FISHERIES TRAINING PROGRAMME

Address of the UNU-FTP
Marine Research Institute
Skulagata 4, 121 Reykjavik, Iceland

Final Project, 2014

AN EXAMINATION OF THE USEFULNESS OF SINGLE-SPECIES BIOMASS MODELS FOR THE MANAGEMENT OF LAKE VICTORIA FISHERIES

Nakiyende Herbert
National Fisheries Resources Research Institute, NaFIRRI,
P.O. Box 343, Jinja-Uganda
Plot 39/45 Nile Crescent, Jinja
nakiyende@yahoo.ie

Supervisor:
Arni Magnusson
Marine Research Institute
Skulagata 4, 121 Reykjavik, Iceland
arnima@hafro.is

ABSTRACT

Nile perch *(Lates niloticus*), tilapia (*Oreochromis spp*), dagaa (*Rastrineobola argentea*, silver cyprinid), and haplochromines (Tribe *Haplochromini*) form the backbone of the commercial fishery on Lake Victoria. These fish stocks account for about 70% of the total catch in the three riparian states Uganda, Kenya, and Tanzania. The lake fisheries have been poorly managed, in part due to inadequate scientific analysis and management advice. The overall objective of this project was to model the stocks of the commercial fisheries of Lake Victoria with the view of determining reference points and current stock status. The Schaefer biomass model was fitted to available data for each stock (starting in the 1960s or later) in the form of landings, catch per unit effort, acoustic survey indices, and trawl survey indices. In most cases, the Schaefer model did not fit all data components very well, but attempts were made to find the best model for each stock. When the model was fitted to the Nile perch data starting from 1996, the estimated current biomass is 654 kt (95% CI 466–763); below the optimum of 692 kt and current harvest rate is 38% (33–73%), close to the optimum of 35%. At best, these can be used as tentative guidelines for the management of these fisheries. The results indicate that there have been strong multispecies interactions in the lake ecosystem. The findings from our study can be used as a baseline reference for future studies using more complex models, which could take these multispecies interactions into account.

TABLE OF CONTENTS

TABLE OF CONTENTS **2**

LIST OF FIGURES **3**

LIST OF TABLES **3**

1.1 Background 4

1.2 Problem statement 5

1.3 Significance of the study 5

1.4 Scope of the study 5

1.5 Objectives of the study 5

2. LITERATURE **6**

2.1 Lake Victoria and its fisheries 6

2.2 Management of the Lake Victoria fisheries 6

2.3 Fish stock assessment models 6

2.4 Fish stock assessment studies and fisheries models on Lake Victoria 7

2.5 Schaefer biomass model 7

3. METHODOLOGY **8**

3.1 Data 8

3.2 Analysis 9

4. RESULTS AND DISCUSSION **10**

4.1 Catch history 10

4.2 Overview of model runs 11

5. CONCLUSION **20**

6. RECOMMENDATIONS **20**

ACKNOWLEDGEMENT **21**

REFERENCES **21**

APPENDIX **24**

LIST OF FIGURES

Figure 1: Map of Lake Victoria, East Africa (www.diercke.com, 2015) 9
Figure 2: Catches of Nile perch, tilapia, dagaa, and the haplochromines on Lake Victoria from 1960 to 2014. 10
Figure 3:Model fitted to the full Nile perch dataset from 1968 to 2014. 13
Figure 4: Model fitted to recent Nile perch data from 1996 to 2014. 14
Figure 5: Model fitted to early Nile perch data from 1968 to 1988. 15
Figure 6: Model results for dagaa: (a) full dataset from 1968 to 2014 and (b) recent data from 1990 to 2014. 16
Figure 7: Model results for tilapia: (a) full dataset from 1965 to 2014 and (b) recent CPUE data from 1990 to 2014. 17
Figure 8: Model results for haplochromines: (a) full dataset from 1960 to 2014 and (b) recent data from 1997 to 2014. 19

LIST OF TABLES

Table 1: Overview of data used in the study. Abbreviated institutes are Kenya Marine and Fisheries Research Institute (KMFRI) and Uganda National Fisheries Resources Research Institute (NaFIRRI). 8
Table 2: Summary of results for Nile perch, dagaa, tilapia, and haplochromines on Lake Victoria. 20

1 INTRODUCTION

1.1 Background

Lake Victoria, situated across the equator at an altitude of 1135 m and covering a total surface area of 68,800 km^2 is the largest tropical and second largest freshwater lake in the world (Welcomme, 1972; Greenwood, 2006). Shared between Tanzania, Uganda and Kenya, Lake Victoria supports one of the world's most productive inland fisheries with a total catch of around one million tonnes per year, landed by about 200,000 fishermen (Kayanda *et. al*, 2009). The total catch from the lake is valued at more than US$ 400 million and constitutes 3–6% of the total GDP of the three countries around the lake (World Bank, 2009; Ogutu-Ohwayo and Balirwa, 2006).
The fisheries of Lake Victoria have been characterized by shifts in abundance of different fish species and changes in fishing effort. Lake Victoria's fish fauna included a large endemic group of over 300 haplochromine cichlid species. About two-thirds of these species have disappeared or are threatened with extinction, the main cause being heavy predation by Nile perch, an introduced predator (Witte *et. al*, 1991). The lake's fisheries have changed from a multispecies fishery to three commercial species, with Nile perch (*Lates niloticus*) forming an important export trade. Before Nile perch was introduced in the lake between 1950 and 1960, the original fish community was dominated by over 100 species of haplochromine cichlids (Tribe *Haplochromini*) and the catfishes *Clarias mossambucus* and *Bagras doccmak* which preyed on them (Hughes, 1986; Ogutu-Ohwayo, 1990b; Achieng, 1990). By around 1980 the introduced Nile perch had established itself as a dominant commercial species, along with another introduced species Nile tilapia (*Oreochromis niloticus*) and the native zooplanktivore dagaa (*Rastrineobola argentea*, silver cyprinid).

Studies on feeding behavior have observed a shift in the diet of Nile perch from haplochromines in the 1960s through the 1970s to the freshwater shrimp *Caradinanilotica*, an indication that the predatory impact of Nile perch on the native haplochromines could have caused their decline (Hughes, 1986; Ogutu-Ohwayo, 1990a; and Kishe-Machumu *et. al*, 2012). Intensive fishing has also affected the lake fish composition, e.g., a decline in tilapia abundance that occurred before the introduction of Nile perch. In later years, there has been a resurgence in the fisheries of the haplochromines and dagaa (LVFO, 2014a; LVFO, 2014b).

The Lake Victoria fisheries are managed mainly through gear size restrictions and control of fishing effort by vessel licensing to restrict access to the resource. Of recent, the Lake Victoria Fisheries Organization (LVFO) harmonized the research processes on the lake where fisheries studies are implemented simultaneously in the three countries to generate uniform management advice for the lake fisheries (Kudoja *et. al*, 2001). Regional scientific meetings are coordinated to harmonize management decisions from such studies. Results of this study are hoped to contribute towards the sustainable management of the lake fisheries.

1.2 Problem statement

Currently the fisheries management on Lake Victoria is based on qualitative analyses of trends in the catch data, catch per unit effort (CPUE) and survey indices. Limited data exist on the catch composition in terms of age and length. The catch and effort data are long time series going back to around 1960, but the fishery-independent surveys began in 1997. All these data components are plagued by inconsistencies in the data collection and missing years of data. Since 2000, data collection on Lake Victoria in the three countries has been standardized and as the survey time series get longer, there is a stronger foundation for using analytical stock assessments as a basis for management advice.

1.3 Significance of the study

Around the world, it is considered good practice to base fisheries management on scientific analysis. Up to date, this has only been the case to a limited degree for the Lake Victoria fisheries, due to the problems outlined above, along with limited resources. This study contributes to the sustainable management of the lake fisheries by using the available data to fit a simple model to generate management advice.

1.4 Scope of the study

The study investigates the status and trends of stocks in four fisheries; Nile perch, tilapia, dagaa and the haplochromines in Lake Victoria. The Schaefer model is used to examine and demonstrate the usefulness of a single species biomass model to provide management advice for the fish stocks of Lake Victoria.

