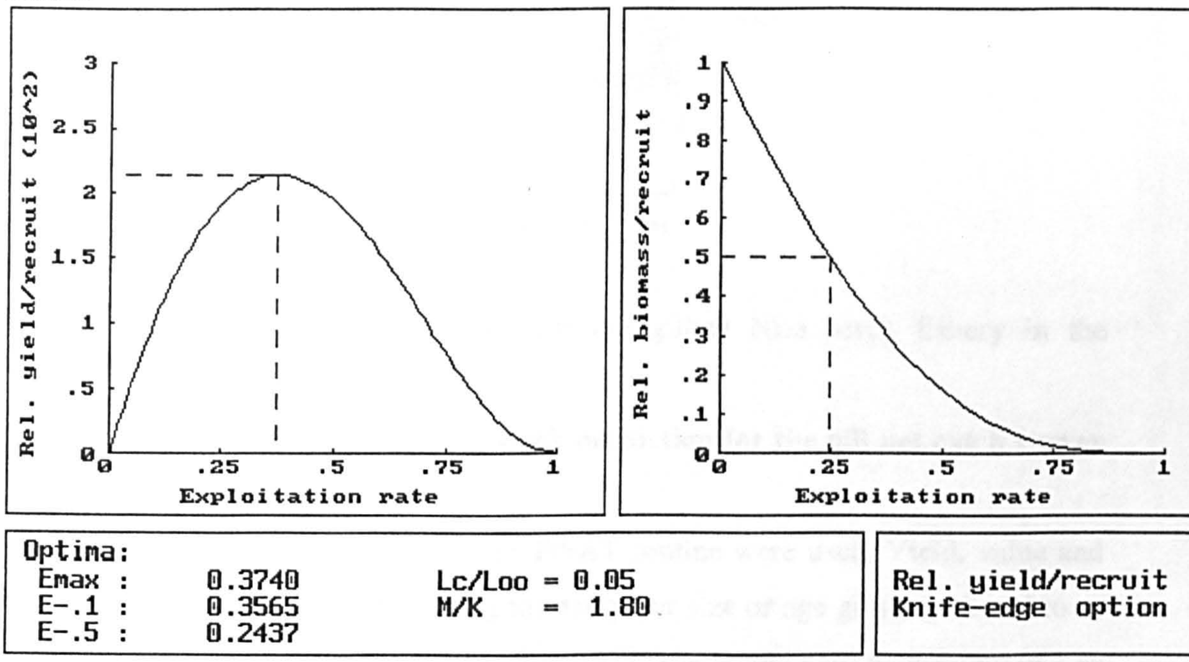


Figure 6.20a Relationship of the relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) to exploitation rate (E), for the Nile perch stock in L. Victoria – Tanzanian waters (L_c = 10.43 cm, M = 0.29, K, = 0.16 & L_∞ = 218 cm)

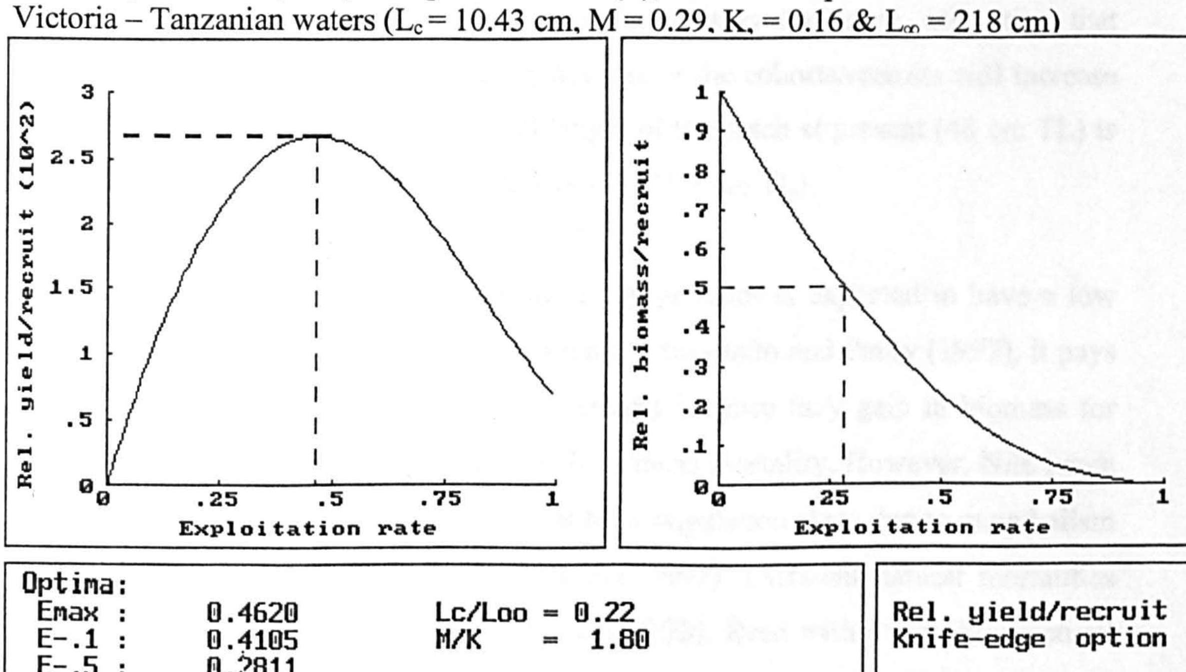


Figure 6.20b Relationship of the relative yield-per-recruit (Y'/R) and relative biomass-per-recruit (B'/R) to exploitation rate (E), for the Nile perch stock in L. Victoria – Tanzanian waters (L_c = 48.0 cm, M = 0.29, K, = 0.16 & L_∞ = 218 cm)

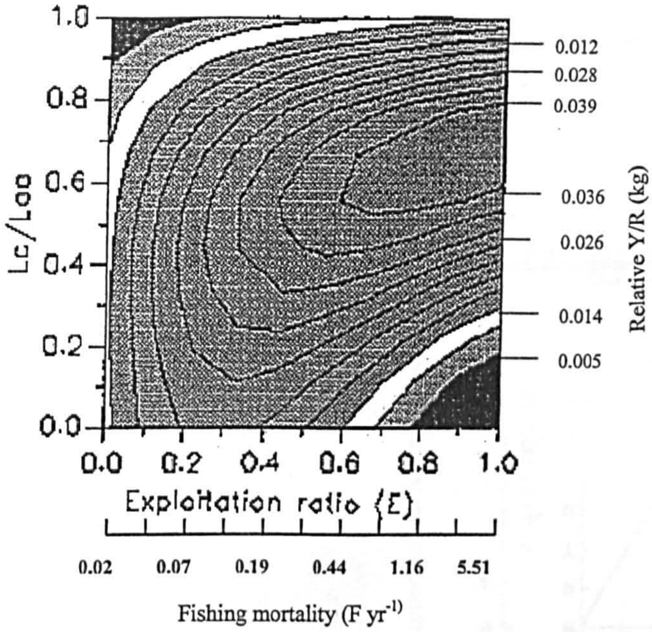


Figure 6.21 Yield isopleths diagram for the gillnet Nile perch fishery in the Tanzanian waters of Lake Victoria

6.3.9 Thompson and Bell yield and stock prediction for the gill net catch survey data

The VPA outputs saved directly by the FiSAT routine were used. Yield, value and biomass for different values of fishing mortality per size or age group (referred to as F-array) were predicted for the fishery (Fig. 6.22). The model used an F-factor of 1 as the current fishing level for the Nile perch population. The model predicted an increase in yield as well as the value as the F-array increases, indicating that increasing fishing effort with increasing size/age of the cohorts/recruits will increase the yield. This is expected, as the modal length of the catch at present (48 cm TL) is well below the L_{opt}, the size at maximum yield (135.9 cm TL).

Nile perch being a long-lived species and a top predator is expected to have a low natural mortality (Wootton, 1990). According to Gayanilo and Pauly (1997), it pays to let the fish grow large before they are caught because they gain in biomass for individual growth exceeds the loss caused by natural mortality. However, Nile perch is known to suffer high natural mortality at high population sizes due to cannibalism (Ogari & Dadzie, 1988; Mkumbo & Ligtvoet, 1992). Different natural mortalities were used to fit the yield-per-recruit curve (Fig.6.23). Even with a very high natural mortality, which according to the model is associated with high fishing effort, it appears the maximum yield per recruit is maintained at the same level and over a wider range of fishing mortality. This probably implies that higher natural mortality is not affecting the yield but rather increases the resilience of the stock to fishing pressure (refer to the discussion).

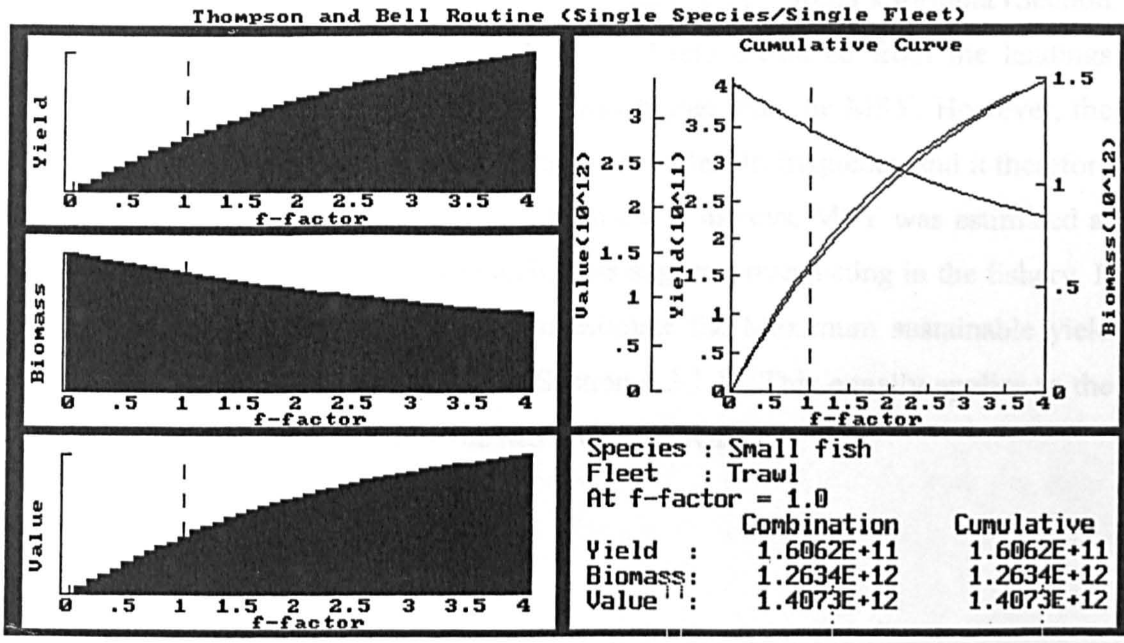


Figure 6.22 Thomson and Bell output for the gillnet catch survey data of Nile perchin Tanzanian waters of Lake Victoria

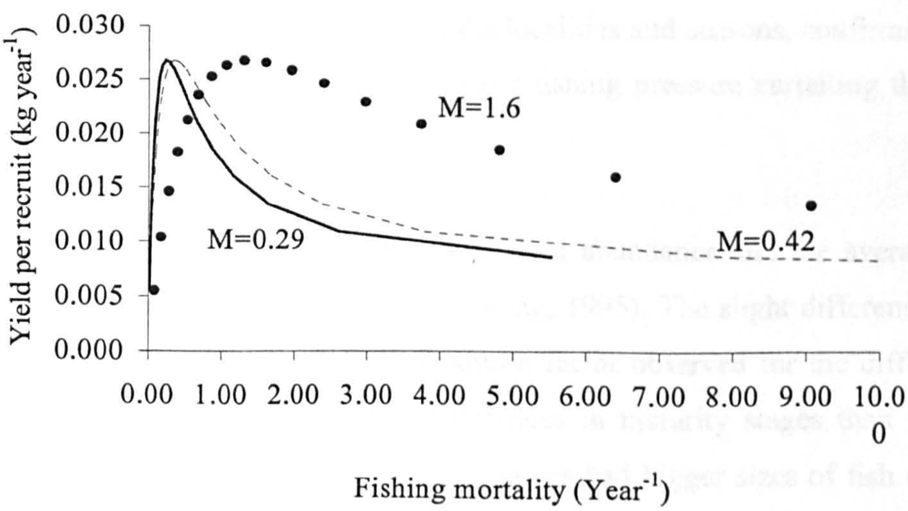


Figure 6.23 Yield-per-recruit curves of Nile perch, illustrating the effect of changing natural mortality (M)

6.3.10 Maximum sustainable yield (MSY)

Using the estimated total catch of 75 154.6 t from VPA with a natural mortality (*M*) of 0.29 yr^{-1} from the catch curve analysis and a biomass of 306 000 t estimated by the swept area method (Chapter Four) as input parameters in Cadima's formula (Section 6.2.8); MSY was estimated at 81 947.3 t yr^{-1}. Yield estimated from the landings (Chapter Three, 138 323.85 ± 81 457.73 t) was higher than the MSY. However, the yield estimated from VPA was based on only gillnet length frequency and it therefore underestimate the MSY. Using the yield from catch surveys, MSY was estimated at 108 941.9 t yr^{-1}, also lower than the catch. This suggests overfishing in the fishery. It has to be noted that the biomass used to estimate the Maximum sustainable yield (MSY) was almost 90% immature fish (Section 6.3.1.1). This equally applies to the yield estimates used and therefore the MSY value given.

6.4 DISCUSSION

The matching patterns of distribution for the Nile perch population in the three zones and in different seasons indicate similarity or complete mixing of the stock(s). However, intensity of recruitment and the size ranges in a particular locality as well as abundance differed depending on the prevailing environmental factors (Chapter Two) and the localized fishing effort. Exceptionally, juveniles less than 50 cm TL dominated the stock in almost all the localities and seasons, confirming a continuous spawning and recruitment with heavy fishing pressure curtailing the population to reach large sizes.

Condition factor usually varies with food abundance and the average reproductive stage of the stock (Wootton, 1990; King, 1995). The slight difference in the length-weight parameters as well as condition factor observed for the different zones was most probably caused by the differences in maturity stages than food abundance (Chapter Five). Zone C with higher values had bigger sizes of fish compared to the other zones, and thus a higher average reproductive stage. Zone B with the highest number of juveniles had the lowest value for condition factor. Although the estimated *b*- value for the length-weight relationship is less than the expected 3 for isometric growth indicating that Nile perch in the Tanzanian waters are lighter for their length, however, the confidence limits included 3 implying no significant difference to the isometric growth. Nevertheless, as growth depends largely on food availability, feeding rates and nutritional value of the food ingested (FAO, 2001; Wootton, 1990), there is a need to assess the nutritional value of the different prey ingested and the feeding rates in relation to dominancy in specific prey items in a respective habitat. This will also help to isolate the causes of the current decline in abundance of the Nile perch stock.

The growth parameters estimated (L_∞ = 218, & K = 0.16) differ from previous estimates in the same lake and also in different lakes (Table 6.5 & 6.6). The parameters estimated even from the same locality differ. This is probably explained by differences in exploitation pattern and environmental characteristics.

Fish are known to exhibit flexibility in their growth characteristics, with the same species showing very different patterns in different environments (Wootton, 1990). In Lake Victoria differences were found between different localities and in different periods. The populations could have been exposed into different exogenous factors as food quantity and quality, temperature and oxygen variations, as well as different levels of water pollution. Likewise, the underlying assumptions for the use of the models as: samples used should represent the size distribution of the stock; all length differences are due to differences in age, and that, growth of fish is similar from one year to the next (Gayanilo & Pauly, 1997; Hilborn & Walter, 1992). These assumptions are rarely met for localised sampling and for a species like Nile perch with continous breeding and a long life span. Individual differences in growth pattern and possibility of seasonal and annually variation in growth influenced by environmental factors (Wootton, 1990) can probably explain the differences in the estimated growth parameters.

However, these parameters were used to calculate *Lopt* (*Lopt* = L_∞ *(3/3+M/K) for comparison with the current *Lopt* estimates and the different lengths at maximum yield are presented (Table 6.5). The differences were influenced by the L_∞ and K values being different but the same natural mortality rate was used (0.3 yr^{-1}; Pitcher & Bundy, 1995). *Lopt* decreased with a higher growth rate and a lower length at infinite. It is therefore important to have accurate growth parameters as these determine the size at maximum yield and thus the size at first capture.

Table 6.5 Growth parameters of Nile perch at different periods in Lake Victoria

Year of study	L_∞ **(cm)**	K **y**$^{-1}$	**Increment (L_1 in cm)**	Source	**Length at max. yield (*Lopt*)**
1964-1977	251	0.09	20.9	Acere (1985)	118.9
1978-1984	205	0.19	44.2	Asila & Ogari (1988)	134.3
1987-1988	185	0.17	34.5	Ligtvoet & Mkumbo (1990)	116.5
ELEFAN 1 Tagging experiments	122 Actual Annual increment	0.26	34.0 29	Asila & Okemwa (1999) Asila & Okemwa (1999)	88.11
1999-2001	218	0.16	39.7	Mkumbo (current study)	135.9

Table 6.6 Growth Parameters for *Lates niloticus* estimated under different studies and localities.

Country	**Locality**	L_∞ **(cm TL)**	K **(yr**$^{-1}$**)**	**Temperature (°C)**	**ϕ'**
Uganda	L. Victoria	251.0	0.091	25.5	3.76
Kenya	Nyanza Gulf L. Victoria	205.0	0.190	26.0	3.90
Burkina Faso	Lake Tapoa (1988–90)	110.0	0.200		3.38
Chad	Malamfatari Lake Chad	181.0	.0.090	25.0	3.47
Nigeria		112.0	0.309		3.59
Egypt	Nosha, Alexandria	180.0	0.177		3.76
Nigeria	Lake Kainji (1997-98)	155.0	0.270		3.81

Source: http://www.fishbase.org/PopDyn/popGrowthlist.cfm?ID=347

Note: mean of ϕ'values = 3.69375, standard deviation (S) = 0.182189; CV = S/mean*100 = 5.2%

Lake Victoria is known to have undergone drastic changes in the past thirty years with increase in nutrient loading resulted to an eutrophic deoxygenation cycle (Ochumba 1990). A series of abrupt and severe changes in the aquatic environment of the lake were recorded during the 1980s, to mid 1990s (Hecky & Bugenyi, 1992; Kaufman, 1992; Muggide, 1993; Gophen *et al.*, 1993). Rainfall patterns and intensity differ in the south and north of the lake. Fishing effort also differs in the different localities and in different national waters. This imposes different fishing mortality on the populations and consequently differences in how the fish respond. All these variations could influence differences in the growth patterns of the Nile perch population, as the growth pattern of fish is the result of interplay between a potential for growth that depends on the genotype of the fish and the complex of environmental conditions and other circumstances as fishing pressure it encounters as it grows (Wootton, 1990).

The growth performance index (ϕ') estimated for all the different studies ranged from 3.90 to 3.38 with a mean at 3.69, while those in Lake Victoria ranged from 3.76 to 3.90 with the present study estimates at 3.88. The 95% CL of the mean is 0.161 and the coefficient of variation (CV) is 5.2%. According to Pauly *et al.* (1998), closely related species have similar values of ϕ', even if their L_∞ and K values differ, while Moreau *et al.* (1986), suggest that the CV of ϕ'for several stocks of the same species should not exceed 5%. The CV of the estimates of growth performance index for *Lates niloticus* is very close to 5%, indicating the differences observed in the growth parameters are just phenotypically driven. So far limited-tagging experiments (Ligtvoet & Mkumbo, 1990) indicated extensive movements of the Nile perch in Lake Victoria. However more work on the migration patterns is required so as to decide on uniformity or localized management strategies for the Nile perch fishery in the lake.

The mortality parameters estimated from both the bottom trawl data and the catch survey data were very similar implying that the data were from the same population. Natural mortality (estimated using Pauly, 1980 formula) appeared to be relatively lower than recorded (0.29 vs. 0.42 & 0.3) (www/Fishbase Org, 2001; Pitcher & Bundy, 1995). Although the variation is explained by differences in the growth parameters (L_∞ & K) used, reduction in predation pressure and fishing for juveniles could have contributed to that.

Recruitment is another major event subsequent to spawning in the life history of an exploited stock as it refers to the time, size and amount of new individuals being added to the fishery. Recruitment is known to depend on stock size in all species (King, 1995) although the variation in recruitment is related to factors other than stock size. The pattern of recruitment is coupled between biological strategies and environmental factors. The size of the spawning stock, variations in reproductive success as well as in the survival of larvae and juveniles are directly related to the recruitment strength. Spawning is correlated in such a way that the juveniles coincides with some favourable aspects in the environment for their survival (Wootton, 1990; King, 1995; Lowe-McConnell, 1987; Welcomme, 1985).

The recruitment pattern for Nile perch in Lake Victoria appeared to have peaks coinciding with the period of complete mixing of the lake (August to October), a major peak, and a minor peak extending during the rain period (November to May) (Chapter Two). This is the time during/and just after nutrients are added to the water either through the water mixing or influx by rains, and thus associated with high productivity. The increased production of phytoplankton has a direct positive impact to the invertebrates, which occupy the secondary trophic level of production in the lake. Cyclopoids and cladocerans were reported to contribute about 70% and 17% respectively to the diet of Nile perch larvae (Ndawula *et al.*, 1999). *Caridina niloticus* contributed almost 100% to juveniles of Nile perch (<30 cm TL) (Chapter Five; Ogari & Dadzie, 1988; Mkumbo & Ligtvoet, 1992). Insect larvae, *Povilla adusta* and corixids (*Macronecta* spp) were also found to be important in the diet of juvenile Nile perch (Owilli, 1999). The adults of these insects inhabit macrophytes, which flourish best just after the rains. These foods to juvenile Nile perch are reported to have increased in abundance (Chapter One & Two). The occurrence of relatively abundant zooplankton and insect larvae throughout the year (Ndawula *et al.*, 1999; Owilli, 1999) explains the strategy of continuous breeding in species like Nile perch and thus distributing the juveniles through-out the year with peaks at peak food availability, which reduces competition for food and increase chances of survival (Wootton, 1990, Beyer, 1989).

Severe growth overfishing was found in the Nile perch fishery. About 88% of the gillnet fishery was below the sizes at first maturity (L_m50 was 54.3 & 76.7 cm TL for males and females respectively), almost 100% below the size of maximum yield (L_{opt}= 135.8 cm TL), although this is very much dependable on the estimated growth parameters. With different sets of growth parameters estimated during different periods (Table 6.5), the L_{opt} varied from 88 cm TL, 117 cm TL, 119 cm TL and 134 cm TL. It is therefore quite difficult to have the exact size of optimum yield taking into consideration the difficulties in estimating the growth parameters given the limitation of the models used. However given the population structure of the catch and the size at first maturity and the different $L_{opt,}$ a size range for optimum yield can be suggested in relation to the yield per recruit isoplets.

The Bhattacharya separation of length frequency means, the results of the length structured VPA (Appendix 11a) showed the population numbers to decrease drastically just after the 1.6 yrs of their life indicating growth overfishing. At 2.5 yrs the size when females start to mature, very few individuals were caught which could indicate signs of recruitment overfishing. The recruitment pattern so far did not implicate any signs of recruitment overfishing as almost a regular pattern of juveniles was found in the monthly length frequency distribution. It is well established that the collapse of many fisheries in the world has been due to reduced recruitment caused by low levels of the spawning stock (Cushing, 1975; King, 1995; FAO, 2001). The minimum level of spawning stock required maintaining recruitment is not known in many species. Generally, species that mature early in life and have a high fecundity, recruitment will only decrease at very low stock sizes (King, 1995). Nile perch has very high fecundity but still precautions need to be taken to protect the spawning stock so that it is maintained at a level where the recruitment is not threatened.

Intensive harvesting of juveniles by the use of under-size gill nets and beach seines has been going on. Management regulations to ban the use of such gears were imposed in the 1996. Enforcement has been almost impossible until recently (1999/2001) when funds for surveillance were made available through the Lake Victoria Environmental Management Project (A World-bank funded project). Establishment of Beach Management units (BMU) under the same project have also assisted in reducing the extent of use but still far from eliminating them. Fishing of juveniles reduces the size/amount to be recruited and the probability of surviving to spawning size. In the long run it leads to instability in recruitment and a possible collapse to a fishery (Pitcher & Hart, 1982; King, 1995). A stock-recruitment curve for Nile perch has to be worked out, as it is the steepness of the initial part of the curve that determines whether recruitment either decreases gradually or collapses suddenly at low stock levels (Wootton, 1990; Clark, 1991; Norris, 1991; King, 1995). Generally if $b>1$ i.e. the slope of the relationship, then recruitment is density dependent (King, 1995; Wootton, 1990). The steeper the curve at low spawning stock size, the most likely the collapse of the fishery if fishing effort increases beyond a certain level. Likewise at very high stock densities recruitment decreases while cannibalism also controls number of new recruits (King, 1995; Smith & Reay, 1991).

Recruitment appears to be density dependent in Nile perch stocks, as cannibalism was rampant when the stock was in very high abundances in the early 1990s (Mkumbo & Ligtvoet, 1992; Ogari & Dadzie, 1988), but currently it is almost negligible except for the very large sizes (Chapter Five), probably due to reduction of stock size by heavy fishing. The very high number of juveniles dominating in the catches is probably a density dependent effect to compensate for the reduction in stock size. The fishery could probably be related to the Atlantic Cod (*Gadus morhua*) in which the young cohorts of age 1 to 2 have been supporting a fishery without collapse of the stocks (Gulland, 1977; Cushing, 1968). However precaution has to be taken as Cod has distinctive stocks that are not equally affected by fishing pressure and thus become more resilient. Also monitoring of the spawning stock sizes and recruitment strength have been going on followed by effective management actions. For some stocks of Cod it was found the size of the spawning stock is a unique determinant of the optimal level of exploitation of the resources. For Nile perch stock, the understanding of the underlying biological processes is still rudimentary and it is probably important to reduce the excessive fishing pressure on the juveniles as attention is given to establish the levels of the spawning stock biomass to maintain the replenishment. Monitoring of other environmental factors that can affect recruitment (Chapter Two) as well as the trophic interactions (Chapter Five) is important for sustainability of the Nile perch fishery.

The yield estimates from total landings from the catch surveys (Chapter Three), was higher than the MSY, which has to be treated with precaution due to dominance of juveniles in the biomass data used for the estimates and it may not indicate the actual state of the fishery. VPA analysis illustrated the fishery dependence on the size groups from 38.0 cm TL to 71 cm TL and highest catch by weight was from the 47 to 50 cm length group, well below the size at first maturity. The highest fishing mortality (4.0) was at the length class of 64-67 cm TL but it was not the length class with highest catch, which implies the reduction in number for the length classes to an extent that increase in effort did not correspond with increase in yield. This was further supported by the present fishing practise (Chapter Three). Fishermen are forced to join three gillnets vertical so as to cover almost the whole water column to increase catch per effort for financial returns. To get the maximum yield/recruit, the current exploitation ratio (0.84) needs to be reduced by more than 50% to match with the maximum exploitation ratio (E_{max}) of 0.37 predicted by relative yield/recruit, knife-edge option or increase the size at first capture.

The relative/yield per recruit isoplets defined the range of maximum yield at L_c/L_∞ of 0.4 to 0.7 corresponding to 3 to 7 yrs age at first capture and exploitation range of 0.4 to 0.6. The size at capture (L_c) has to be increased to 87.2 cm TL under the present exploitation pattern so as to get the maximum yield per recruit. Otherwise the present fishing effort of 1.55 has to be reduced to F_{max} of 0.62. Fishing mortality estimates using isopleths of yield-per-recruit in previous years (Pitcher & Bundy, 1995) indicated a peak yield-per-recruit at F = 3 and the L_{opt} of 120 cm TL equivalent to 4.6 yrs age at first capture. It was also found that, with the legal minimum mesh size of 127 mm, the optimal fishing mortality was 0.4.

However, the model is limited in the assumption of steady state as the effect of cannibalism and possibilities of very minimal natural mortality at large sizes being the top predator could not be accounted. Thus, it may be misleading to manage the Nile perch stock using the yield-per-recruit model, but it may still be considered to give indication of the levels of exploitation and the need to reduce effort is given. The assessment used in varying the *M* gave an indication that increase of natural mortality in the stock and therefore the cannibalistic effect may not have a negative effect on the yield per recruit but rather increases the resilience of the stocks to fishing pressure, possibly explained by the density–dependent recruitment (Wooton, 1990; Beyer, 1989). Some of the most stable and resilient fisheries in the world as some of hake stocks are documented to be cannibalists with up to 40% cannibalism (Pitcher & Alheit, 1994).

The Thomson and Bell yield and stock prediction model predicted increase in yield with increase in fishing effort as the recruits increase in size/age. This corroborates the predictions of the relative yield-per-recruit model. To have the maximum yield the length at capture has to be increased to match with the range of maximum yield-per-recruit. The total yield estimated from the catch surveys (138 323.85 ± 81 457.73 t, Chapter Three) was higher than MSY estimated using Cadima's estimator (108 941.9 t yr^{-1} for Tanzanian waters). Pitcher and Bundy (1995) fitted surplus production model to catch and effort data for the whole lake and came up with MSY ranging from 269 600 – 317 000 t yr^{-1}. Assuming about 36% of the yield came from Tanzanian waters (Chapter Three), then the MSY from that sector would be ranging from 97 056 to 114 336 t yr^{-1}, the current MSY being within the range. However, when comparison was made for MSY values (71 019.7 to 107 039.9 t yr^{-1} for Tanzanian waters and 197 277 to 297 333 t yr^{-1} for the whole lake) estimated by the same method i.e. Cadima's estimator (Pitcher & Bundy, 1995), the current value was close to the upper limit. Conversely, an estimate of the current total catch from Tanzanian waters (138 323.85 t; Chapter Three) is almost the same to annual yield in the early 1990s yield of about 140 000 t (Bwathondi, 1990; Katunzi, 1990, FAO, 1992). This shows minimal reduction in total catch over the years, but then the exploitation characteristics of the fishery have changed markedly (Chapter Three).

The biomass estimated for the whole lake during the fishery's peak production (500 000 to 700 000 t) was comparable to the current estimates (620 000 t, Chapter Four) and thus does not show any impact of overfishing. However, more than 88% of the data used were below size at first maturity. It is possible that the stock has responded by producing more recruits. That could be related to their early maturity and the dominance of juveniles in the length frequency distribution. Almost 50% of the catch population in the bottom trawls was juveniles below 11.5 cm TL.

Using the surplus-production assessment Pitcher and Bundy (1995) made projections of catch and stock biomass for different effort scenarios. A collapse of the stock was projected by 1997 if the effort was to increase at 7% rate per year from the 1990 effort, which was about 21 000 canoes. With the current fishing effort of 41 000 canoes, the fishery of Nile perch does not, from the recruitment pattern given, render an immediate threat to collapse, despite the huge increase in effort. The intense fishing of the juveniles is probably what sets the fishery on a serious threat to collapse. Although there is an indication of increased resilence of the stocks, more understanding on the Nile perch stock-recruitment relationships need to be investigated. The present fishing mortality of 1.64 from the bottom trawl data and 1.55 for the catch survey data was higher than previously (Asila & Ogari, 1988), when *F* averages 1.3 between 1981 and 1985. That was comparable to Pitcher and Bundy (1995) estimate. The increase in fishing effort in terms of gears and canoes, and drop in the gill net mesh sizes over the years (Ligtvoet & Mkumbo, 1991; Chapter Three) explains the high yields in the scale of 1990s landings. During the peak Nile perch production in the lake, only large individuals in the population were targeted (Ligtvoet & Mkumbo, 1990). With decrease in size, the effort shifted to the smaller sizes in the population by reducing the mesh sizes.

