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Growth, Mortality and Exploitation of Nile tilapia, *Oreochromis niloticus* (L.) in Lake Chivero, Zimbabwe and Implications on the Management of the Artisanal Fishery

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Abstract
Age and growth of Nile tilapia, *Oreochromis niloticus* (L.) were determined using sample from Lake Chivero (Zimbabwe) caught from 2009 to 2011. The length-weight relationship for all individuals was $W = 0.015\ TL^{0.304}$. The sex ratio of female to male was 1:1.27. Fish age derived from both length frequencies and scales showed no significant difference ($p > 0.05$, Paired T-test). The length frequency age data were used to estimate the growth parameters of the von Bertalanffy equation. The mean values from 2009 to 2011 were: $L\infty$ 39.41, K = 0.41, (ø) = 2.798, Lm_{50} = 23.33 cm, Lc_{50} = 22.60 cm, Z = 1.84 $year^{-1}$, M= 0.81 $year^{-1}$, F = 1.04 $year^{-1}$ and E = 0.58 $year^{-1}$. Growth, mortality and exploitation parameters $L\infty$, K, (ø) and Z were compared from year to year and results showed the fishery is over-exploited. Fish below age/length at first maturity form the bulk of the fish harvested by the fishery. Increasing length at first capture could increase yield per recruit and also protect spawning stock. Other implications on the management of the fishery are discussed.

Keywords: Exploitation, Fisheries, Growth, Management, Mortality, Nile tilapia

Introduction
Fisheries based on exotic fish species in many aquatic environments have been of interest to scientists and managers over the World. Important aspects range from the establishment and performance of the new species in the new environment, interspecific interaction to environmental impact and socio-economic benefits associated with the exotic species (Nyakuni, 2009).

Nile tilapia, *Oreochromis niloticus* (L.) is a perch-like fish occurring naturally in North Africa (Nile River system) and Madagascar, and also in the Central and South America Tropical Zone (Fryer and Iles, 1972; Morales, 1991; Froese and Pauly, 2016). In the last four to five decades, *O. niloticus* has been advertently or inadvertently introduced into many tropical and sub-tropical countries. Once a population is established, it is extremely difficult to manage the population or remove it because of its high competitiveness (Goudswaard *et al*., 2002; Ahmed *et al.*, 2003; Zambrano *et al*., 2006). Nile tilapia *O. niloticus* was introduced into

Lake Chivero sometime in the 1990s, by escapees from aquaculture ponds.

Lake Chivero is a reservoir which over the years has been polluted by sewage effluent from the City of Harare which has led to rapid eutrophication and promoted prolific growth of phytoplankton (Falconer *et al.*, 1970; Marshall, 1997). Increased primary and secondary productivity has made it possible to support high fish populations in the lake (Moyo, 1997). The fisheries of Lake Chivero are estimated to produce about 300-500 tons of fish annually. Commercial fishing commenced in 1956 and was based on a catch of 26 fish species (FAO Technical Paper18/1, 1990; Marshall and Lockett, 1976). The main fish species of commercial importance then were the cichlids *Oreochromis macrochir* and *Oreochromis mossambicus* (Marshall and Lockett, 1976).

During the period 1956-1980 the fish community was dominated (as a percentage by weight) in variable proportions over the years by a largely different assemblage consisting of *Clarias gariepinus, O. macrochir, Labeo altivelis, Hydrocynus vittatus* and *Tilapia rendalli* (Marshall, 1982). In 2000, seventeen species were collected in an intensive survey, and *O. niloticus* comprised 19% of the catch numerically and 36% of the ichthyo-biomass. Today the fishery has evolved into a single species fishery comprising over 95% of the catch being *O. niloticus* (ZNPWMA Fisheries Statistics Report, 2011). The success of *O. niloticus* has been attributed to many factors that are key characteristics of invasive species and these include the following: abundant in its native range; ability of securing and ingesting a wide range of food; fast growth; has a broad native range; a high genetic variability; high reproductive potential; high adaptability to different environments; invasive in its native range; habitat generalist; pioneering in disturbed areas (Marshall, 1982; Trewavas, 1983; Balirwa 1998; Njiru *et al.*, 2004).