1.5 Objectives of the study

The overall objective of the study is to examine the feasibility of using a single-species biomass model to generate management advice for the Lake Victoria commercial fish stocks. Thus, the first task was to collect all available data from the Nile perch, tilapia, dagaa, and haplochromine fisheries of Lake Victoria. For each stock, the specific research questions are:

i. Does a simple Schaefer biomass model fit the data, or at least a subset of the data?
ii. What do the model results indicate about the current and historical biomass and harvest rates as well as reference points? Do these estimates seem realistic?
iii. Is the model potentially useful for giving management advice?
iv. If yes, what level of harvest rate is estimated as optimal? How does it compare with the current harvest rate?

2. LITERATURE

2.1 Lake Victoria and its fisheries

Currently, Lake Victoria is dominated by for major fisheries; Nile perch, dagaa, tilapia and the haplochromines. The other species of the lake include *Bagras spp*, *Clarias spp*, *Synodontis spp* and the African lung fish, *Protopterus aethiopicus*. Gillnets and hooks are the main gears used in the Nile perch and tilapia fisheries while the small seines are mainly used in the harvest of dagaa and the haplochromines on the lake (LVFO, 2012). The mean size of the individual fish landed in the commercial catches has been declining steadily since the 1980s as fishers progressively switch to fishing gears catching smaller fish and fishing effort has equally increased over time. It is becoming increasing hard to enforce the gear regulations on the lake partly due to financial constraints and the expansion of numerous fish landing sites on the lake shores.

2.2 Management of the Lake Victoria fisheries

Management of the Lake Victoria fisheries is mainly by gear size restrictions and control of fishing effort, an indirect way of regulating catch and based on management advice generated from fisheries dependent and independent data. Data collection on the lake has however been plagued by inconsistencies and data gaps in sampling mainly due to inadequate funding to fisheries research. Data from reliable fishery independent surveys is limited and scanty. Reports on the more frequently collected fishery dependent data are not detailed, contain information on total catch by major commercial species and gear categories but no analysis of fish biomass, harvest rates, or reference points.

2.3 Fish stock assessment models

Modeling the dynamic behavior of an exploited fishery in its ecosystem is important for providing realistic management advice for its stocks and is an integral component of many fish stock assessment studies (Haddon, 2011). Numerous models are available for providing key information about the fish stock size, including biomass models and age-structured models.
Biomass models are simplistic and require only time series of landed catch and biomass indices from CPUE or surveys (Chen and Andrew, 1998). Age-structured models are fitted to age or length distributions and are generally considered more reliable when these data are available, although Ludwig and Walters (1985) argued that biomass models can provide equally useful management advice as age-structured models, given that there is contrast in the biomass index that corresponds to the removals. The age and length data required in the age-structured models is not readily available for the lake Victoria fisheries. Aging fish population on the lake has registered less success with only two experimental studies undertaken on Nile tilapia and Nile perch (Bwanika *et. al*, 2007; Nkalubo, 2012).

Biomass models are useful for estimating the historical and current stock status in terms of biomass and harvest rate. They can also be used to evaluate reference points such as maximum sustainable yield (MSY), biomass at MSY (B_{MSY}) and the optimal harvest rate (u_{MSY}), and determine the stock status relative to these reference points.

2.4 Fish stock assessment studies and fisheries models on Lake Victoria

Collection of fisheries data on Lake Victoria is always characterized by inconsistencies and often lacks critical components necessary for meaningful stock assessment using many available methods (Cowx and Van der-Knaap, 2003). Length as well as age structured data are conspicuously missing or inadequate for all the exploited species on Lake Victoria. Without such data, it is near to impossible to predict long-term trends of fish stocks, besides generating reliable management advice for the lake stocks.

There have been previous attempts to use biomass models on Lake Victoria; analyses based on the two models, GADGET (Nyamweya, 2012) and Cadima (Kayanda *et.al*, 2009) have been presented as an exploratory basis for management advice. The two models however require data which is not easily available on the stocks of Lake Victoria. Only a few years of length data are available from trawl surveys of Nile perch and tilapia, but the sampling was inconsistent and covered only small parts of the lake, while the current collection of commercial catch data does not provide for collection of length data. Age data on the other hand is difficult to obtain in the tropical fisheries and little success has been registered in aging Nile perch (Nkalubo, 2012) and Nile tilapia (Bwanika *et.al*, 2007). The two models have shown the Nile perch and tilapia to be under intensive exploitation above the maximum sustainable yields from the lake, which findings other studies (Kolding *et.al*, 2014) dispute, the later suggesting other factors besides fishing pressure to be responsible for the observed trends within the commercial stocks of the lake.

Another concern is that majority of the previous fish stock assessment studies on Lake Victoria focused on Nile perch, with little or no attention to the other equally important fisheries of Lake Victoria (Taabu, 2004; Nyamweya, 2012). This is partly because Nile perch is the major export commodity for the international market while the other commercial species are traded and consumed within the region. Until now, no study has examined and compared the main commercial stocks in a consistent manner using analytical methods.

2.5 Schaefer biomass model

The Schaefer biomass model (Schaefer, 1954) describes the dynamics of the stock in terms of biomass. It is a logistic population growth model with catches removed annually (Musick and Bonfil, 2004). The estimated parameters are the intrinsic rate of population increase (r), carrying capacity (K), and a catchability coefficient (q) that is a scaling factor between a relative biomass index and the population size. In addition, the biomass in the first year can either be estimated as an explicit parameter or assumed to be at carrying capacity. The Schaefer model is based on the following assumptions (Haddon, 2011):

i. there are no species interactions,
ii. r is independent of age composition,
iii. no environmental factors affect the population,
iv. r responds instantaneously to changes in biomass,

v. q is constant,
vi. there is a single stock unit,
vii. fishing and natural mortality take place simultaneously,
viii. no changes in gear or vessel efficiency have taken place, and that
ix. catch and effort statistics are accurate.

In practice, many of the above assumptions are not met, but this does not mean that the method cannot be used. As long as the model is used critically, the Schaefer model is a very powerful tool for an initial assessment of a stock (Ludwig and Walters, 1985; Musick and Bonfil, 2004,).

3. METHODOLOGY

3.1 Data

The study uses data collected on Lake Victoria since the 1960s. Missing years of catch data (2009, 2012, 2013) and effort data (odd years since 2000) were calculated using linear interpolation. Effort was defined as the number of boats involved in each fishery in a given year.

Table 1: Overview of data used in the study. Abbreviated institutes are Kenya Marine and Fisheries Research Institute (KMFRI) and Uganda National Fisheries Resources Research Institute (NaFIRRI).

Stock	Catch	Effort	CPUE indices	Trawl survey Indices	Acoustic survey indices
Nile perch	1965–2004 (Kolding *et. al*, 2013); 2005–2014 (LVFO, 2014a)	1968–1999 (Nyamweya, KMFRI, unpubl. data; 2000–2012 (LVFO, 2012)	Calculated by dividing catch by effort	1997–2012 (Bassa, NaFIRRI, unpubl. data	1999–2014 (LVFO, 2014b)
Dagaa	1968–2004 (Kolding *et. al*, 2013); 2005-2014 (LVFO, 2014a)	1968–1999 (Nyamweya, KMFRI, unpubl. data; 2000–2012 (LVFO, 2012)	Calculated by dividing catch by effort	1997–2012 (Bassa, NaFIRRI, unpubl. data	1999–2014 (LVFO, 2014b)
Tilapia	1965–2004 (Kolding *et. al*, 2013); 2005–2014 (LVFO, 2014a)	1965–1999 (Nyamweya, KMFRI, unpubl. data; 2000–2012 (LVFO, 2012)	Calculated by dividing catch by effort	1997–2012 (Bassa, NaFIRRI, unpubl. data	1999–2014 (LVFO, 2014b)

Haplochromines	1959–2004 (Kolding *et. al*, 2013); 2005–2014 (LVFO, 2014a)	1959–1999 (Nyamweya, KMFRI, unpubl. data; 2000–2012 (LVFO, 2012)	Calculated by dividing catch by effort	1997–2012 (Bassa, NaFIRRI, unpubl. data	1999–2014 (LVFO, 2014b)

