

**ESTIMATING SUSTAINABLE HARVESTS
OF LAKE VICTORIA FISHERY**

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Abstract: A study was conducted to develop an environmentally sound strategy for sustainable harvesting of fish species of the Lake Victoria fishery. Its objectives were: firstly, to estimate current harvesting rates of fish species; secondly to show how the biomass stock is changing in response to growth rates and harvesting rates; and finally, using a mathematical model, to predict sustainable levels of harvesting the fish species. Lake wide catch data from year 2005 to 2011 were used for various fish species and were analyzed using Least square method with the aid of MAPLE. Harvesting efforts were computed; 0.2805 for the Nile perch representing a maximum sustainable harvest of 74412.8447 tonnes per year; 0.0593 for the Nile tilapia representing a maximum sustainable harvest of 4834.4503 tonnes per year; 0.5334 for the small pelagic silver fish representing 259538.9165 tonnes per year; 0.1158 for the Haplochromines representing a maximum sustainable harvest of 12569.7240 tonnes per year and 0.0108 for the other fish species representing a maximum sustainable harvest of 87.1936 tonnes per year. Further the study revealed that the lake Victoria

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fishery is yet sustainable however its sustainability is under 50% for most of fish species.

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1. Introduction

Lake Victoria in East Africa is the second largest fresh water body in the World, and is shared by Kenya, Uganda and Tanzania. The Lake Victoria fishery contributes immensely to the socio-economic development of the riparian states. The East African Community has designated the lake basin as an economic growth zone with the potential to develop into a major economic region. The fishery is vital in creating employment opportunities, mostly rural-based, thereby helping to reduce rural-urban migration. Fish is also a rich source of animal protein for human consumption and provide raw material (fishmeal) for processing animal feeds. The fish industry contributes to GDP of the riparian states and has continued to be an important source of foreign exchange earnings through fish exports to the regional and international markets [20]. Moreover, the fish industry contributes to the national and local government revenues through various taxes, levies and license fees. The sector has also contributed directly and indirectly to the improvement of physical infrastructure and social facilities, such as roads, schools and hospitals, particularly in remote fishing communities.

Fish received increased attention as potential source of micronutrients, essential fatty acids, proteins and minerals [1, 15, 25]. Fish meat contains significantly low lipids and higher water than beef or chicken and is favored over other white or red meats [17, 18]. The nutritional value of fish meat comprises the contents of moisture, dry matter, protein, lipids, vitamins and minerals plus the caloric value of the fish [6, 13, 21]. Due to this nutritional importance of fish for so many people, a large-scale collapse of fisheries or significant increase in the price of fish products could seriously affect the nutritional status and the food security of many population.

Currently the lake Victoria fisheries are undergoing a transition associated with intense exploitation and ecosystem change, especially eutrophication [2, 19]. This change has led to considerable disagreement about exploitation and status of the fisheries between user groups and riparian countries, despite

a general consensus that the fisheries of lake Victoria must be managed sustainably to meet both local and national interests. On the one side there are arguments that continued intensification of the efforts will lead to decline in the fishery, a perspective raised by Pitcher & Bundy [4], Cowx *et. al* [10], and Witte & Densen [23], whilst on the other it is argued that the fishery can sustain greater fishing pressure as the stocks are not showing any visible sign of collapsing in terms of overall catches, despite the declining CPUE (Catch per Unit Effort) [5, 11, 14, 22, 24]. The decline of CPUE could be the sign of overfishing. If overfishing and other negative human impacts on the lake continue, ecosystem can be driven to irreversible states of decline and this may affect the food supply for future generations.

The purpose of this research article is to estimate the harvesting rates, growth rates, carrying capacities, the maximum sustainable yields (MSY) and the steady states using lake wide catch data of various fish species from year 2005 to 2011, these estimates will be used as the base of suggesting the sustainable harvesting levels of lake Victoria fishery. The results of the study will deliver information and indicators to aid decision-making in the context of policy, development and management plan evaluation of the healthy of fishery. Moreover the results will help to assess the general state of the stock.

2. Materials and Methods

2.1. The study data

The data for this study (Table 1) was obtained from Lake Victoria Fisheries Organizations (LVFO). The major fish species under consideration were Nile perch, Nile tilapia, Small pelagic silver fish, Haplochromines and the rest of the fish species were grouped under others.