Despite an initial boom in the fishery, the catches of *O. niloticus* in Lake Chivero have been declining significantly over the last four years (2008-2011), although the fishing effort has remained more or less constant. There have been no fisheries studies of the *O. niloticus* dominated fishery of Lake Chivero. The reason could be that in Southern Africa, *O. niloticus* is largely considered a fish species for aquaculture, and also an invasive pest. Therefore, in countries where it was introduced sometimes little priority is given to studying the fish in the wild as it displaces indigenous fish species populations and affects local biodiversity (Zambrano *et al.*, 2006). Today, the Lake Chivero fishery is facing management challenges which is partly attributed to lack of basic biological and ecological information on fish species needed to guide management. The aim of the study was to understand the growth and reproductive biology of *O. niloticus* in Lake Chivero, and to determine fisheries parameters necessary for management decision making.

Materials and Methods

Study Area

Lake Chivero is situated 37 km Southwest of Harare (Figure 1). The primary purpose of the reservoir was to supply the City of Harare with water for domestic use. Later, other multiple uses including recreation, irrigation, and an important fishery developed. Lake Chivero is downstream of the City of Harare and it became a receptacle of the city's treated sewage effluent but infrastructure breakdowns in the in the sewage treatment has resulted in partially treated and raw sewage being discharged into the lake.

Key morphometric features of the reservoir are: altitude = 1364 m; surface area = 26.3 km^2; volume = 25 km^3; maximum depth = 27.4 m; mean depth = 9.4 m; and catchment area = 2136 km^2. The rainfall season is in summer from November to March (mean 807 mm) while the winter months, May to August are dry (mean 19 mm). Zimbabwe is in the subtropics and there is a distinct summer (hot, wet season) and winter (cool, dry season), while the traditional temperate latitude seasons of spring and autumn are not as pronounced in Zimbabwe. The sampling sites were randomly assigned so that they simulated the way local fishers also lay their nets but also ensuring a representative coverage of the lake. As a result, individual sampling sites were not indicated on the map, but the map is presented for spatial reference.

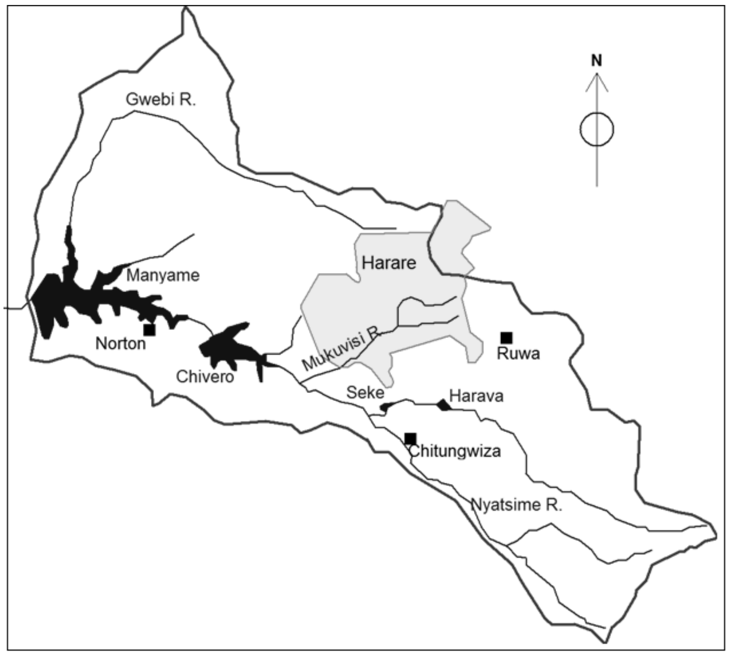

Figure 1: Map showing location of Lake Chivero (17°54'S; 30°47'E) in the Upper Manyame catchment, Zimbabwe