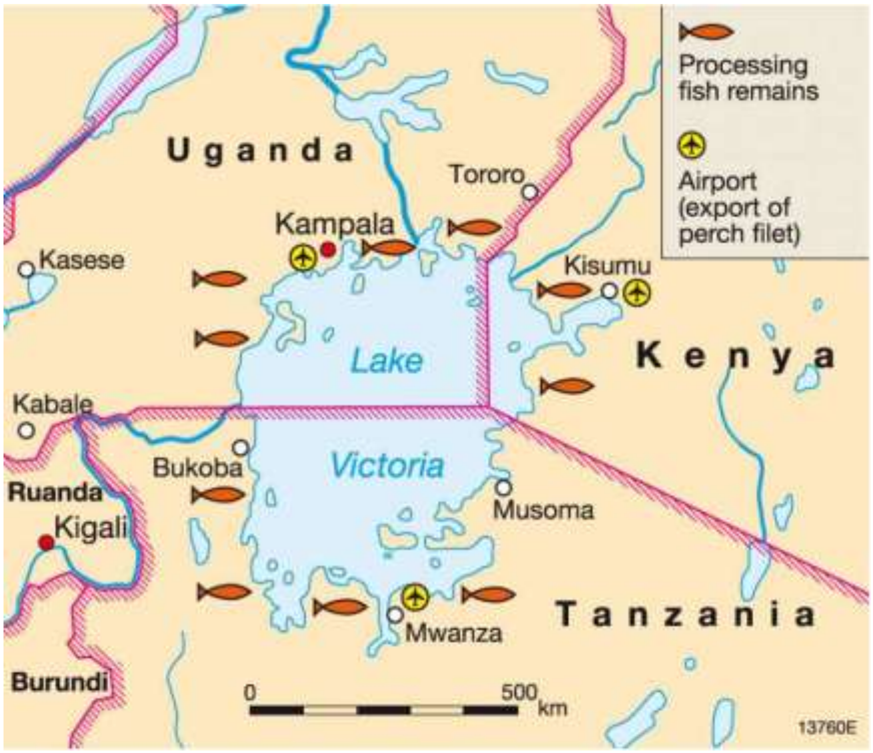

Figure 1: Map of Lake Victoria, East Africa (www.diercke.com, 2015)

3.2 Analysis

The Schaefer model parameters intrinsic growth rate (*r*), catchability (*q*), carrying capacity (*K*) and initial biomass (B_{init}) were estimated by minimizing the residual sum of squares (RSS).

The population dynamics are:

$$B_{t+1} = B_t + rB_t\left(1 - \frac{B_t}{K}\right) - C_t \qquad (1)$$

Where B_t is stock biomass at time t, and C_t is the total catch in year t. The parameters r and K refer to the logistic equation whose distinctive property is that maximum production occurs at $\frac{K}{2}$

and the optimal harvest rate is $\frac{r}{2}$. Harvest rate in a given year is defined as the catch divided by biomass.

The model is fitted to biomass indices from CPUE and surveys, where the fitted index is calculated as:

$$I_t = qB_t \qquad (2)$$

Model residuals are calculated as log(observed) minus log(fitted), except when fitting to CPUE data from the early years of the fisheries, where the observed CPUE values are close to zero. In those model runs, residuals are calculated simply as observed minus fitted values.

The reference points for each stock were evaluated using the following equations.

$$\text{Maximum sustainable yield, MSY} = \frac{rK}{4} \qquad (3)$$

$$\text{Biomass at MSY, } B_{MSY} = \frac{K}{2} \qquad (4)$$

$$\text{Harvest rate at MSY, } u_{MSY} = \frac{r}{2} \qquad (5)$$

4. RESULTS AND DISCUSSION

4.1 Catch history

Starting with the mid 1980s, the four stocks have varied in their contribution to the commercial catch landings on Lake Victoria (Figure 1). The Nile perch fishery dominated between the 1980s and 1990s but has since been overtaken by the dagaa in the recent years starting in 2005.

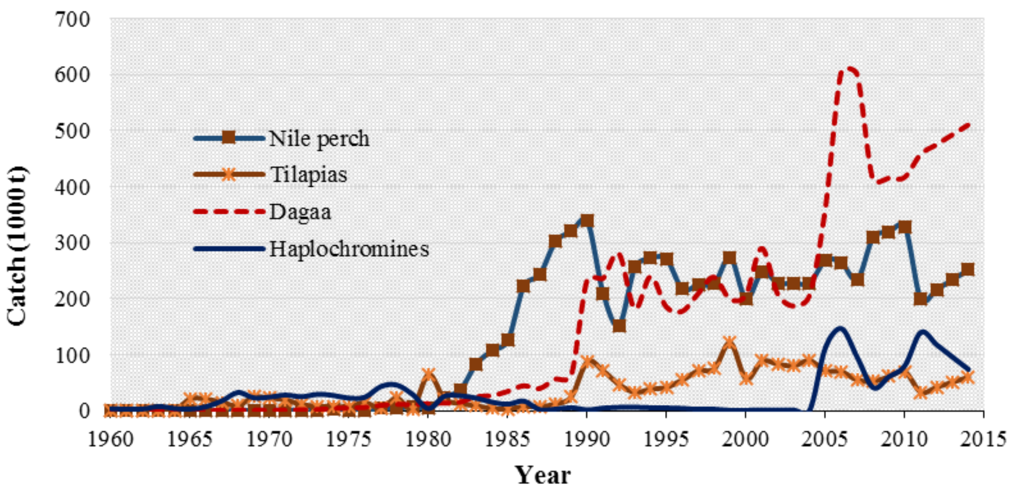

Figure 2: Catches of Nile perch, tilapia, dagaa, and the haplochromines on Lake Victoria from 1960 to 2014.

The catch landing in the four fisheries have fluctuated over time since the 1960s (Figure 8). The haplochromines which dominated the commercial fishery but still in small quantities from the 1960s up to 1980 were quickly over taken by Nile perch after full establishment of the latter. Studies have shown that the Nile perch significantly contributed to the decline of the haplochromines through predation (Hughes, 1986; Ogutu-Ohwayo, 1990a; Ogutu-Ohwayo, 1990b) and that after the Nile perch depleted their food source, the species composition of the lake changed. The complete disappearance of the haplochromines from the commercial fishery in 1990 corresponds with a decline in the Nile perch catch, after which the Nile perch catch has fluctuated between 200 and 250 thousand tonnes and has never reached a maximum catch record of the 1990. Catch results generally show the catches of Nile perch and tilapia to have remained relatively stable in the last two decades. Recent years starting from 2005 have however witnessed a drastic increase in the dagaa fishery on the Lake, overtaking the Nile perch by a two-fold increase. This change could be attributed to increased directed fishing towards the dagaa.

4.2 Overview of model runs

Figures 3–7 present results of the Schaefer biomass model fitted to CPUE, trawl and acoustic survey indices for the stocks of Nile perch, dagaa, tilapia and the haplochromines. For each fishery, the model was first fitted to the full dataset from the 1960s onwards (a), and then fitted to a subset of the data that the model can fit (b).

Three models were fitted to the Nile perch data. The full model (1968–2014) shows the entire dataset and an overall lack of fit. The model fitted to the recent data (1990–2014) fits better and is used as the main model for this stock. Finally, a model fitted to the early CPUE data series (1968–1988) provides an opportunity to estimate the r parameter in a period that is informative about the maximum growth rate that occurs at a low population size.

For dagaa, catch and CPUE data (1966–2014), trawl survey indices (1997–2012) and acoustic survey indices (1999–2014) were used in two models, one from 1966 to 2014 and the other from 1990 to 2014. The tilapia model 1965–2014 used catch and CPUE data (1965–2014) and trawl survey indices (1997–2012) while that for the period 1990–2014 used only CPUE and catch data covering that period. The model for haplochromines (1960–2014) used CPUE indices covering that period besides trawl survey indices (1997–2012) and acoustic survey indices (1999–2014) while that for the later periods (1997–2014) used CPUE indices (1997–2014), trawl survey indices (1997–2012) and acoustic survey indices (1999–2014).

For all the models, the blue dots represent the observed while the red lines represent the fitted indices. Table 2 summarizes the results from the best model fits for all the four fisheries. The most recent data subsets for all the four fisheries provided the best fit with the Schaefer biomass model.