Both VPA and Yield-per-recruit models demonstrated the high exploitation rates and fishing mortality far exceeded the effort at MSY and exemplified the reduction of effort or the exploitation rate by half. Surplus production analysis in the 1990s (Pitcher & Bundy, 1995) suggested a reduction of the canoes to about 14,000 by 1993 and this should have been held constant. It would stabilize the stocks at a biomass of about 400 000 to 500 000 t yr^{-1} and a yield of about 200 000 to 250 000 t yr^{-1} for Nile perch in the whole lake. Although the current biomass and yield was higher than the predicted values, almost 50% of that is juveniles and effort has almost tripled. This indicates a high resilience of the Nile perch stock to fishing pressure, which is probably a result of high turnover or high production/biomass ratio. P/B ratio is known to be equals to the *Z* value since growth conforms to von Bertalanffy growth curve (Allen, 1971; Marshall & Mubamba, 1993; Pet *et al.*, 1996). The value estimated for *Z* (1.84 yr^{-1}, Catch curve analysis) is very high compared to 0.39 in 1971-72 and 0.95 in 1985-86 (Moreau, 1995), implying an increase in the turnover. The utilization of the biological fish production, which is catch divide by production times 100 (i.e. C/P*100; where P = B*Z, and B = biomass), using B of 306 000 t calculated by the swept area method (Chapter Four), was found to be 13%. This also indicates overexploitation, being higher than the normal 10% utilization for lakes and reservoirs (Pet *et al.*, 1996). Despite the high turnover, which explains, why the stock seems not to behave according to the predictions, there is an urgent need to protect the juveniles and reduction of effort in terms of number of canoes and gillnets per canoe. Concurrently, a monitoring programme has to be maintained to establish the stock-recruitment relationship so as to ascertain .the extent needed to protect the spawning stock as well.

Using a modal length–mesh size relationship of '$y = 10x - 1.7143$', $r = 0.998$ (Asila, 1999), the current recommended minimum mesh size of 127mm (5") for gill nets has the modal length of the catch at 48 cm TL, but 88% of the catch from 5" gillnets was immature (Chapter Three). This calls for an immediate reconsideration of the legal minimum mesh size for the Nile perch gill net fishery. Schindler *et al.* (1998) predicted a maximum harvest of Nile perch from gillnet mesh size restrictions between 152 mm (6") and 254 mm (10"). Using the equation above, the modal length of the catch from the gill nets would range from 58 cm to 98 cm TL. This is much below the size range of optimum yield predicted in the present study (135.9-cm TL), as well as the size of 120 cm TL recommended by Pitcher and Bundy (1995). Under yield-per-recruit isopleths, a fishing factor at $F_{0.1}$ or E-10 is advisable for sustainable management, which is the value of F at which the yield per recruit curve is 10% of its initial value. It is a level of fishing mortality lower than that required obtaining the maximum yield and is believed to provide greater profitability and a buffer against recruitment overfishing (Gayanilo & Pauly, 1997). That would fall on the size range of 87.2 cm TL at which the fish would be aged 3 yrs. This implies an equivalent gill net mesh size of 265 mm (10.4 inches). With the current size structure in the Nile perch catch, use of gillnets of 265 mm (10.4") mesh sizes, would have rarely any catch, but it is still important to select a slot size which will safeguard both the juveniles and the brooding/spawning stock. A range of gillnets from 6" to 10" would protect both juveniles and spawners as about 50% of Nile perch catch from a fleet of gillnets of mesh sizes 6" and above was found to be mature (Chapter Three).

6.5 Summary

Length frequency data from fishery dependent catch assessment surveys (Chapter Three) and bottom trawl surveys (Chapter Four) were used to assess recruitment patterns, estimate population parameters and yield to support management options for the Nile perch stocks in the Tanzanian waters of Lake Victoria.

The parameters *a* and *b* for the functional relationship between total length and weight were 0.000018 and 2.92 respectively and no significant difference was found for the slope to the expected isometric growth of 3

Monthly length frequency distributions revealed continuous recruitment throughout the year, but with higher concentrations in the shallow sheltered bays, especially in zone B, the area bordering Kenya waters. Relatively high numbers of recruits were recorded in March, April, May, June, July and October to December, although more sampling in shallow waters in these months could have influenced the differences in recruitment intensity. However, the breeding peaks (Chapter Five) associated with the dry and rain seasons were evident.

Growth parameters for Nile perch were estimated at L_∞ =218 & *K*=0.16. Using Taylor's (1958) formula, t_{max} the approximate maximum age for Nile perch was 18 years. Using the von Bertalanfffy growth model, Nile perch grow to about 39 cm in one year and reach size at first maturity at age 1.6 yr for males and 2.5 yr for females. Hence juveniles of less than two years (83% of the catch) sustained the fishery [L_{m50} =54.3 cm TL (males) & 76.7 cm TL (females)].

High values for fishing mortality (1.55) and exploitation rates (0.84) were derived using the length converted catch curve. Natural mortality (*M*) estimated using Pauly (1980) formula was 0.29. Both VPA and Yield-per-Recruit models suggested growth overfishing. The fishing effort and exploitation rates were far beyond that of optimum yield and the length at capture well below the size at first maturity. The current fishing effort needs to be reduced by half and the sizes at capture to be increased to 3 to 7 years or Lc of 87 cm TL. However, the model is limited in the assumption of steady state as the effect of cannibalism and possibilities of decline in natural mortality with size, Nile perch being the top predator, could not be accounted for. Thus, it may be misleading to manage the Nile perch stock using the yield-per-recruit model. Nevertheless an indication of the levels of exploitation was derived, and the need to reduce effort is evident. Varying input value of natural mortality (*M*) in the Y'/R model did not affect yield. That could imply cannibalistic effect may not have a negative effect on the yield per recruit but rather it increases the resilience of the stocks to fishing pressure, possibly explained by the density–dependent recruitment.

The current yield was close to the optimum yield recorded in the early 1990s due to a three-fold increase in effort and dependence on juveniles. Although the biomass estimated was within the range estimated at the peak Nile perch production in the lake in 1987, almost 88% of current biomass comprised of juveniles.

The ability of the Nile perch stock to withstand high fishing pressure over the years instead of collapsing as predicted is associated with the high turnover or the production/biomass ratio, which also increased over the years. The dominance of juveniles in the population supports this argument. Due to high fecundity and high recruitment of the Nile perch stock, which resulted to high resilient to fishing, recruitment overfishing may not be an immediate threat to the fishery. However, increasing the size at first capture will give greater chances for more fish to escape to the spawning stock, while further studies are conducted to understand the dynamics in stock recruitment, stock size and the effects of fishing for management purposes.

CHAPTER SEVEN

TOWARDS SUSTAINABLE EXPLOITATION OF NILE PERCH

7.1 INTRODUCTION

Sustainable use of Lake Victoria resources is the main objective in the strategic vision of Lake Victoria Fisheries Organisation (LVFO); an organ charged with the responsibility of coordinating and harmonizing management issues of the lake ecosystem (LVFO, 1999). Achieving sustainable exploitation of Nile perch fishery does not imply that the catches will be constant but rather is to have a regulated fishery through management strategies to ensure fishing practices, effort and the yield vary as the population size fluctuates. The role of fisheries research and stock assessment is to provide information on the resource status and the ecological processes that control the population dynamics and advice on possible management strategies to achieve the management objectives (King, 1995; Rosenberg *et al.*, 1993). The preceeded chapters attempted to provide the information required on the Nile perch stock and its environment, the status of its fishery and the dynamics of the population to facilitate the knowledge base for management of this fishery. This chapter aims at summarising the information on the state of the stocks and the fishery and to propose the management options and strategies to be implemented to rescue the Nile perch fishery from collapsing towards a sustainable exploitation. The Chapter identifies the management objectives and the key issues to be addressed while points out the setbacks in the existing regulations and any earlier attempts in the management of Lake Victoria fisheries. Actions in a form of projects are also identified. Emphasis on some immediate actions for any hope for a sustainable Nile perch fishery in Lake Victoria concludes the study.

7.2 OVERVIEW BACKGROUND AND ECONOMIC IMPORTANCE OF THE FISHERIES OF LAKE VICTORIA

Before the early 1970s the Lake Victoria multi-species fishery was based mostly on tilapiines. (The endemic species of *Oreochromis esculentus* and *O.variabilis*, the exotic introduced *Tilapia zilliii*, *O. leucostictus* and *O. niloticus*) the catfishes, *Bagrus, Clarias, Synodontis* and *Schilbe*, the lungfish *Protopterus aethiopicus*, the mormyrids *Mormyrus kannume* and the *Labeo, Barbus,* and *Brycinus*. The fishery was basically at the subsistence level serving local markets (Graham, 1929;

Greenwood, 1974; 1981; Cadwalladr, 1965; Fryer, 1973). The haplochromines which constituted 80% of the fish biomass by the early 1970 (Kudhongania & Cordone, 1974) were mainly grass smoked and sent to hinterland markets in the rural areas while the dagaa, *Rastrineobola argentea*, were mostly sun dried and transported to some of East African urban and rural areas for animal feeds or human consumption (Marten, 1979; Scully, 1972). There was also a limited trade for ice-chilled tilapia transported by rail to Nairobi, Dar-es-Salaam and Kampala, the three cities in East Africa. The fisheries continued to be almost exclusively operated by small-scale rural fishermen to the mid 1980s. CPUE were reported to have been declining (Beauchamp, 1956; Fryer, 1973; Lowe-McConnell, 1997), although there was a steady increase in total yields (Turner, 1996). The importance of the Lake Victoria fisheries to the respective nations and in the international arena was not prominent until the transformation of the multi-species fishery to three species fishery, Nile perch dominated followed by dagaa and *O. niloticus* in the late 1980s (CIFA, 1988).

The five-fold increase in total landings from Lake Victoria from 100 000 t lake-wide in the 1960s, to late 1970s, to 500 000 t in 1989 resulted in the lake becoming the most important fishery in the region (CIFA, 1992). In 1998 the lake contributed 60% of the fish landed in Tanzania and 90% of Kenya landings, and some 48% of the fish landed in Uganda in 1994 (SEDAWOG, 1999b). In the early 1990s Nile perch constituted about 60% of the total landings in Tanzania & Kenya and about 80% in Uganda (CIFA, 1992; Chapter Three). However, Nile perch accounted for 90% of the bottom trawl catches in Tanzania (Ligtvoet & Mkumbo, 1990). With the Nile perch boom, the harvesting, processing and marketing sectors also experienced major transformations. In the 1980s the market in East Africa absorbed three times the supply of fish than in the 1970s. With new processing techniques, smoking, salted & sun dried and frozen, the Nile perch was found in almost all the markets in East Africa (Abila, 1994). The markets soon expanded beyond the three riparian countries to Zaire, Rwanda, Burundi and Zambia. With excess supply over demand in the existing markets, fish processing factories were established to supply fillets (chilled and frozen) to the industrialized countries; currently markets exist in EU, Middle East, Japan, Australia, northern and southern America (SEDAWOG, 1999a). The first plant was established in Kenya in 1980, and eventually 35 were established in the three countries, but 27 are now operational ((Abila 1994, SEDAWOG, 1999a) with a further three coming on line in Uganda. Likewise people in the harvesting, processing and distribution sectors of the fishery benefited greatly from the developments brought about by the increase in the Nile perch catches. Many people unemployed or underemployed were attracted to the fishing industry and were able to obtain an income at levels never experienced before. Nile perch was such a blessing to the extent it was nicknamed 'the saviour' by the communities around the lake (Reynolds & Greboval, 1988; Reynolds *et al.*, 1995)

The Lake Victoria fisheries produced a total value US$ 289million per year between 1975 and 1989 (Reynolds *et al.*, 1995), and employment increased from 158 000 employees in fishing and related activities to 422 000 in the entire lake in 1992 (Wilson, 1993). Although catches dropped to 383,000 t in 1994 with Uganda contributing 27% and Kenya 29% and the rest from Tanzania, revenues from those landings were enormous. For Tanzania, the revenues collected, including exports was US $200 million, while from exports only was US$ 103 million. In 1994 in Uganda the revenue from landings was US$ 77.13 million but by 1998 the revenue from fish exports increased to US$ 82 million, whilst in Kenya revenue from fish was US$ 80 million of which fish exports contributed US$ 35 million (SEDAWOG, 1999b). With the escalation of economic value, people directly benefiting from the industry also increased. Currently, about 0.5-1 million Ugandans, more than 0.5 million Tanzanians and 0.8-1.5 million Kenyans operate in the lake fishery (Bwathondi *et al.*, 2001). Nile perch has therefore created a remarkable stream of economic benefits; being very important as a source of food almost world-wide, creating employment opportunities and revenue to the people directly or indirectly engaged in the fishing industry, but also as a foreign currency earner to the three governments through the export of chilled and frozen fillets. The overwhelming economic and social benefits call for joint efforts to ensure the sustainability of the Nile perch fishery.

However, commercialization of the Lake Victoria fisheries as a result of the growth in Nile perch exports business is faced with a number of conflicting demands to the socio-economic sector as well as to the ecosystem. Despite of the economic benefits, there has been higher risk of overfishing and loose of biodiversity, a skewed distribution of income and increasing food insecurity. The situation is briefly discussed and managemnt options and measures proposed for the sustainability of the fisheries of Lake Victoria, ecosystem integrity and the welfare of al the communities.

7.3 EXPLOITATION LEVELS AND STRUCTURE OF THE FISHERY

7.3.1 Stock size and status of the fishery

7.3.1.1 *Stock abundance and distribution*

In 1999/2000 the Nile perch stock size lake-wide was estimated at 685 082.2 t with an average CPUA of 10.28 t km^{-2} using the swept area method. The mean standing crop was higher for Kenyan waters (11.73 t km^{-2}) than Tanzanian and Ugandan waters (9.86 and 9.94 t km^{-2} respectively, Chapter Four). By the end of 2001, the standing stock had declined to 540 000 t. A declining trend in the biomass was also indicated from the hydro-acoustic surveys, from 1.58 to 0.89 million t between 2000 and 2001 (LVFRP/UNECIA Final Report). The Nile perch biomass was estimated at 17.2 t km^{-2} in 1985 (Moreau, 1995), before the peak production of Nile perch in the lake. The current estimates therefore indicate a marked decline in Nile perch abundance, which was also predicted in an ECOPATH IV model (Villanueva & Moreau, 2002). Nevertheless the decline was not as severe as was predicted by Pitcher and Bundy (1995).

A decrease in the catch rates has been observed over the years. In Tanzanian waters with different research vessels, Nile perch catch rates fell from 283.69 kg hr^{-1} (*RV TAFIRI II*) to 247.52 kg hr^{-1} in 1999/2000, and 129.57 kg hr^{-1} in 2001 (*RV Victoria Explorer*; Chapter Four). However in Uganda waters, a slight increased from 115 kg hr^{-1} in 1997/1998 to 159 kg hr^{-1} in 1999 was recorded, possible due to changes in the gear used (Okaronon *et al.*, 1999). Although the data were collected from different vessels of different efficiency used during different periods while species composition was also changing, a clear indication of decline in relative abundance was evident.

Marked variations were observed between different sampling areas and seasons suggesting a tendency for aggregation behaviour in Nile perch which poses another threat as it makes the stock more vulnerable to overexploitation (Hilborn and Walters, 1992). Areas of high densities were localised and quite temporary. Pockets of high density could be found in either very shallow or offshore deep waters and at different depths in the water column depending on oxygen concentrations (Chapter Four).

7.3.1.2 Trends in landing statistics and current estimated catch

Despite the unreliability of the catch statistics (Chapter Three) an explosion in Nile perch catches from 1987 to 1990 followed by a decline was depicted. The decline was more severe for the Kenyan sector of the lake followed by Tanzania and then Uganda. The contribution of Nile perch to the total landings has changed and differs between the countries with regard to the time of the expansion of the Nile perch stock size and the levels of exploitation. In the early 1990s Nile perch contributed 60% of the total landings in Tanzania rising to 80% in 1995, but by the end of 1990s Nile perch contributed only 40% and dagaa catches expanded to contribute 49% of the total estimated catch. It is possible the Nile perch stock has decreased in importance but it can also be reflecting the shortcomings in catch statistics of not recording dagaa catches. Haplochromines were again recognized in the catches after almost disappearing in the landings in the mid 1990s. Despite a decline in CPUE, the increase in number of gillnets used per boat probably reduced the actual decline, as effort was based on the number of boats/canoes without consideration of the amount of gear per boat. Nevertheless CPUE has decreased from 110 kg canoe^{-1} in 1988 (Ligtvoet & Mkumbo, 1990) to about 70 kg canoe^{-1} for motorized gillnet canoes in 2000; if canoes with sails and paddles are included, then CPUE dropped to 40 kg canoe^{-1} in 2000 (Chapter Three). In the same referred chapter, there was an indication of decline in catch per net by 67% from 1997 to 2000. However without long-term CPUE data with changes in total effort and also with scant details in net per boat during the study, it has not been possible to establish the declining trend in CPUE. Nevertheless, the changes in fishing practices of decrease in gillnet mesh sizes and vertical joining of nets or active gillnetting are all known to be responses of fishermen to decline in abundance of a targeted stock (FAO, 2001; Borgstrøm, 1992), and thus attempt to increase CPUE.

The estimated MSY of 81 947.3 t yr^{-1} (Chapter Six) was well below the lower level of the 95% confidence limits of the current catch (138 323.85 ± 6 229.14 t, Chapter Three), indicating a need to reduce catch and effort. The exploitation rates and fishing mortalities were found to be very high (E = 0.84; and F = 1.55 yr^{-1}) and with VPA, the yield per recruit model indicated a reduction in effort by half for maximum yield (Chapter Six). There is very high demand for fish both to the local market and to the processing factories, which are operating at under capacity although almost

77% of the Nile perch landed is sold to the processing factories (Wilson *et al.*, 1999). With the decline in Nile perch catches more pressure is also being directed towards dagaa, *O. niloticus* and the recovering haplochromines, plus *Brycinus, Clarias* and *Protopterus.*

In Kenya, peak production was in 1991 when Nile perch contributed 57% of the total landings. Kenya invested more heavily in Nile perch fishery being the first to adventure into fish processing factories (SEDAWOG, 1999a). As a result the decline in Nile perch catches was first experienced in Kenya. Catches declined from a peak of 122 780 t in 1991 to about half, 61 416 t in 1998. As early as 1995, the contribution of Nile perch dropped to 47%, almost equal to the contribution by dagaa (44%). CPUE decreased from 180 kg boat day^{-1} in 1989 to 80 kg boat day^{-1} in 1999 (Othina and Tweddle, 1999).

In Uganda the same declining trend in Nile perch catches was recorded although not to the magnitude of the other two countries as the industry developed later. Annual yield declined from 120 000 t in 1991 to 103 000 t in 1994 and to about 72 632 t in 1999, with CPUE at about 72 kg boat day^{-1} (Okaronon, 1994; Muhoozi & Ogutu-Ohwayo, 1999).

7.3.1.3 *Population structure and size at maturity*

Fisheries independent surveys revealed a predominance of juveniles in the population of Nile perch indicating good recruitment to the stock. Almost 98% of the bottom trawl catch was below 54 cm TL (Chapter Six). Fisheries dependent surveys (Chapter Three) indicated the modal length for Nile perch catch from gillnets was 43 cm TL while for long lines was at 46 cm TL and 19 cm TL for the beach seine fishery. The modal length for the legal mesh size of 5 inches was at 48 cm TL. The Virtual Population Analysis illustrated the dependence of juveniles in the Nile perch fishery. Highest catch in weight was at 47 to 50 cm TL while the size at maximum yield was about 135 cm TL (Chapter Six).

The size at first maturity for males is 54.2 cm TL and 76.4 cm TL for females (Chapter Five), having decreased from 60 cm TL for males and 95-100 cm TL for females in the early 1990s (Ligtvoet & Mkumbo, 1991). All these are indicators of overfishing. The maximum age of about 18 years that Nile perch can live (Chapter

Six) is also of concern as it indicates the potential for large un-sustainable yields. Long-lived fish species sustain very high yield at the beginning of a fishery, but once the size classes are fished down the stock is not given time to build up (Hilborn & Walters, 1992; Turner, 1996). The current decline in the Nile perch fishery is therefore expected but will the juveniles support a sustainable fishery? Example is drawn from the cod (*Gadus morhua*) fishery in Baltic Sea, a relatively long-lived species (t_{max} = 12 years) with high fecundity. Although maximum yield of the stock was found at about 4 years of age, 1 & 2-year class have supported the fishery (King, 1995). However, cod cohorts become established as several discrete stocks, and thus impact of fishing is also localized. Further investigation on the spawning grounds and migration patterns can provide more light on the dynamics of the fishery for its sustainability.

7.3.2 Characteristics and structure of the fishery

7.3.2.1 *Composition and distribution of fishing effort*

Along with the rapid increase in the Nile perch stock, fishing effort also increased. In Tanzania, the number of canoes increased from 4 457 in 1979 to 7 757 in 1989, but by 2000 in Tanzania it had increased to 15 533 canoes, which was 38% of all the canoes deployed in the lake (41 091 canoes). Almost the same magnitude of increase was recorded for the other two countries. In Uganda canoes increased from 8 000 in 1989 to 15 544 in 2000, which was 38% of all the canoes while in Kenya the increase was from 5 500 canoes in 1989 to 10 014 canoes in 2000, which was 24% of all the canoes. There has also been a marked increase in the number of gears used. For example, gillnets increased from 87 778 in 1991 of which 50% where of mesh sizes 7 inches and above, to 226 063 in 2000 of which only 15% were of mesh sizes 7 inches and above. Kenya had the highest effort with almost 2.4 canoes and 35-gillnets km^{-2}, while for Tanzania and Uganda it was less than one canoe with 6 and 10 gillnets km^{-2}. The highest numbers of illegal gears operate in Kenya; with 74% of the 7 076 beach seines recorded in the 2000 frame survey while 23% of her gillnets were below 5 inches mesh size; while for Uganda 18% and Tanzania 11% of the gillnets were below 5 inches mesh sizes. Tanzania had most of the long lines (65%) while Kenya had 28% and Uganda 7% of the 3 443 385 hooks recorded in the 2000 frame survey (Chapter Three; LVFO, 2000). Likewise such variations in composition and magnitude of effort are also found for different areas within the national waters. In Tanzania more effort was in Zone A or the

Mwanza Region with 49% of the canoes, over 50% of gillnets and beach seines, and 49% of long lines recorded in Tanzania waters. Such variations in effort are important aspects to consider in any attempt to regulate fishing effort in Lake Victoria.

7.3.2.2 *Structure of the fishing industry*

The fishing industry during the pre-Nile perch era was totally artisanal except for the semi industrial haplochromine trawling in the late 1970s in the Tanzanian waters. The majority of the fishermen owned a single canoe with minimal number of gillnets which increased in 1988 to a fleet of 30-50 nets per canoe as the Nile perch fishery was developing (Ligtvoet & Mkumbo, 1991; Ligtvoet *et al.*, 1995a). More women joined the processing and marketing sector along the beaches as well as the inland markets around the lake zone. With the development of more markets and the establishment of fish processing factories for fillets to the outside markets, the structure of the Nile perch fishing industry completely changed. In order for the factories to ensure fish supply, a credit relationship with the fishermen or the fish-buying agents was established. Fishermen were given credit in terms of equipment on condition they supply the catch to the specific factory. At the same time factories were directly involved by engaging their own fishermen in fishing. With the capital, they formed large camps with hundreds of canoes and thousands of gillnets and with a collecting vessel they moved from one camp to another to collect fish for the factories. This practice marginalized the fishermen who had no contract with the factories and as a result conflict started. The successful fishermen started to control the rich fishing grounds while the less successful ones concentrated inshore and engaged in using the illegal gears mainly because they are cheap and also not stolen. Theft of gillnets and engines had become so common in the lake to an extent that fishermen sponsored by the factories form camps with one armed patrol boat taking guard over the night (Personal observation).

The same transformation occurred in the marketing and processing sector. Credit relationship was also formed between prominent fish traders and the fish processing factories. They could afford large canoes with insulated containers and capacity 2 to 4 tonnes, and directly provided with ice from the factories. These fish traders are contracted to supply fish at a given price per kilogram and thus control fish prices in the landing beaches or directly on the fishing grounds. Fish traders with limited capital were phased out or specialized in buying the poor quality or juveniles rejected by the factory buyers. The same applied to processors, they shifted to process the rejected fish or juveniles and due to competition some, especially women, were completely forced out of business (SEDAWOG, 1999b; Personal observation).

Alongside the high demand for fish both to the factories and local market augmented by the decrease in catch rates, fishermen innovated catching techniques to increase gear efficiency. Gillnets were joined to form nets to 3 km long drifted by outboard engine canoe, locally referred to as 'tembea'. The practise changed the passive gillnets to an active gear while at the same time destroying other nets set passively and yank off long lines. The practice affects the stocks and is also a source of conflict between fishermen (SEDAWOG, 1999b). Gillnets were also joined vertically two to three, so a fleet of 80 nets in one canoe is actually 240 nets (80 nets horizontally * 3 nets vertically). This is an enormous increase of effort, which was not recorded in the frame survey (Personal observation; Othina & Tweddle, 1999).

7.4 MANAGEMENT OBJECTIVES

The Fisheries Department has policy guidelines for the utilization of fisheries resources formulated under the broad national objectives for the fishery sector;

- To alleviate poverty by ensuring income to the people.
- Reduce the rate of malnutrition by increasing per capita consumption of protein food.

These objectives have the following goals;

- To raise the contribution of fisheries to the economy through higher export and foreign exchange earning capacity.
- To increase per capita protein consumption through increased production of fish.
- To improve the living conditions of fishing communities by ensured higher economic benefits in the fishing industry.
- To generate employment opportunities in the fish harvesting, processing and marketing

With these sector policies, which apply to all the three riparian countries, investment in the harvesting processing and marketing of Nile perch fishing industry has been encouraged.

7.5 KEY ISSUES

7.5.1 Over-exploitation of the resources

7.5.1.1 *Decrease in CPUE*

The current effort deployed in the fisheries of the lake is way above what the resources can support. Catch per boat was shown to decrease despite increases in number of gears per boat, reduction of gillnet mesh sizes and the change in fishing practices to drifting gillnets as well as the double or triple joining of gillnets.

7.5.1.2 *Growth and recruitment overfishing*

Juveniles dominate the stock and juveniles support the fishery. Almost 80 % of the catch of Nile perch was below the size at first maturity, indicating a serious growth over-fishing and danger of depleting the stock as fewer and fewer escape to the spawning size for replenishment of the stock. The use of under sized gillnets, beach seines and hooks of small size so as to increase the catch rates is encouraged by the market for juvenile fish. Some export markets prefer fillets from juveniles of up to 0.5 kg due to low fat content, while the local market and markets in bordering countries, e.g. Zambia and the Democratic Republic of Congo, take juveniles of any size.

7.5.1.3 *High demand and uncontrolled effort*

Involvement of the fish-processing factories in fishing, either directly or indirectly through credit relationships without any conditions or guidance from the governments is encouraging the increase in effort without any control. All the factories are operating at under capacity and unless controlled, effort will keep increasing to meet demand.

7.5.1.4. *Open access to the fishery*

Entry to Lake Victoria fisheries is open to all provided you pay for the fishing licence, and the vessel being used is registered. Such an open access system has encouraged a rapid increase in effort. The fish processing factories or prominent fishermen can register any number of canoes without limit, and pay a fishing licence for each canoe. Then he can look for youths and engage them in fishing as long as the vessel is registered and fishing licence is paid. The numbers of nets to be used have no limit as long as the vessel can carry them. There is no system of ensuring the fishermen have legal gears apart from what is reported during registration. Thus licensing is more for revenue collection than anything to do with controlling access to the fishery. With the decreasing CPUE, new fishers may hesitate to join the industry, but those established may tend to increase effort to cope with the demand. Using one engine for a number of boats reduces the running cost. Thus a fleet of canoes can be towed to distant fishing grounds at a minimum cost. This will encourage further investment as running cost is minimized and despite the decrease in CPUE, the operation can still realize profit.

7.5.1.5 *Destructive fishing practices and use of illegal gears*

Fishing practises have changed to meet market demands. The transformation in the industry from artisanal to semi-industrial and the control by few successful players is encouraging the use of illegal gears. The fishing pressure is directed to the stock recruited to the fishery by the prominent fishermen while the marginalized fishermen using beach seines and under-mesh nets are directing fishing effort to juveniles along the bays. With such a set-up it is difficult for the over-exploited Nile perch stock to recover, and collapse of the stock is inevitable. The inshore waters are the nursery grounds for juveniles of many species in the lake (Witte *et al.*, 1995b). Inshore fishing with under-size gear is further threatening biodiversity in Lake Victoria.

7.5.2 Socio-economic aspects within the fishing industry

7.5.2.1 *Control of resources and conflicts among uses*

Local fishers have in a way lost control over exploitation, processing and marketing to the industrial investors. In the harvesting sector, investors own the means of exploitation, like boats and gear and hire or employ the fishermen to fish for them. The system of fishing camps with fleets under one owner or one fish-processing factory and the area patrolled by an armed boat is denying the local fishers the rights to fish in certain fishing grounds on the lake.

In fish pricing, due to lack of storage facilities, the local fisher is forced to engage into contract with the factories so as to get ice otherwise his catch will be rejected. On such agreements, it is the buyer who has full control of prices.

The same applies in the marketing and processing sector. Fish traders with credit relationship with the factories or those with enough capital are likely to get enough ice from the factories. It is only what is rejected can go to the local processors or trades as the supply is not enough to meet the demand in the fish processing factories. Local traders and processors, with minimal capital and risks of the fish spoilage due to limited ice have opted for the Nile perch frames after filleting. Even for such product, it is the factory that decides on the price. Currently, the Nile perch fishery is almost completely controlled by the fish processing factories.

While fish factory processors over the region have an association, they meet and lay strategies and dictate terms in the industry, fishermen do not have a forum for a common stand. They are totally at the mercy of the fish processing factories. As long as the factories have control over the prominent/successful fishermen through credit and at the same time are involved in fishing, they have direct access and control of the resource. Thus, there is no incentive for responsible fishing behaviour for the local fisher folk. The set-up is also encouraging hostility and violence within the fishing community and thus the common interest of protecting the stocks for the future is eroding. Increasing differences between those with the capital, and thus the means of exploitation, and those who do not have the means has led to a common practise of theft of gear in Lake Victoria. People are injured, killed and drown either as a result of actual theft or just out of suspicion when seen near a fishing ground. There is a need for immediate intervention by the government authorities to solve the conflicts.

7.5.2.2 *Food security and nutritional status of the community*

Lake Victoria has been a source of cheap animal protein to the communities around the lake from the beginning of its fishery. With the declining of all the other food fishes as the Nile perch exploded, the communities had to adopt and adjust their feeding preferences to Nile perch (Witte *et al.*, 1999). There was a marked improvement in food security in the initial years of Nile perch boom; there was plenty of fish at an affordable price (Greboval & Mannini, 1992). As domestic and external markets for Nile perch expanded less fish was available to the local community. With related business increasing on the landing beaches and in nearby towns, more tilapiines served the hotels and thus less was available for the local poor communities as prices also increased. Establishment of fishmeal factories for animal feeds escalated the dagaa prices, while the less prominent traders in the Nile perch changed to trade on dagaa and tilapiines and some are exported to distant markets. Thus even the alternative fish protein from dagaa and tilapia is now expensive for the common people, and this has worsened food security. The rejected fish from the processing factory were serving the local community but due to high market demand, they are salted and sun dried for the Zaire and Congo markets. There is competition for the frames of Nile perch by the fishmeal factories, which utilize them for animal feeds. Juvenile Nile perch is also sun dried for fishmeal factories. Highest levels of malnutrition are reported within the lakeshore communities (Odongkara, 2002; Ikiara, 1999). Lack of alternative sources of income is encouraging the communities to clear the wetlands to plant tomatoes or other vegetables for their subsistence. This is increasing pollution in the lake and as a result is threatening sustainability of the fishery.