Sample collection

Oreochromis niloticus specimens were obtained from experimental gillnets with a mesh size ranging from 2 inches (5.1 cm) to 5.5 inches (13.97 cm), with 0.5 inch (1.27 cm) increments with a panel length of 50 meters each. The data was collected from January to December 2011, and similarly collected historical data dating back to January 2009 was also analysed. The historical data was collected by the Lake Chivero Research Centre which is under the Zimbabwe National Parks and Wildlife Management Authority (ZNPWMA). The methods for collecting the 2011 data were the same as that of the historical data from a monitoring programme. The fishing catch returns are submitted by the cooperatives at the end of each fishing month. The fishing return forms detail the species caught by gillnets as well as the mesh size and effort in the form of the lengths of nets used and number of days fished. The returns also record the number and weight of fish caught by seine nets as well as the effort in the form of the number of hauls made. These data were used to assess catch and effort trends of the *O. niloticus* fishery in Lake Chivero from 2009 to 2011.

Length and weight measurements

Fish length were measured to the nearest 0.1 cm using a calibrated measuring board and weighed to the nearest 0.1 gm using a digital scale. Both total length and standard length were measured but total length was used in the data analysis.

The length-weight relationship was estimated by using the equation (King, 1995)

$$W = a L^b$$

and the logarithmic transformation:

$$Log\ W = Log\ a + b\ Log\ L,$$

where W = weight in grams; L = total length (cm); ***a*** is constant (intercept); and ***b*** is an allometric growth parameter (slope) which describes growth type.

Condition factor

Condition factor was calculated by:

$$CF = \frac{W}{L^b}$$

where CF = condition factor, W = weight of fish (g) and L = total length (cm), (King, 1995).

Data Analysis

The computer programme FAO-ICLARM Stock Assessment Tool (FISAT) was used to analyse length-frequency data (Gayanilo et al., 2005). The software was used for computing the von Bertalanffy growth function (VBGF), asymptotic length L∞, growth constant (k), natural mortality (Z), fishing mortality (F) and exploitation (E). Growth was modelled by pooling data without differentiating on the basis of the sex of fish because routine monitoring of *O. niloticus* catch does not allow for sexing of fish. Furthermore, sex differentiation is not currently important for management purposes as catches are always mixed. Segregated data was however used to determine length-at-first maturity for females, and sex ratio of *O. niloticus* population in Lake Chivero. Fish ages were determined from length-frequency data in FISAT. The mean length-at-age from the Bhattacharya's method (1967) was compared with length-age data from aging using scales for validation.

For the estimation of population parameters, data for four weeks was pooled together into a single file and analysed by month. The estimate of the growth parameters were based on the von Bertalanffy growth formula (VBGF) (Sparre and Venema, 1998) expressed by the form:

$$Lt = L\infty\ (1\text{-}exp^{(-K1(t-to))})$$

where, Lt is the predicted length at age t, L∞ is the asymptotic length, K is a growth constant, t is the age, t_o is the age the fish would have been at zero length. The growth performance index (ø) was computed according to Pauly and Munro (1984):

$$ø = log\ 10\ K + 2\ log\ 10\ L\infty$$

where K is the growth constant (per year) and L∞ is the asymptotic length. Age at time zero or the birthday of the fish was computed using Pauly (1979) empirical formula:

$$t_o = -0.3922 - 0.2752\ log\ L\infty - 1.038\ log\ K$$

The growths estimates L∞, K and t_o were also obtained directly from the VBGF derived from length at age obtained after the aging exercise using scales.