Nile perch

Full model (1968–2014) with CPUE, acoustic survey, and trawl survey (Figure 3). The model did not fit the CPUE data probably due to the fast growth of the Nile perch in the 1980s and immediate decline of the species afterwards in the 1990s. The Nile perch commercial fishery became significant on the Lake in the 1980s (Okemwa, 1984; Hughes, 1986) and this could have led to the rapid increase in its catch landings. This trend was however short lived and was immediately followed by a sudden two-fold decline in the catch between 1990 and 1992. By not fitting the CPUE data, the model could not attribute this sudden collapse of the fishery to fishing and density dependence but rather other factors. The haplochromines which formed a major diet of the Nile perch in the 1980s, are reported to have significantly declined after the Nile perch establishment, a period coinciding with a shift in the diet of Nile perch from the haplochromines to the freshwater shrimp *Caradinanilotica* (Hughes, 1986; Ogutu-Ohwayo, 1990a). Other factors such as exhausted food resources could have caused a population decline around 1990.

The Nile perch model (1996–2014) gave the best fit with CPUE, trawl and acoustic survey indices (Figure 4). The model estimated *r* at 0.704 and *k* at 1.4 million tonnes. The model also estimated biomass in 2014 at 654 thousand tonnes and a harvest rate of 38% (Table 2). The maximum sustainable yield from the Nile perch fishery on Lake Victoria was estimated at 244 thousand tonnes. The model shows a lower current biomass compared to B_{MSY} and over harvest of the species (Table 2). It is clear from this study that once the optimal harvest rate of 35% is attained, the stock biomass of the species would increase by about 5%. This would require reducing fishing involved in the Nile perch fishery on the lake. The results of this model are comparable with those estimated using GADGET (Nyamweya, 2012) and CADIMA (Kayanda *et.al*, 2009) models. The two earlier models estimated Nile perch biomass between 500 to 700 thousand tonnes. Given appropriate data, the Schaefer single species biomass model can still be used to provide appropriate management advice for this species on Lake Victoria.

The model fitted to CPUE data (1968-1988) during the early years of the Nile perch establishment gave an indication on Nile perch performance in a relatively stable environment (Figure 5). The intrinsic growth rate *r* of Nile perch in those early years was estimated at 0.95 and the maximum carrying capacity *k* as 2 million tonnes. This high growth rate refers to a period when the lake environment was quite different from today, in terms of species composition, food availability, and interspecies competition.

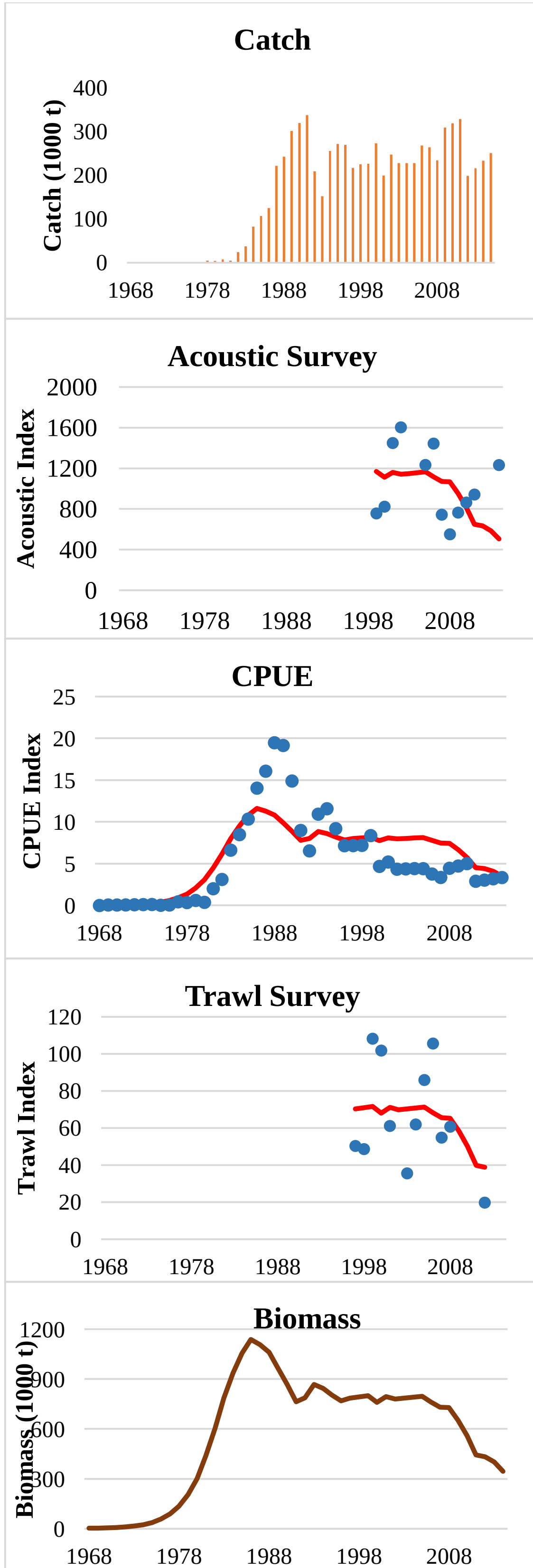

Figure 3:Model fitted to the full Nile perch dataset from 1968 to 2014.

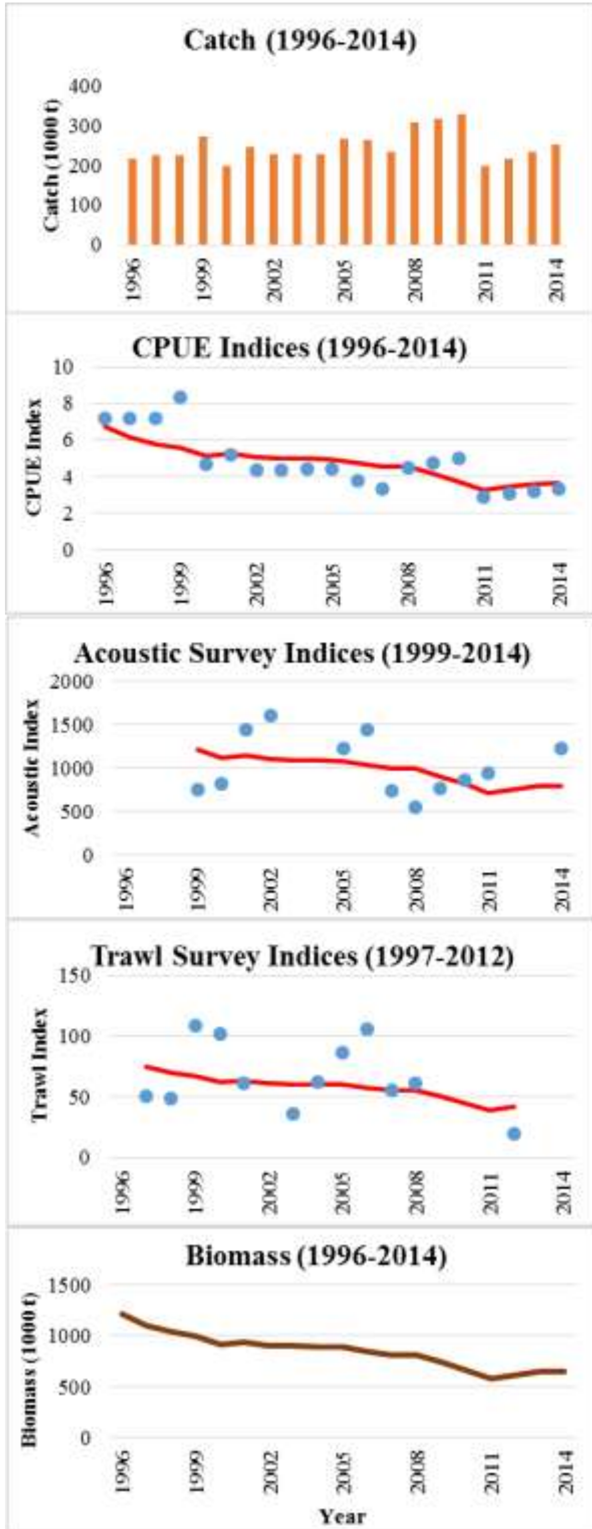

Figure 4: Model fitted to recent Nile perch data from 1996 to 2014.