Growth rate of any living organism follows a sigmoid curve which increases slowly during the early ages, rapidly during middle ages, then slows again during maturity as the population approaches its carrying capacity (the maximum number of fish or biomass an environment can support). In 1840 Verhust used this observation to develop a mathematical model called the logistic model. Edwards & Hamson [12] expressed this model by the differential equation

$$\frac{dB}{dt} = rB \left[1 - \frac{B}{K} \right], \quad (1)$$

Year	Nile perch	Nile tilapia	Small pelagic	Hpchr.	Others	Total
2005	286716.60	71531.70	453006.60	138451.50	5304.00	955010.40
2006	264070.00	69635.60	602295.60	146533.20	7063.60	1089598.00
2007	233941.30	54650.20	600659.70	95211.50	14436.60	998899.30
2008	309099.50	52242.00	413352.30	40091.90	10595.50	825381.20
2010	276428.70	43196.00	403912.20	70449.10	12254.40	806240.40
2011	198624.00	32976.00	456721.20	139728.00	11733.60	839782.80

Table 1: Estimated lake wide annual catches in tonnes from the year 2005 to 2011 in tonnes.

Source: LVFO, (2011): Regional Catch Assessment Survey Synthesis Report (2005-2011).

where for the case of this study,

$$\frac{dB}{dt} = \text{rate of change of biomass (tonnesyr}^{-1}\text{)},$$

$$B = \text{total biomass (tonnes)},$$

$$K = \text{the carrying capacity (tonnes)},$$

$$r = \text{proportional growth rate of biomass (yr}^{-1}\text{)}.$$

Bio-mathematicians and bio-economists such as [7, 16] have used this model to predict growth and sustainable yield of renewable resources such as fish. When a resource such as fish is being harvested, the rate of change of biomass (1) is reduced to reflect the harvest as follows

$$\frac{dB}{dt} = rB \left[1 - \frac{B}{K} \right] - H, \quad (2)$$

where $H = EB$, and $E(\text{yr}^{-1})$ is defined as the effort involved in harvesting to be the proportion of harvested to total biomass per year, and thus (2) is transformed to be:

$$\frac{dB}{dt} = rB \left[1 - \frac{B}{K} \right] - EB. \quad (3)$$

The specific factors that influence fish abundance and biomass are typically described by three dynamic rate functions: mortality, growth, and recruitment. Mortality is usually divided into two categories: death due to fishing and death due to natural causes. Fishing mortality is often the focus of fisheries managers because it can be controlled with management actions. Natural mortality is almost always unobserved and is often outside managers' control [3, 8, 9]. Thus, managing fishing mortality is one of the most common practices of fisheries managers.

Fish species	Harvesting effort(E)
Nile perch	0.2805
Nile tilapia	0.0593
Small pelagic fish	0.5334
Haplochromines	0.1158
Others	0.0108

Table 2: Harvesting efforts of fish species.

2.2. Estimating harvesting efforts, Carrying capacities, and Proportional growth rates of fish species biomass

The rate of harvesting of each species is obtained by determining the harvesting effort, E . Since the amount of biomass harvested, B_h , is given by a linear model of the form

$$B_h = EB, \quad (4)$$

then E can be estimated using Least square method with Maple. Table 2 summarizes the estimates of harvesting efforts of each species.

In this case the rate of harvesting [harvesting effort(E)] is regarded as **fish-ing mortality**-a measurement of the rate of removal of fish from a population by fishing.

Re-arranging (3) we obtain

$$\frac{1}{B} \frac{dB}{dt} = (r - E) - \frac{r}{K} B. \quad (5)$$

To estimate the proportional growth rate of biomass and the carrying capacity, we need to estimate the parameters $(r - E)$ and $-\frac{r}{K}$ from equation (5) first. This equation suggest that a linear model of the form

$$Y = \theta - aB, \quad (6)$$

where

$$Y = \frac{1}{B} \frac{dB}{dt} \quad (7a)$$

$$\theta = (r - E) \quad (7b)$$

$$a = \frac{r}{K}. \quad (7c)$$

Fish species	Growth rate (r)	Carrying Capacity (K)
Nile perch	0.4770	644050.5448
Nile tilapia	0.1112	174701.5943
Small pelagic fish	0.6546	2630619.2140
Haplochromines	0.2293	219277.3427
Others	0.0667	9603.1643

Table 3: Estimates of proportional growth rates and carrying capacities for different fish species.