Total mortality coefficient (Z) was estimated using a length-converted catch curve (Pauly, 1984). The natural mortality coefficient (M) was estimated following Pauly's empirical formula (Pauly, 1980), linking natural mortality with the von Bertalanffy parameters, K (yr^{-1}), L∞ (cm) and the mean annual temperature (T^oC) of the water in which the fish stock lives (in this case 21^0C) as:

Log (M) = 0.0066 – 0.279 Log (L∞) + 0.6543 Log (K) + 0.4634 Log (T⁰C)

$$\log(M) = 0.0066 - 0.279\log(L_\infty) + 0.6543\log(K) + 0.4634\log(T^0C)$$

Length at first capture (Lc_{50}) was determined using cut-off length, growth rate values, asymptotic length, natural mortality, total mortality and the nets selectivity curve. Calculation of Lm_{50} was estimated using length of fish and sexual maturity stages.

Gear selection was estimated by backward extrapolation of the catch curve, thus estimating the number of juveniles which ought to have been caught had it not been for incomplete selection and recruitment (Pauly, 1984). Growth parameters estimates of $L\infty$ and K were used as inputs in this analysis in applications of the FISAT program (Gayanilo *et al*., 2005).

State of the gonads and length at first maturity

The sex and the state of the gonads were determined by dissecting the fish and macroscopically examining the gonads. The gonad state was noted and recorded using the classes below (Bagenal and Braum, 1968; Tesfaye, 1998):

(i) **Inactive (I)**: stage includes the immature fish and adults in the resting stage. Sexual products have not yet begun developing, gonads are very small and eggs indistinguishable to the naked eye. Ovaries are small, thread like and colourless.

(ii) **Inactive/Active (I/A)**: stage where ovaries are long and thick and occupy two thirds of body cavity and ova are yellow and discernible, maturing and ripening. The testes are also easily distinguishable to the naked eye but do not produce sperm when light pressure is applied to the belly.

(iii) **Ripe (R)**: stages when the eggs become distinguishable to the naked eye and testes change from transparent to a pale white colour to when the sexual products can be discharged in response to very light pressure on the belly ("milking"). Ovaries at this stage are large and yellow and almost filling peritoneal cavity. The ova are well developed and could flow out when pressed.

(iv) **Spent (S)**: stage after sexual products have been discharged and gonads appear deflated. The ovaries may contain a few left over eggs or testes may have residual sperm. Ovaries and testes are shrunken.

The length at first sexual maturity $Lm_{50,}$ the total length (TL) at which 50% of fish become sexually mature) was estimated by fitting the maturation curve between the observed points of mid-class interval on the length and maturity data from the gill net survey and the percentage maturity of fish corresponding to each length interval.

Aging Using Scales

Age determination using scales was done to compare and validate age determinations using length frequencies. The scales used for age determination are those between the head and the dorsal fin in the region between the middle of the pectoral fin and the lateral line (Tesch 1968; Ruiz-Dura *et al.*, 1970). The fish were first washed under cold running water, and rubbed lightly in a head-to-tail direction in order to remove any loose scales which may have rubbed off other fish. Using forceps, a scale was taken from the fish. The scale was then cleaned by dipping in fresh water and rubbing between thumb and forefinger to remove any dirt or mucus before drying and storing in paper envelops (FAO 1990).

The scales were then mounted on glass microscope slides, convex side up and reading was in low-power under a Nikon 57829 Binocular Microscop**e**. A soft lead pencil was run from focus to the edge of the scale to help develop and improve the clarity of the scale surface. The lowest magnification (20X) was used because it enabled the whole scale pattern to be seen. The rings that continue around the entire circumference of the scale were counted and the total number of these rings used to estimate the age of each specimen. The relationship between TL and median anterior scale radius was determined and used to estimate length and age at each annulus by back calculation for individual fish. The linear relationship of anterior scale radius and fish length was validated by regression of a series of scale radii against the fish lengths for fish that covered many ages/lengths.

Assuming the relationship is linear; lengths are then estimated for each age by the following formula:

$$L_e = D_r/D_m * L_t + Y\text{-intercept}$$

where L_e = estimated length, D_r = distance from core to chosen ring, D_m = radius of scale,

L_t = total length of fish at capture.