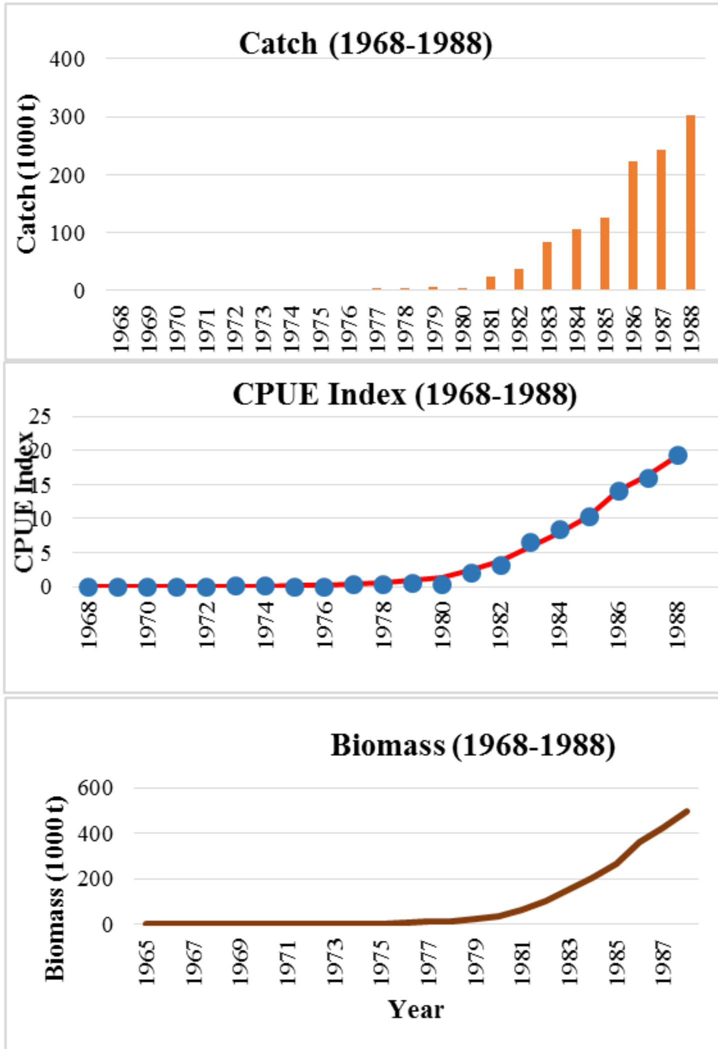

Figure 5: Model fitted to early Nile perch data from 1968 to 1988.

Dagaa

The Schaefer biomass model was fitted to the entire time series dagaa data 1968–2014 (Figure 6a) and then to a subset covering 1990 to 2014 (Figure 6b). The model did not fit well the entire time series data and gave infinity estimates of biomass and *k*. When fitted to CPUE, acoustic and trawl survey indices of 1990–2014, the model gave a somewhat better but still unrealistic fit. The model estimated *r* of 0.103, k of 17 million tonnes and optimal harvest rate of 5% for the short lived species (Table 2).The highest biomass estimate for this species on the lake was 1.6 million tonnes (LVFO, 2014b; Kayanda *et.al*, 2009). It is also known that short lived species tend to have high values of r and can sustain higher harvest rates than the long lived species. The failure of the model to fit the data could have been due to lack of contrast mainly in acoustic and trawl survey indices. Elsewhere, biomass models have proved less useful by providing parameter estimates that are biologically impossible or unrealistic including negative values of parameters, extremely high or low virgin biomass coupled with very low or high population growth rate (Chen and Andrew 1998). This in part is due to over generalization of the biological complexity of the fishery (Hilborn, 1979; Ludwig and Walters, 1985) and lack of contrast in the data e.g. between fishing effort and stock abundance (Hilborn, 1979) or problems with unreliable indices of abundance; large process error, which occurs in the dynamics of fish populations, and observation error, which occurs in measuring catch and (or) abundance index. All these factors could have contributed to the failure of the dagaa model. Results of dagaa model cannot therefore be used to provide management advice for the dagaa fishery, there is need for multi-species model for this fishery, besides improving data collection on the species.

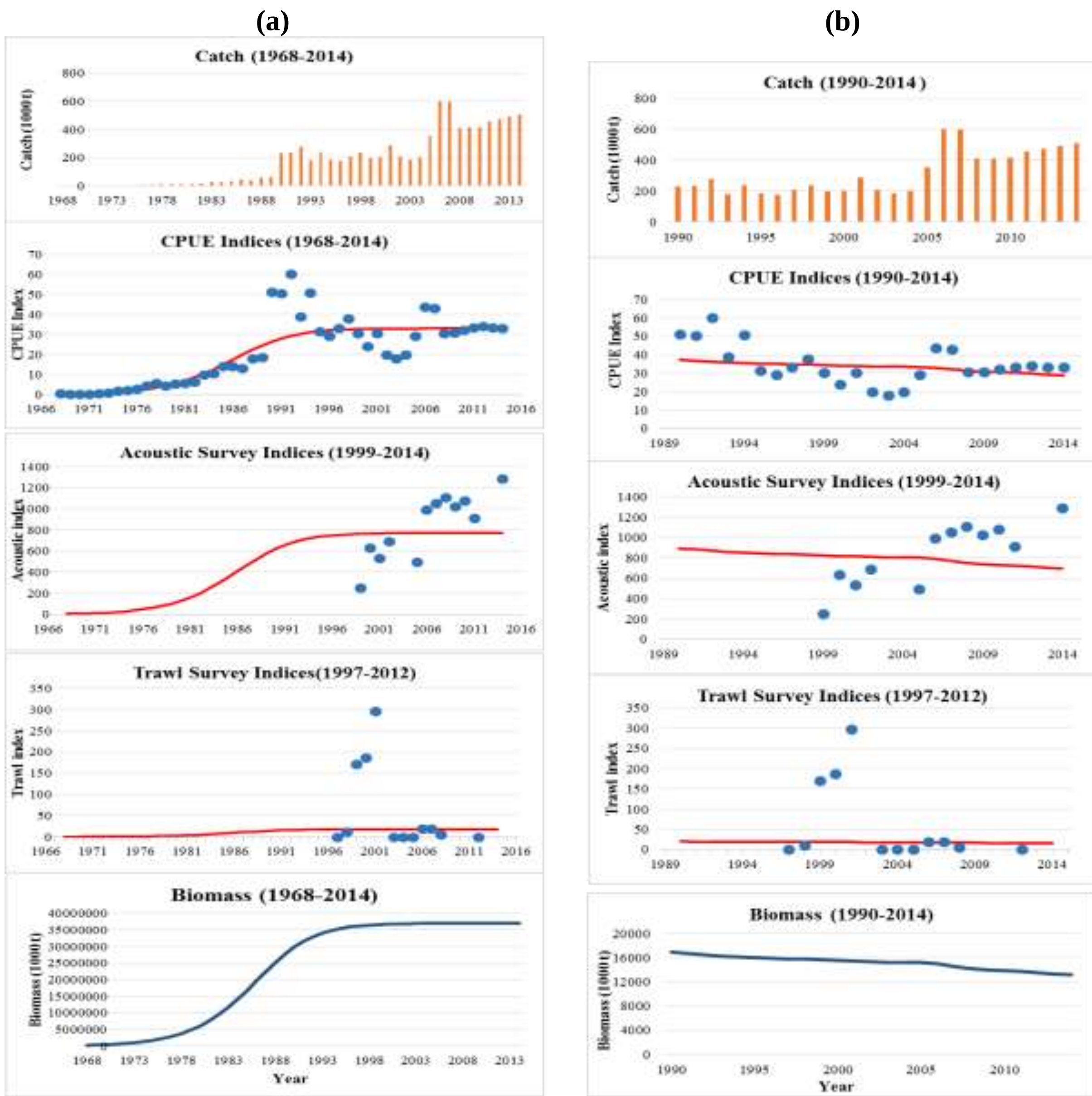

Figure 6: Model results for dagaa: (a) full dataset from 1968 to 2014 and (b) recent data from 1990 to 2014.