7.5.2.3 *Loss of employment and livelihood: Gender issue*

Although Nile perch has brought undeniable economic benefits to the sector and foreign currency to the governments, concurrently it has increased the gap between the vessel and gear owners and the fisherman (crew or labourer) and led to loss of employment for some while creating jobs to others. Women traditionally dominated the fish processing and marketing sector. Some of the created jobs are too demanding for women and need to be done either by shifts or at times when women are needed to handle other family responsibilities. With the traditional processing and marketing, women could go with their children to the sites of their self-employment. Currently they have to sacrifice either the job or the care of children. The jobs created by fish processing factories are also causal, temporary, low paying and have no long-term benefits (Abila & Jansen, 1997; Bokea & Ikiara, 2000). For example in Tanzania, a causal labourer in a processing factory is paid 1,000 TShs per day (almost equivalent to one US$). He/she has to travel long distances sometimes during the nights and is not paid any transport allowance. He is not entitled any leave or sick pay and once sick, sometimes is automatically out of job. The type of job is therefore hand- to – mouth and the labourers are getting poorer and poorer while the factories are making big profits out of the resources. Women are equally struggling to earn a living by either processing the skeletons/ heads, frying them and selling to consumers or are engaged by the factories to clean the swim bladders at a minimal pay. There is a threat of further unemployment in the processing and trading of the Nile perch skeletons as they are finding their way to fishmeal factories.

There is therefore a serious imbalance in the social sector, which indirectly affects the sustainability of the fishing industry. With lose of employment directly connect to the Nile perch fishing industry, more pressure is directed to the other commercial species, the dagaa and *O. niloticus* and even to the other species showing signs of recovery such as haplochromines, *Clarias, Protopterus* and *Brycinus*. This will impact on the ecosystem stability and in turn to the fishery.

7.5.3 Ecosystem instability

7.5.3.1 *Disruption of the food web in Lake Victoria*

There have been profound changes in the ecosystem of Lake Victoria as changes in species compositions and abundance occurred. Predation by Nile perch was one of the factors, which influenced the changes by creating incomplete links in the trophic web. In Mwanza gulf, around 7 trawls were operating in the 1980s and some inshore waters were fished with beach seines (Witte, *et al.*, 1992b; Bundy & Pitcher, 1995). They may have contributed to localised decline of the grazers of blue green algae, the phytoplanktivorous haplochromines. However, these species declined throughout the lake as Nile perch populations expanded. Whatever the cause, populations of these haplochromines could not control the phytoplankton resulting in algae blooms. This in turn resulted to accumulation of detritus as the detritivorous fishes were also reduced. As a result of decomposition of the detritus, oxygen in the deep layers was depleted causing anoxia in deep waters. With the changes some species like *Caridina niloticus* and *Rastrineobola argentea* increased and also became dominant food items to Nile perch (Chapter One; Chapter Five). With the reduction of Nile perch through fishing, some of the species are reappearing and it is expected that the stability in the ecosystem to some extent will be restored, although it is not clear whether the increase is due to reduction in predation (Turner, 1996). Unfortunately fishing pressure is directed both to recovering species as the haplochromines, and also to *Caridina* and *Rastrineobola argentea* (Witte *et al.*, 2002; Personnal observation). This can destabilize the ecosystem by further disruption of the food web and at the same time threaten the sustainability of Nile perch and the other fisheries in the lake. However, it is uncertain whether overfishing of Nile perch can lead to an increase in transfer efficiency of the fishery (Turner, 1996).

7.5.3.2 *Pollution and land use practices*

Environmental changes are known to have similar impacts as predation and overfishing on the instability of the Lake Victoria ecosystem. Water transparency decreased due to increased eutrophication, which was linked to excessive use of fertilizers and nutrient loading from industrial and sewage discharges. The main sources of pollution in the lake are from the point sources from industrial and municipal wastewater discharge and non-point sources from agro - chemicals, soil erosion and sedimentation. Clearing of wetlands, which act as buffer zones and poor land use practises have resulted in runoffs, solid waste inputs and siltation to the lake. Possibly due to improvements in practices the situation is slightly improved. The reported anoxic layer in water below 50 m is no longer permanent and transparency has also increased (Chapter Two). Such limnological changes are directly related to changes in the biota of the lake (Riedmiller, 1994). The recovery of the species recorded is therefore probably influenced or influences the abiotic changes and thus the water quality and the ecosystem at large, although reduction in Nile perch may also be a contributing factor. Every component of an ecosystem has a crucial role for the stability of that system, and management of one aspect has to take into consideration the interactions within the system.

7.6 EXISTING MANAGEMENT REGULATIONS AND THEIR DRAWBACKS

7.6.1 Existing regulations

Lake Victoria is a shared resource between the three countries, Kenya, Uganda and Tanzania. In recognition of the uniformity of the lake and her resources, any attempts to manage the fishery and the environment need to be done regionally. The first attempts to manage and assess the stocks were the 1927-1928 surveys and the recommendations to establish a research laboratory, East African Freshwater Fisheries Research Organization (EAFFRO) and an organ to collect fisheries statistics, give advice and enforce legislation, Lake Victoria Fisheries Services (LVFS). The two were established in 1947. With independence of the three states, the Sub-Committee for Lake Victoria of the Committee for Inland fisheries of Africa (CIFA) continued to bring the states together on management issues in the lake. This role has now transferred to the Lake Victoria Fisheries Organization (LVFO). The LVFO is an organ established in 1996 to bring together institutions concerned with the development and management of the Lake Victoria fisheries. Three research institutes, handle the research issues: the Tanzania Fisheries Research Institute

(TAFIRI), the Kenya Marine and Freshwater Fisheries Research Institute (KMFFRI) and in Uganda the Fisheries Resource Research Institute (FIRRI). The activities of the then LVFS were left for the respective fisheries departments in each of the riparian states.

Some regulations exist in the fisheries acts of the respective countries and attempts to harmonise them have been going on since the CIFA Sub-committees for Lake Victoria of the Committee for Inland Fisheries of Africa (CIFA, 1992). With the establishment of LVFO, and under the Lake Victoria Fisheries Research project, a number of forums have been organised with the objective of harmonising the regulations. Of such meetings one was held in Mukono, Uganda in May 2001 drawing fisheries researchers and mangers together to come up with management initiatives to ensure sustainable fishery in Lake Victoria. The existing regulations were reviewed and a number of management options were considered. The resolutions and recommendations from that forum are summarized below.

Input controls

- Gear regulation:
  - It was recommended to enforce the existing regulations on gears and mesh sizes for Nile perch and Nile tilapia (*O. niloticus*) A minimum mesh size of 5" for gillnets was agreed under CIFA (1992), while the 10 mm mesh net regulation for *Rastrineobola argentea* was to be introduced for Kenya and Uganda and enforced for Tanzania as effort to implement the regulation was underway
  - Emphasis was directed to implementation of the ban for trawling and beach seining prohibited in Lake Victoria. This was implemented at different times. It was only in 2001 that Kenya banned beach seining and trawling.
  - Research on the effect of long lines to Nile perch fishery was called for as the researchers expressed concern on the impact of such gear to the spawning stock. There is no regulation on hook-size, although for Tanzania hook sizes 8 to 11 are recommended. Long-line for Nile perch is also encouraged in Tanzania and Uganda. The implication of the minimum mesh size regulation to the other fish stock recovering was also identified an area for research.

- Cast nets are banned, and it was recommended to prohibit any introduction of new gears in Lake Victoria without prior consultations.

- Limiting effort
- Access: Any fishing vessel has to be registered and fishermen have to get a licence before engaging in the fishery. This was considered inadequately enforced and recommended the communities to observe that under co management initiatives. Property rights system was recognised as necessary option against the existing open access system. Co management was considered a step towards that option. In Tanzania Beach Management Units (BMUs) and in Uganda, Landing Management Committees (LMCs) initiated as the management organs at community level needed reestablishment under co management and should be given legal status (Geheb & Crean, 2000).
- Closed area and Closed seasons

In Tanzania the Minister may declare a controlled area in relation to fish and fish products, or fishing restriction in specific bays and river mouths. In Uganda, the minister can ban fishing at a specific period of the year, while in Kenya the Director of Fisheries is empowered to declare close seasons for specific areas, species or methods of fishing. More research was recommended to incorporate indigenous knowledge before the regulation is harmonised. However, in Tanzania 24 bays are gazetted as closed areas for spawning/nursery grounds following a survey conducted under Lake Victoria Environmental Management Programme (LVEMP).

- Closed season on processing factories was considered inappropriate as it can seriously affect the livelihoods of those who totally depend on the sector.

- Output controls
- The minimum size of fish to be landed in Uganda is 280 mm for tilapia and 460 mm for Nile perch, while Kenya has a minimum size of 250 mm. The regulation is not observed by any of the countries. This was reviewed and a slot size regulation with limits of 50-85 cm TL for Nile perch was recommended for the processing factories. That was aimed at getting a size range that is common enough to keep the factories

running, while allowing some big ones to escape to breed. However from the current study, L_{opt} calculated from growth parameters of this study as well as from previous studies was well above the upper limit of the slot size but also not viable economically from the population stucture. It is therefore adviced to increase the upper limit to 87 cm TL, i.e. the size at first capture *Lc* at the range of maximum yield on theyield-per-recruit isopleths.

- Quotas: allocation of quotas to processing factories as a measure to control excessive effort was recommended.

- Policy instruments and enforcement

- Fisheries Departments in the three countries have been the sole organs in formulating management policies as well as enforcing and surveillance.
- Co-management was considered the most cost-effective mechanism in enforcing regulations in the management process of Lake Victoria fisheries.

7.6.2 Drawbacks/constraints in the regulations and their implementation

7.6.2.1 *Institutional and legal limitations*

Most of the regulations are within the sector policies of the respective governments and there is no clear institutional or legal framework for implementation. Stakeholders at different levels are not involved in decision-making but rather it is a 'top-down' system or a 'command and control' style, and there is no efficient system of monitoring, control and surveillance. The Fisheries Department staff are expected to offer extension services and at the same time collect fisheries statistics and enforce the regulations. With no clearly defined roles, the fishing communities have no conviction to abide by the regulations. There is always a compromising altitude when the law-enforcer is also an extension person. Although the Fisheries Acts clearly state the laws and penalties to defaulters, the legal institutions in the respective governments are ignorant of the Fisheries' sector policies and thus convicting a defaulter has always been a problem. In Tanzania, the sector has recently decided to train prosecutors for the sector to overcome the problem.

Under decentralization policy in Tanzania and Uganda, the Fisheries assistant staff (Tanzania) or fish guards (Uganda), are directly under the District or local governments, and are more taxed with revenue collection for the districts through licensing, boat registration and fish sells than management issues.

7.6.2.2 *Poor infrastructure and lack of facilities*

The majority of landing sites are in remote areas with very poor roads that are accessible only during the dry season, but still with difficulty. Currently substantial fishing for Nile perch is going on around the islands and almost permanent camps are established. The Fisheries staffs lack boats and outboard engines to reach such landings for monitoring and surveillance.

7.6.2.3 *Poverty and Corruption within the community*

Low-income to fisheries staff in all the three countries has rendered them susceptible to corruption. Instead of enforcing the regulations, the staffs collude with the offenders to continue with the practise provided he/she is given a certain percentage of the income accrued. For example, in Tanzania a beach seine owner can agree with a fisheries staff to remit a certain amount of money every month and continue to use the gear. Whenever a patrol for illegal gear is planned, the offender is confidentially informed not to use the gear on the specific day.

Poverty within the community is also encouraging the use of illegal gears and breach of the laws. Poor fishermen can afford the relatively cheap under-mesh nets, hooks or they use beach seine, which are not easily stolen. Few rich persons in the community can buy the legal gears and patrol the fishing grounds. The relatively poor consumers can only afford juveniles of Nile perch, which are currently cheaper than any other fish product. The poor traders with minimum capital are the ones creating a market for the juvenile fish caught by illegal gears.

7.6.2.4 *Sense of ownership*

With the open access system in Lake Victoria fisheries, where anyone has a right to exploit the resources provided he/she has a fishing license, sense of ownership and therefore responsible fishing altitude has eroded in the fishing community. With the prominent investors controlling the Nile perch fishing industry, the marginalized local fishing community atitudes have changed. Some believe that the lake has been sold to some foreigners (SEDAWOG, 1999b). Sense of being deprived of ownership, which traditionally has been in the community (Geheb, 1997), renders them very irresponsible in the fishing practises. Due to intense competition for fish to meet the demand of the processing plants, the prominent fishers are also competing to harvest more, factories to buy more than a nearby factory or in the other country. The issue of sustainability of the resource only arises if all the investors are concerned. Thus failure to have clear policy on the utilization of resources is a serious pitfall in the implementation of the regulations.

7.6.2.5 *Insufficient scientific backing*

Most of the regulations in the Fisheries Acts of the respective countries were formulated way back before the transformations in the fisheries of Lake Victoria or were based on very limited scientific findings or for specific species. For example the regulation on closed area and closed season, which addressed specifically the tilapiines in the early 1960. The uses of 5 inches as minimum mesh size was also from the first gillnet survey in Lake Victoria (Graham, 1929), although amended in the 1990s. Other key parameters on the fish stocks were from very localised research in the three countries. The basic information for management, the CPUE and the stock sizes are either unreliable or missing. Lack of reliable and long term monitoring scientific information made both managers and resource users reluctant to enforce and implement the regulations.

7.7 MANAGEMENT OPTIONS AND STRATEGIES FOR SUSTAINABILITY OF THE NILE PERCH FISHERY

7.7.1 Management approach and institutional framework

The need to manage Lake Victoria as an entity has been identified above, and it is considered that an ecosystem management approach is crucial for a healthy lake. The sustainability of the Nile perch fishery will very much depend on the right choices of the approach taken for management, how each of the other components in the ecosystem are utilized and managed, the environmental and biological interrelationships and the socio-economic activities linked to the fishery. The Fisheries Management Plan prepared for Lake Victoria Fisheries Research Project (LVFRP) provides a wide coverage (Bwathondi *et al.*, 2001). The plan also stipulated the different options for management of natural resources and elucidated on the need to combine different approaches taking into consideration the perturbations occurring in the lake, both in the habitat and in the biological production systems. Due to the complexity of the ecosystem, the abrupt changes which have been occurring and insufficient scientific information on the interactions between all components of ecosystem both adaptive and precautionary management strategies need to be applied. Adaptive management approach will allow rapid adjustment of options and regulations undertaken as changes in the stock size or in the socio-economy sector occur, while the precautionary management approach will allow actions for management to be taken before sound scientific evidence is available and linked to continuous monitoring. With the adaptive approach the regulations can be changing accordingly (FAO, 1997; 1995; King, 1995; Hilborn & Walters, 1992). However, with the current set-up in the fishing industry and the level of awereness on management issues, it is almost impossible to implement adaptive approach in the management process of Lake Victoria fisheries. A functional system may be a principal start and access and ownership may need to be defined before the advocated approach become viable.

Co management is singled out as the most effective strategy for the implementation of the specified approaches. Co management is a collaborative arrangement between the state and a community of the resource users aiming to conserve a resource base (Geheb *et al.*, 2002) or being a system that employs two or more groups of stake holders in the management of a resource base, and in which all stake holders have equal power to make decisions (Gehab & Crean, 2000). It considers that the communities or different parties in Lake Victoria under adaptive and precautionary approach would respond faster to any indicator of overexploitation or any detrimental activity than waiting for the existing top-bottom system. Given legal recognition, beach level communities can make bylaws to serve-guard the resources while negotiations and interactions continue at different levels for harmonization of the initiatives taken. The Fisheries Management Plan (Bwathondi *et al.*, 2001) and Geheb *et al.*, (2002) gave a comprehensive over-view on the organisational set-up of co-management in Lake Victoria and the responsibilities of the different stakeholders at each level of cooperation. The institutional set-up within the co-management strategy of implementation is summarized below (Fig.7.1).

The committees at each level have to be nominated by the stakeholders themselves and should have complete representation of the different social groups in that community/category. Trust, transparency and equity should exist in discussions to enact, implement and enforce regulations. Mangement efforts are geared towards sustainability of the fishing industry, and it is expected the processing factories to have a supporting role as are the ones with high investments and profit from the industry. The Lake Victoria Fisheries Organisation should be the organ to bring the National Committees together. The Directors of Fisheries and Research Institutes of the three countries, as well as government representatives from the ministries responsible for fisheries; other international NGOs and project leaders as well as a representative from the East African Community and the East African Bank will be members. Resolutions made at national committees on issues regarding the management of the fisheries will be harmonised at the regional committee level.

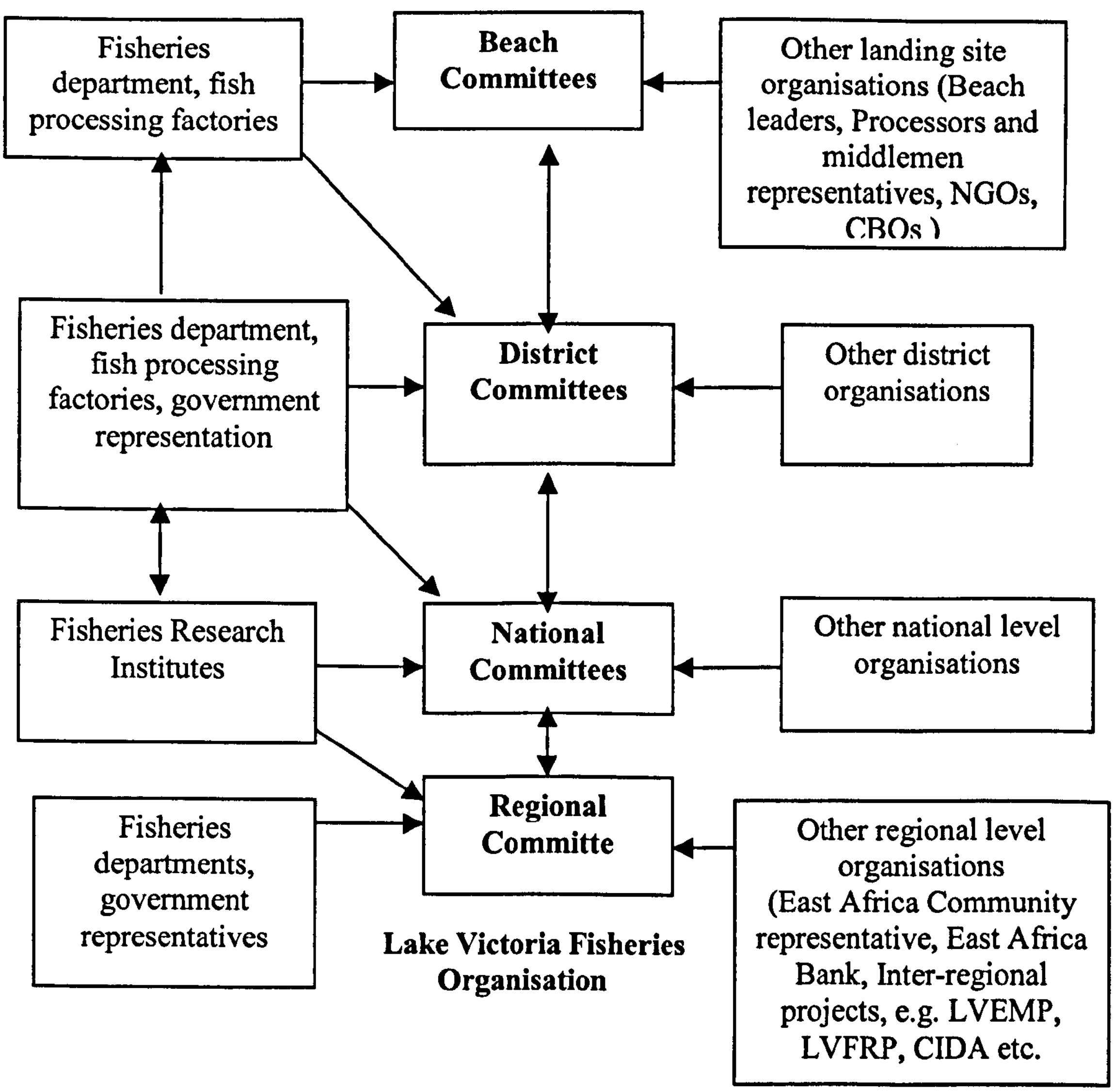


Figure 7. 2 Institutional framework for Co management strategy in management of Lake Victoria Fisheries (From Geheb et al., 2002 with some modifications)

7.7.2 Management options and implementation

To ensure the sustainability of the Nile perch fishery and all the other fisheries of Lake Victoria, the institutional set-up needs immediate attention to accommodate the co-management strategy and operate the combined adaptive and precautionary approach. At each level of the institutional framework outlined above, roles and responsibilities have to be well identified and accepted by all stakeholders (Geheb *et al.*, 2002). This must be the first action the management initiatives in Lake Victoria have to endure. Inception of such a framework will automatically bring aboard the implementation of other options/regulations to safeguard and responsibly use the resources, as each level comprehends its role. Regulations without a strategy for implementation within a functional system are mere policies. The following final section therefore the current study suggests options for a functional system and outlines the priority areas and the implementation in a form of project identification.

7.7.2.1 *Instigation of a functional MCS system under Co-management strategy*

In setting fisheries policy, the previous records of success and failure in monitoring, control and surveillance in the fisheries of the region, State or local area are important in evaluating the likelihood of success of the approaches proposed in the new policy. (FAO, 1997. *FAO Technical Guidelines for Responsible Fisheries.* Fisheries management (2.2.4(ii) 34 p.). It is evident from the review above, that failure in monitoring control and surveillance is a main drawback in the management of Lake Victoria fisheries. It is therefore of paramount importance to set a proper functional system of MCS before trying to make more regulations which will not be implemented. The existing regulations take care of almost all the over-exploitation prevalent in the fisheries, but since the colonial era, the phenomenon has been repeating itself: Over-exploitation of tilapiines was followed by riverine species, followed by other endemic table fishes, then the haplochromines, and currently the Nile perch and signs of overfishing for dagaa and *O. niloticus*. The fisheries of Lake Victoria are actually not managed at all (Fryer, 1972; 1973). To overcome this, initiatives have to be undertaken by the current administrative boards to bring the different stakeholders together, to create awareness and change the preconceived ideas that management is for the Fisheries Department staff alone. With meetings for discussions and interactions, the respective stakeholders themselves will appoint the committee at each level, and roles and responsibilities must be identified. Each level proposed will be involved with MCS to different degrees.

The Beach Committees will ensure that all fishermen in their area have licences and are using the right gears and right practises. They can decide on byelaws in their stakeholder meetings, and how to punish offenders. The representatives from the District Committees and Fisheries Departments can give technical advice whenever required, and guidelines whenever the beach committee may be diverting from the overall sector policies. Monitoring can also be done at the beach level by creating a system of reporting on catches or gear size and amount per each fisherman. A researcher from the research institutions or a member of staff from the Fisheries Department can collaborate with the committee in data collection. At the district level, the committee will be responsible for bringing different beach committees together and harmonising decisions at the district level. At national level, districts within a country are brought together. The regional level committee under the guidance of LVFO will harmonise decisions that apply to the whole lake. At each level a patrol team with a patrol boat could be provided for surveillance whenever the need arise, but the beach committee will be involved day-by day with MCS by using the fishing communities, each one becoming the police of the other, while a patrol team to ensure safety of the fishermen could operate, especially during rough weather.

To ensure operational funds are available, a system of fisheries trust –funds at all levels can be established. Each stakeholder can contribute in relation to his/her income from the fisheries. For example, donor organisations and the processing factories could allocate a budget to assist in the initiation process and also for the operations. Fishermen can give to the fund a fish or more each day depends on the catch. So far the BMUs currently operating in some Tanzanian beaches are using the contribution of fish to meet the operational costs. It has to be stressed that trust and transparency should exist at all levels to combat existing corruption in the sector.

Project Title: Integration of all stakeholders in co-management for the Lake Victoria Fisheries.

Goal/Overall objective

To adopt co-management as a functional mechanism for establishing a MCS system to help manage the fisheries of Lake Victoria.

Specific objectives

- To devolve the existing top-down administrative framework in the fisheries sector to a bottom –up framework were beach committees, district, national and regional committees will have equal power and legal status in the process of policy formulation and implementation.
- Create face-to face negotiations in formulation and complying with byelaws for a given community or for the fisheries policies/regulations.
- To identify roles and responsibilities at each level for MCS in the implementation of regulations/policies for Lake Victoria fisheries.

Inputs

- Finances for the community/stakeholder meetings and trainings, and for committee meetings at different levels.
- Manpower, all stakeholders have to sacrifice their time and be committed to the whole process; while for the initiation, consultants may be needed to offer training at all levels for co-management principles in the adaptive and precautionary management approaches.
- Equipments for the different activities especially for MCS and transport both on land and water.

Activities

- Identification of different stakeholders at each level.
- Bringing stakeholders at different levels together and train them on the approach and strategy earmarked for fisheries management in the lake.
- Formation of the different committees at different level and identify their role and responsibility by discussions and negotiations.
- Initiate a system of stakeholder meetings at each level to discuss management related issues and agree on how MCS could be handled.
- Ensure the agreed MCS system is put in operation and is functional.
- Initiate a system of revolving funds within the sector at different levels and from the respective governments, NGOs, fish processing factories and international projects within the region.
- Monitor the continuity of the whole system and the success or failures.
- Through negotiations rectify drawbacks.

Outputs

- Established fisheries management committees at the beach, district, national and regional levels.
- Sensitised stakeholders on the principles of co-management and adaptive and precautionary management approach in fisheries.
- Established functional system for MCS.
- Established forums for negotiations and evaluating the success of management options enacted.

Indicators

- Functional management committees at the four levels of administration.
- Partnership in management of the fisheries, and the guidelines of CCRF (Code of Conduct for Responsible Fisheries) observed.
- A functional system of MCS at the beach level.
- A system for revolving funds or trust funds in place and operational funds for the different management activities available.

7.7.2.2 *Control/reduction of fishing effort*

With a functional MCS system then the effectiveness of the existing regulation can be measured and adjustments done accordingly. It is therefore crucial to ensure implementation of the existing regulation though the functioning MCS system: (i) effect the minimal mesh size regulation of five inches (127 cm), and encourage fishers to use gillnets of six and seven inches; (ii) complete eradication of beach seines and other illegal fishing practises (iii) harmonise and implement the existing regulation in Uganda of minimum size of fish to be landed; (iv) the existing closed area and season regulation needs some updated inventory of the areas especially from indigenous knowledge, that be harmonised regionally. For Tanzania such an inventory was done under LVEMP by the fisheries management and administration subcomponent.

Due to the current excessive effort targeting the Nile perch stock, findings of the current study suggested a reduction in effort by half. Due to the socio-economic implications of such a measure gradual reduction in effort has to be considered through deliberate interventions under the co management strategy through a functional MCS system to ensure: (i) fish processing factories with the capital should play a leading role to ensure responsible fishing is conducted; they can assist beach committees with patrol boats as well as supporting data collection for the monitoring of the health of the fisheries (ii) entry to the fishery be controlled, each fishermen should be allowed a maximum number of canoes and any extra canoes already owned should be heavily taxed; (iii) there should be maximum number of gillnets per boat so as to control effort and limit the problems of unmonitored increase in effort, (iv) Slot size regulation to processing factories should be introduced. To protect the spawning stock: (v) use of long lines for Nile perch should be discouraged. Limiting the hook sizes can be difficult to implement. However, with the ban of beach seines, it is expected that use of long lines will be limited as getting bait will be more difficult and time consuming. With harmonisation of regulations within the regional committee under co-management, (vi) it should be possible to monitor and regulate effort deployed in respective national waters and observe the national boundaries. So far effort in Kenyan waters and the use of illegal gears surpasses the other countries. These must be among the issues to discuss openly under the regional committee.

To ensure effective MCS on the outlined issues relating to use of illegal gears and excessive effort, a pioneer project to register the fishermen and their gears and their landing beaches and issue identities should be conducted. This will help tracking fishermen's movements and control the increase in gears as well as theft and conflict. A beach committee should have the power and legal rights to prohibit a fisherman from fishing if not complying to regulations. A fisherman who is not registered with any beach committee will not be allowed to sell his catch. In co-management, the traders and processors should cooperate to facilitate the implementation of byelaws and regulation. With registered membership in a beach community, it is easy to have occasional meetings to discuss and agree on issues pertaining to management. For security purposes, the law offenders could confidentially be reported to the management of the BMUs for disciplinary measures.

Project title: Development of a modified access control system for the fisheries of Lake Victoria through beach community membership

Goal or overall objective

To control effort and ensure fishermen comply with responsible fishing for sustainability of the fisheries.

Specific objectives

- To eliminate illegal fishing and illegal gears.

- Control increase in effort and limit entry.
- Monitor fishermen's migration to ensure conformity and involvement in co-management.
- Limit or eliminate theft and conflict between the fishers.
- Create conditions for a more effective MCS system.
- To facilitate the collection of fisheries statistics and bi-annual frame surveys.

Input

- Financial and human resources in mobilising and training fishermen on co-management and the benefits of community membership.
- Equipment and transport for the beach committee to ensure all fishermen within their area are registered and the reported gears checked.
- Research information on effort (the number of nets per boat and number of boats per fishermen) in relation to national waters and type of fishery.

Activities

- Training sessions to communities on co-management.
- Registration of fishers and gears.
- Issuing of membership identity cards.
- Surveys to counter-check gears and vessels ownership and legality.
- Patrols by beach committee members to ensure compliance of all fishermen to the regulations.
- Frequent checks in fish processing factories to ensure the slot size regulation is observed.

Outputs

- Fishermen identities produced and harmonised for all the lake.
- Illegal fishing gears and practises banned.
- Access to fishing regulated and processing factories disengagement from fishing.
- A functional MCS system established.
- Laws/regulation and byelaws initiated at beach level communities and harmonised through the different committees.

Indicators

- Increased harmony in the communities and reduction in gear theft and piracy in the lake.
- Increased size of fish landed and in the long-term increase in CPUE.

- Increased number of spawners, recorded through fisheries independent surveys for monitoring.

7.7.2.3 *Harvesting strategies in relation to target stocks/species and their abundances.*

To ensure ecosystem stability through the trophic relations: (i) fishing for haplochromines and *Caridina* should be banned; and (ii) responsible fishing for dagaa and tilapiines should be implemented; (iii) The other endemic species that are recovering should also be protected from excessive fishing pressure, until their abundances are proved to sustain fishery. As it was found in this study, some changes in some of environmental parameters such as increase in water transparency and disappearance of the permanent oxycline layer, although associated with complex interactions in the system, a complete food web also plays an important role. Haplochromines, *Caridina* and dagaa are currently under threat from fishing Witte *et al.*, 2002; Budeba & Cowx, 2000; Othina & Tweddle, 1999), but they also form very important links in the food web as well as being the main prey items in the diet of Nile perch.