The relative stage of ring formation on the outer edge of a scale's margin was also determined by edge analysis. Code 1 was assigned to the presence of an opaque ring at the edge and codes 2, 3, and 4 were assigned to progressive development of the translucent ring at the edge. Observing the monthly frequency of occurrence of Code 1 through a calendar year can validate whether the formation of the opaque ring occurs on an annual basis, and hence the determination of the age of fish. The percentage of fish having a specific edge code was compared by month of capture and a graph of percentage code (ring on edge) was plotted against month of capture (Yamaguchi *et al.*, 1990).

Relative yield-per-recruit and biomass-per-recruit

The relative yield per recruit and biomass per recruit were determined as a function of the mean ratios of length at first capture (L_c) and asymptotic length (L_∞) in the expression L_c/L_∞ and the ratios of mortality rate (M) and growth constant (K), that is M/K. These were the inputs into the FISAT program to generate the relative yield per recruit and biomass per recruit curves. Length–at-first capture was simulated using simulated values of 24 cm and 25 cm. A simulation testing the use of larger meshes (24 cm & 25 cm) was intended to predict the associated gain in yield and biomass per recruit, although the L_c of 22.6 cm being caught in the fishery using the minimum legal net size. The result of the prediction would result in new legal net size designation if necessary. The parameters used to determine whether the fishery is over or underfished are presented in Table 1.

Table 1: Options for managing a tropical stock with high M/K ratio (>2) by manipulating mesh size adapted from Beverton and Holt (1964) yield per recruit models

Option	Relative size of fish caught[a]	Fishing mortality[b]	Results (in Y/R terms)
A	Large	Low	Under fishing
B	Large	High	Eumetric fishing[c], high yield/recruit
C	Small	Low	Eumetric fishing[c], low yield/recruit
D	Small	high	Overfishing

[a]As defined by the ratio of mean Lc50:asymptotic length, with 0.5 cut off point.
[b]As defined by the ratio F/(F+M) with 0.5 as cutoff point
[c]Eumetric fishing is defined by the line linking the combinations of size at first capture (mesh size) and mortality which maximize Y/R.

Results

Catch statistics of O. niloticus

Catch statistics of *O. niloticus* captured in Lake Chivero are presented in Table 2. The selectivity of the different mesh sizes was apparent in the size of the fish caught. For example, the smallest mesh size of 2.0 inches captured fish ranging from 11.1 – 24cm (TL), while the largest mesh size of 5 inches only captured fish ranging from 23.5 – 37.2cm (TL). A similar trend was observed for the weight of the fish in relation to mesh size. Therefore on average, the larger mesh sizes caught larger fish. The highest proportion of the catch (25%) was captured in the 3 inch mesh size, followed by 3.5 inches, 2.5 inches and 2 inches. Very few fish (2.8% & 0.9%) were caught in the largest mesh sizes of 4.5 and 5 inches, respectively. Males dominated the population at a ratio of 56% (716) to 44% (561) of the females. This is a ratio of 1:1.27 respectively. The overall sex ratio of males to females for *O. niloticus* differed significantly from the normal expected ratio of 1:1 (χ^2 44.38 $p<0.05$).

Table 2: Catch statistics of *O. niloticus* caught in the different gillnet mesh sizes (2009-2011)

	Mesh sizes (inches)						
	2.0	**2.5**	**3.0**	**3.5**	**4.0**	**4.5**	**5.0**
Mean TL (cm)	14.6	18.4	21.2	24.8	24.1	27.5	29.5
Max TL (cm)	24.0	29.6	31.1	30.1	35.2	33.4	37.2
Min TL (cm)	11.1	13.4	15.0	16.8	12.0	21.4	23.5
Std. Deviation	1.4	2.4	2.4	1.9	3.2	3.1	3.7
% Catch (number)	14.6	19.7	25.0	23.9	13.2	2.8	0.9
Number of Fish	186	251	319	305	168	36	11
Mean Weight (g)	51.5	104.1	161.7	258.8	239.4	357.4	442.7
Total Weight (kg)	9.6	26.1	51.6	78.9	40.2	12.9	4.9

Length-frequency distribution

The length frequency distribution for the years showed a low prevalence of fish between 17 and 21 cm TL for the years 2009 to 2010. This proportion of fish in this size class increased in 2011 (Figure 2). A decline in the maximum length achieved is also evident as well as a general decline in the frequency of old fish.