Tilapia

The Schaefer biomass model was fitted to CPUE, trawl and acoustic data for the period 1965–2014 (Figure 7a). As observed with the first model of the dagaa fishery, the model did not fit the entire time series tilapia data. The model gave unrealistic estimates of reference points. Similar reasons explaining the failure of model fit in the dagaa could be at play in this model as well. The model when fitted to the CPUE data of 1990–2014, excluding the trawl survey indices gave a better and more realistic fit, estimating *r* at 0.57 and *k* at 451 thousand tonnes while the current harvest rate and biomass were estimated at 59% and 103 thousand tonnes respectively (Figure 7b). The current harvest rate is twice the optimal while the current biomass is half the biomass at MSY (Table 2). Tilapia is the most sought after fishery in the inshore areas of Lake Victoria and this pressure threatens the sustainability of this fishery (LVFO, 2014a). Earlier studies have already observed heavy fishing pressure on the tilapia fishery in the lake (Kayanda *et.al,* 2009) and this study shows an escalation of this trend in the recent years. A reduction in the current fishing effort involved in the tilapia fishery by a half to allow a complete recovery of the species is recommended.

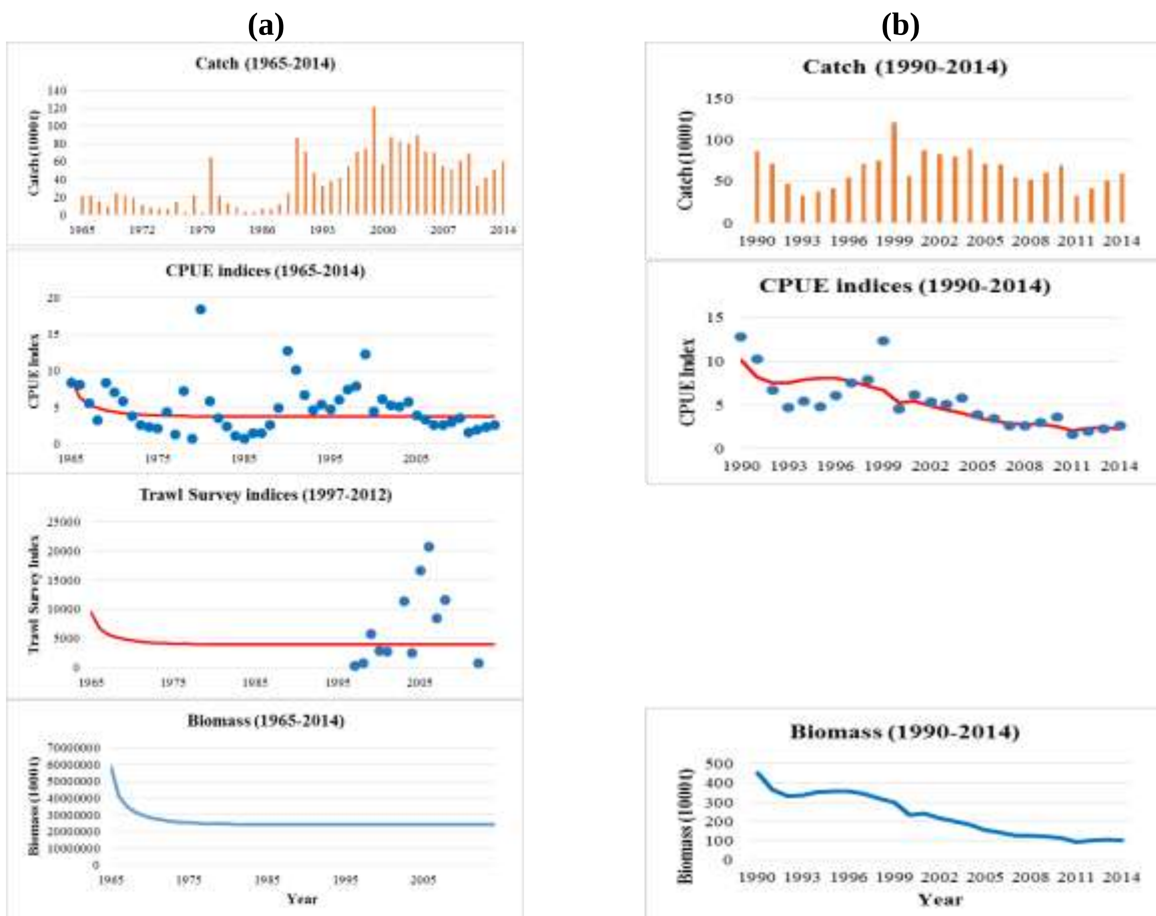

Figure 7: Model results for tilapia: (a) full dataset from 1965 to 2014 and (b) recent CPUE data from 1990 to 2014.

Haplochromines

As observed in the dagaa and tilapia fisheries, the Schaefer biomass model when fitted to the entire time series haplochromine data (1960 to 2014) gave infinity estimates of biomass and *r* and unrealistic *k* values (Figure 8a). The interspecies predator-prey interactions between the Nile perch and the haplochromines already discussed above (Hughes, 1986; Ogutu-Ohwayo, 1990a; Ogutu-Ohwayo, 1990b), coupled with poor quality catch, acoustic and trawl data on this fishery could be attributed to the failure in the model fit. The model however fitted quite well when fitted to the most recent CPUE, acoustic and trawl data series (Figure 8b). The model estimated current biomass at 555 thousand tonnes while *r* and current harvest rate were estimated at 0.54 and 13% respectively (Table 2). These results suggest that the harvest rate for this fishery could be doubled without affecting its stocks. The haplochromine fishery is mainly concentrated on the Tanzania side of Lake Victoria, with little information on catch in the other two countries that share the lake (LVFO, 2014a). Although there are indications of resurgence in the haplochromines on Lake Victoria, the total biomass as well as number of species involved is not well known (Balirwa *et.al*, 2003). This species is known to be a preferred diet for the Nile perch (Hughes, 1986; Ogutu-Ohwayo, 1990a; Ogutu-Ohwayo, 1990b). Exploitation of the haplochromine fishery should take into account the predatory pressure of the Nile perch. Given the scanty information on this fishery, a precautionary approach in using estimates of this model for the management of its fishery is recommended. The current harvest rate should be maintained until further investigations on this fishery are concluded using the multispecies stock analytical models.

(a) (b)