Sustainability of the Nile perch fishery will also depend on the availability and sustainability of its prey species. Fishing effort directed at dagaa was found to have increased considerably, especially in Kenya and Tanzania. This does not only affect the dagaa, but as pointed out in this study, a substantial amount of haplochromines and *Caridina* are caught by the dagaa seine nets and lift nets. It was learned from the fishermen that there are specific periods of the lunar-cycle when more haplochromines are caught and specific months of the year and in specific fishing grounds when more *Caridina* are caught. With a co-management strategy and adaptive management approach, the fishing community can comply to protect these areas and decline from fishing during the specific periods. As the adaptive and the precautionary management approaches go on, a project could be running concurrently to assess the stock abundances, the spawning and nursery areas, the temporal and spatial distribution and the impact of fishing practices and the gears used. This should be a research project monitoring the catches from each gear and at the same time assess their biomass, population structure and distribution and adjust the measures accordingly.

Project title: Fisheries dependent surveys to assess species composition in catches, fishing grounds and time for development of fishing strategies to protect less abundant or endangered species

Overall objective

To ensure ecosystem stability through conservation of biodiversity for optimisation of the fisheries for commercially important species.

Specific objectives

- To collect catch and effort data for relative abundances of species.
- To assess the effect of different gears to the targeted species and to other species.
- To assess changes in catch structure in different areas and seasons for management purposes.

Inputs

- Financial and human resources to run the surveys.
- Equipments for weighing and measuring fish.
- Transport both on water and land to ensure thorough coverage of landing beaches.

Activities

- Beach surveys to collect catch and effort data.
- Visits to dagaa landings during different lunar-cycles and assess catch composition by weight.
- Assess bycatches in the other commercial fisheries.
- Advise on the appropriate time and areas for dagaa fishery so as to minimize capture of haplochromines and *Caridina*.

Outputs

- Inventory of gears used.
- Accurate records of CPUE.
- Up-to-date records of species abundances and their variations in area and time.
- Behaviour of different species in relation to distribution and vulnerability to different fishing gear.
- Composition of catches in relation to spawning time, area and feeding and nursery areas.

Indicators

- Fishing strategy to protect less abundant and minimize bycatch.
- Protected nursery and breeding areas.
- Accurate records of CPUE and the variations for continuous amendments within the adaptive and precautionary management approaches.
- Increase in species diversity and a more stable ecosystem reflected in increase in catches.

Project title: Fisheries independent surveys for limnological and biological assessment of ecological and trophic interrelations and the life history strategies of the commercially important fish species.

Environmental parameters have a profound influence in the life history patterns of species in a given habitat which in-turn influences the trophic interactions and the overall ecological interrelations. Different life stages can occur either inshore or offshore, at different water depths or at different times of the year, influenced by either temperature or oxygen or nutrients, which influence the growth of phytoplankton and composition and the zooplanktons thereafter. The composition, abundance and distribution of these will influence the distribution and abundance of higher trophic levels in the food web. As analysed (Chapter Two), rainfall patterns influence seasonal changes in limnological parameters and in turn the abundances and distribution (Chapter Four). Changes in population structure induced by fishing influences the trophic interactions especially for species with ontogenic shifts in feeding behaviour like Nile perch. Integrating biological and environmental findings with information on catch and fishing effort make possible the establishment of the status of the resources to determine the levels at which it can be sustainably exploited. Such initiatives have been going on under the Lake Victoria Fisheries Research Project (LVFRP), the present study being part of that, and it is therefore important to advance such initiatives for management purposes.

Overall Objective

To have a continuation process of gathering the basic information needed on species interactions, abundances, fluctuations and the possible causes of the variations for management purposes.

Specific objectives

- To gather information on rainfall and limnological parameters and how they influence changes in the lake ecosystem. Availability of such data will help to eliminate other courses than fishing to fluctuations in sock abundances and recruitment.
- Identify the breeding and nursery areas for commercially-important species, especially Nile perch.
- To monitor the changes in abundance of the main prey species for Nile perch and how that influences changes in Nile perch biomass
- To estimate species abundances at all levels in the trophic interactions in Lake Victoria for development of an ecosystem model so as to predict possible changes in the fishery for management purposes

Input

- Finances and manpower.
- A research vessel equipped with facilities and equipment for all the activities.
- Outboard engines canoes and gillnets to cover shallow areas.
- Both bottom water and mid-water/pelagic trawl nets and accessories.
- Collaboration with the Meteorological Departments for rainfall and surface temperature data.
- Training on some aspects of the SEABIRD software and ECOPATH.

Activities

- Trawl surveys both bottom and pelagic, to assess species abundances.
- Feeding and reproductive/fecundity studies.
- Limnological studies.
- Larvae and juvenile sampling to identify breeding areas and to assess recruitment patterns.
- Gillnet surveys in shallow areas and in rocky substrata.

Outputs

- Records on limnological parameters and patterns.
- Detailed information on feeding, reproduction and abundance estimates of main commercial species.
- Relative abundance indices of all the aquatic ecosystem biotic components.
- Breeding and nursery areas of commercially important species established.

Indicators

- Success of different management regulations assessed and options amended accordingly.
- Stock biomass and other scientific information to back management options available.
- Breeding and nursery areas demarcated.
- Recruitment patterns and how they are related to the spawning and changes in stock abundance.

7.7.2.4 *Monitoring of socio-economic shifts in the fishery sector and developing a system to control their adverse impacts to the community*

To understand fisheries systems, the social and cultural features and the economic characteristics of the people and communities within the system have to be well understood (FAO, 1997). One of the hindrances in implementing the fisheries regulations in Lake Victoria is the shift of control of the resources and imbalance in economic benefits accrued from the industry. Fish processing factories with few successful fishermen and traders are now in control while the less successful fishermen are edged out and turn to illegal fishing or increase pressure on the other species. In the marketing and processing sector, those with minimal capital and women are the ones buying the juveniles of Nile perch and the frames, but fishmeal factories are further denying them of any economic means in the sector. The poor sector of the community is even further disadvantaged for the benefit of those with capital. Co-management support should provide an effective control for such activities to give them a livelihood. The social economic issues have to be addressed and solutions formulated to resolve the dilemma. There should be a genuine political will to consider alternative strategies to the excessive dependence of different stakeholders on the industry, as currently there is a conflict not only on equity of wealth distribution but also between constraint of sustainability with social and economic priorities (Cochrane, 2000).

The control of effort by limiting number of canoes per fisher and nets per boat, and membership in beach communities; should give priority to the traditional fishermen. A system of credits to ensure they acquire the right gear should also be developed. A thorough marketing study is needed to find a balance to allocate processing quotas to fish processing factories according to the capacity so that some fish could be left for the local processors and traders and for local consumption. This would improve or minimise the socio-economic gap in the sector and ensure enough protein for the people to meet the food security policy of the sector. A socio-economic project can be formulated to address these needs, while the beach committees can identify the disadvantaged individuals. A revolving fund within the committees could be used to help such individual while training and alternative employment opportunities are sought.

Under the LVFRP a number of socio-economic studies were conducted such as marketing and nutritional studies to establish the marketing structure and distribution of benefits in Nile perch fishery, co management studies to assess the possibilities and the existing infrastructure for the implementation of co management approach in the management of Lake Victoria fishery. There is a need to advance such studies to improve the understanding on the socio-economic sector of Lake Victoria fisheries for management purposes.

Project title: Assessment of Social-economic impact of management options and possible solutions

Overall objective

Limit socio-economic gap between different social groups and improve food security for the local communities.

Specific objectives

- Identify the economic and social dependence levels on the fishery for the different stakeholders.
- Study and assess how the limited resource can be allocated to meet the demand of different markets, local and international without jeopardizing the other.
- Identify alternative sources of employment and income to different groups of stakeholders.
- Provide credits through a revolving fund in the committees to replace illegal fishing gears and assist small-scale traders and processors to meet quality products of high economic value.

Inputs

- Finance and manpower.

- Transport both on water and land.
- Transparency from different stakeholders on their income and livelihood activities.
- Transparency from fish processing factories of the capacity and running cost of the factories.

Activities

- Surveys in the communities to identify different stakeholder social groups and their income.
- Analysis of resource and market options so as to supply both local and international markets.
- Analysis of supply and demand and capacity of both fish processing and fishmeal processing factories for advice on quotas and limit to animal feeds.
- Training of disadvantaged group on alternative employment and sources of income.
- Training on business and financial management aspects for credit beneficiaries.
- Continuous monitoring of some key social-economic indicators, such as demographic changes, movement of people, trends in markets and costs in relation to supply and demand in the fishery related products so as to assess the impact of the management options.

Outputs

- Socio-economic structure for different stakeholders.
- Disadvantageous groups identified and trained.
- Credit funds available and illegal gears replaced.
- Possible processing quotas for the fish processing factories.
- Control on what type and kind of species or products can be processed for fishmeal for animal feeds.

Indicators

- Harmony of different social groups in the community.
- Controlled use of illegal gears, and theft and piracy minimized.
- Improved income and food security.

7.8 CONCLUSION

The Nile perch fishery in Lake Victoria is under a serious biological overexploitation, social conflicts and prone for social-economic disaster unless the excessive effort and growing economic dependence on the industry are immediately addressed. Although the stock size and the recruitment pattern do not indicate danger of collapse, the size composition of the population (fisheries independent data) and structure of the catch (fisheries dependent data) in relation to the existing fishing practises poses a serious threat. The sustainability of the fishery is further questionable when size at first maturity is considered in conjunction to the amount of juveniles harvested. The varying patterns of abundance and distribution, greatly influenced by environmental conditions, do not indicate any offshore fish resources not utilized. The aggregation behaviour of Nile perch with the longevity of its life span adds to the possibility of the fishery to collapse. The open access system in the Lake Victoria fisheries, which has eroded any sense of responsible fishing, coupled with a growing demand for export as well as local market is the underlying cause for the collapse of the fishery.

The problems in achieving sustainable exploitation in Nile perch fishery can be very challenging as the fishery developed to overexploitation without any control in access and fishing effort. Also scientific information has not been adequately integrated to management policies. However, the challenge is not insurmountable, the key problem of open access needs an immediate address. It has to be emphasized that, the social and political difficulties of controlling access to fishery resources is the underlying reason for the existing biological, ecological economic and social crisis in the sector (Cochrane, 2000). The difficulties in resolving the underlying dependence on the Nile perch fishery should not be undermined, particularly due to lack of alternative opportunities and with no social welfare. The revenue collected from the industry, especially from the exports should be channelled back in a special programme of subsidy for alternative livelihoods especially to those who have traditionally relied on the fishing industry. Involvement of all stakeholders in the management process with fishing community taking the leading role will create a sense of ownership and this implies duties and responsibilities. This will also identify the actual fishermen and eliminate or limit the involvement of fish processing factories in the harvesting process. Slot size or size of fish to the fish processing factories while CMS (Control, Monitoring and Surveillance) system is observed by the community under co management is another immediate remedy to the growth overfishing and possible collapse of the Nile perch fishery. The limited numbers of projects outlined in this chapter are presented in the order of priority areas. However, the management plan for Lake Victoria fisheries (Bwathondi *et al.*, 2001) is more comprehensive. To achieve sustainable exploitation in the fishery of Nile perch and other fish resources in Lake Victoria, scientific advice based on biological, social and economic considerations have to be integrated at all levels of the co-management process in the development of management policies.

Uncertainty in any management decisions taken cannot be ruled-out (Cochrane, 2000; Ludwig *et al.*, 1993). Likewise the scientific findings have an inherent variability due to the complexity of ecological systems and the fluctuation in the hydrographical and limnological factors and the instabilities outlined for Lake Victoria ecosystem. Changes in the political, social and economic system also have different impact to the fishing industry and therefore to management decisions. It is therefore important to adopt the precautionary and adaptive management process, which takes into consideration uncertainty and thus leaves room to update scientific findings and modify the management strategies accordingly. Sustainable exploitation of Nile perch fishery will also guarantee sustainability of the other fisheries of dagaa and tilapiine, as any displaced fishermen from Nile perch turns to the other two fisheries as alternative livelihood. The overall impact will be a well-managed rational and sustainable Nile perch fishery, which will continue to provide jobs, income, food and foreign exchange.

REFERENCES

Abila R.O. (1994) The Socio-economics of Nile perch Frames Marketing in Kisumu. Proceedings of the KMFRI seminar on the Utilization of Nile perch By-products, Kisumu, June 7-10, 1994, Kenya marine and Fisheries Research Institute, Kisumu.

Abila R.O. & Jansen E.G. (1997) From Local to Global markets – The fish exporting and Fishmeal industries of Lake Victoria. *IUCN Eastern Africa Programme, Report No. 2* Nairobi.

Acere T.O. (1985) Observations on the biology, age, growth, maturity and sexuality of Nile perch, *Lates niloticus* (L.), and the growth of its fishery in the northern waters of Lake Victoria. *FAO Fisheries Report* **335**, 42-52.

Allen K.R. (1971) Relation between production and biomass. *Journal of the Fisheries Research Board of Canada* **28**, 1573-1581.

Akiyama T., Kajumulo A.A & Olsen S. (1977) Seasonal variations of plankton and physico-chemical condition in Mwanza Gulf, Lake Victoria. *Bulletin of Freshwater Fisheries Research Laboratory* **27**, 49-61.

Arunga J. (1981) A case study of the Lake Victoria Nile perch *Lates niloticus* fishery. In: Proceedings of the Workshop of the Kenya Marine and Fishery Research Institute on aquatic resources of Kenya, 13-19 July 1981, Mombosa. *Kenya National Academy for the Advancement of Arts and Science*, pp. 165-183.

Asila A. (2001) Selectivity of gill nets on Nile perch populations of Lake Victoria, Kenya. Masters thesis submitted to Moi University, Kenya.

Asila A.A. (1999) Selectivity of gillnets for Nile perch, *Lates niloticus* (L.) in Lake Victoria, Kenya. In: I.G Cowx and D Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 92-98.

Asila A.A. & Okemwa E. (1999) Growth parameters for *Lates niloticus* (L.), *Bagrus docmak* (Forsskal), *Oreochromis niloticus* (L.), *Clarias gariepinus* (Burchell) and *Synodontis* species derived from tag returns. In: I.G Cowx and D Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 204-207

Asila A.A. & Ogari J. (1988) Growth parameters and mortality rates of Nile perch (*Lates niloticus*) estimated from length-frequency data in the Nyanza Gulf (Lake Victoria). In:S. Venema, J. Moller-Christensen and D. pauly (eds). Contributions to tropical fisheries biology. *FAO Fisheries Report* **389**, pp. 272-287.

Bazigos G.P. (1974) The design of fisheries statistical surveys – inland waters. *FAO Fisheries Technical Paper* **133**, 122 pp.

Beadle L.C. (1974) *The Inland Waters of Tropical Africa.* Longman, London. 365 pp.

Beauchamp R.S.A. (1961) *East African fisheries.* Corona, *13*(2), 57-60.

Beauchamp R.S.A. (1956) The efficient utilisation of the fisheries of Lake Victoria. *East Africa Fisheries Research Organisation Report* 1955-1956, pp. 1-7.

Begenal T.B. (ed.) (1978) *Methods of Assessment of Fish Production in Fresh Water.* IBP handbook No. 3. Blackwell Scientific Publications. 365 pp.

Begon M. & Mortimer M. (1986) *Population Ecology A Unified Study of Animals and Plants.* 2nd edition. Oxford: Blackwell Scientific Publications. 220 pp.

Begon M., Harper J.L.& Townsend C.R. (1986) *Ecology individuals, populations and Communities*. Oxford: Blackwell Scientific Publications. 876 pp.

Bergstrand E. & Cordone A.J. (1971) Exploratory bottom trawling in Lake Victoria. *African Journal of Tropical Hydrobiology and Fisheries* **1**, pp. 13-23 illustrations.

Bernacsek G.M. (1986) Kenya, Tanzania and Uganda. Evaluation of statistical services for Lake Victoria fisheries. *Mission report.* FAO/CIFA/Sub-Committee for the development and management of the fisheries of Lake Victoria. September 1986. 25 pp.

Beverton R.J.H. (1992) Patterns of reproductive strategy parameters in some marine teleost fishes. *Journal of Fish Biology* **41**(B), 137-160.

Beverton R.J.H. & Holt S.J. (1966) Manual of methods for fish stock assessment. Part II. Tables of yield function. *FAO Fisheries Biology Technical Paper,* **38** (Rev. 1), 67 pp.

Beyer J.E. (1989) Recruitment stability and survival – simple size-specific theory with examples from the early life dynamics of marine fish. *Dana*, **vol. 7** pp. 45-147.

Bhattacharya C.G. (1967) A simple method of resolution of a distribution into gaussian components. *Biometrics* **23**,115-135.

Bokea C. & Ikiara M. (2000) The Macro-economy of the export fishing industry in Lake Victoria (Kenya). Socio-economics of the Lake Victoria fisheries. *IUCN Eastern Africa Programme Report* No. **7** Nairobi.

Bon J. & Ibrahim K.H. (1975) Small fur could boost the fish harvest from Lake Victoria. *Fishing News International* **14**(70), 32 – 33.

Borgstrøm R. (1992) Effect of population density on gillnet catchability in four allopatric populations of brown trout (*Salmo trutta). Canadian Journal of Fisheries and Aquatic Science*, **49**, 1539-45.

Bruton M.N. (1990) The Conservation of the fishes of Lake Victoria, Africa: an ecological perspective. *Environmental Biology of Fishes* **27**, 161-175.

Budeba Y.L. & Cowx I.G. (2000) The role of *Caridina nilotica* (Roux) in the Lake Victoria fisheries with reference to *Lates niloticus* (L.). In: Proceedings of the symposium "Lake Victoria 2000: A New Beginning", Jinja, 16-19 May 2000.

Budeba Y.L. & Mous P.J. (1995) Fisheries statistical service system and governmental framework. In: F. Witte and L.T. van Densen (eds) *Fish Stocks and Fisheries of Lake Victoria: A handbook for field observations*. Samara Publishing Limited, pp. 173-186.

Bundy A. & Pitcher T.J. (1995) An analysis of species changes in Lake Victoria: did the Nile perch act alone? In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes*. Chapman and Hall, London, pp. 111-135

Bwathondi P.O.J., Ogutu-Ohwayo R. & Ogari J. (2001) Lake Victoria Fisheries Management Plan. I.G. Cowx and K. Crean (eds). *LVFRP Technical Document* No. **16**. LVFRP/TECH/00/16.

Bwathondi P.O.J. (1990) The state of Lake Victoria fisheries, Tanzania sector. In: CIFA. Report of the fifth session of the sub-committee for the development and management of the fisheries in Lake Victoria, 12-14 September 1989, Mwanza, Tanzania. *FAO Fisheries Report* **430**, 29-35.

Bwathondi P.O.J. (1985) The future of the fisheries in the Tanzanian part of Lake Victoria in view of the predominance of Nile perch *Lates niloticus*. *FAO Fisheries Report* **335**, 143-145.

Caddy J.F. & Bazigos G.P. (1985) Practical guidelines for statistical monitoring of fisheries in manpower limited situations. *FAO Fisheries Technical Paper* **257**. FAO, Rome.

Caddy J.F. & Gulland J.A. (1983) Historical patterns of fish stocks. *Marine policy* **7**, 267-278.

Cadwalladr D.A. (1965) The decline in the *Labeo victorianus* Boulenger (Pisces: Cyprinidae) fishery of Lake Victoria and an associated deterioration in some indigenous fishing methods in the Nzoia River, Kenya. *East Africa Agriculture and Forestry Journal* **30**, 249-256.

Carpenter S.R., Kitchell J.F. & Hodgson J.R. (1985) Cascading trophic interactions and lake productivity. *BioScience* **35**, 634-639.

Choat J.H. & Axe L. (1996) Growth and longevity in acanthurid fishes; an analysis of otolith increments. *Marine Ecological Progress*, Series **134**, 15-36.

CIFA (1992) Report of the Sixth Session of the Sub-Committee for the Development and Management of the Fisheries in Lake Victoria, 10-13 February 1992, Jinja, Uganda. *FAO Fisheries Report* **475**. FAO, Rome.

CIFA (1988) Report of the Fourth Session of the Sub-Committee for the Development and Management of the Fisheries in Lake Victoria, 6-10 April 1987, Kisumu, Kenya. *FAO Fisheries Report* **338**. FAO, Rome.

CIFA (1982) Report of the First session of the sub-committee for the development and management of the fisheries of Lake Victoria, 12-14 October 1981, Mwanza, Tanzania. *FAO Fisheries Report* **262**, FAO, Rome.

Clark W.G. (1991) Groundfish exploitation rates based on life history parameters. *Canadian Journal of Fisheries and Aquatic Science* **48**, 734-750.

Cochrane K.L. (2000) Reconciling sustainability, economic efficiency and equity in fisheries: the one that got away? *Fish and Fisheries*, **1**, 3-21

Cowx I.G., Mkumbo O.C., Okaronon J., Getabu A., Muhoozi L., Othina A., Nsinda P. & Tweddle D. (2000) Are Nile perch in danger of extinction? In: Proceedings of the symposium "Lake Victoria 2000: A New Beinning", Jinja, 16-19 May 2000.

Cowx I.G., Muhoozi L., Othina A., Asila A., Nsinda P., Mkumbo O.C. & MacLennan D. (2002) Exploitation patterns in the Nile perch long line fisheries of Lake Victoria. *LVFRP Technical Document* (In preparation).

Cowx I.G. & Tweddle D. (eds) (1999) Lake Victoria Fisheries research project. Phase II. Report of the fourth FIDAWOG workshop held at Kisumu, 16 to 20 August 1999. *LVFRP Technical Document* No. **7**. 211 pp.

Cowx I.G. (1996) The integration of fish stock assessment into fisheries management. In: I.G. Cowx (ed.) *Stock Assessment in Inland Fisheries*. Fishing news Books, Blackwell Science Ltd., pp. 495-507.

Craig P.C. (1999) The von Bertalanfffy Growth Curve: Why a Good Fit is not Good Enough. *NAGA, ICLARM Quarterly Report* **22**(4), pp. 28-29.

Craig P., Choat H., Axe L. & Suacerman S. (1997) Population biology and harvest of the coral reef surgeonfish *Acanthurus lineatus* in American Samoa. *Fisheries Bulletin* **95**, 680-693.

Crul R.C.M. (1989) General information on the catchment area of Lake Victoria. In: *Fish stocks and fisheries in Lake Victoria.* A handbook to the HEST/TAFIRI and FAO/DANIDA regional seminar, Mwanza, January/February 1989. HEST/TAFIRI Report 53, pp. 1-17.

Csirke J. & Sharp G.D. (1984) Reports of the expert consultation to examine changes in abundance and species composition of neritic fish resources. *FAO Fisheries Report* No. 291.

Cushing D.H. (1975). *Marine ecology and fisheries.* Cambridge University press

Cushing D.H. (1968) *Fisheries Biology A Study in Population Dynamics.*The University of Wisconsin Press.200pp.

Dache S.A.O. (1994) Observations on the Fisheries, Growth and Mortality Rate of *Oreochromis niloticus* (Tilapia) in the Nyanza Gulf of Lake Victoria. In: E. Okemwa, E. Wakwabi and G. Getabu (eds) Proceedings of the second EEC Regional seminar on Recent Trends of Research on Lake Victoria Fisheries. 25-27th September 1991, Kisumu, Kenya, pp. 59-66.

Dickson W. (1993) Estimation of the capture efficiency of trawl gear. I: Development of a theoretical model. II: Testing a theoretical model. *Fisheries Research* **16**, 239-272.

FAO (2001) *Inland Fisheries: Ecology and Management.* Complied by R.L. Welcomme. Fishing News Books.358 pp.

FAO (1997) *FAO Technical Guidelines for Responsible Fisheries.* No. **4**: Fisheries Management, p. 82

FAO (1995) *Code of Conduct for Responsible Fisheries.* Rome, FAO, p. 41.

FAO (1992) CIFA, Report of the Sixth session of the Sub-committee for the Development and Management of the Fisheries of Lake Victoria, Jinja, Uganda, 10-14 February 1992. *FAO Fisheries Report* No. **475**, p. 18

Fish G.R. (1957) A seiche movement and its effect on the hydrology of Lake Victoria. *Fisheries Publication London* **10**, pp. 1-68.

Fowler J. & Cohen L. (1990) *Practical statistic for field biology.* John Wiley & Sons Ltd. 227 pp.

Froese R., Lourdes M., Palomares D. & Pauly D. (2000) Estimation of Life History Key Facts of Fishes. *World Wide Web electronic Publication*, *http://www.fishbase.org/dowhload/keyfacts.zip*, Ver.**14.2.2000**, p.9.

Fryer G. (1973) The Lake Victoria fisheries: some facts and fallacies. *Biological Conservation* **5**, pp. 304-308.

Fryer G. (1972) Conservation of the Great Lakes of East Africa: a lesson and a warning. *Biological Conservation,* **4**(4), pp. 256-262.

Garrod D.J. (1961) The selection characteristics of nylon gillnets for *Tilapia esculenta* Graham. *Journal du Conseil International pour L'Exploration de la Mer* **26**, 191-203.

Gayanilo T.C. Jr. & Pauly D. (2001) FISAT II version 0.1.0 Software. FAO-ICLARM Fish Stock Assessment Tools. FAO, Rome, Italy.

Gayanilo T.C. Jr. & Pauly D. (eds.) (1997) FAO-ICLARM stock assessment tools. Reference manual. *FAO Computerized information Series*, No. **8**: Fisheries. 262 pp.

Gayanilo T.C. Jr., Sparre P. & Pauly D. (1996) FAO-ICLARM stock assessment tools. User,s manual. *FAO Computerized information Series*, No. **8**: Fisheries. 126 pp.

Gee J.M. (1969) A comparison of certain aspects of the biology of *Lates niloticus* (Linnaeus) in some East African lakes. *Review of the Zoology and Botany of Africa* **80**, pp. 244-262.

Gee J.M. (1964) Nile perch investigation. *EAFFRO Annual Report.* (1962/63), pp.14-24.

Geheb K., Crean K., Medard M., Kyangwa M., Lwenya C. & Onyango P. (2002) On pitfalls and building blocks: towards the management of Lake Victoria's fisheries. In: K. Geheb and M. T. Sarch (eds) *Broaching the Management Impasse: Perspectives on Fisheries and their management from the Inland Waters of Africa.* Kampala, Fountain Publishers Ltd.

Geheb K & Crean K (eds) (2000) The Co-management Survey: Co-managerial perspectives for Lake Victoria's fisheries. *LVFRP Technical Document* No. **11**. LVFRP/TECH/00/11. The Socio-economic Data Working Group of the Lake Victoria Fisheries Research Project, Jinja. 183 pp.

Geheb K. (1997) The regulators and the regulated: fisheries management, options and dynamics in Kenya's Lake Victoria Fishery. D.Phil. Thesis. Falmer, Brighton, University of Sussex.

Getabu A., Tumwebaze R. & MacLennan D.N. (2002) Spatial and temporal distribution of fish populations in Lake Victoria. A paper presented in the 6th ICES Symposium on Acoustics in Fisheries and Aquatic Ecology. Montpellier, France, 10-14 June 2000.

Getabu A. & Nyaundi J. (1999) Relative abundance and distribution of fish in Kenyan waters of Lake Victoria. In: I.G. Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 63-77.

Getabu A. (1992) Growth parameters and total mortality in *Oreochromis niloticus* (Linnaeus) from Nyanza Gulf, Lake Victoria. *Hydrobiologia* **232**, pp. 91-97.

Goldschmidt P.C. & J.H. Wanink (1993) Cascading effects of the introduced Nile perch on the detritivorous/phytoplanktivorous species in the sublittoral areas of Lake Victoria. *Conservartion Biology* **7**, 686-700.

Gophen M., Ochumba P.B.O. & Kaufman L.S. (1995) Some aspects of perturbation in the structure and biodiversity of the ecosystem of Lake Victoria (East Africa). *Aquatic Living Resources* **8**, 27-41.

Gophen M., Ochumba P.B.O., Pollingher U. & Kaufman L.S. (1993) Nile perch (*Lates niloticus*) invasion in Lake Victoria (East Africa). *Verhandlungen*

Internationale Vereiniging fur theoretische und angewandte Limnologie **25**, 856-859.

Goudswaard P.C. & Ligtvoet W. (1988) Recent developments in the fishery for *Haplochromis* sp. (Pisces, Cichlidae) and Nile perch, *Lates niloticus* (Pisces, Centropomidae), in Lake Victoria. *FAO Fisheries Report* **388**, 101-112.

Graham M. (1929) *The Victoria Nyanza and its fisheries*. Waterlow & Sons, London, England.

Greenwood P.H. (1981) *The haplochromine fishes of the East African lakes. Collected papers on their taxonomy, biology and evolution (with an introduction and species index)*. Kraus International Publications, Munich.

Greenwood P.H. (1974) The cichlid fishes of Lake Victoria East Africa: The biology and evolution of species flock. *Bulletin of the British Museum of Natural History (Zoology)* Suppl. **6**, 1-134.

Greboval D. & Mannini P. (1992). The fisheries of Lake Victoria: review of basic data. UNDP/FAO Regional Project for Inland Fisheries Planning Development and Management in Eastern/Central/Southern Africa (IFIP), Bujumbura. FAO, Rome, RAF/87/099/WP/16/92.

Gulland J.A. (ed.) (1988) Fish population dynamics: the implications for management. Chichester, John Wiley and Sons Ltd., 2nd ed. 422 pp.

Gulland J.A. (ed.) (1977) *Fish Population Dynamics*. John Wiley and Sons Ltd. 372 pp.

Gunderson D.R. (1993) *Surveys of fisheries resources*. Wiley N.Y., 248 pp.

Hamblyn E.L. (1966) The food and feeding habits of Nile perch: *Lates niloticus* (Linné) (Pisces: Centropomidae).*Review of Zoology and Botany of Africa* **74**, 1-28.

Hamblyn E.L. (1962) Nile perch investigation. *EAFFRO Annual Report* **(1961)**, 23-28.

Hamblyn E.L. (1961) The Nile perch project. *EAFFRO Annual Report* **(1960)**, 26-32.

Hart A. & Russ G. (1996) Response of herbivorous fishes to crown-of-thorns starfish *Acanthaster planci* outbreaks III. Age growth, mortality and maturity indices of *Acanthurus nigrofuscus*. *Marine Ecology Programme* Series **136**, 25-35.

Hart A. (1995) Genaral introduction: The impact of species changes in African Lakes. In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes*. Chapman and Hall, London, pp.xxvii-xxxii.

Hastenrath S. & Kruss P.D. (1992) Greenhouse indicators in Kenya. *Nature London* **355**, 503.

Hecky R.E., Bugenyi F.W.B., Ochumba P., Talling J.F., Muggide R., Gophen M. & Kaufman L. (1994) Deoxygenation of the deep water of Lake Victoria, East Africa. *Limnology and Oceanography* **39**, 1476-1481.

Hecky R.E. (1993) The eutrophication of Lake Victoria. *Verhandlungen Internationale Vereiniging fur theoretische und angewandte Limnologie*, **25**, 39-48.

Hecky R.E. & Bugenyi F.W.B. (1992) Hydrology and Chemistry of the African great Lakes and water quality issues: problems and solutions. *Mitteilungen.*

Verhandlungen Internationale Vereiniging fur theoretische und angewandte Limnologie. **23**, 45-54.

Hilborn R. & Walters C.J. (1992) *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainity.* Chapman and Hall. 570 pp.

Holden M.J. (1963) Report on the fisheries of Lake Albert. Uganda Fisheries Department. Entebe. 112 pp.

Hopson A.J. (1982) The biology of *Lates niloticus* (L.) in Lake Turkana. In: A.J. Hopson (ed.) Lake Turkana, A report on the findings of the Turkana Project 1972-1975. (**5**), 1285-1299 pp. Overseas development administration London.