There was a dispersion in the total length (Figures 3 & 4) and anterior scale radius (Figure 5), corresponding to a particular fish age. Statistics for the dispersion of ages per length are shown in Table 3.

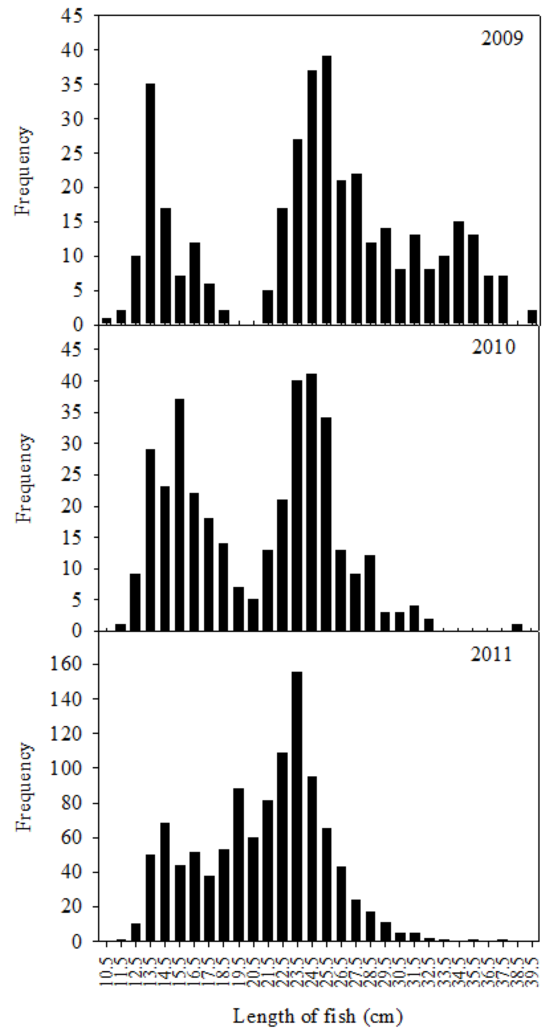

Figure 2: Length frequencies for *O. niloticus* in Lake Chivero (2009-2011).

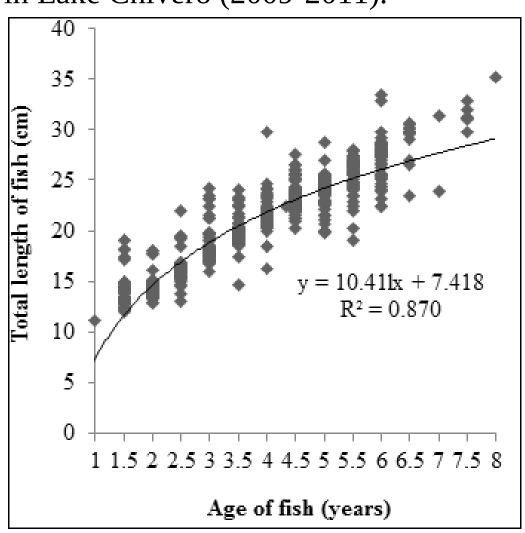

Figure 3: Von Bertalanffy plot of *O. niloticus* in Lake Chivero from scale age data.