Fish species	Growth rate (r)	Harvesting effort (E)
Nile perch	0.4770	0.2805
Nile tilapia	0.1112	0.0593
Small pelagic fish	0.6546	0.5334
Haplochromines	0.2293	0.1158
Others	0.0667	0.0108

Table 4: Comparisons of growth rate (r) and Harvesting effort (E).

With the data of Table 1 and Least square methods we obtain the following bestlines of fits,

$$\text{Nile perch : } Y_N = 0.1964569214 - 0.0000007405750418N \quad (8a)$$

$$\text{Nile Tilapia : } Y_T = 0.05188563716 - 0.000000636426824T \quad (8b)$$

$$\text{Small pelagic fish : } Y_S = 0.1210410301 - 0.0000002488525569S \quad (8c)$$

$$\text{Haplochromines : } Y_H = 0.1135624361 - 0.000001045773936H \quad (8d)$$

$$\text{Others : } Y_W = 0.05584211536 - 0.00000694403962W . \quad (8e)$$

Relating equations (8) and (6) with (7) we obtain the estimates of proportion growth rates and carrying capacities as summarized in Table 3.

Carrying capacity can be thought of as the amount of fish an area of habitat will support. The carrying capacities means that if all harvesting activities were suspended and proper management were followed then over time, the Nile perch, Nile tilapia, Small pelagic silver fish, Haplochromines and other fish species would grow to a maximum biomass of about 644050.5448 (tonnes), 174701.5943 (tonnes), 2630619.2140 (tonnes), 219277.3427 (tonnes) and 9603.1643 (tonnes), respectively.

We observe that in each case the proportional growth rate (r) is greater than the proportional harvesting effort (E). This suggest that this fishery is

still sustainable, however the sustainability is under 50% for all fish species except the case of small pelagic silver fish. At most 47.70% of the Nile perch, and 11.12% of the Nile tilapia, and 65.46% of small silver fish, and 22.93% of Haplochromines, and 6.67% of other fish species should be harvested each year. Any harvest beyond that is unsustainable.

2.3. Derivation of Steady states and Maximum Sustainable Yields

Maximizing the biomass of each fish species is equivalent to maintaining a constant resource level of each species. With reference to our model, this means the rate of change of biomass, $\frac{dB}{dt}$, should be equal to zero in equation (3) and then solving for B results into

$$B = K \left[1 - \frac{E}{r} \right] \quad (9)$$

as the steady state of stand fish biomass, and

$$B_{MSY} = EK \left[1 - \frac{E}{r} \right] \quad (10)$$

as the maximum sustainable yield (MSY).

Maximum sustainable yield or MSY is the largest yield (or catch) that can be harvested over an indefinite period. The largest average catch that can be taken continuously (sustained) from a stock under average environmental conditions. This is often used as a management goal. The management of renewable resources has long been practised using the MSY (maximum sustainable yield) concept whose primary objective is to avoid over exploitation. The MSY is a simple way to manage resources taking into consideration that overexploitation of resources lead to a loss in productivity. Therefore, our aim is to determine how much we can harvest so that long run sustainability of the population can be achieved.

The computational of Steady States (SS) and Maximum Sustainable Yield (MSY) for each fish species is based on equations (9) and (10) respectively.

Steady state (SS) means that if the sustainable harvest levels are followed, then in the long run the lake Victoria will have a constant biomass of about 949832.73 tonnes given by the sum of individual steady states of each fish species.

Fish species	MSY (tonnes)	SS (tonnes)
Nile perch	74412.8447	265276.1844
Nile tilapia	4834.4503	81526.4768
Small pelagic fish	259538.9165	486396.568
Haplochromines	12569.7240	108591.7633
Others	87.1936	8041.7334

Table 5: Maximum Sustainable Yield (MSY) and Steady States (SS) for the fish species.

3. Discussion and Conclusions

Analysis of the results indicated that lake Victoria fishery is yet sustainable, however its sustainability is below 50% for most of fish species, therefore fishery management actions should be intensified in order to up-lift the level of sustainability. Harvesting fish in an unsustainable manner also means harvesting them inefficiently. It should be noted that when we put fish stocks at risk we also put at risk the economic welfare of millions of people dependent on this fishery.

References

[1] M.T. Arts, R.G. Ackman and B.J. Holub, Essential fatty acids in aquatic ecosystems: a crucial link between diet and human health and evolution, *Journal of Fisheries Aquatic Science*, **58** (2001), 122-137.