Hopson A.J. (1972) A study of the Nile perch, *Lates niloticus* (L.), in lake Chad. HMSO Overseas Research publications **19**, Foreign and Commonwealth office, London.

Hopson A.J. (1969) A description of the pelagic embryos and larval stages of *Lates niloticus* (L.) (Pisces: Centropomidae) from Lake Chad, with a review of early development in lower percoid fishes. *Zoological journal of Linneaus Society* **48**, pp. 117-134.

Hughes N.F. (1992) Growth and reproduction of the Nile perch, *Lates niloticus*, an introduced predator, in the Nyanza Gulf, Lake Victoria, East Africa. *Environmental Biology of Fishes* **33**, 299-305.

Hughes N.F. (1986) Changes in the feeding biology of the Nile perch, *Lates niloticus* (L.) (Pisces: Centropomidae), in Lake Victoria, East Africa since its introduction in 1960, and its impact on the native fish community of the Nyanza Gulf. *Journal of Fish Biology* **29**, 541-548.

Hughes N.F. (1983) A study of the Nile perch, an introduced predator, in the Kavirondo Gulf, Lake Victoria. Oxford University, Nile perch Project, Oxford.

Hyslop E.J. (1980) Stomach contents analysis: a review of methods and their application. *Journal of Fish Biology* **17**, 411-429.

Hyvärinen P. & Salojärvi K. (1991) The applicability of catch per effort (CPUE) statistics in fisheries management in Lake Oulujärvi, Northern Finland. In: I.G.Cowx (ed.) *Catch Effort Sampling Strategies: Their application in freshwater fisheries management.* Fishing News Books. 241-261 pp.

Ikiara M. (1999) Sustainability, Livelihoods, Production and Effort supply in a declining fishery: The case of Kenya's Lake Victoria fisheries. Thela Thesis. Amsterdam, 1999.

Isarankuru A.P. (1971) Assessment of stocks of demersal fish off the west coast of Thailand and Malaysia. FAO/UNDP, Indian Ocean Programme, Rome, IOC/DEV/71/20. 20 pp.

Katunzi E.F.B. (1990) Aspects of migration, size structure and mortality of juvenile Nile perch in Mwanza Gulf of Lake Victoria. In: P.O.J. Bwathondi (ed.) The prevailing activities on the Lake Victoria basin with particular reference to the lake fisheries. Proceedings of the workshop organized by the European Community under the project No.5100.36.94.401, 8-9 March 1990, Mwanza, Tanzania. Tanzania Fisheries Research Institute (TAFIRI), pp. 72-74.

Katunzi E.F.B. (1985) Current status of the fisheries in the Tanzanian waters of Lake Victoria. In: CIFA. Report of the third session of the sub-committee for the development and management of the fisheries of Lake Victoria, 4-5 October 1984, Jinja Uganda. *FAO Fisheries Report* **335**, pp. 107-109.

Kaufman L. (1992) Catastrophic change in species-rich freshwater ecosystems: the lessons of Lake Victoria. *BioScience* **42**, 846-858.

Kenchington F.E. (1939) observation on the Nile perch (*Lates niloticus)* in the Sudan. *Proceedings of Zoological Society of London* (Series A).

Kitaka G.E.B. (1972) An instance of cyclonic upwelling in the southern offshore waters of Lake Victoria. *African Journal of Tropical Hydrobiology and Fisheries* **1**, 85-92.

King M. (1995) *Fisheries Biology, Assessment and Management*. Fishing News Books. 341 pp.

Kudhongania A.W. & Chitamweba B.R. (1995) Impact of environmental change, species introductions and ecological interactions on the fish stocks of Lake Victoria. In: T.J. Pitcher and P.J.B. Hart (eds). *The impact of Species Changes in African Lakes*. 19-32 pp.

Kudhongania A.W. & Coenen E.J. (1992) Trends in development, prospects and limitations for Lake Victoria (Ugandan sector). In: G.W. Ssentongo and F.L. Orach-Meza (eds) Development and Management of the Ugandan Fisheries of Lake Victoria, Jinja, Uganda, 6-8 August 1992. RAF/87/099 – TD/31/92, 59-76pp.

Kudhongania A.W. & Cordone A.J. (1974) Batho-spatial distribution patterns and biomass estimates of the major demersal fishes in Lake Victoria. *African Journal of Tropical Hydrobiology and Fisheries* **3**, 15-31.

Laevastu T. (1993) *Marine Climate Weather and Fisheries: The Effects of weather and Climatic Changes On Fisheries and Ocean Resources*. Fishing News Books. 204 pp.

Laevastu T. & Favorite F. (1988) *Fishing and stock fluctuations*. Fishing News Books Ltd. 237 pp.

Laevastu T. & Hayes M.L. (1981) *Fisheries Oceanography and Ecology*. Fishing News Books Ltd. 199 pp.

Ligtvoet W., Mkumbo O.C., Mous P.J. & Goudswaard P.C. (1995a) Monitoring fish stocks from survey data. In: F. Witte and L.T. van Densen (eds) *Fish Stocks and Fisheries of Lake Victoria: A handbook for field observations*. Samara Publishing Limited, pp. 119-134.

Ligtvoet W., Mous P.J., Mkumbo O.C., Budeba Y.L., Goudswaard P.C., Katunzi E.F.B., Temu M.M., Wanink J.H. & Witte F. (1995b). The Lake Victoria fish stocks and fisheries. In: F. Witte and L.T. van Densen (eds) *Fish Stocks and Fisheries of Lake Victoria: A handbook for field observations*. Samara Publishing Limited, pp. 11-53.

Ligtvoet W. & Mkumbo O.C. (1991) A pilot sampling survey for monitoring the artisanal Nile perch (Lates niloticus) fishery in southern Lake Victoria (East Africa). In: I.G. Cowx (ed.) *Catch Effort Sampling Strategies. Their Application in Freshwater Fisheries Management*. Fishing News Book. Blackwell Scientific Publications Ltd., pp. 349-360.

Ligtvoet W & Mkumbo O.C. (1990) Synopsis of ecological and fishery research on Nile perch (*Lates niloticus*) in Lake Victoria, conducted by HEST/TAFIRI.

In: CIFA Report of the fifth session of the sub-committee for the development and management of the fisheries in Lake Victoria, 12-14 September 1989, Mwanza, Tanzania. *FAO Fisheries Report* **430**, 35-74

Ligtvoet W., Chande A.I. & Mosille O.I.I.W. (1988) Preliminary description of the artisanal Nile perch (*Lates niloticus*) fishery in southern Lake Victoria. Report of the Fourth Session of the Sub-Committee for the Development and Management of the Fisheries of Lake Victoria. Kisumu, Kenya, 6-10 April 1987. *FAO Fisheries Report* **338**, 72-85.

Lowe-McConnel R.H. (1997) EAFRO and after: a guide to key events affecting fish communities in Lake Victoria (East Africa). *South African Journal of Science* Vol. **93**, 570-574.

Lowe-McConnel R.H. (1987) *Ecological studies in tropical fish communities.* Cambridge: Cambridge University Press. 416 pp.

Ludwig D., Hilborn R. & Walters C. (1993) Uncertainity, Resource Exploitation, and Conservation: Lesson from History. *Ecological Applications* **3(4)**, 547-549.

LVFO (2000) Results of the first regional frame survey on Lake Victoria conducted in 2000. Lake Victoria Fisheries Organization, Jinja, Uganda (in press).

LVFO (1999) Strategic Vision for Lake Victoria (1999-2015). The Lake Victoria Fisheries Organisation, PO Box 1625, Jinja Uganda. 62 pp.

Lyimo E., Nhwani L.B. & Mkisi M. (1990) The fisheries statistics of Lake Victoria Tanzania sector. In: Ssentongo G.W. (ed.) Workshop on Fisheries Statistics and information Systems for Lake Victoria. FAO, Rome, *UNDP/FAO Regional Project for Inland Fisheries planning (IFIP)*, RAF/87/099-TD/14/90 (En), pp. 23-29.

Maembe T.W. (1990) A review of the main characteristics of long distance fish trade from Lake Victoria, Tanzania. In: *Proceedings of the symposium on Socio-economic Aspects of Lake Victoria Fisheries* FAO, Rome. UNDP/FAO Regional project for Inland Fisheries Planning (IFIP), RAF/87/099-WP/05/89. Vol. **5**, 68-100.

Marshall B.E. (1995) Why is *Limnothrissa miodon* such a successful introduced species and is there anywhere else we should put it? In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes.* Chapman and Hall, London, pp. 527-545.

Marshall B.E. & Mubamba R. (1993) Symposium on biology, stock assessment and exploitation of small pelagic fish species in the African Great Lakes. *CIFA/OP19*, 243 p.

Marten G.G. (1979) Impact of fishing on the inshore fishery of Lake Victoria (East Africa). *Journal of Fisheries Research Board of Canada* **36**, 891-900.

Mkumbo O.C., Ezekiel C., Budeba Y.L. & Cowx I.G. (2002) Analysis of exploitation patterns for Nile perch, *Lates niloticus*, in Lake Victoria. In: I.G. Cowx (ed.) *Management and Ecology of Lake and Reservoir Fisheries.* Fishing News books, pp. 84-95.

Mkumbo O.C., Ezekiel C., Budeba Y.L. & Cowx I.G. (2000) The fishery of Lake Victoria, Tanzania: pre-post Nile perch era and the future. In: Proceedings of the symposium "Lake Victoria 2000: A New beginning", Jinja, 16-19 May 2000.

Mkumbo O.C & Katunzi E.F.B. (2000) Towards sustainable exploitation of *Lates niloticus*. Paper presented at the LVEMP-National Workshop on Harvesting and Processing of immature Nile perch, 09-10 August, 2000 Mwanza. Tanzania. 10 pp.

Mkumbo O.C. & Cowx I.G. (1999) Catch trends from Lake Victoria – Tanzanian waters. In: I.G. Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. 7, pp. 99-107

Mkumbo O.C., Katunzi E.F.B., Bwathondi P.O.J., Msuku B.S., Budeba Y.L., Nsinda P.E., Kishe M.A., Ezekiel C.N., Bayona J.D.R., Ngatunga B.P., Nhwani L.B. & Katonda K.I. (1996) Report of the biological and socio-economic study of the fisheries of Mwanza and Speke Gulfs following the ban of the use of non-selective gear. A paper presented at a national workshop on fish stocks and biodiversity of Lake Victoria fisheries, Mwanza, 11- 14 December 1996.

Mkumbo O.C. & Ligtvoet W. (1992) Changes in the diet of Nile perch, *Lates niloticus* (L.) in Mwanza Gulf, Lake Victoria. *Hydrobiologia* **232**, 79-83.

Moreau J. (1995) Analysis of species changes in Lake Victoria using ECOPAPH, a multispecies trophic model. In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes*. Chapman and Hall, London, pp. 137-161.

Moreau J., Ligtvoet W. & Palomeres M.L.D. (1993) Trophic relationship in the fish community of Lake Victoria, Kenya, with emphasis on the impact of Nile perch (*Lates niloticus*). In: V. Christensen and D. Pauly (eds) *Trophic models of aquatic ecosystems. Manila: ICLARM Conference Proceedings*, **26**, 144-152.

Moreau J., Bambino C. & Pauly D. (1986) A comparison of four indices of overall growth performance, based on 100 tilapia populations (Fam. Cichlidae). In: J.L.Maclean, L.B. Dizon and L.V. Hosillos (eds). *The first Asian fisheries forum. Asian Fisheries Society*, Manilla, Philippines, pp. 201-206.

Mous P.J., Budeba Y.L., Temu M.M. & van Densen W.L.T. (1991) A catch effort data recording system for the fishery on the small pelagic *Rastrineobola argentea* in the southern part of Lake Victoria. In: I.G. Cowx (ed.) *Catch Effort Sampling Strategies. Their Application in Freshwater Fisheries Management.* Fishing News Book. Blackwell Scientific Publications Ltd., pp. 335-348

Muggide R. (1993) The increase in phytoplankton primary productivity and biomass in Lake Victoria (Uganda). *Verhandlungen Internationale Vereiniging fur theoretische und angewandte Limnologie* **25**, 846-849.

Muhoozi L.I. & Ogutu-Ohwayo R. (1999) The relationship between boat size and fish catches in the gillnet fishery of Lake Victoria, Uganda. In: I.G. Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 63-77.

Mwebaza-Ndawula L.M. (1998) Distribution and abundance of zooplankton and *Rastrineobola argentea* (Pisces, Cyprinidae) and their trophic interactions in northern Lake Victoria, East Africa. *PhD Thesis*, University of Vienna.

Newell B.S. (1960) Hydrobiology of Lake Victoria. *Hydrobiologia*, **15**, 363-383.

Newman S.,Williams D. & Russ G. (1996) Variability in the population structure of *lutjanus adetii* (Castelnau, 1873) and *L. quinquelineatus* (Botch, 1790) among reefs in the central Great Barrier Reef, Australia. *Fisheries Bulletin* **94**, 313-329.

Ndawula L.M., Kiggundu V. & Ochieng H. (1999) Invertabrate communities in northern Lake Victoria, with reference to their potential for fishery production. In: I.G. Cowx and D Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 142-154.

Njiru M., Othina A. & Cowx I.G. (2002) Lake Victoria invasion by water hyacinth a blessing for Lake Victoria fisheries. In I.G. Cowx (ed.) *Management and Ecology of Lake and Reservoir Fisheries.* Oxford: Fishing News Books Blackwell Science, pp. 255-263.

Njiru M. (1999) Changes in feeding biology of Nile tilapia, *Oreochromis niloticus* (L.), after invasion of water hyacinth, *Eichhornia crassipes* (Mart.) Solms, in Lake Victoria, Kenya. In: I.G Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 175-183.

Norris J.G. (1991) Further perspectives on yield per recruit analysis and biological reference points. *Canadian Journal of Fisheries and Aquatic Science* **48**, 2533-2542.

Nsinda P.E. (1999) Stock assessment of *Lates niloticus* (L.), *Oreochromis niloticus* (L.) and *Rastrineobola argentea* (Pellegrin) using fisheries – dependent data from Tanzania waters of Lake Victoria. In: I.G Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 108-117.

Ochumba P.B.O. (1995) Limnological changes in Lake Victoria since the Nile perch introduction. In: T.J. Pitcher and P.J.B. Hart (eds) *The Impact of Species Changes in African Lakes.* Chapman and Hall, pp. 33-43.

Ochumba P.B.O. (1990) Massive fish kills within the Nyanza Gulf of Lake Victoria. *Hydrobiologia* **208**, 93-99.

Ochumba P.B.O. & Kibaara D.I. (1989) Observation on blue-green algal blooms in the open waters of Lake Victoria, Kenya. *African Journal of Ecology* **27**, 23-34.

Ochumba P.B.O. (1987). Periodic massive kills in the Kenyan part of Lake Victoria. *Water Quality Bulletin* **12**, 119-122.

Odongkara K. (2002) Poverty in the fisheries: A Framework for Analysis and Intervention for Lake Victoria , Uganda. PhD thesis, University of Hull.

Ogari J. & Asila A.A. (1990) The state of Lake Victoria fisheries, Kenya waters. *FAO Fisheries Report* **430**, 18-23.

Ogari J. (1988) Predator-prey relationship in L. Victoria with special reference to the Nile perch *Lates niloticus* (Linnaeus). In: D. Lewis (ed.) Predator-prey relationships, population dynamics and fisheries productivities of large African Lakes *FAO/CIFA Occasional Paper* **15**, 53-68.

Ogari J. & Dadzie S. (1988) The food of the Nile perch, *Lates niloticus* (L.) after the disappearance of the haplochromine cichlids in the Nyanza Gulf of Lake Victoria. *Journal of Fish Biology* **32**, 571-577.

Ogari J. (1985) Distribution, Food and Feeding habits of *Lates niloticus* in Nyanza Gulf of Lake Victoria (Kenya). *FAO Fisheries Report* **335**, 68-80.

Ogutu-Ohwayo R. (1995) Diversity and stability of fish stocks in Lakes Victoria, Kyoga and Nabugabo after establishment of introduced species. In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes.* Chapman and Hall, London, pp. 59-81.

Ogutu-Ohwayo R. (1990) Changes in the prey ingested and the variations in the Nile perch and other fish stocks of Lake Kyoga and the northern waters of Lake Victoria (Uganda). *Journal of Fish Biology* **37**, 55-63.

Ogutu-Ohwayo R. (1988) Reproductive potential of the Nile perch, *Lates niloticus* L. and the establishment of the species in Lakes Kyoga and Victoria (East Afrika). *Hydrobiologia* **162**, pp. 193-200.

Oijen, M.J.P. van (1982) Ecological differentiation among the piscivorous haplocromine cichlids of Lake Victoria (East Africa). *Netherlands Journal of Zoology* **32**, 336-363.

Oijen M.J.P. van, Witte F. & Witte-maas E.L.M. (1981) An introduction to ecological and taxonomic investigation on the haplochromine cichlids from the Mwanza Gulf of Lake Victoria. *Netherlands Journal of Zoology* **31**, 149-174.

Okaronon J.O., Muhoozi L.I. & Bassa S. (1999) Current status of the fish stocks of Lake Victoria (Uganda). In: I.G. Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 10-25.

Okaronon J.O. (1994) Current composition, distribution and relative abundance of the fish stocks of Lake Victoria, Uganda. *African Journal of Tropical Hydrobiology and Fisheries* **5**, 89-100

Okaronon J.O., Acere J.O. and Ocenodongo D.L. (1985) The current state of the fisheries in the northern portion of L. Victoria (Uganda). *FAO Fisheries Report* **335**, 89-98.

Okedi J. (1981) The *Engraulicypris* 'dagaa' fishery of Lake Victoria: with special reference to the southern waters of the lake. In: Proceedings of the Workshop of the Kenya Marine and Fishery Research Institute on aquatic resources of Kenya, 13-19 July 1981, Mombosa. *Kenya National Academy for the Advancement of Arts and Science*, pp. 445-484.

Okedi J. (1971) Further observations on the ecology of the Nile perch (*Lates niloticus* Linnaeus) in Lake Victoria and Lake Kyoga. *EAFFRO Annual Report* **1970**, 42-55.

Okemwa E.N. (1984) Potential fishery of Nile perch, *Lates niloticus* (Pisces: Centropomidae) in the Nyanza Gulf of Lake Victoria, East Africa. *Hydrobiologia* **108**, 121-126.

Orach-Meza F.L. (1992) Present status of the Ugandan sector of Lake Victoria fisheries. *FAO Fisheries Report* No. **475**, 24-29.

Orach-Meza F.L. (1991) Statistical sampling methods for improving the catch assessment of lake fisheries. In: I.G. Cowx (ed.) *Catch Effort Sampling Strategies. Their Application in Freshwater Fisheries Management.* Fishing News Book. Blackwell Scientific Publications Ltd., pp. 323-334.

Othina A. & Tweddle D. (1999) The status of the artisanal fishery of Lake Victoria, Kenya, with notes on improvements to the catch data collection system. In:

I.G. Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 78-91.

Orkin M. & Drogin R. (1975) *Vital statistics*. MCGraw-Hill, Inc. New York. 388 pp.

Owilli M. (1999) Zooplankton –fish interaction in the littoral zone of Nyanza Gulf, Lake Victoria. In: I.G.Cowx and D. Tweddle (eds) *LVFRP Technical Document* No. **7**, pp. 163-175.

Paine R.T. (1992) Food-web analysis through field measurement of per capita interaction strength. *Nature* **355**, 73-75.

Pauly D., Moreau J. & Gayanilo F.C. Jr. (1998) Auximetric analyses In: R. Froese and D. Pauly (eds) *Fishbase 1998: concepts, design and data sources*. ICLARM, Manila, Philippines, pp. 130-134.

Pauly D. (1987) A Review of the ELEFAN System for Analysis of length-frequency data in Fish and Aquatic Invertebrates. In: D.Pauly and G.R.Morgan (eds) *Length-based Methods in Fisheries Research*. ICLARM Contribution No.**325**, 7-34

Pauly D. & Soriano M.L. (1986) Some practical extensions to Beverton and Holt's relative yield-per-recruit model. In: J.L. Maclean, L.B. Dizon and L.V. Hosillo (eds) *The First Asian Forum. Asian Fisheries Society*, pp. 491-496.

Pauly D. (1984) Length-converted catch curves. A powerful tool for fisheries research in the tropics. (Part III: Conclusion). *ICLARM Fishbyte* **2**(3), 9-10

Pauly D. & Munro J.L. (1984) Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte* **2**(1), 21.

Pauly D. (1983) Some simple methods for the assessment of tropical fish stocks. *FAO Fisheries Technical Paper* **234**, 52 pp.

Pauly D. (1980) A selection of simple methods for the assessment of tropical fish stocks. *FAO Fisheries Technical Circular* **729**, 54 pp.

Pauly D., David N. & Ingles J. (1980) *ELEFAN 1: User's instructions and program listing*. International Centre for Living Aquatic Resources Management (ICLARM), Manila, Philippines.

Pet J.S., Gevers G.J.M., van Densen W.I.T. & Vijverberg J. (1996) Management options for a more complete utilization of the biological fish production in Sri Lankan reservoirs. *Ecology of Freshwater Fisheries* **5**(1), 1-5.

Pitcher T.J., Bundy A. & Neill W.E. (1996) The fishery for *Rastrineobola argentea* in Lake Victoria: estimation of potential yields using a new approximate model based on primary production. *Fisheries Research* **28**(1996), 133-149.

Pitcher T.J. & Bundy A. (1995) Assessment of the Nile perch fishery in Lake Victoria. In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes*. Chapman and Hall, London, pp. 163-180.

Pitcher T.J. (1995) Species change and fisheries in African Lakes: Outline of the issues. In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes*. Chapman and Hall, London, pp. 1-18.

Pitcher T.J. & Alheit J. (eds) (1994) What makes a hake? A review of the critical biological features that sustain global hake fisheries, in *Hake: Fisheries, ecology and markets*. Chapman and Hall, London, pp. 1-14.

Pitcher T.J. & Hart P.J.B. (1982) *Fisheries Ecology*. Croom Helm, London. 414 pp.

Rabuor C.O. (1991) Catch and effort sampling techniques and their application in freshwater fisheries management: with specific reference to Lake Victoria, Kenyan waters. In: I.G. Cowx (ed.) *Catch Effort Sampling Strategies. Their Application in Freshwater Fisheries Management.* Fishing News Book. Blackwell Scientific Publications Ltd., pp. 373-381.

Reinthal P.N. & Kling G.W. (1994) Exotic species, trophic interactions and ecosystem dynamics: a case study of Lake Victoria. In: D. Stouder, K. Fresh, and R. Feller (eds) *Theory and Application in Fish Feeding Ecology.* University of South Carolina Press, Columbia, pp. 295-313.

Reynolds J.E., Dominique D.F. & Mannini P. (1995) Thirty years on: the development of the Nile perch fishery in Lake Victoria. In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes.* Chapman and Hall, London, pp. 181-214.

Reynolds J.E., Wadanya J. & Nyeko D. (eds) (1989) Fisheries statistics and information management in Uganda: past approaches, current status and future prospects. FAO, Rome, FISHIN' Note. Rec., Fisheries Statistics and Information Systems (FISHIN'). UGA/87/007-FD/1. 84 pp.

Reynolds J.E. & Greboval D.F. (1988) Socio-economic Effects of the Evolution of Nile perch Fisheries in Lake Victoria: A Review. *CIFA Technical Paper* No. **17**. Committee for the Inland Fisheries of Africa, FAO, Rome.

Ribbink A.J. (1987) African lakes and their fishes: conservation scenarios and suggestions. *Environmental Biology of Fishes* **19**, 3-26.

Riedmiller S. (1994) Lake Victoria fisheries: the Kenyan reality and environmental implications. *Environmental Biology of Fishes* **39**, 329-338.

Ricker W.E. (1975) Computation and interpretation of biological statistics of fish populations. *Fisheries Research Board of Canada Bulletin*, **191**.

Rosenberg A.A., Fogarty M.J., Sissenwine M.P., Beddington J.R. & Shepherd J.G. (1993) Achieving Sustainable Use of Renewable Resources. *Science* **262**, 828-829.

Rzóska J. (1957) Notes on the crustacean plankton of Lake Victoria. *Proceedings of Linn. Society of London* **168**, 116-125.

Scheren P.A., Zanting H.A. & Lemmens A.M.C. (2000) Estimation of water pollution sources in Lake Victoria, east Africa: application and elaboration of the rapid assessment methodology. IJournal of Environmental Management **58**, 235-248.

Schindler D.E, Kitchell J.R. & Ogutu-Ohwayo R. (1998) Ecological consequences of alternative gillnet fisheries for Nile perch in Lake Victoria. *Conservation Biology* **12**, pp. 56-64.

Scully R.J. (1975) The importance of furu (the *haplochromis* 'species flock')in Lake Victoria's gillnet fisheries. Part I of a completion report on the passive gear fisheries in the Tanzania waters of Lake Victoria. *East African Freshwater Fisheries Research Organisation (EAFFRO)*, Jinja, Uganda. MS.

SEDAWOG (1999a) Marketing study. LVFRP Technical Document No. 2, 130 pp.

SEDAWOG (1999b) The survey of Lake Victoria's Fisheries. *LVFRP Technical Document* No. 5, 37 pp.

Seehausen O., van Alphen J.J.M & Witte F. (1997) Cichlid fish diversity threatened by euthrophication that curbs sexual selection. *Science* 227, 1808-1811.

SIDA (1999) Strategy for Support to Sustainable Development in the Lake Victoria Region. Prepared by: The Lake Victoria Strategy Task Team, December 20, 1999. 19 pp.

Smith D.C. & Reay P. (1991) Cannibalism in teleost fish. *Reviews in Fish Biology and Fisheries* **1**, 41-64.

Sparre P. & Venema S.C. (1998) Introduction to tropical fish stock assessment. FAO Fisheries Technical Paper 306.1 (Rev.2), 49 pp.

Sparre P. & Venema S.C. (1992) Introduction to tropical fish stock assessment. Part 1. Manual. *FAO Fisheries Technical Paper* **306.1** (Rev.1), 376 pp.

Sparre P., Ursin E. & Venema S.C. (1989) Introduction to tropical fish stock assessment. Part 1. Manual. FAO Fisheries Technical Paper 306, 337 pp.

Ssentongo G.W. (ed.) (1992) Report on a national seminar on the development and management of the Tanzanian fisheries of Lake Victoria, 15-17 October 1991, Mwanza. RAF/87/099-TD/35/92 (En.). UNDP/FAO regional project for Inland Fisheries planning (IFIP), Rome.

Ssentongo G.W. (ed.) (1990) Workshop on Fisheries Statistics and Information Systems for Lake Victoria. FAO, Rome. UNDP/FAO Regional Project for Inland Fisheries Planning (IFIP), RAF/87/099-TD/14/90 (EN), 36 pp.

Ssentongo G.W. & Welcomme R.L. (1985) Past history and current trends in the fishery of Lake Victoria. *FAO Fisheries Report* No. **355**, 123-136.

Talling J.F. (1966) The annual cycle of stratification and phytoplankton growth in Lake Victoria (East Africa*). International Review ges. Hydrobiology* **51**, 545-621.

Taylor C.C. (1958) Cod growth and temperature. *Journal of Conservation*. CIEM **23**, 366-370

Temple P.H. (1964) Lake Victoria levels. *Proceedings of East Africa Academy* Vol. **II**, 50-58.

Tumwebaze R., Getabu A., Bayona J., MacLennan D. & Cowx I.G. (2002) Fisheries of Lake Victoria: an underwater perspective. In: I.G. Cowx (ed.) *Management and Ecology of Lake and Reservoir Fisheries*. Fishing News books, pp. 70-83.

Turner G.F. (1996) Maximization of yields from African lakes. In: I.G. Cowx (ed.) *Stock Assessment in Inland Fisheries*. Fishing News Books, pp. 465-481.

Turner G.F. (1995) Management, conservation and species changes of exploited fish stocks in Lake Malawi. In: T.J. Pitcher and P.J.B. Hart (eds) *The impact of species changes in African Lakes*. Chapman and Hall, London, pp. 365-395

Twongo T.F., Bugenyi F.W. & Warda F. (1995) The potential for further proliferation of water hyacinth in Lake Victoria, kyoga and Kwania and some urgent aspects for research. *African Journal of Tropical Hydrobiology and Fisheries* **6**, 1-10.

Verschuren D., Johnson T.C., Kling H.J., Edgington D.N., Leavitt P.R., Brown E.T., Talbot M.R. & Hecky R.E. (2002) History and timing of human impact on Lake Victoria, East Africa. *Proceedings of The Royal Society of London* **269**, 289-294.

Villanueva M.C. & Moreau J. (2002) Recent trends in the Lake Victoria fisheries assessed by ECOPATH. In: I.G. Cowx (ed.) *Management and Ecology of Lake and Reservoir Fisheries*. Fishing News Books, pp. 96-111.

Walters C., Christensen V. & Pauly D. (1997) Structuring dynamic models of exploited ecosystems from trophic mass balanced assessments. *Reviews in Fish Biology and Fisheries* **7**, 139-172.

Wanink J.H. (1998a) How predictable were the effects of Nile perch introduction on the Lake Victoria ecosystem? In: P.C. Chifamba (ed.) Proceedings of the ULKRS Seminar Series, University of Zimbabwe. *ULKRS Bulletin* **1/96**, 35-44.

Wanink J.H. (1998b) The pelagic cyprinid *Rastrineobola argentea* as a crucial link in the disrupted ecosystem of Lake Victoria. Dwarfs And Giants – African Adventures. Proefschrift, June 1998. 288 pp.

Wanink J.H & Kashindye J.J. (1998) Short-term variations in pelagic photosynthesis demand well-timed sampling to monitor long-term limnological changes in Lake Victoria. *Hydrobiologia* **377**, 177-181.

Wanink J.H. (1991) Survival in a perturbed environment: the effect of Nile perch introduction on the zooplantivorous fish community of Lake Victoria, In: O.Ravera (ed.) *Perturbation and recovery of Terrestrial and Aquatic Ecosystem*. Ellis Horwood, Chichester, pp. 269-75.

Wanink J.H. (1988) The ecology and fishery biology of *Rastrineobola argentea* (Pellegrin) 1904. App. II. In: Fish stocks and fisheries in Lake Victoria. A handbook to the HEST/TAFIRI & FAO/DANIDA regional seminar, Mwanza, January/February 1989. *HEST/TAFIRI Report* **53**.

Wanjala B. & Marten G. (1974) Survey of the Lake Victoria fishery in Kenya. *EAFFRO Annual Report* **(1974)**, 81-85.

Weatherley A.H. (1972) *Growth and Ecology of Fish populations*. Academic Press London.

Welcomme R.L. (1995) Relationship between fisheries and the integrity of river systems. *Regulated Rivers: Research and Management* **11**, 121-136.

Welcomme R.L. (1988) International introductions of inland aquatic species. *FAO Fisheries Technical Paper* **249**. FAO, Rome.

Welcomme R.L. (1985) River fisheries. *FAO Fisheries Technical paper* No. **262**. FAO, Rome.

Welcomme R.L. (1970) Studies on the effect of abnormally high water levels on the ecology of fish in certain shallow regions of Lake Victoria. *Journal of Zoology, London* **160**, 405-436.

Welcomme R.L. (1968) Observations on the biology of the introduced species of Tilapia in L. Victoria. *Review of Zoology and Botany of Africa* **76**, 249-279.

Welcomme R.L. (1966) Recent changes in the stocks of Tilapia in Lake Victoria. *Nature London* **212**, 52-54.