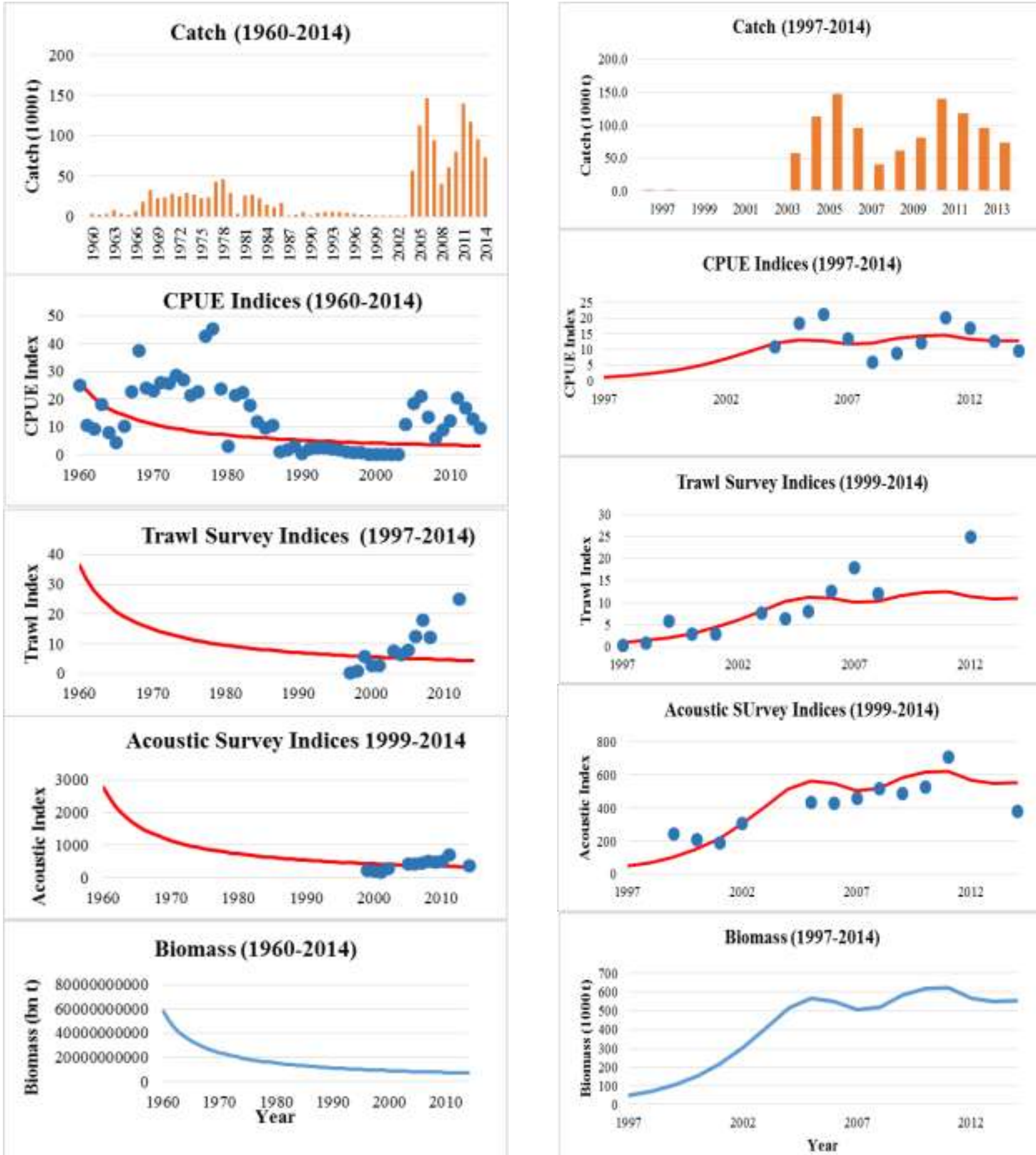

Figure 8: Model results for haplochromines: (a) full dataset from 1960 to 2014 and (b) recent data from 1997 to 2014.

Table 2: Summary of results for Nile perch, dagaa, tilapia, and haplochromines on Lake Victoria.

	Nile perch	Dagaa	Tilapia	Haplochromines
r	0.704	0.103	0.570	0.537
***k* (1000 t)**	1390	17000	451	836
***MSY* (1000 t)**	244	439	64	112
B_{2014} (1000 t)	654	13200	102	555
B_{MSY} (1000 t)	693	8500	226	418
u_{2014} (%)	38	4	59	13
u_{MSY} (%)	35	5	28	27

5. CONCLUSION

The Schaefer biomass model does not fit the whole time series data (1960-2014) of CPUE, trawl survey and acoustic survey indices. The model only fitted well a subset of data from the 1990 or later, suggesting a relatively stable lake ecosystem with fishing as the main driver of the fishery from the 1990s. Besides fishing, multispecies interactions contributed to the population drastic decline of the Nile perch in the earlier years. Given realistic data, the Schaefer biomass model can still provide management advice for the fisheries of Nile perch, tilapia and haplochromines on Lake Victoria. Management advice from these models should serve as interim solution in absence of the more accurate length and age based models. The available data on the measure of abundances for the dagaa fishery is unrealistic and not useful for modeling their stocks using the Schaefer biomass model. The current harvest rates for the tilapia fishery is unsustainable since it is above the optimum.

6. RECOMMENDATIONS

In the current study, fishing effort was defined as the number of boats involved in a given fishery. This is not the most appropriate way of defining effort. Effort is better defined as the number of fishing days or fishing units targeting the fishery. In the current form, regional frame survey reports do not provide details of fishing effort in terms of the number of fishing vessels per target species nor the number of crafts by gear type. This information is required in estimating survey indices (catch per unit effort). The collection and reporting of frame data should be improved to provided the above details.

The current fishing effort targeting tilapia on Lake Victoria should be reduced to achieve optimal sustainable harvest rates for this stock. There is inadequate and scantly length data on the exploited fish species of Lake Victoria. Future catch assessment studies should include collection of length data required in the length based analytical models. Reference points estimated from the single species biomass models should be used cautiously in the management of the lake Victoria fish stocks. The multispecies analytical models should be explored for providing management advice on the lake.

ACKNOWLEDGEMENT

First, I extend special thanks to my dear wife Nakasiita Flavia Gloria for her continued support and encouragement and to our lovely sons Nakiyende Mark, Nakiyende Mathew and Nakiyende Marvin for enduring the lonely six months I spent away from home. I am grateful to the profound love and guidance from my parents Mr and Mrs Mudiima Sande George William.

I thank the United Nations University of Fisheries Training Program staff Dr. Tumi Tomasson, Mr. Thor H. Asgeirsson, Ms. Sigridur Kr. Ingvarsdottir and Ms. Mary Frances Davidson for giving me a chance to participate in this training and for the guidance provided during the course. I sincerely appreciate the dedicated guidance from my supervisor Arni Magnusson towards the production of this thesis.

I thank the director of the National Fisheries Resources Research Institute (NaFIRRI), Dr. Balirwa John and my institute supervisors Dr. Taabu Anthony Munyaho and Dr. Mbabazi Dismas for endorsing me to participate in this training. I also appreciate Mr. Nyamweya Chrispine of KMFRI for availing me the effort data used in this project. I thanks Mr. Bassa Samuel, Mr. Muhumza Elias and Ms. Kagoya Esther of NaFIRRI for the support rendered throughout the training.

REFERENCES

Achieng, A. (1990). The impact ofthe introduction of Nile perch, *Lates niloticus* (L.) on the fisheries of Lake Victoria . *Journal of Fish Biology*, 37 (supplement A) 17–23.

Achieng, A. P. (1990). The impact of the introduction of Nile perch, *Lates niloticus* (L.) on the fisheries of Lake Victoria. *Journal of fish biology*, 37 (Supplement A), 17-23.

Bwanika, G.N., Murie, D.J., and Chapman, L.J. (2007). Comparative growth and age of Nile tilapia (Oreochromis niloticus L.) in lakes Nabugabo and Wamala, Uganda. *Hydrobiologia* , 589: 287–301.

Chassot, E., Nishida, T., and Fonteneau, A. (2009). *Application of surplus production models to the indian ocean bigeye (Thunnus obesus) tuna fishery.*

Chen, Y. and Andrew, N. (1998). Parameter estimation in modelling the dynamics of fish stock biomass: are currently used observation-error estimators reliable? *Canadian Journal of Fisheries and Aquatic Sciences*, Vol. 55:749–760.

Chien-Pang Chin and Kwang-Ming Liu. (2015, February 12). *Estimate of the intrinsic rate of population increase for the blue shark in the North Pacific. Working document submitted* *to the ISC shark working group workshop, 16-24 april,2015*. Retrieved from https://www.google.es/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=0CDQQFjAC&url=http%3A%2F%2Fisc.ac.affrc.go.jp%2Fpdf%2FSHARK%2FISC13_SHARK_2%2F04-intrinsic%2520population%2520growth%2520rate%2520for%2520NPac%2520blue%2520shark.pdf&ei=83zcVLH2M4fVywPelYG.

Cowx, I., and Knaap, M. Van Der. (2003). Improving fishery catch statistics for Lake Victoria. *Aquatic Ecosystem Health and Management*, 6(3):299–310.

Donald Ludwig and Carl J. Walters. (1985). Are age-structured models appropriate for catch-effort data? *Canadian Journal of Fisheries and Aquatic Sciences*, 42:1066-1072.

FAO. (2014). *The state of world fisheries and aquaculture. Food and Agricultural Organization of the United Nations.*

GoU. (2003). *Statutory instruments 2003 No. 35. The fish (BEACH MANAGEMENT) Rules, 2003.* Entebbe: The Uganda Gezzette.

GoU. (2010). *The fish (FISHING) Rules, 2010* . Uganda parliament, legislation. Entebbe: The Uganda Gazette No. 53 Volume CIII.

Graham, M. (1929). *The Victoria Nyanza and its fisheries. A port on the fishing survey of Lake Victoria 1927-1928, 225 pp.* London : Crown Agents for the Colonies.

Greenwood, P. (2006). *Lake Victoria. (K. Martens, B. Goddeeris, and G. Coulter, Eds.) Victoria 44:19–26). Berlin/Heidelberg: Springer-Verlag.*

Haddon, M. (2011). *Modelling and quantitative methods in fisheries. Second edition. A Chapman and Hall Book. 449pp.* London: CRC Press.

Hilborn, R. (1979). Comparison of fisheries control systems that utilize catch and effort data. *Journal of Fish. Res. Board Canada*, 36: 1477–1489.

Hillary, R. (2006). *Bayesian Pella-Tomlinson model for Indian Ocean bigeye tuna. IOTC-WPTT-2006-34.* .