[2] J.S. Balirwa, A.C. Chapman, L.J. Chapman, I.G. Cowx, K. Geheb, L. Kaufman, R.H. Lowe-McConnel, O. Seehausen, J.H. Wanik, R.L. Welcomme and F. Wite, Biodiversity and fishery sustainability in the Lake Victoria basin: An unexpected marriage?, *Bioscience*, **53** (2003), 703-716.

[3] L. Botsford, Optimal fishery policy for size-specific density dependent population models, *Journal of Mathematical Biology*, **12** (1981), 265-293.

[4] A. Bundy and T.J. Pitcher, An analysis of species changes in Lake Victoria: Did the Nile perch alone?, *The Impact of Species Changes in African Lakes* (1995), 111-135.

[5] J.F. Caddy and R. Mahon, Reference points for fisheries management, *FAO Fisheries Technical Paper*, **347** (1995).

- [6] K. Chandrashekar and Y.G. Deosthale, Proximate composition, amino acids, mineral and trace element content of the edible muscle of fish species, *Journal of Food Composition Analysis*, **6** (1993), 195-200.
- [7] C.W. Clark, *Mathematical Bioeconomics, the Optimal Control of Renewable Resources*, Wiley, New York (1976).
- [8] D.L. Cushing, *Fisheries Biology: A Study in Population Dynamics*, The University of Wisconsin Press, Madison (1981).
- [9] A.J.R. Cotter and S.T. Buckland, Using the EM algorithm to weight data sets of unknown precision when modelling fish stocks, *Mathematical Biosciences*, **190** (2004), 1-7.
- [10] I.G. Cowx, M. Van der Knaap, L.I. Muhoozi and A. Othina, Improving fishery catch statistics for the Lake Victoria, *Journal of Ecosystem Health and Management*, **6** (2003), 299-310.
- [11] K. Crean and K. Geheb, Sustaining appearances: Sustainable development and the fisheries of lake Victoria, *Natural Resources Forum*, **25** (2001), 215-224.
- [12] D. Edwards and M. Hamson, *Guide to Mathematical Modelling*, Macmillan Education Ltd, London (1989).
- [13] S.L. Evangelos, G. Aggelousis and A. Alexakis, Metal and proximate composition of the edible portion of 11 freshwater fish species, *Journal of Food Composition Analysis*, **2** (1989), 37-38.
- [14] A. Getabu, *Assessment of Fish Stocks in Lake Victoria Using a Combination of Acoustic and Trawling Methods*, PhD thesis, University of Hull (2003).
- [15] D. Kromhout, E.J. Feskens and C.H. Bowles, The protective effect of a small amount of fish on coronary heart disease mortality in an elderly population, *International Journal of Epidemiology*, **24** (1995), 340-345.
- [16] J.D. Murry, *Mathematical Biology*, Springer-Verlag, New York (1993).
- [17] J.S. Neil, Fish consumption, fish oil, lipids and coronary heart disease, *Circulation*, **94** (1996), 2337-2340.
- [18] P.J.N. Nestel, Fish oil and cardiovascular disease: lipids and arterial function, *Amer. J. Clin. Nutr.*, **71** (2000), 228-231.

- [19] R. Ogutu-Ohwayo, The decline of native fishes of Lake Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*), *Environmental Biology of Fishes*, **27** (1996), 2337-2340.
- [20] A.O. Richard, K.O. Odongkara and P.O. Onyango, Distribution of economic benefits from the fisheries of Lake Victoria, *African Journal of Tropical Hydrobiology and Fisheries*, **12** (2009), 78-82.
- [21] W. Steffens, Freshwater fish-wholesome foodstuffs, *Bulgaria Journal of Agricultural Science*, **12** (2006), 320-328.
- [22] M. Van der Knaap, M.J. Ntiba and I.G. Cowx, Key elements of fisheries management on Lake Victoria, *Journal of Ecosystem Health and Management*, **5** (2002), 245-254.
- [23] F. Witte and W.L.T. Densen, *Fish Stocks and Fisheries of Lake Victoria, A Handbook for Field Observations*, Samara Publishing, Cardigan, UK (1995).
- [24] F. Witte, T. Goldschmidt, P. Goudswaard, W. Ligtoet, M. Van Oijen and J.H. Wanik, Species extinction and concomitant ecological changes in Lake Victoria, *Netherlands Journal of Zoology*, **42** (1995), 214-232.
- [25] T. Zenebe, G. Ahigren and M. Boberg, Fatty acid content of some freshwater fish of commercial importance from tropical lakes in the ethiopian rift valley, *Journal of Fish Biology*, **53** (1998), 987-1005.