Wetherall J.A. (1986) A new method for estimating growth and mortality parameters from length frequency data. *Fishbyte* 4(1), 12-14.

Williams G.C. (1966) *Adaptation and Natural Selection.* Princeton University Press, Princeton, NJ.

Williams D., Newman S., Cappo M. & Doherty P. (1995) Recent advances in the aging of coral reef fishes. In: Joint Forum Fisheries Agencies-South pacific Commission. Workshop on Management of South Pacific Inshore Fisheries, 26 June – 7 July 1995. New Caledonia. *Biological Paper* **74**, 5 pp.

Wilson D.C. (1993) Fisheries management on Lake Victoria, Tanzania. Paper presented at the Annual meeting of the African Studies Association, 4-7 December 1993.

Wilson D.C., Medard M., Harris C.K & Wiley D.S (1999) The implications for participatory fisheries management of intensified commercialisation on Lake Victoria. *Rural Sociology* **64**(4), 554-572.

Witte F., Msuku B.S., Wanink J.H., Seehausen O., Katunzi E.F.B., Goudswaard P.C. & Goldschmidt T. (2000) Recovery of the cichlid species in Lake Victoria: an examination of factors leading to differential extinction. *Reviews in Fish Biology and Fisheries* **10**, 233-241.

Witte F., Goudswaard P.C., Katunzi E.F.B., Mkumbo O.C., Seehausen O. & Wanink J.H. (1999) Lake Victoria's ecological changes and their relationships with the riparian societies In: H. Kawanabe, G. Coulter and A. Roosevelt (eds) *Ancient Lakes: Their Cultural and Biological Diversities.* Kenobi Productions, Ghent, pp.189-202.

Witte F & Densen L.T. van (eds) (1995) *Fish Stocks and Fisheries of Lake Victoria: A handbook for field observations.* Samara Publishing Limited. 404 pp.

Witte F., Goldschmidt T. & Wanink J.H. (1995a) Dynamics of the haplochromine cichlid fauna and other ecological changes in the Mwanza Gulf of Lake Victoria. In: T.J. Pitcher and P.J.B. Hart (eds) *Impact of species changes in African Lakes.* Chapman & Hall, London, pp. 83-110.

Witte F. & de Winter W. (1995) Biology of the major fish species of Lake Victoria. In: F. Witte and L.T van Densen (eds) *Fish Stocks and Fisheries of Lake Victoria. A handbook for field observations.* Samara Publishing limited, pp. 301–302.

Witte F., Hoogenboezem W., Goldschmidt T. & Westbroek I. (1995b) Major food types of the fish species in Lake Victoria. In: F. Witte and L.T van Densen (eds) *Fish Stocks and Fisheries of Lake Victoria. A handbook for field observations.* Samara Publishing limited, pp. 337–347.

Witte F., Goldschmidt T., Goudswaard P.C., Ligtvoet W., van Oijen M.J. & Wanink J.H. (1992a) Species Extinction and concomitant Ecological changes in L. Victoria. *Netherlands Journal of Zoology* **42**(2-3), 214-232.

Witte F., Goldschmidt T., Wanink J., van Oijen M., Goudswaard K., Witte-Maas E. & Bouton N. (1992b) The destruction of an endemic species flock: quantitative data on the decline of the haplochromine cichlids of Lake Victoria. *Environmental Biology of Fishes* **34**, 1-28.

Witte F. & van Oijen M.J.P. (1990) Taxonomy, ecology and fishery of haplochromine trophic groups. *Zoological Verh. Leiden* **262**, 1-47.

Witte F. & Goudswaard P.C. (1985) Aspects of the haplochromine fishery in southern Lake Victoria. *FAO Fisheries Report* **335**, 81-88.

Witte F. (1981) Intial results of the ecological survey of the haplocromine cichlid fishes from the Mwanza Gulf of Lake Victoria, Tanzania: breeding patterns, trophic and species distribution. *Netherlands Journal of Zoology* **31**, 175-202.

Wootton R.J. (1990) *Ecology of Teleost Fishes*. Chapman and Hall, London. 404 pp.

Worthington E.B. (1933) *Inland waters of Africa. The results of two expeditions to the great lakes of Kenya and Uganda, with accounts of their biology, native tribes and development.* MacMillan & Co., London.

Worthington E.B. (1931) Vertical movement of freshwater macroplankton. *International Review ges. Hydrobiology and Hydrography* **25**, 394-436.

Worthington E.B. (1930) Observations on the temperature, hydrogen ion concentrations and other physical conditions of the Victoria and Albert Nyanzas. *International Review Gesamt. Hydrobiology* **24**, 328-357.

Worthington E.B. (1929) A report on the fishing survey of Lakes Albert and Kyoga. London: Crown Agents.

APPENDICES:

Appendix 1: Mean annual rainfall (mm) with the 95% C.L. calculated for different periods in Mara, Mwanza and Kagera.

YEAR	1980-1985		1986-1990		1991-1995		1996-2000	
REGION	Mean (mm)	95% C.L.	Mean (mm)	95% C.L.	Mean (mm)	95% C.L.	Mean (mm)	95% C.L.
Mara	844.1	183.9	1 005.3	151.2	818.9	256.3	858.7	194.6
Mwanza	962.1	190.9	1 252.9	243.8	1 030.8	257.9	986.7	341.7
Kagera	2 044.7	196.	2 080.0	626.1	1 909.3	514.6	1 806.3	379.5

Appendix 3: Secchi disk depth (m) averaged in 10 m depth categories of the depths at sampled stations for the different sampled dates in Lake Victoria.

Water dep (m)	Febr'00 Secchi dep (m)	95% C.L.	Oct-Nov.'00 Secchi dep (m)	95% C.L.	Aug-Sept.'00 Secchi dep (m)	95% C.L.	Febr.'01 Secchi dep (m)	95% C.L.	Aug-Sept'01 Secchi dep (m)	95% C.L.
5-10	1.47	0.49	0.84	0.30	1.90	1.02	1.90	2.45	1.32	2.35
10-20	1.61	0.59	1.94	0.88	2.04	0.44	1.78	0.74	1.51	0.30
20-30	2.30	1.00	3.88	1.59	2.69	0.61	2.73	0.63	1.88	0.68
30-40	2.41	0.63	2.75	1.64	3.76	1.47	2.67	0.34	1.92	0.70
40-50	2.51	0.46	4.00		5.06	0.72	2.54	0.74	3.35	1.33
50-60	3.27	0.36	5.50		5.52	1.70	3.08	0.62	3.25	0.60
60+	3.50	0.45			3.62	0.68	4.07	0.55	3.36	1.08

Appendix 2: Mean water conductivity and mean chlorophyll concentration values calculated for the different sampled station in the three zones of the Tanzanian waters of Lake Victoria (95% C.L. included).

CONDUCTIVITY

Zone A Mwanza

	Feb.'00		July '00		Aug-Sept.'00		Nov. '00		Feb.'01		Aug-Sept.'01	
Depth	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.
Surface	83.86667	12.17681			92.9	2.647112	95.86	19.57833	85.74	14.62075	55.705	17.63196
10 m	98.55106	1.344626			93.48	0.777407	94.95133	1.538006	96.95521	5.332494	94.91333	1.284977
20 m	96.94119	1.254642			93.31026	1.140308	94.1	2.541191	93.72613	4.2264	100.32	29.46739
30 m	94.03005	4.700632			93.35	0.635346	93.85	4.447133	93.00562	3.740342	94.665	27.763
40 m	94.8				93.1		94.4		92.71		171.81	

Zone B Mara

	Feb.'00		Aug-Sept.'00		Feb.'01		Aug-Sept.'01	
Depth	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.
Surface	97.18571	1.90769	87.58889	6.84271	90.98	5.535802	54.55833	17.05838
10 m	95.20437	1.033211	93.85409	0.35232	93.81925	0.732563	94.00334	0.506677
20 m	94.50883	0.465169	93.72652	0.151126	93.5501	0.983938	93.662	0.233683
30 m	94.43351	1.280767	93.53381	0.244769	92.8475	0.452942	93.616	0.44028
40 m	95.30631	5.417625	93.25161	0.45615	93.13125	0.699519	93.43	0.506865
50 m	93.43333	0.872397	92.95896	0.486306	92.8	0.895674	93.495	1.067385
60 m	93.97687	2.508035	93.03103	0.63314	93.007	0.667706	92.86	0.937097
68 m	142.9926		92.9		93.43		92.37	

Zone C Kagera

	Feb.'00		July '00		Aug-Sept.'00		Nov. '00		Feb.'01		Aug-Sept.'01	
Depth	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.
Surface	93.21667	1.72687	92.8	2.499479	88.32	6.063807	90.21	6.956723	80.47143	9.870575	53.074	36.93132
10 m	94.21615	0.48474	93.53654	0.240179	93.32818	0.678408	94.62625	0.931557	93.26934	0.23695	93.098	0.496543
20 m	93.91042	0.423308	93.53874	0.134853	92.87231	0.226737	93.92	0.551109	92.58205	0.204559	92.974	0.575511
30 m	93.88572	0.33034	93.57258	0.303269	92.7853	0.216479	94.16667	0.517115	92.34268	0.375792	92.9	0.550762
40 m	93.56453	0.229374	93.16333	0.715166	92.87229	0.296457	94		92.2708	0.34086	92.68	0.836663
50 m	93.66223	0.537084	93.4		92.70786	0.278205	93.79		91.973	0.927573	92.73667	0.596367
60 m	93.85	3.176586			92.5							
68 m												

CHLOROPHYLL CONCENTRATIONS

Zone A Mwanza

	Feb.'00		July '00		Aug-Sept.'00		Nov. '00		Feb.'01		Aug-Sept.'01	
Depth	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.
Surface	3.381667	6.179248			5.382	6.496559	4.842	2.545922	4.23	3.972383	2.648233	0.65401
10 m	11.61906	7.876447			19.77415	11.69794	14.8187	29.25578	17.83938	12.29769	26.33412	9.062313
20 m	2.992805	3.842653			11.24987	74.87993	7.666802	3.598358	6.730138	3.777061	21.2081	17.93272
30 m	1.101969	0.102039			9.255007	50.37997	4.697875	32.43403	4.112895	10.81743	11.56045	4.163171
40 m	0.927357				4.06		3.01		6.05		5.64	

Zone B Mara

	Feb.'00		Aug-Sept.'00		Feb.'01		Aug-Sept.'01	
Depth	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.
Surface	5.784286	6.362571	8.073333	6.50455	11.67563	14.22068	2.080317	0.202466
10 m	3.196128	1.086219	11.77112	7.726692	13.65984	10.13729	9.97315	4.632106
20 m	1.683677	0.624299	5.823834	3.212482	7.163766	5.449834	7.59802	3.193667
30 m	1.092381	0.155625	3.975738	2.095259	2.743554	0.882946	5.2826	1.806194
40 m	1.013315	0.29406	3.769761	2.394645	2.342729	0.984031	5.69545	1.381494
50 m	0.889991	0.028849	4.047746	2.899701	2.056532	0.5273	4.231925	2.10576
60 m	0.854429	0.071456	4.386913	5.554446	1.978267	0.392665	2.8157	0.738652
68 m	0.840628		6.92		2.13		3.15	

Zone C Kagera

	Feb.'00		July '00		Aug-Sept.'00		Nov. '00		Feb.'01		Aug-Sept.'01	
Depth	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.	Mean	95% C.L.
Surface	3.936667	2.004583	3.002667	1.66517	4.701	2.442143	7.292	5.028737	5.042857	6.430498	3.68364	3.791595
10 m	5.150152	1.829996	11.81822	4.69915	7.427254	5.322088	14.03587	6.433136	14.19463	6.252788	14.98992	12.59569
20 m	3.705955	1.587657	10.3353	5.140497	4.763573	1.845487	6.675145	2.916934	6.655283	3.431985	11.17164	7.04025
30 m	2.369558	1.26384	5.326483	1.169574	4.270511	1.177286	5.344187	3.634121	4.319671	1.124625	8.63776	5.723268
40 m	1.198572	0.397895	4.759373	4.365718	3.627508	1.19727	2.63		3.00541	0.668047	4.319325	3.595373
50 m	0.873553	0.050064	4.11		2.779516	1.096334	2.3		2.6958	3.992271	3.412767	1.208459
60 m	0.841321	0.525037			2.336214							
68 m												

Appendix 4A-D: Results of the t test for comparison of catch rates (kg $boat^{-1}$ $gear^{-1}$) from different gears and different means of propulsion (Note: ** indicate significance difference between mean).

A: Catches from motorized gill net boats (GN/M) compared with gillnet sails boats (GN/S), gillnet paddled boats (GN/P), longline sails boats (LN/S) and longline paddled boats (LN/P).

	GN/M V	GN/S	GN/P	LN/S	LN/P
Mean	71.67	36.77	29.10	44.91	56.70
Variance	1916.31	348.57	211.86	590.58	264.57
Observations	155.00	62.00	48.00	54.00	11.00
df		214.00	200.00	167.00	23.00
t Stat		8.23	10.39	5.54	2.48
P(T<=t) two-tail		1.82E-14***	1.67E-20***	1.14E-07***	0.021**
t Critical two-tail		1.97	1.97	1.97	2.07

B: Catches from gill net sails boats (GN/S) compared with gillnet paddled boats (GN/P), longline sails boats (LN/S) and longline paddled boats (LN/P).

	GN/S V	GN/P	LN/S	LN/P
Mean	36.77	29.10	44.91	56.70
Variance	348.57	211.86	590.58	264.57
Observations	62.00	48.00	54.00	11.00
df		108.00	99.00	15.00
t Stat		2.42	-2.00	-3.66
P(T<=t) two-tail		0.017**	0.05	0.002**
t Critical two-tail		1.98	1.98	2.13

C: Catches from gill net paddled boats (GN/P) compared with longline sails boats (LN/S) and longline paddled boats (LN/P); & D: Catches from longline sails boats (LN/S) compared with longline paddled boats (LN/P).

C:

	GN/P V	LN/S	LN/P
Mean	29.10	44.91	56.70
Variance	211.86	590.58	264.57
Observations	48.00	54.00	11.00
df		88.00	14.00
t Stat		-4.04	-5.17
P(T<=t) two-tail		0.000116**	0.00014**
t Critical two-tail		1.99	2.14

D:

	LN/S V	LN/P
Mean	44.91	56.70
Variance	590.58	264.57
Observations	54.00	11.00
df		20.00
t Stat		-1.99
P(T<=t) two-tail		0.06
t Critical two-tail		2.09

Appendix 5A-D: Details of the recorded data during the quarterly catch assessment survey, giving boats with means of propulsion, gear type & size and catch per boat for the Nile perch fishery in Tanzanian part of Lake Victoria.

5.1A: First quarter 1999

BEACH:Kayenze

Feb-99

Total number of fishing crafts 23
Number of crafts went fishing 18
Number of crafts sampled10

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
MUM 2519	MOT	GN	5"(400,6'(20)	99.7
MUM 8714	MOT	GN	6"(30),7"(57)	68.82
MUM 2263	SAIL	LN	No.7(800)	35.22
MUM 2510	MOT	GN	5"(30),5.5"(10),7"(20)	55.27
MUM 2278	MOT	GN	5"(15)	66.17
MUM 1612	MOT	GN	5"(10),6"(40)	47.16
MUM 2487	SAIL	LN	No.8(700)	40.6
Unknown	SAIL	LN	No.10(500)	21.46
MUM 1543	SAIL	LN	No.10(200)	27.43
MUM 2268	MOT	GN	5"(9),6"(40),7"(7)	60.52

Nyamikazi
March/April. 1999
Total number of fishing crafts 19
Number of crafts went fishing 15
Number of crafts sampled 8

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
BBKT 14	MOT.	GN	5"(100*2)	32.50
BBKT 1840	MOT.	GN	5"(50*2)	106.26
BBKT 275	MOT.	GN	6"(59*2)	162.46
BBKT 3314	MOT.	GN	6"(50*2)	94.50
BBKR 746	MOT.	GN	6"(60*2)	107.96
BBK 5334	MOT.	GN	5.5"(36*2),6"(24*2)	146.65

5.1B: Second quarter 1999

Beach: Kayenze

May-99

Total number of fishing crafts 86

Number of crafts went fishing 18

Number of crafts sampled 8

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
MUM 2	MOT.	GN	5"(15), 6"(17)	12.90
Unknown (1)	MOT.	GN	5"(30), 6"(30), 7"(10)	75.68
MUM 2277	MOT.	GN	5"(80), 6"(30)	48.16
MUM 2566	MOT.	GN	5"(25), 6"(25)	42.30
MUM 2519	MOT.	GN	6"(35), 7"(35)	158.14
MUM 1050	SAIL	LN	No. 10 (200);	26.26
MUM 208	SAIL	LN	No. 9(150), No. 10(100)	43.10
MUM 2632	SAIL	LN	No. 7(150), No. 10(150)	52.70

Kibaara

Jun-99

Total number of fishing crafts 33

Number of crafts went fishing 33

Number of crafts sampled 8

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RBD 2032	MOT	GN	5"(20), 5.5"(15), 6"(925)	77.44
MMW 6737	MOT	GN	5.5"(20), 6"(12)	15.86
MMW 6736	MOT	GN	5"(30), 6"(20)	23.98
RBD 1387	SAIL	LN	No. 10(500), 11(500).	27.36
RBD 3028	SAIL	LN	No. 10(700).	13.94
RBD 2517	SAIL	LN	No. 10(1000).	17.26
RBD 2576	SAIL	LN	No. 10(300), 11(300), 12(200).	66.3
RBD 1109	SAIL	LN	No. 9(300), 10(300).	58.64

Nyamikoma

Jun-99

Total number of fishing crafts 26

Number of crafts went fishing 26

Number of crafts sampled 7

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
MUM 2165	MOT	GN	5"(35), 6"(20)	126.68
MUM 1795	MOT	GN	5"(20)	45.68
MUM 1555	MOT	GN	4.5"(7), 5"(23)	88.32
MUM 1954	MOT	GN	5"(20), 6"(30)	38.56
MUM 2412	MOT	GN	5"(42)	56.64
MUM 2479	MOT	GN	4.5"(15), 5"(40)	168.96
MUM 2177	MOT	GN	5"(20), 6"(18)	66.56

5.1C: Third quarter 1999

Beach: Nyangombe

Jul-99

Total number of fishing crafts 11

Number of crafts went fishing 10

Number of crafts sampled 12

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RM 5	MOT	GN	6"(8),7"(32)	62.9
RTE 3375	SAIL	GN	5"(5),6"(20),7"(16)	26.2
RTE 1916	MOT	GN	6",7"{45}	35.65
Unknown(1)	SAIL	LN	No.8&9{40}	30.3
RTE 1575	SAIL	LN	No.9(80)	53.4
RTE 1206	SAIL	LN	Nos.7, 8&10{60}	52.2
RMU 1844	MOT	GN	5",7"{40}	29.66
Unknown(2)	MOT	GN	5",6",7"{41}	163.42
RTE 1397	MOT	GN	5",6"6.5",7"{68}	36.86
RTE 1036	MOT	GN	5",6",7"{50}	155.4
RTE 1891	SAIL	LN	No.7(70),No.6(30),No.8(50)	41.7
MGA 3711	SAIL	LN	Nos.5,7,10{194)	64.8

Kome

July 1999

Number of crafts sampled 12

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RBD 1563	SAIL	LN	No.10(300),No.11(100)	43.62
RMU 1546	SAIL	LN	No.10(300),No.11(200)	34.58
RMU 1521	SAIL	GN	5"(18),6"(26)	45.2
RMB 181	SAIL	GN	6"(35)	18.72
RMU 4555	SAIL	GN	6.5"(15),7"(10)	26.02
RMU 4909	SAIL	GN	5"(13),5.5"(47)	20.84
RMU 3953	SAIL	GN	5"(15),6"(14),7"(8)	23.18
RMB 239	SAIL	GN	5"(38),6"(7)	35.9
RMU 3901	SAIL	GN	6",7"{30}	63.28
RMU 2823	SAIL	LN	Nos.9&10{800)	66.7

5.1C: Third quarter 1999(cont.)

Ruhanga
Sept.,1999
Total number of fishing crafts 22
Number of crafts went fishing 21
Number of crafts sampled 10

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unknown (1)	Paddle	GN	7' (5)	13.00
Unknown (2)	Paddle	GN	5" (13),6" (12)	32.45
Unknown (3)	Paddle	GN	6" (7),7" (15)	12.68
Unknown (4)	Paddle	GN	5" (5),6" (6),7"(9)	28.60
Unknown (5)	Padd le	GN	5" (15),6" (16)	37.07
Unknown (6)	Paddle	GN	5" (10),6.5" (10),7" (5)	45.22
Unknown (7)	Paddle	GN	5" (10),6" (10)7" (10)	47.10
Unknown (8)	Paddle	GN	6.5" (17),7" (3)	14.90
Unknown (9)	Paddle	GN	5" (5),6"(24)	43.24
Unknown (10)	Paddle	GN	5" (15),6" (10)	30.14

Nyamukazi
Sept.,1999
Total number of fishing crafts 21
Number of crafts went fishing 15
Number of crafts sampled 6

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
BBKR 999	MOT.	GN	5"(30, 6"(50)	70.62
BBKR 411	MOT.	GN	5"(101)	110.92
BBKT 354	MOT.	GN	5"(70), 6"(16)	58.04
BBKR 618	MOT.	GN	5"(90)	117.08
BBKT 429	MOT.	GN	5.5"(40), 6"(20)	103.8
BBKR 757	MOT.	GN	5.5"(100)	91.2

5.1D: Fouth quarter 1999

BEACH:Kayenze

Nov. 1999
Total number of fishing crafts: 36
Number of craft that went fishing 33
Number of fishing crafts sampled: 7

Boat no.	Propulsion	Gear type	Gear size	Catch(kg)
MMW 1743	SAIL	GN	5" & 6"(40)	27.52
MUM 2431	MOT	GN	5"(22),6"(28)	103.6
MUM 5128	MOT	GN	5"(25),6"(25)	86.25
MUM 780	SAIL	GN	6"(10),5"(20)	16.91
MUM 1948	MOT	GN	5(55),6"(52)	119.12
MUM 2705	MOT	GN	5"(20),6"(29)	56.85
MUM 1759	SAIL	GN	5"(15),6"(15)	47.02

5.1D: Fourth quarter 1999(cont.)

Kisorya Oct-99

Total number of fishing crafts: 21

Number of craft that went fishing 12

Number of fishing crafts sampled: 9

Boat no.	Propulsion	Gear type	Gear size	Catch(kg)
Unknown(1)	SAIL	LN	No.10 & 11(800)	9.08
Unknown(2)	SAIL	LN	No.10 & 11(300)	58.3
RBD 2036	SAIL	LN	No.9 & 10(1500)	81.16
RBD 2554	SAIL	LN	No.9(200),12(350)	61.18
MUK 7006	Paddle	GN	5'(1),5.5'(2)	5.16
Unknown(5)	SAIL	LN	No.10(300),11(300)	19.19
RBD 2429	SAIL	LN	No.11(600),12(500)	60.62
RBD 2298	MOT.	GN	6",6.5"(52)	24.32
RBD 2376	MOT.	GN	5.5",6"(32)	28.68

Kibara

Oct-99

Total number of fishing crafts: 5

Number of craft that went fishing 3

Number of fishing crafts sampled: 3

Boat no.	Propulsion	Gear type	Gear size	Catch(kg)
RBD 2253	SAIL	Longline	No.10(800)	87.04
Unknown (1)	SAIL	Longline	No.10(800)	96.84
RBD 2138	SAIL	Longline	No.10 & 11(900)	60.84

Nyamikoma

Oct-99

Total number of fishing crafts: 35

Number of craft that went fishing:22

Number of fishing crafts sampled: 10

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
MUM 8056	MOT	GN	5"(20);6"(20)	54.08
MUM 1777	MOT	GN	5"(30),6"(20)	44.62
RBD 1757	MOT	LN	No.8&9(1300)	24.9
MUM 2720	SAIL	GN	5"(20),5.5"(30)	15.64
Unknown(1)	MOT	GN	5.5"(29),6"(19)	25.22
MUM 2594	MOT	GN	5"(60,6"(11)	56.5
Unknown(2)	SAIL	GN	5"(20),6"(10)	4.82
Unknown(3)	SAIL	GN	5"(30),6"(4)	25.54
MUM 2717	SAIL	GN	5'(20),6"(15),7"(5)	71.8
MUM 2718	MOT	GN	5'(35),5.5'(40)	58.76

5.1D: Fourth quarter 1999 (cont.)

Nyang'ombe

Nov-99

Total number of fishing crafts: 43

Number of craft that went fishing: 31

Number of fishing crafts sampled: 14

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unregistered(1)	MOT	GN	6"&7"(35)	118.96
Unregistered(2)	Paddle	GN	6"(3),7"(7),8"(3)	18.52
RTE 1397	MOT	GN	6"(15),7"(20)	30.34
RMU 4895	MOT	GN	6"(8),7"(17)	24.8
Unregistered(3)	MOT	GN	5",6",7"(45)	22.22
Unregistered(4)	Paddle	GN	6",7",8"{25}	28.88
RTE 1036	MOT	GN	5",6",7"{50}	32.44
RTE 969	MOT	GN	5",6",7"{40}	24.68
Unregistered(5)	Paddle	GN	4",5",6",7",8"{19}	6.66
RTE 1897	MOT	GN	5",6.5",7"{30}	33.08
RTE 850	Paddle	GN	3",5",6"{30}	29.42
RTE 1205	MOT	GN	5",6",7"{47)	21.54
RNU 1239	MOT	GN	6",7"{30}	35.52
RTE 1124	Paddle	LN	No. 8,9,10{200}	64.08

Kome

Nov-99

Date:19/11/99

Total number of fishing crafts: 22

Number of craft that went fishing: 3

Number of fishing crafts sampled: 3

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RMB 248	Paddle	LN	No.9&10(700)	48.68
RMU 4710	Paddle	LN	NO.9,10&11	80.5
MUM 2489	Paddle	LN	No 9&10 (900)	69.94

Burungu

Nov-99

Total number of fishing crafts: 28

Number of craft that went fishing: 17

Number of fishing crafts sampled: 11

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RMU 2760	SAIL	GN	5"(30)	42
RMU 1200	SAIL	GN	4.5",5"()	5.18
RMU 4580	SAIL	LN	No.9&10 (280)	19.46
RBD 1066	SAIL	LN	No.3(6)	47.2
RBD 2159	Paddle	GN	6"(10),7"(28)	37.86
RMU 519	SAIL	LN	No.7(45),No.10, 11{60}	38.84
RMU 4222	SAIL	GN	5"(34),6"(6)	55.4
RMU 3277	SAIL	GN	4.5"(20),5"(5)	20.14
Unregistered (1)	SAIL	LN	No.7(188)	22.6
RBD 2527	SAIL	LN	No.10(200)	35.38
RBD 2545	SAIL	LN	No.10(400)	28.34

5.2A: First quarter 2000

Kayenze Jan-00

Total number of fishing crafts: 48

Number of craft that went fishing: 33

Number of fishing crafts sampled: 13

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unknown	Paddle	LN	No.10(700)	26.72
MUM 1960	MOT	GN	5"(37),6"(15)	133.04
MUM 2277	MOT	GN	5"(20),6"(40)	120.28
MUM 4028	MOT	GN	5"(30),6"(20)	60.76
MUM 2	MOT	GN	5"(150,6"(30)	202.98
MUM 2773	SAIL	GN	4.5"(3),5"(27)	49.19
MUM 2526	MOT	GN	5'(30),6"(30)	232.02
MUM 2723	MOT	GN	5"(25),6"(25)	156.48
MUM 4028	MOT	GN	5"(30),6"(20)	94.12
MMW 5241	MOT	GN	5"(30),6"(31)	144.84
MUM 2582	Paddle	GN	6"(9),7"(6)	37.65
MUM 2481	MOT	GN	5"(25),6"(25)	37.12
MMW 6345	MOT	GN	5"(32),6"(45)	104.68

Nyamkazi

Total number of fishing crafts:29

Number of boats that went fishing: 29

Number of boats sampled: 11

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unregistered (1)	Paddle	GN	5" (50)	37.65
Unregistered (2)	MOT	GN	5" (50)	153.72
BBKR 356	MOT	GN	5" (100)	111.44
BBKR 776	MOT	GN	6" (50)	49.84
BBK 5237	MOT	GN	5" (50)	129.8
BBKT 474	MOT	GN	5" (40)	122.62
BBKT 275	MOT	GN	5" (50)	103.64
BBKT 276	MOT	GN	5" (55)	78.39
BBKT 502	MOT	GN	5" (100)	139.88
BBKR 801	MOT	GN	5" (85)	116.16
BBKT 128	MOT	GN	5" (60)	79.96

Ruhanga

Total number of boats: 20,

Number of boats that went fishing: 18

Number of boats sampled: 7

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unregistered(1)	Paddle	GN	5"(2)& 6(20)	19.34
Unregistered(2)	Paddle	GN	5"(25)	17.85
Unregistered(3)	Paddle	GN	5"(10), 6"(10)&6.5"(5)	31.44
Unregistered(4)	Paddle	LN	No.6(10)	57.44
BME 3117	Paddle	GN	5"(15) & 6"(7)	26.58
BME 5681	Paddle	GN	5"(12),6"(10)&6.5"(5)	38.31
BME 5418	Paddle	GN	5"(15) &6"(15)	34.84

5.2B Second quarter 2000

Kayenze Apr-00

Total number of boats 54

Number of boats that went fishing 42

Number of boats sampled 20

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Uregistered(1)	Paddle	LN	No. 10 (500)	25
Uregistered(2)	Paddle	LN	No. 11(300) & 12(200)	34.7
Uregistered(3)	SAIL	LN	No. 10 (600)	46.44
MMW 1540	SAIL	LN	No. 11 (1000)	69.26
MUM 1734	SAIL	LN	No. 11(500) & 12(250)	34.28
MUM 1732	SAIL	LN	No. 10 (600)	19.36
MUM 2256	SAIL	LN	No. 10 (500) & 11(500)	13.9
MUM 1050	SAIL	LN	No. 10 (500) & 11(320)	45.7
MUM 2424	SAIL	LN	No. 11(600)	37.78
MUM 2762	SAIL	LN	No. 11(600) & 12(40)	20.6
MUM 2277	MOT	GN	5"(28) & 6"(52)	43.22
MUM 1710	MOT	GN	5"(25) & 6"(25)	39.26
MUM 2757	SAIL	GN	5"(36)	96.52
MUM 2481	MOT	GN	5"(30) & 6"(31)	158.56
MUM 2261	Paddle	GN	5"(31) & 6"(19)	52.82
MUM 2244	MOT	GN	5"(40) & 6"(20)	80.96
MMW 4028	MOT	GN	5"(33) & 6"(22)	95.68
MMW 3485	MOT	GN	5"(33) & 6"(20)	99.48
MMW 4726	MOT	GN	5"(30) & 6"(20)	53.92
MMW 6699	MOT	GN	5"(60) & 6"(20)	82.34

Kibara May-00

Total number of boats: 14

Number of boats that went fishing: 8

Number of boats sampled: 7

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RBD 2688	SAIL	LN	No. 10 (1500)	96.68
RBD 2549	SAIL	LN	No. 11(1200)	62.58
RBD 2559	SAIL	LN	No. 10(600)	21.9
RBD 2422	SAIL	LN	No. 10(1000) & 11(1000)	102.44
RBD 2094	SAIL	LN	No. 10 (1500)	118.02
RBD 2643	SAIL	LN	No. 10(1125) & 11(1125)	56.72
RBD 3067	SAIL	LN	No. 10(1000) & 11(1000)	47.02

5.2B: Second quarter 2000(cont.)