Hillary, R., and Mosqueira, I. . (2006). *Assessment of the Indian Ocean bigeye tuna stock using CASAL. IOTC-2006-WPTT-15.*

Hughes, N. F. (1986). Changes in the feeding biology of 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 Biol.*, 29, 541-548.

Jeppe Kolding, Medard Modesta, Oliva Mkumbo, Paul van Zwieten. (2014). Status, trends and management of the Lake Victoria fisheries. In R. e. (eds), *Inland fisheries evolution and management, FAO fisheries and aquaculture technical paper 579,* (pp. 49-62).

John S. Balirwa, Colin A. Chapman, Lauren J. Chapman, Ian G. Cowx, Kim Geheb, Les Kaufman, Rosemary H. Lowe-Mccnnell, Ole Seehausen, Jan H. Wannink, Robin L. Welcomme, and Frans Witte. (2003). Biodiversity and fishery sustainability in the Lake Victoria Basin: An unexpected marriage? *BioScience* , Vol. 53(8):703-715.

Kudoja, W. M, Ntiba, M. J., and Mukasa, C. T. (2001). Management issues in the Lake Victoria water shed. *Lakes & Reservoirs: Research and Management* , 6: 211–216.

LVFO. (2012). *Regional status report on Lake Victoria bi-ennial Frame Surveys between 2000 and 2012 for Kenya, Tanzania and Uganda.* Lake Victoria Fisheries Organization. Jinja.

LVFO. (2014a). *Regional catch assessment survey synthesis report, june 2005 to april 2014.* Lake Victoria Fisheries Organization. Jinja.

LVFO. (2014b). *Draft region report of Hydroacoustic Surveys on Lake Victoria.* Jinja: LVFO.

Mary, A., Kishe-Machumu, Frans, W., Jan, H. W., and Egid, F. B. K. (2012). The diet of Nile perch, *Lates niloticus* (L.) after resurgence. *Hydrobiologia*, 682:111–119.

Muhoozi, L. (2002). *Exploitation and management of the artisanal fisheries in the Ugandan waters of Lake Victoria.* PhD thesis , University of Hull U.K.

Musick, J.A. and Bonfil, R. (2004). *Elasmobranch fisheries management techniques, pp. 133-164. Asia-pacific economic cooperation (APEC) fisheries working group, Singapore.*

Nishida, T., & Shono, H. (2006). *Updated stock assessment of bigeye tuna (Thunnus obesus) resource in the Indian Ocean by the age-structured production model (ASPM) analyses (1960-2004). IOTC-WPTT-2006-22.*

Nkalubo, W. (2012). *Life history traits and growth of Nile perch, Lates niloticus (L.) in Lake Victoria, Uganda: Implication for managment of the fishery.* Kampala: Makerere University.

Nyamweya, C. (2012). *Modelling and forward projections of Nile perch, Lates niloticus, stock in Lake Victoria using GADGET framework.* Thesis, United Nations University of the Fisheries Training Progremme, UNU-FTP, Reykjavik. Retrieved january 26, 2015, from http://www.unuftp.is/static/fellows/document/chrisphine12prf.pdf

Ogutu-Ohwayo. (1990b). The decline of the native fishes of lakes Victoria and Kyoga (East Africe) and impact of their introduced species, especially the Nile perch, Lates Niloticus, and the Nile tilapia, Oreochromis niloticus*. *Environmental Biology of fishes, 27*, 81-96.

Ogutu-Ohwayo, R. (1990a). Changes in the prey ingested and varations 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. and J.S. Balirwa . (2006). Management challenges of freshwater fisheries in Africa. . *Lakes & Reservoirs: Research and Management 11: 215-226.*

Okemwa, E. N. (1984). Potential fishery of Nile perch, *Lates niloticus* Linne (Pisces: Centropomidae) in nyanza gulf of Lake Victoria, East Africa. KMFRI, Mombasa, Kenya. *Hydrobiologia*, 108: 121-126.

Robert Kayanda, Anthony M. Taabu, Rhoda Tumwebaze, Levi Muhoozi, Tsuma Jembe, Enock Mlaponi and Peter Nzungi. (2009). Status of the major commercial fish stocks and proposed species-specific management plans for Lake Victoria. *African Journal of Tropical Hydrobiolgy and Fisheries*(12), 15-21.

Schaefer, M. (1954). *Some aspects of the dynamics of populations important to the management of commercial marine fisheries* . Bulletin, inter-american tropical tuna commission .

Taabu, A. (2004). *Assessment of the status of the stock and fishery of Nile perch in Lake Victoria, Uganda.* project thesis, United Nations University of the Fisheries Training Program, Reykjavik. retrieved january 26, 2015, from http://www.unuftp.is/static/fellows/document/taabuprf04.pdf

Welcomme, R. (1972). A brief review of the floodplain fisheries of Africa. *African Journal of Tropical Hydrobiology*(Special issue 1), 67-76.

Witte, F., Goldschmidt, T., Goudswaard, P.C., Ligtvoet, J., Van, O.P., and Wanink, J.H. (1991). Species extinction and concomitant ecological changes in Lake Victoria. *Netherlands Journal of Zoology*, Volume 42, Issue 2:214–232.

World_Bank. (2009). *LVEMP II project appraisal document. report No.45313-AFR, 197 pp.*

APPENDIX

Appendix 1: Catch data from 1959 to 2004 (Kolding *et. al*, 2013) and 2005–2014 (LVFO, 2014b).

Year	Nile perch	Tilapia	Dagaa	Haplochromines
1959				4219.0
1960				3503.0
1961				2490.0
1962				2985.0
1963				7452.0
1964				3964.0
1965	3.0	20985.0		2631.0
1966	6.0	20610.0		7080.0
1967	2.0	14883.0		17529.0
1968	3.0	8797.0	732.0	32400.0
1969	617.0	24489.0	520.0	22815.0
1970	648.0	22270.0	524.0	24173.0
1971	759.0	19122.0	573.0	27907.0
1972	878.0	10969.0	1323.0	24788.0
1973	1121.0	7978.0	1768.0	29068.0
1974	1222.0	6876.0	3757.0	27119.0
1975	301.0	7412.0	4558.0	22458.0
1976	637.0	14330.0	5662.0	23992.0
1977	4478.0	4038.0	9217.0	43096.0
1978	3557.0	22364.0	11312.0	45721.0
1979	7411.0	3333.0	10486.0	28914.0
1980	4439.0	64551.0	12335.0	3729.0
1981	23895.0	21331.0	13580.0	25596.0

1982	37121.0	12588.0	14999.0	26641.0
1983	82782.0	8792.0	24489.0	22297.0
1984	106860.0	3522.0	26736.0	15163.0
1985	125083.0	3095.0	34118.0	11578.0
1986	221870.0	7061.0	44343.0	16970.0
1987	242643.0	7120.0	39209.0	1676.0
1988	301805.0	12120.0	56059.0	2752.0
1989	319671.0	24925.0	62284.0	5331.0
1990	338115.0	87262.0	232249.0	1324.0
1991	209291.0	70937.0	235615.0	4595.0
1992	152303.0	46619.0	280214.0	6006.0
1993	255635.0	32906.0	181760.0	6081.0
1994	272057.0	38211.0	239130.0	5119.0
1995	269561.0	41742.0	184783.0	4844.0
1996	216799.0	54925.0	177152.0	3914.0
1997	225004.0	71099.0	208645.0	2454.0
1998	226663.0	74757.0	238170.0	2577.0
1999	273459.0	120927.0	198803.0	528.0
2000	199068.0	56752.0	205349.0	527.0
2001	247166.0	88227.0	289450.0	1195.0
2002	227947.0	82915.0	208735.0	1029.0
2003	227947.0	79961.0	186387.0	1020.0
2004	227947.0	89324.0	204167.0	
2005	268152.0	71038.0	356842.0	112902.0
2006	264070.0	69636.0	602295.0	146534.0
2007	233941.0	54650.0	600660.0	95212.0
2008	309120.0	52242.0	413346.0	40938.0
2009	318914.0	60763.5	414764.5	60631.0
2010	328708.0	69285.0	416183.0	80324.0
2011	198624.0	32976.0	456721.2	139728.0
2012	216103.7	41877.8	474346.8	117670.7

2013	233583.5	50779.5	491972.5	95613.3
2014	251063.2	59681.3	509598.1	73556.0

Appendix 2: Photographs of the four major commercial species groups on Lake Victoria, East Africa.