Nyamikoma Jun-00

Number of boats sampled: 19

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unregistered(1)	MOT	GN	5" (40) & 5.5 (40)	70.12
Unregistered(2)	SAIL	GN	5" (45)	83.71
MMW 2544	SAIL	GN	5" (45)	56.9
MUM 880	SAIL	GN	5" (20) & 6"(20)	43.84
MSR 6348	SAIL	GN	5" (15), 6" (30) & 7" (30)	77.32
MUM 1450	SAIL	GN	5" (20) & 6" (18)	34.88
MUM 2522	SAIL	GN	5" (16) & 5.5" ((14)	41.91
MUM 2570	SAIL	GN	5" (30)	35.04
MUM 4920	SAIL	GN	5" (16) & 6" (14)	31.72
MMW 5733	SAIL	GN	5" (40)	47.58
MUM 1248	MOT	GN	6" ( ) & 7" ( ) - (38)	77.76
MUM 2412	MOT	GN	5" (20), 6" (30) & 7" (40)	40.88
MUM 1772	MOT	GN	4.5" (5) & 5" (40)	33.38
MUM 1954	MOT	GN	5" (45)	61.84
MUM 1500	MOT	GN	5" (30) & 6" (30)	63.9
MUM 1501	MOT	GN	5.5" (60)	129.72
MUM 1773	MOT	GN	5" (50)	66.06
MUM 1777	MOT	GN	5" (38) & 6" (20)	50.88
MUM 2715	MOT	GN	5.5" (50)	33.08

Nyang`ombe Jul-00

Total number of fishing crafts: 55

Number of craft that went fishing: 25

Number of fishing crafts sampled: 13

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unregistered(1)	MOT	GN	5"	117.16
Unregistered(2)	MOT	GN	6" & 7"	58.64
Unregistered(3)	MOT	GN	6" & 7"	43.88
Unknown(1)	Paddle	LN	No. 9 & 10	53.7
Unknown(2)	MOT	GN	6" & 7"	52.92
Unknown(3)	MOT	GN	6" & 7"	53.82
RTE 2055	MOT	GN	6" & 7"	74.5
RTE 1281	MOT	GN	5" & 6"	41.14
RTE 1952	Paddle	GN	6" & 7"	19.88
RMU 3738	MOT	GN	5" ,6" & 7"	34.66
RMU 3577	MOT	GN	5"	47.12
RMU 4978	MOT	GN	5" ,6" & 7"	26.44
RTE 2051	MOT	GN	6", 6.5" & 7"	74.32

5.2C: Third quarter 2000(cont.)

Kome Jul-00

Total number of fishing crafts: 63

Number of craft that went fishing: 25

Number of fishing crafts sampled: 17

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RMU 3831	MOT	GN	5", 6" & 7"	52.22
RMU 4047	Paddle	GN	5"	156.28
RMU 1855	Paddle	GN	7"	19.68
RMU 4170	Paddle	GN	5", 6" & 7"	57.04
RMU 4559	Paddle	GN	5"	55.64
RMU 2385	SAIL	GN	5" & 5.5"	45.14
RMU 3901	SAIL	GN	5", 6" & 7"	28.01
RMU 2442	SAIL	GN	6" & 7"	55.8
RMU 1521	SAIL	GN	5", 5.5" & 6"	29
MMW 6139	Paddle	GN	6"	86.4
RMB 181	Paddle	GN	5.5"	26
RMB 538	Paddle	GN	5", 6" & 7"	14.34
RMB 151	SAIL	GN	5"	29.76
RTE 1549	Paddle	LN	No. 7	49.72
RMU 3302	SAIL	LN	No. 10 & 11	103.2
Unregistered(1)	SAIL	LN	No. 10	12.7
Unregistered(2)	Paddle	LN	No. 9 &10	63.36

Kayenze Sep-00

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
MUM2510	MOT	GN	5" & 6"	29.39
MUM2614	MOT	GN	5" & 6"	73.46
MMW6346	MOT	GN	5" & 6"	69.08
MUM2510	MOT	GN	5" & 6"	42.56
MUM 1900	MOT	GN	5.5" & 6"	51.22
MUM1948	MOT	GN	5" & 6"	69.29
MMw 8515	MOT	GN	5" & 6"	92.63
MUM 2759	MOT	GN	5.5" & 6"	57.39
MMW 3203	MOT	GN	5" & 6"	38.51
MMW6245	MOT	GN	5" & 6"	129.77
Unknown	MOT	GN	6"	28.57
MUM 2748	MOT	GN	5" & 6"	47.42
MUM 1244	MOT	GN	5" & 6"	87.74
MUM1487	MOT	GN	5" & 6"	44.6

5.2D: Fourth quarter 2000

Kome Oct-00

Total number of fishing crafts 24

Number of crafts that went fishing 24

Number of fishing crafts sampled 14

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
MMW 6139	MOT	GN	5.5"(50)	24.75
RMB 446	MOT	GN	6"(20);7"(20);8"(18)	34.5
RMU 3831	MOT	GN	5"(20);6"(15)	23.9
MGA 6052	SAIL	GN	5"(20);6"(20)	50.95
RMM 56	SAIL	GN	5"(10);5.5"(10)	17.4
RMB 239	SAIL	GN	5"(7);6"(19)	17.25
RMU 1921	SAIL	GN	5"(14);5.5"(24);6"(24)	15.55
RMB 697	SAIL	GN	5"(16);5.5"(10);6"(10)	18.01
RMU 2385	SAIL	GN	5"(10);5.5"(20);6"(6)	12.1
RMB 538	SAIL	GN	5.5"(4);6"(30);7"(28)	33.6
RMU 3119	SAIL	GN	5"(11);6"(22);7"(9)	17.55
RMU 4170	SAIL	GN	5"(10);6"(20);7"(20)	61.75
RMM 57	SAIL	GN	6"(27);7"(28)	21.55
RMU 4909	SAIL	GN	5"(30);5.5"(40)	18.25

Nyangombe Oct-00

Total number of fishing crafts 55

Number of crafts that went fishing 27

Number of fishing crafts sampled 19

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
RMU 1595	MOT	GN	5"(15);6"(15),7"(15)	36.48
Unknown (1)	MOT	GN	5"(45)	28.9
RTE 1602	MOT	GN	6"(10);6.5"(5);7"(15)	24.7
RMU 3738	MOT	GN	6"(30);7"(10)	21.9
RMU 438	MOT	GN	5"(38)	51.72
RTE 1775	SAIL	LN	No.9(200)	18
RTE 5054	MOT	GN	5.5"(2);6"(20);6.5"(20)	87.75
RTE 1036	MOT	GN	6"(28);7"(20)	51.55
RMB 688	MOT	GN	6"(20);6.5"(20)	104
Unknown (2)	MOT	GN	5"(16);6"(13);7"(13)	37.3
RTE 1969	MOT	GN	6"(20);7"(30)	60.22
RTE1987	MOT	GN	7"(40)	89.55
RMU 4	MOT	GN	6"(10);7"(12);8"(13)	24.9
RTE 1578	Paddle	GN	6"(10);7"(8)	40.3
RMU 3774	MOT	GN	6"(30);7"(20)	80.9
Unknown (3)	Paddle	LN	No.8(3)	103
RTE 2002	MOT	GN	6"(12);7"(28)	37.8
RMU 4975	Paddle	LN	No.10(600)	48
RMB 628	MOT	GN	5"(30);6"(5)	76.55

5.2D: Fourth quarter 2000(cont.)

Nyamukazi Dec-00

Total number of fishing crafts 20

Number of crafts went fishing 16

Number of crafts sampled 12

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
BBKT 539	MOT	GN	5"(60)	79.24
BBKT 592	MOT	GN	5"(60)	128.06
Unknown(1)	MOT	GN	6"(50)	227.32
BBKR 1080	MOT	GN	5"(60)	56.68
BBKT 571	MOT	GN	5"(50)	22.5
BBKT 128	MOT	GN	5"(20),6"(40)	45.82
BBKT 463	MOT	GN	5"(60)	59.92
BBKT 472	MOT	GN	5"(40)	38.14
BBKT 354	MOT	GN	5"(60)	20.52
BBKT 516	MOT	GN	5"(60)	30.84
BBKT 276	MOT	GN	5"(30)	70.96
BBKT299	MOT	GN	5"(80)	30.96

Ruhanga Dec-00

Total number of fishing crafts 17

Number of crafts went fishing 16

Number of crafts sampled 14

Boat no.	Propulsion	Gear type	Gear size	Catch(Kg)
Unknown(1)	Paddle	GN	5"(20),6"(4),6.5(5)	33.72
Unknown(2)	Paddle	GN	5'(40,6"(23)	30.02
Unknown(3)	Paddle	GN	5"(12),6.5"(15)	33.14
BME 3504	Paddle	GN	5"(20),6"(14)	40.37
Unknown(4)	Paddle	GN	7"(22)	32
Unknown(5)	Paddle	GN	5'(10),6"(20)	30.48
Unknown(6)	Paddle	GN	5"(20),6"(10)	27.84
BME 5894	Paddle	GN	6"(20)	24.5
Unknown(7)	Paddle	GN	5"(14),6"(14)	29.46
Unknown(8)	Paddle	GN	5"(5),6"(19),7"(5)	34.32
Unknown(9)	Paddle	GN	6"(10),6.5"(10),7"(8)	36.58
Unknown(10)	Paddle	GN	5"(30)	26.72
Unknown(11)	Paddle	GN	5"(15),6"(15)	54.72
Unknown(12)	Paddle	GN	5"(17),6"(18)	44.82

5.2D: Fourth quarter 2000(cont.)

Kijiweni Dec-00

Total number of fishing crafts
20

Number of crafts went fishing 16

Number of crafts sampled 10

Boat no.	Propulsion	Gear type	Gear size	TW(Kg)
MSR 449	MOT	GN	5"(20),6"(15)	52.99
Unknown(1)	SAIL	LN	No.10(300),11(500)	42
MSR 2207	SAIL	LN	No.10(300),11(300)	49.1
Unknown(2)	SAIL	LN	No.9(500),10(500)	51.54
MSR 7569	Paddle	GN	5"(20)	38.91
MSR 6695	SAIL	LN	No.10(400),11(600)	61.63
MSR 5684	SAIL	LN	No.7(500),9(300)	57.64
MSR 7312	SAIL	LN	No.11(1000)	46.88
MSR 6804	SAIL	LN	No.10(500),11(400)	56.16
MSR 6101	SAIL	LN	No.10(700)	30.22

Appendix 6: Summary of catch rates by quarter for the different gears with different means of propulsion for (a) 1999 & (b) 2000, in the Tanzanian waters of lake Victoria (95% confidence limits (C.L.) included).

(a) 1999

GN/M Sample size	CPUE ±C.L.	GN/S Sample size	CPUE ±C.L.	GN/P Sample size	CPUE ±C.L.	LN/S Sample size	CPUE ±C.L.	LN/P Sample size	CPUE ±C.L.
1st Q	y87.33				16.20		31.18		
12	±25.20			8	±3.98	4	±13.43		
2nd Q	69.72						38.20		
15	±26.69					8	±16.51		
3rd Q	86.30		32.42		30.44		48.41		
12	±28.68	8	±12.70	10	±9.46	8	±11.08		
4th Q	48.88		30.18		17.02		48.41		
21	±14.51	11	±14.37	6	±11.08	15	±14.83		
Overal	69.26		31.12		22.34		44.11		65.8
60	±11.087	19	±8.96	24	±5.15	35	±7.35	4	±21.14

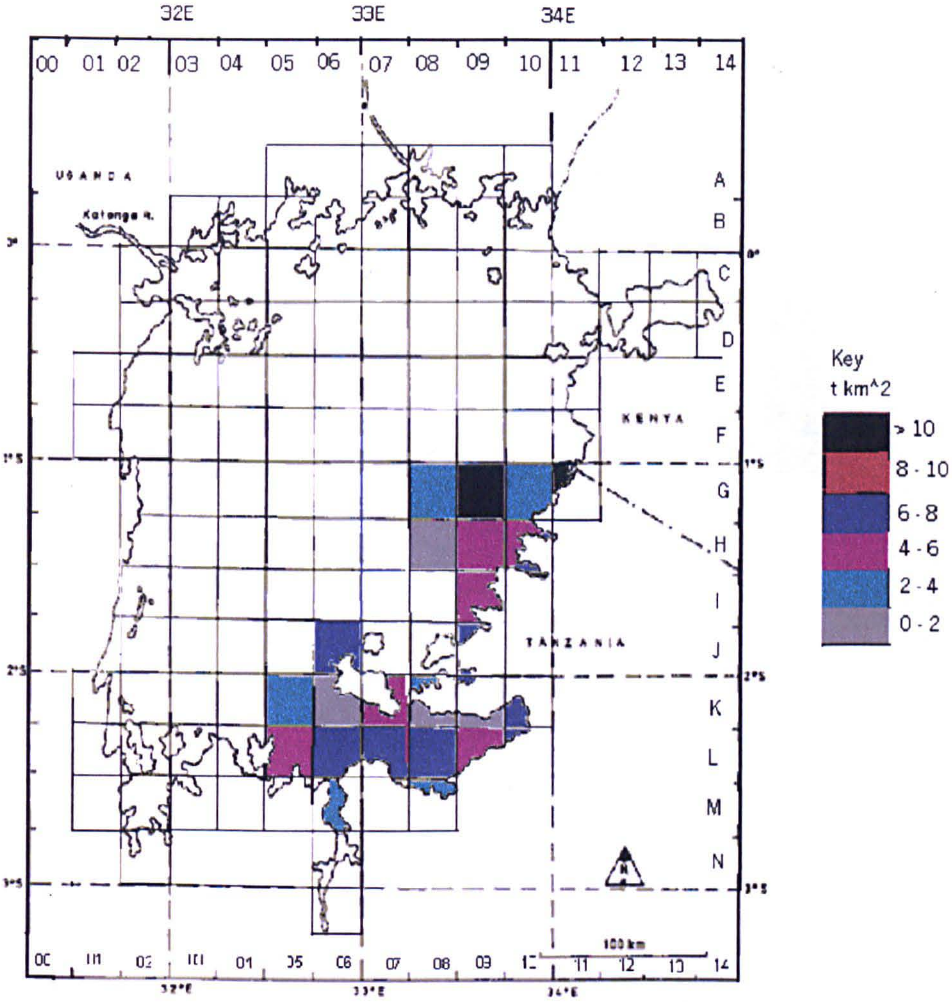
(b) 2000

GN/M Sample size	CPUE ±C.L.	GN/S Sample size	CPUE ±C.L.	GN/P Sample size	CPUE ±C.L.	LN/S Sample size	CPUE ±C.L.	LN/P Sample size	CPUE ±C.L.
1st Q	118.62				29.09				
20	±22.27	1	31.34	8	±6.55			2	57.01
2nd Q	71.17		54.94				40.98		
18	±16.71	10	±16.43			15	±12.94	2	29.85
3rd Q	59.17		49.54		29.85				62.26
26	±10.40	5	±14.42	7	±12.21	2	57.95	3	±15.08
4th Q	56.82		31.26		45.91				
31	±15.3	27	±4.93	9	±10.78	2	75.5		
Overal	73.19		39.26		35.62		46.40		51.5
95	±9.06	43	±5.65	24	±5.96	19	±14.21	7	±15.08

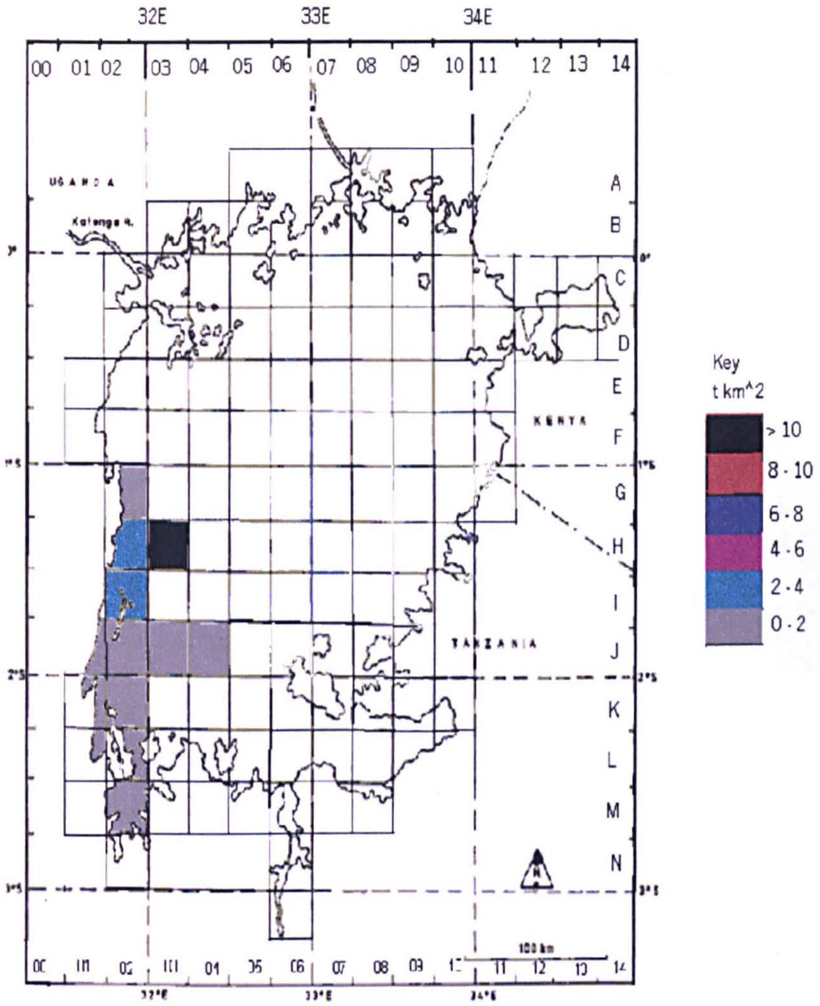
Appendix 7 Bottom trawl surveys (Swept area method) :Estimates of Abundance indices and standing crop biomass (t km^{-2}) per surveyed area (km^2) in the Tanzanian waters

GRID	Area (km^2)	Number	Mean	catch	Abundance index (t)		Standing Crop (t km^{-2})	
		of Hauls	N/p	O.n	N/p	O.n	N/p	O.n
G02	771.7	11	189.5209	11.03182	11394.88	663.2843	14.76595	0.859511
G05	771.7	1	218	0	13107.18	0	16.98481	0
G06	771.7	3	128	0	7695.956	0	9.972731	0
G08	771.7	3	96.95667	2.033333	5829.487	122.2535	7.554084	0.158421
G09	771.7	7	117.2671	0.628571	7050.647	37.79264	9.136513	0.048973
G10	694.6	15	98.06467	0	5307.029	0	7.64041	0
G11	61.7	6	262.9533	0.666667	1264.061	3.204779	20.48721	0.051941
H02	555.6	23	188.0739	0.812727	8141.322	35.18124	14.65321	0.063321
H03	764	5	186.3	0.044	11089.46	2.619088	14.515	0.003428
H04	771.7	3	22.26667	0	1338.776	0	1.73484	0
H05	771.7	1	27	0	1623.366	0	2.103623	0
H08	771.7	3	71.61333	0	4305.727	0	5.579535	0
H09	756.3	27	123.463	0.803704	7275.032	47.35809	9.619241	0.062618
H10	308.7	22	66.03636	1.831818	1588.268	44.05783	5.145022	0.142721
I01	30.9	2	261.8	0	630.2781	0	20.39735	0
I02	710	16	177.115	0.3375	9797.557	18.66965	13.79938	0.026295
I03	771.7	2	116.34	0	6994.903	0	9.064277	0
I04	771.7	2	97.25	0	5847.123	0	7.576938	0
I07	771.7	1	0	0	0	0	0	0
I08	756.3	9	104.0511	0	6131.192	0	8.106826	0
I09	339.6	19	99.71421	7.306667	2638.328	193.3264	7.76893	0.569277
I10	46.3	4	355.3075	12.0125	1281.709	43.33298	27.6827	0.935917
J01	216.1	10	167.144	0.095	2814.166	1.599494	13.02252	0.007402
J02	756.3	9	163.3244	2.148889	9623.863	126.6229	12.72493	0.167424
J03	771.7	3	133.6667	0	8036.663	0	10.41423	0
J04	771.7	1	170.1	0	10227.2	0	13.25282	0
J05	771.7	2	45.5	0	2735.672	0	3.544994	0
J06	648.3	3	260.1667	0	13141.1	0	20.27009	0
J07	656	10	104.566	0	5344.394	0	8.146942	0
J08	532.5	12	231.8625	3.030769	9619.539	125.7409	18.06486	0.236133
J09	100.3	4	186.165	14.13333	1454.799	110.4459	14.50448	1.101156
K01	247	8	52.765	1.485714	1015.423	28.59146	4.111025	0.115755
K02	725.4	11	122.5591	0.0058	6926.713	0.327801	9.548819	0.000452
K03	756.3	13	125	0.008462	7365.602	0.498595	9.738995	0.000659
K04	771.7	6	77.06667	0	4633.607	0	6.004415	0
K05	771.7	9	98.76444	0.0075	5938.179	0.450935	7.694931	0.000584
K06	532.5	11	77.06545	0.094444	3197.301	3.918322	6.004321	0.007358
K07	439.6	18	97.51278	0.915882	3339.822	31.36906	7.597412	0.071358
K08	362.7	21	71.21429	4.899048	2012.421	138.4406	5.548445	0.381694
K09	293.3	24	131.1204	3.575	2996.308	81.69439	10.21585	0.278535
K10	146.6	7	82.97143	8.731429	947.6908	99.72945	6.464467	0.680283
L01	123.5	2	57.325	2.4	551.5884	23.0931	4.466303	0.186989
L02	509.3	6	63.45833	1.15	2518.062	45.63265	4.944163	0.089599
L03	478.5	11	146.8255	0.158273	5473.781	5.900545	11.43946	0.012331
L04	270.1	13	76.86231	0.216154	1617.492	4.548746	5.988493	0.016841
L05	540.2	12	112.7867	0.264167	4746.97	11.11826	8.78743	0.020582
L06	524.8	23	131.6078	1.095	5381.207	44.77257	10.25382	0.085314
L07	563.4	25	173.6868	0.52244	7624.086	22.93282	13.53228	0.040704
L08	740.9	27	150.083	1.347778	8663.535	77.80043	11.69326	0.105008
M02	524.8	13	112.3381	3.931538	4593.301	160.7535	8.75248	0.306314
M06	154.3	10	90.904	8.15375	1092.831	98.02288	7.082509	0.635275
M08	54	2	67.75	0	285.0409	0	5.278535	0

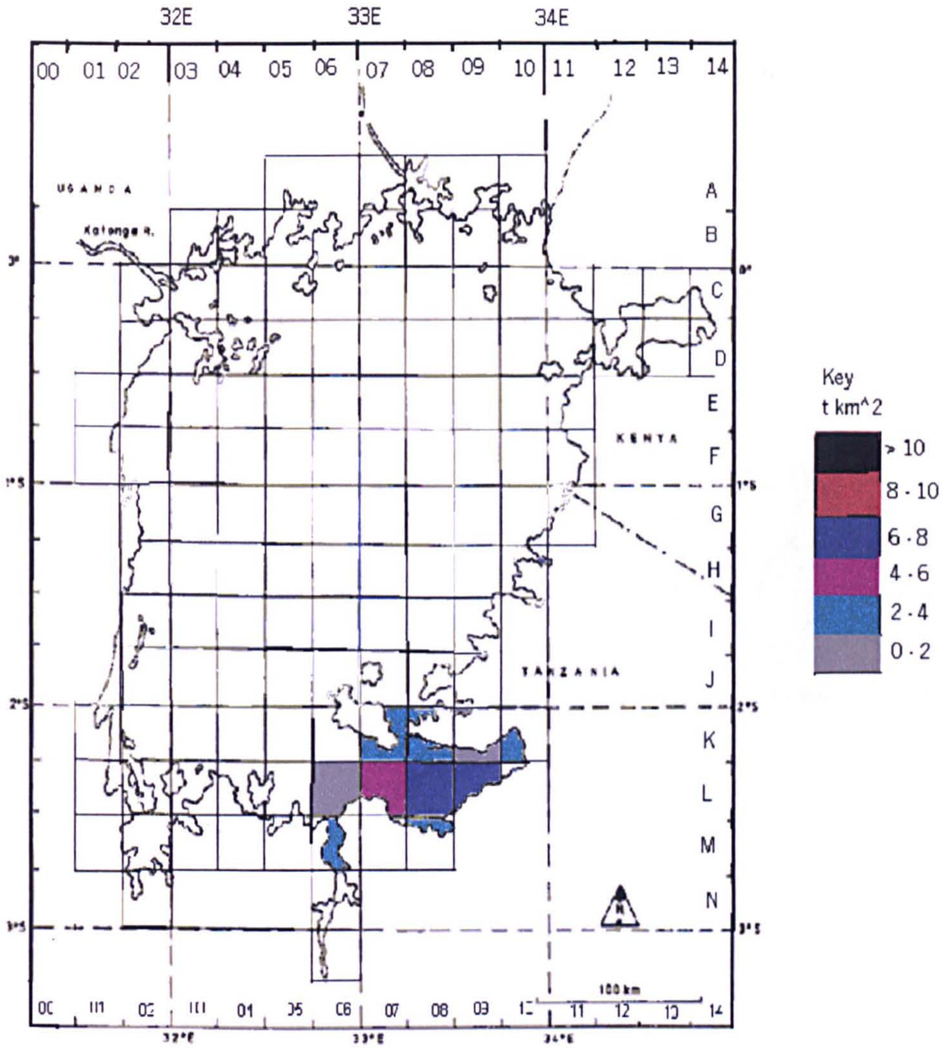
Appendix 8 1-11 Abundance distributions of Nile perch (t km^{-2}) in the different squares surveyed in different quarters



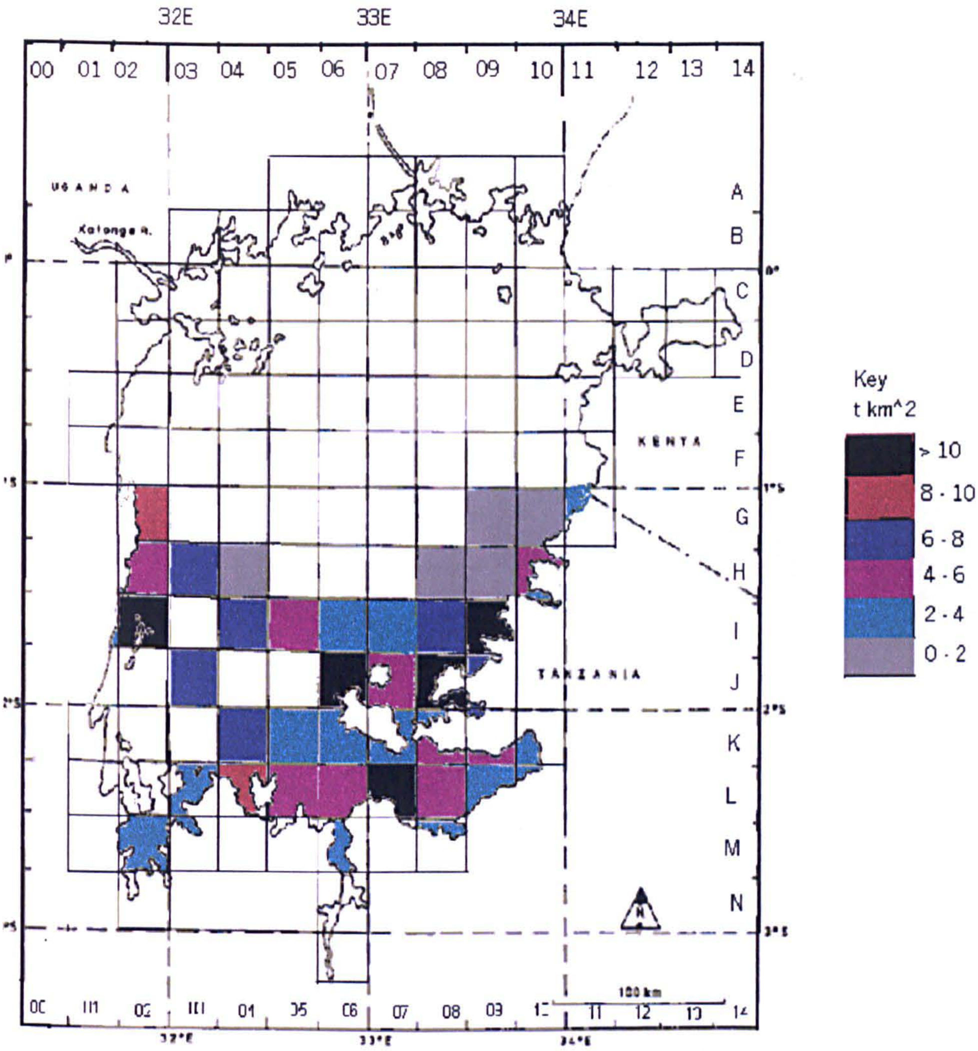
Appendix 8. 1 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 4th quarter of 1997 in zone A and B of Tanzanian waters of Lake Victoria



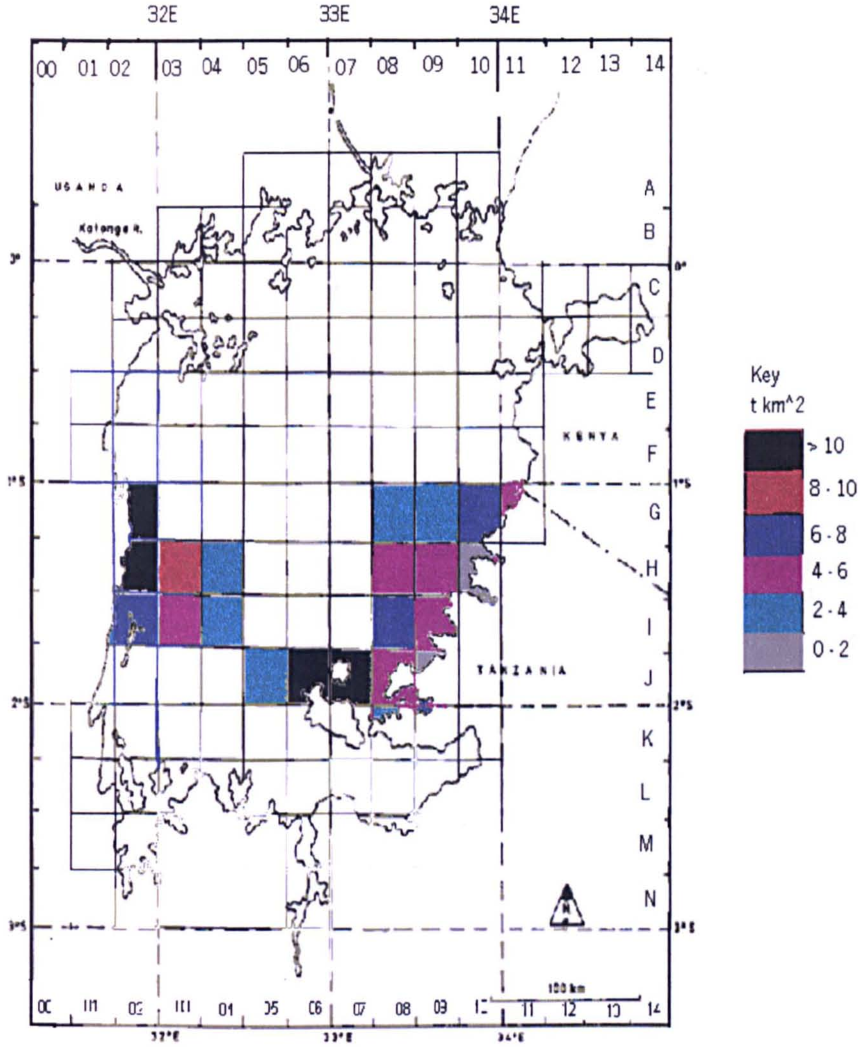
Appendix 8.2 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 1st quarter of 1998 zone C of Tanzanian waters of Lake Victoria



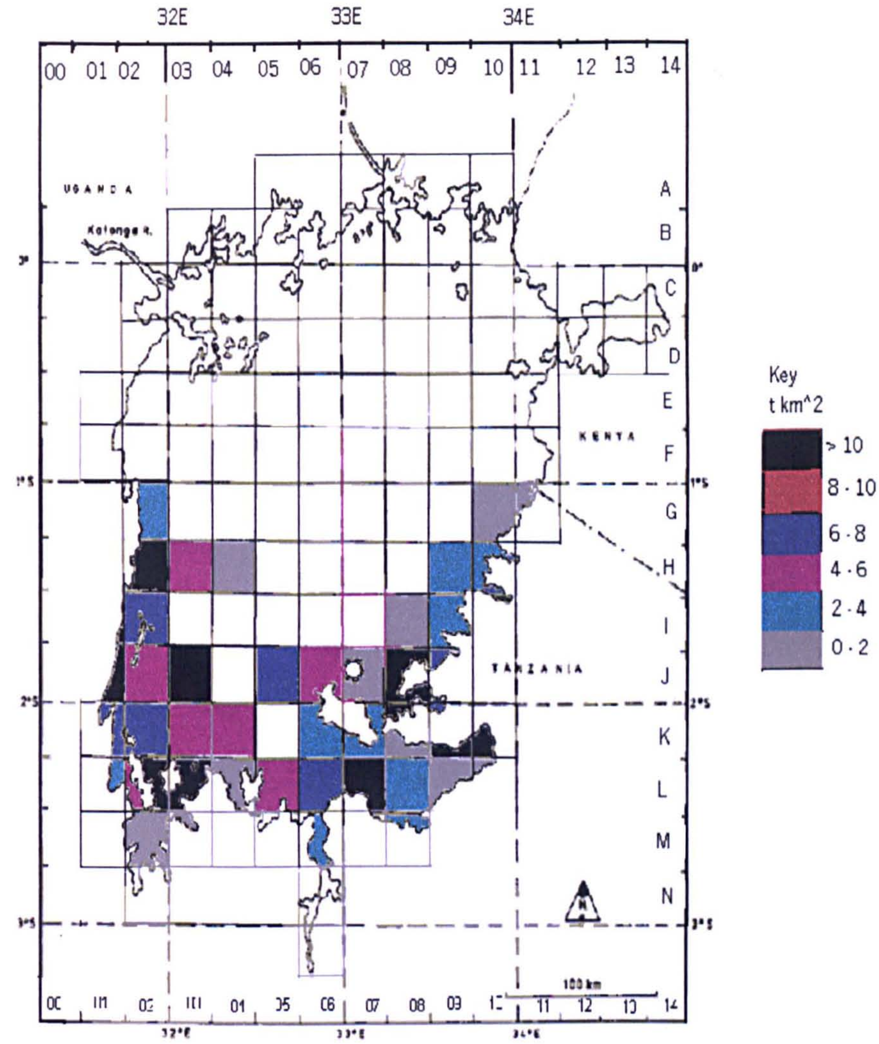
Appendix 8.3 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 1st quarter of 1999 zone A of Tanzanian waters of Lake Victoria



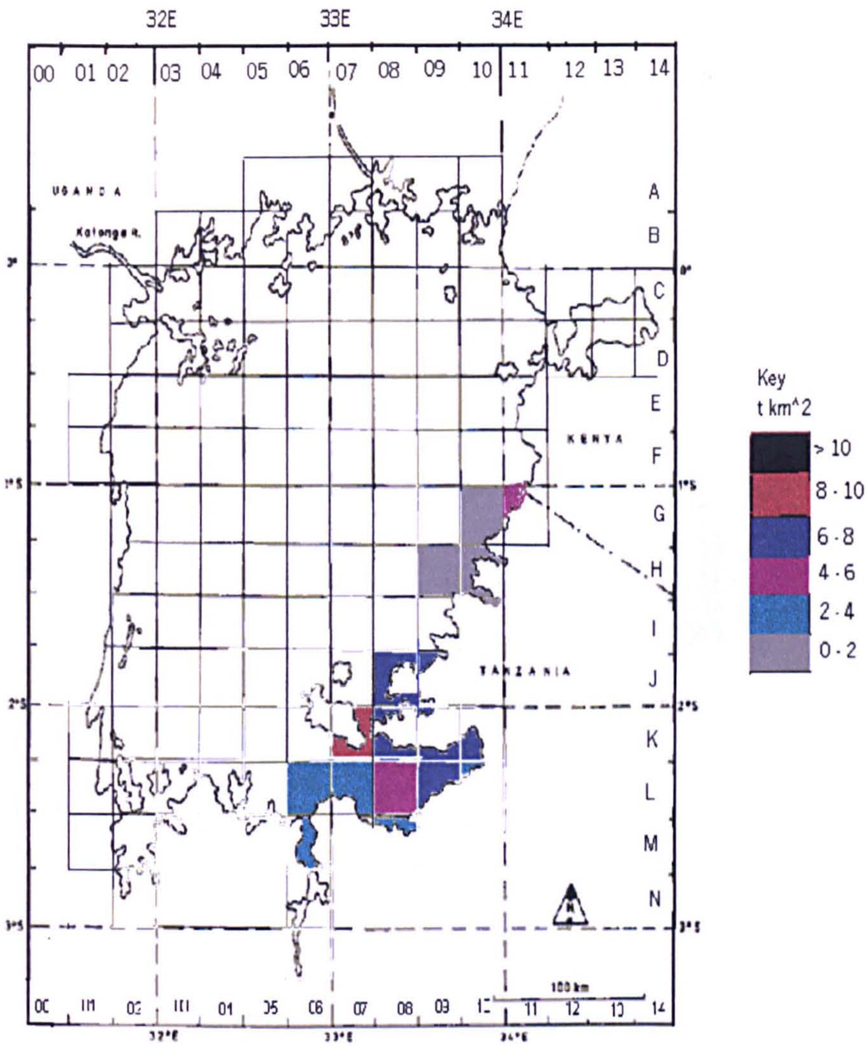
Appendix 8.4 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 2nd quarter of 1999 in zone A, B & C of Tanzanian waters of Lake Victoria



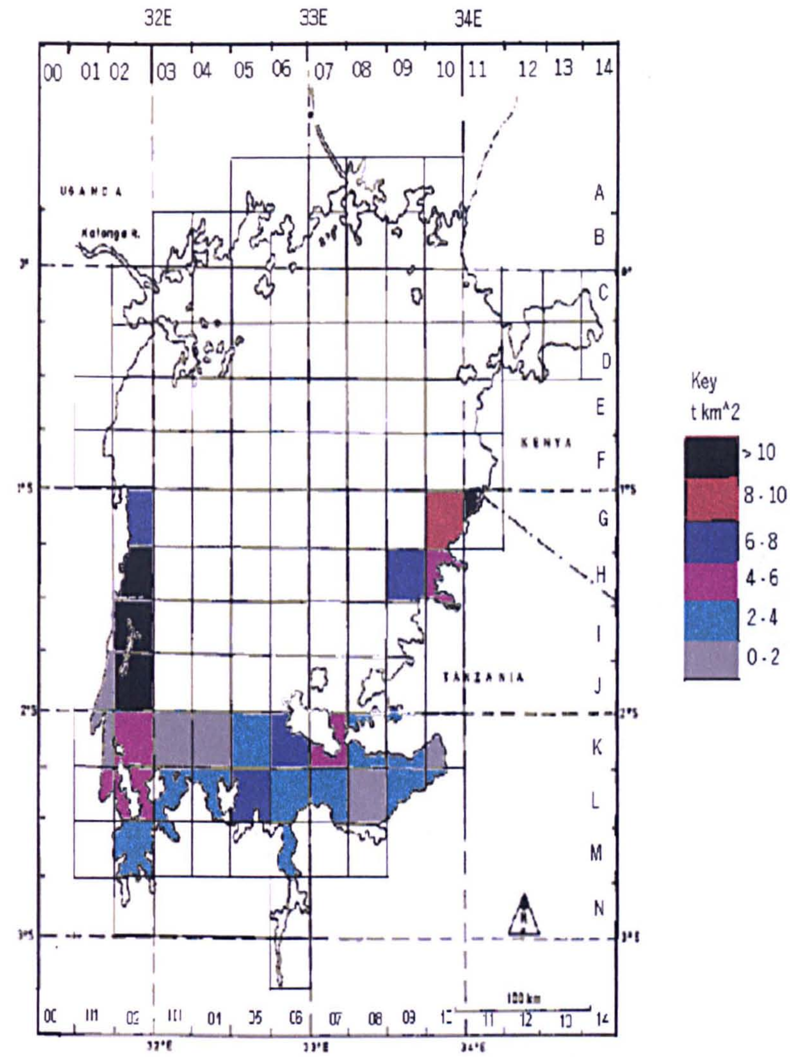
Appendix 8.5 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 3[rd] quarter of 1999 in zone B & C of Tanzanian waters of Lake Victoria



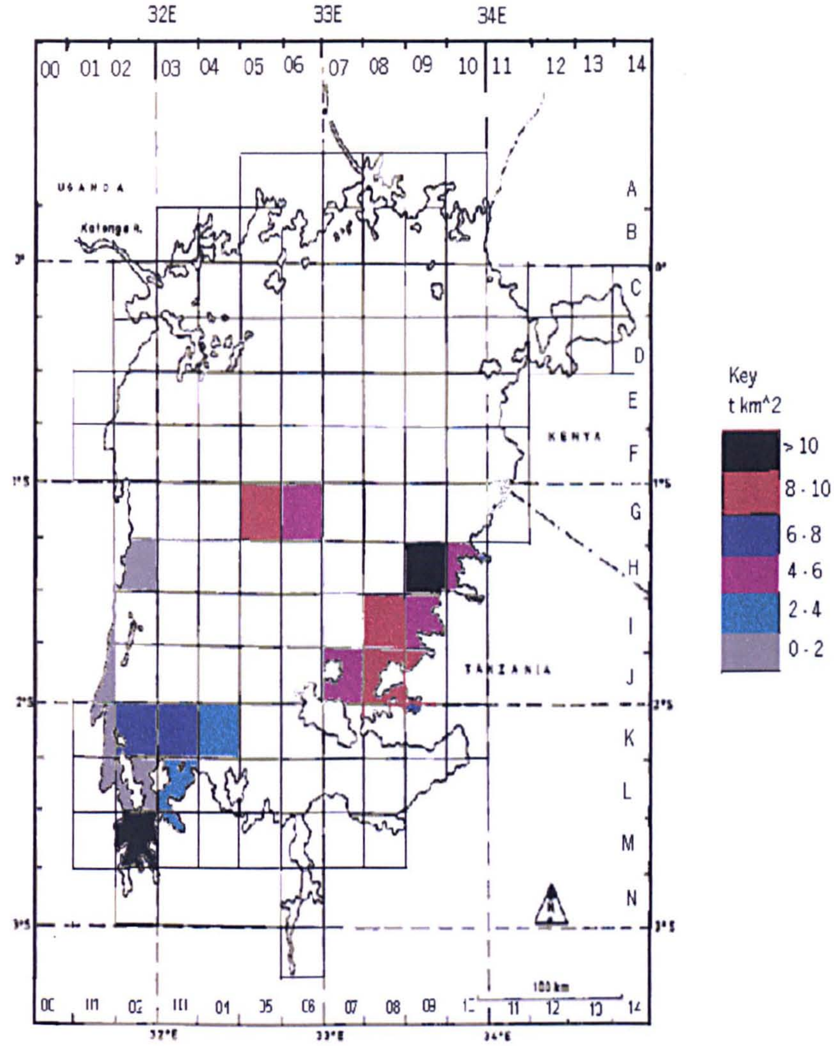
Appendix 8.6 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 4th quarter of 1999 in zone A, B & C of Tanzanian waters of Lake Victoria



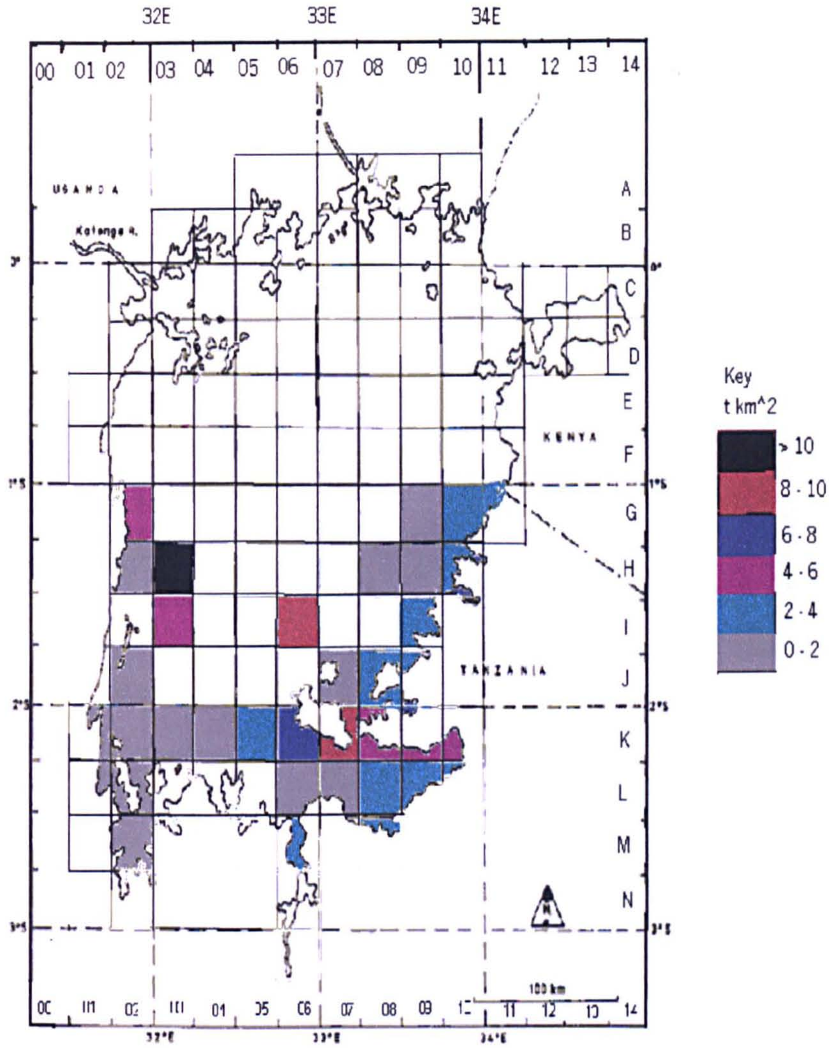
Appendix 8.7 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 1st quarter of 2000 in zone A & B of Tanzanian waters of Lake Victoria



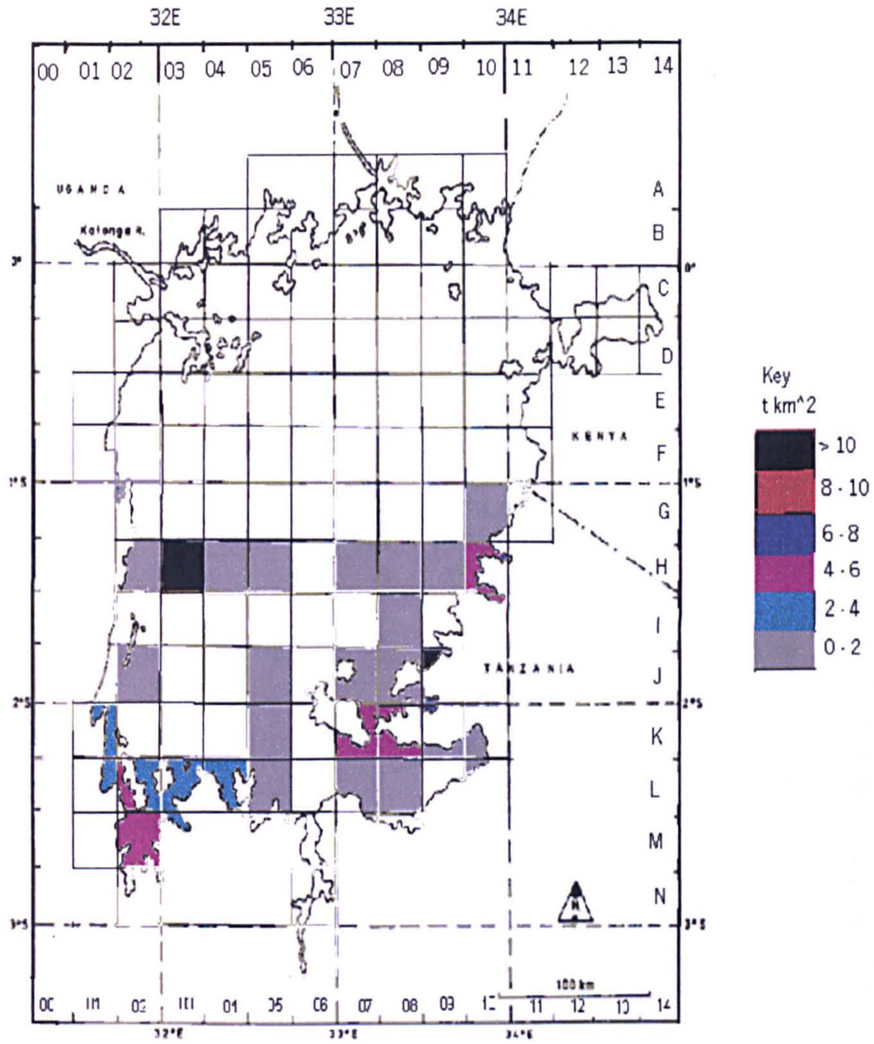
Appendix 8.8 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 2nd quarter of 2000 in zone A, B & C of Tanzanian waters of Lake Victoria



Appendix 8.9 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 3rd quarter of 2000 in zone B & C of Tanzanian waters of Lake Victoria



Appendix 8.10 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 4th quarter of 2000 in zone A, B & C of Tanzanian waters of Lake Victoria



Appendix 8.11 Nile perch standing crop biomass (t km^{-2}) per 15 by 15 nautical mile square surveyed for the 2nd quarter of 2000 in zone A, B & C of Tanzanian waters of Lake Victoria

Appendix 9: Bottom trawl surveys conducted by RV "Victoria Explorer", October 1997 to November 2000. Analysis of *L. niloticus* abundances by quarters using the swept area method

Year/Quarter		Zones surveyed	No. of hauls	CPUA (t/km^2)	Surveyed area (km^2)	Abundance index (t)
1997	4	A	42.00	9.63	4584.07	44125.41
		B	21.00	10.01	6042.63	60468.31
		C				
		All	63.00	9.84	10626.70	104593.72
1998	1	A				
		B				
		C	36.00	4.95	7424.03	36716.60
		All	36.00	4.95	7424.03	36716.60
1999	1	A	24.00	8.80	3565.39	31362.65
		B				
		C				
		All	24.00	8.80	3565.39	31362.65
1999	2	A	42.00	9.99	4584.07	45782.56
		B	32.00	5.61	7987.39	44838.26
		C	35.00	14.32	7416.31	106193.80
		All	109.00	9.85	19987.77	196814.61
1999	3	A				
		B	29.00	11.44	7987.39	91346.08
		C	12.00	14.12	5116.56	72255.71
		All	41.00	12.48	13103.95	163601.79
1999	4	A	23.00	10.42	4437.44	46241.41
		B	26.00	9.48	5525.58	52376.34
		C	45.00	13.83	9175.85	126923.19
		All	94.00	11.78	19138.86	225540.94
2000	1	A	29.00	10.25	3418.76	35028.30
		B	17.00	3.12	2917.13	9100.69
		C				
		All	46.00	6.96	6335.89	44128.99
2000	2	A	36.00	6.97	4584.07	31958.45
		B	12.00	14.49	1821.28	26389.92
		C	29.00	9.98	7292.83	72790.30
		All	77.00	9.57	13698.18	131138.67
2000	3	A				
		B	21.00	14.44	4993.08	72107.64
		C	19.00	8.72	5054.82	44055.99
		All	40.00	11.56	10047.90	116163.63

Appendix 10: Bottom trawl surveys in Lake Victoria 1997 - 2000. Analysis *of L. niloticus* catches by the swept area method. Results by country and for the whole lake.

Index 1 is the abundance in the surveyed area. Index 2 is scaled to the total area within national boundaries. Values in italics have been interpolated.

Year/Quarter		Country	CPUA (t/km^2)	Surveyed area (km^2)	Abundances (t) index 1	Index 2
1997	4	Kenya	10.01	2886.26	28884.24	35026.18
		Tanzania	9.84	10626.70	104593.72	339567.62
		Uganda	3.54	11445.00	40500.76	94442.57
		All	**6.97**	**24957.96**	**173978.71**	**469036.38**
1998	1	Kenya				67454.79
		Tanzania	4.95	7424.03	36716.60	170624.74
		Uganda	6.83	11445.00	78210.29	225812.74
		All	**6.09**	**18869.03**	**114926.89**	**463892.27**
1998	2	Kenya	28.54	2886.26	82368.53	99883.39
		Tanzania				203838.00
		Uganda	5.45	11445.00	62406.34	154107.05
		All	**10.10**	**14331.26**	**144774.88**	**457828.44**
1998	3	Kenya	16.09	2886.26	46443.08	56318.75
		Tanzania				237051.00
		Uganda				122271.00
		All	**16.09**	**2886.26**	**46443.08**	**415640.75**
1998	4	Kenya	15.13	2886.26	43675.82	52963.06
		Tanzania				270264.00
		Uganda	3.56	11444.70	40731.70	90434.29
		All	**5.89**	**14330.96**	**84407.52**	**413661.36**
1999	1	Kenya	10.13	2886.26	29244.75	35463.36
		Tanzania	8.80	3565.39	31362.65	303476.70
		Uganda	10.42	11445.00	119209.14	319479.20
		All	**10.05**	**17896.65**	**179816.54**	**658419.26**
1999	2	Kenya	12.72	2886.26	36704.72	44509.62
		Tanzania	9.85	19987.77	196814.61	339713.02
		Uganda	8.98	11444.70	102820.29	256776.23
		All	**9.80**	**34318.73**	**336339.62**	**640998.87**
1999	3	Kenya	12.99	2886.26	37502.59	45477.15
		Tanzania	12.48	13103.95	163601.79	430729.86
		Uganda	14.36	11444.70	164310.16	436071.68
		All	**13.32**	**27434.91**	**365414.54**	**912278.69**
1999	4	Kenya	11.00	2886.26	31744.49	38494.65
		Tanzania	11.78	19138.86	225540.94	406563.44
		Uganda	10.86	11445.00	124290.61	269762.87
		All	**11.40**	**33470.13**	**381576.05**	**714820.96**
2000	1	Kenya	9.85	2886.26	28435.49	34482.02
		Tanzania	6.96	6335.89	44128.99	240289.87
		Uganda	10.00	11444.70	114416.40	305028.37
		All	**9.05**	**20666.85**	**186980.88**	**579800.25**
2000	2	Kenya	8.81	1335.09	11755.92	30818.67
		Tanzania	9.57	13698.18	131138.67	330283.62
		Uganda	8.63	11444.70	98753.23	216361.56
		All	**9.13**	**26477.97**	**241647.82**	**577463.85**
2000	3	Kenya				30819.00
		Tanzania	11.56	10047.90	116163.63	398853.86
		Uganda	10.87	11444.70	124455.49	342264.94
Mean/Quarter			**11.20**	**21492.60**	**240619.12**	**771937.80**

Appendix 11a: Results of the length structured VPA using year 2000 catch survey length frequency raised to annual catch. Fishing mortality per length class given.

Length-structured VPA results for

LENGTH CLASS	CATCHES (N) (C*10^ 3)		POPULATION (N*10^ 4)		F. MORTALITY	
1.00- 4.00	0.00		6,532,641.50		0.0000	
4.00- 7.00	3,000.00		6,369,869.50		0.0005	
7.00- 10.00	0.00		6,208,644.50		0.0000	
10.00- 13.00	15,000.00		6,049,571.00		0.0028	
13.00- 16.00	108,000.00		5,890,871.50		0.0202	
16.00- 19.00	72,000.00		5,724,893.50		0.0136	
19.00- 22.00	42,000.00		5,564,616.50		0.0081	
22.00- 25.00	36,000.00		5,409,358.00		0.0070	
25.00- 28.00	54,000.00		5,256,673.50		0.0106	
28.00- 31.00	136,500.00		5,104,186.50		0.0273	
31.00- 34.00	303,000.00		4,945,597.00		0.0617	
34.00- 37.00	750,000.00		4,772,872.00		0.1565	
37.00- 40.00	1,305,000.00		4,558,875.50		0.2823	
40.00- 43.00	2,553,000.00		4,294,319.50		0.5861	
43.00- 46.00	6,147,000.00		3,912,689.75		1.6079	
46.00- 49.00	7,560,000.00		3,187,121.25		2.5054	
49.00- 52.00	6,477,000.00		2,343,615.50		2.9424	
52.00- 55.00	4,785,000.00		1,632,078.13		3.1012	
55.00- 58.00	3,519,000.00		1,108,832.63		3.3520	
58.00- 61.00	2,385,000.00		726,487.69		3.4304	
61.00- 64.00	1,608,000.00		467,825.50		3.5639	
64.00- 67.00	1,125,000.00		293,941.13		4.0072	
67.00- 70.00	639,000.00		173,299.53		3.7466	
70.00- 73.00	336,000.00		104,453.48		3.0973	
73.00- 76.00	117,000.00		67,707.52		1.4814	
76.00- 79.00	120,000.00		53,717.14		1.9347	
79.00- 82.00	78,000.00		39,918.38		1.6285	
82.00- 85.00	60,000.00		30,729.34		1.5924	
85.00- 88.00	39,000.00		23,636.62		1.2926	
88.00- 91.00	24,000.00		18,861.64		0.9535	
91.00- 94.00	39,000.00		15,731.70		1.9527	
94.00- 97.00	9,000.00		11,252.51		0.5571	
97.00-100.00	27,000.00		9,884.04		2.0855	
100.00-103.00	15,000.00		6,808.58		1.5858	
103.00-106.00	0.00		5,034.27		0.0000	
106.00-109.00	21,000.00		4,798.77		3.4951	
109.00-112.00	0.00		2,524.53		0.0000	
112.00-115.00	12,000.00	(Ct)	2,400.00	(Nt)	0.2900	(Ft)

Total catch : 40,519,491,584.00
Mean E : 0.620 (from Lmin
Mean F : 0.474 to Lmax)

Natural mort. : .29
Loo : 218 cm
K : .16

Appendix 11b: Results of the ...

PA II results for (a= .000018 ; b= 2.92)

ML (cm)	DELTA T (years)	MEAN N	CATCH (tonnes)	STEADY-STATE BIOMASS
2.50	0.087	%5612833792.00	0.00	1.96
5.50	0.088	%5549141504.00	0.01	15.51
8.50	0.090	%5485278720.00	0.00	52.58
11.50	0.091	%5420673536.00	0.34	124.00
14.50	0.092	%5350969856.00	4.83	239.45
17.50	0.094	%5278513664.00	5.56	407.78
20.50	0.095	%5208926720.00	5.14	637.54
23.50	0.096	%5140832256.00	6.56	936.43
26.50	0.098	%5071969792.00	13.96	1311.07
29.50	0.099	%4997921792.00	48.23	1766.00
32.50	0.101	%4911208960.00	142.00	2301.57
35.50	0.103	%4792978944.00	454.70	2905.82
38.50	0.104	%4622609408.00	1002.41	3550.76
41.50	0.106	%4356207616.00	2440.92	4164.97
44.50	0.108	%3823049216.00	7204.57	4480.79
47.50	0.110	%3017446912.00	10718.75	4278.21
50.50	0.112	%2201292544.00	10980.33	3731.81
53.50	0.114	%1542949760.00	9599.90	3095.54
56.50	0.116	%1049829504.00	8278.65	2469.78
59.50	0.118	695249984.00	6525.42	1902.22
62.50	0.121	451188192.00	5078.81	1425.06
65.50	0.123	280746496.00	4074.39	1016.77
68.50	0.125	170554432.00	2637.45	703.96
71.50	0.128	108481352.00	1571.68	507.43
74.50	0.131	78978608.00	617.05	416.53
77.50	0.133	62026600.00	710.18	367.08
80.50	0.136	47897888.00	515.74	316.70
83.50	0.139	37680104.00	441.45	277.23
86.50	0.143	30171532.00	318.09	246.08
89.50	0.146	25170486.00	216.23	226.78
92.50	0.149	19971948.00	386.88	198.12
95.50	0.153	16154098.00	98.00	175.90
98.50	0.157	12946817.00	321.78	154.30
101.50	0.161	9458975.00	195.13	123.05
104.50	0.165	8120938.00	0.00	115.02
107.50	0.170	6008426.00	323.06	92.43
110.50	0.174	4294007.00	0.00	71.59
113.50	0.179	41379312.00	216.33	745.96
TOTAL		%85541117952.00	75154.52	45553.79

Appendix 12: Results of the Relative Yield-per-recruit and Biomass-per-recruit model with $M = 0.29$, $K = 0.16$, $L_\infty = 218$ and L_c = (a) 10.43 cm & (b) 48.0 cm

(a)

RELATIVE YIELD/RECRUIT : Knife-edge
Parameters : Lc/Loo = .05 M/K = 1.8

E	Y'/R	B'/R	E	Y'/R	B'/R
0.05	.0054627	.883485	0.55	.0175881	.122493
0.10	.0101028	.773975	0.60	.0154168	.087487
0.15	.0139238	.671624	0.65	.0129520	.059366
0.20	.0169339	.576579	0.70	.0103300	.037685
0.25	.0191475	.488961	0.75	.0077057	.021864
0.30	.0205860	.408875	0.80	.0052491	.011170
0.35	.0212795	.336394	0.85	.0031350	.004709
0.40	.0212679	.271555	0.90	.0015239	.001441
0.45	.0206028	.214348	0.95	.0005231	.000234
0.50	.0193494	.164706	1.00	.0001141	.000000

Optima:
Emax = 0.374
E-.1 = 0.356
E-.5 : 0.244

(b)

RELATIVE YIELD/RECRUIT : Knife-edge
Parameters : Lc/Loo = .22 M/K = 1.8

E	Y'/R	B'/R	E	Y'/R	B'/R
0.05	.0055180	.899331	0.55	.0258924	.181721
0.10	.0104080	.803514	0.60	.0246768	.141117
0.15	.0146621	.712697	0.65	.0230069	.106266
0.20	.0182743	.627023	0.70	.0209546	.077034
0.25	.0212419	.546633	0.75	.0186090	.053209
0.30	.0235651	.471660	0.80	.0160778	.034478
0.35	.0252489	.402226	0.85	.0134869	.020416
0.40	.0263032	.338440	0.90	.0109791	.010464
0.45	.0267444	.280391	0.95	.0087057	.003930
0.50	.0265963	.228141	1.00	.0068086	.000000

Optima:
Emax = 0.462
E-.1 = 0.410
E-.5 : 0.281