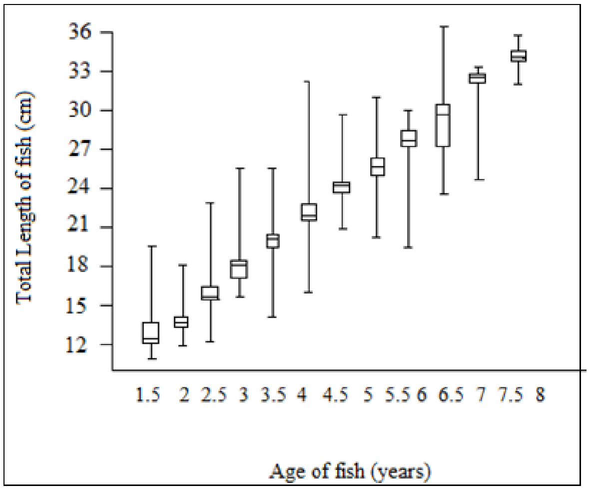

Figure 4: Median length-at-age estimated from scales of *O. niloticus.*

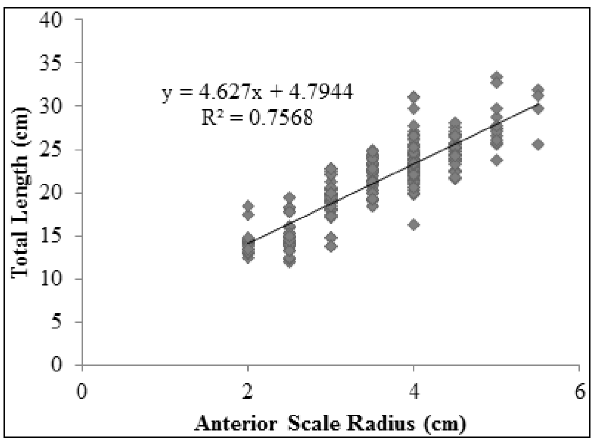

Figure 5: Plot of total length *vs*. anterior scale radius of *O. niloticus*.

Table 3: Age statistics of *O. niloticus* in Lake Chivero (2009-2011)

	Age				
Statistic	2 years	3 years	4 years	5 years	6 years
No. of fish	25	102	178	158	52
Minimum length (cm)	13.5	16	16.3	19.8	22.5
Maximum length (cm)	15.1	24.2	29.8	28.8	33.4
Mean length (cm)	14.4	18.2	21.5	24.2	27.6
Std. error	0.077	0.149	0.087	0.093	0.296
Stand. dev	0.386	1.499	1.16	1.173	2.135

Length-weight relationship

A total of 1123 specimens of *O. niloticus* ranging from 11-37 cm TL and 25-1100 g were assessed for length-weight relationships. The plot of length against weight was curvilinear (Figure 6a), and after log transformation a straight line graph (Figure 6b) which provided ***a*** & ***b*** parameters. The length-weight relationship for *O. niloticus* in Lake Chivero is expressed by the equation W = 0.0015*L$^{3.040}$ (R^2 = 0.92). The ***a***-value was 0.015 while the exponent ***b*** was 3.040. The log transformed straight line graph gave the equation: Log W = - 1.817+3.040 Log L (R^2= 92). The condition factor varied within narrow limits in this study ranging between 1.5 and 2.

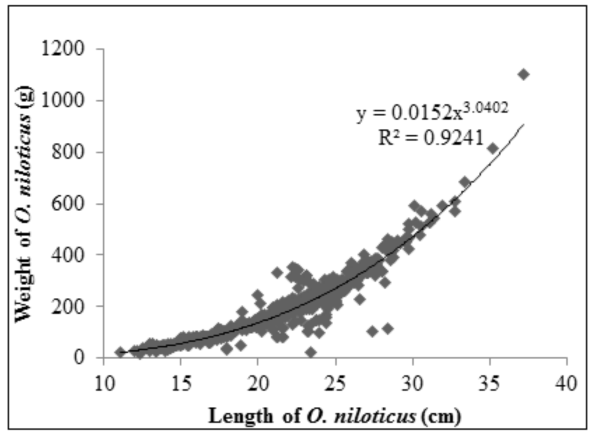

Figure 6a: Curvilinear length-weight relationship of *O. niloticus* in Lake Chivero.

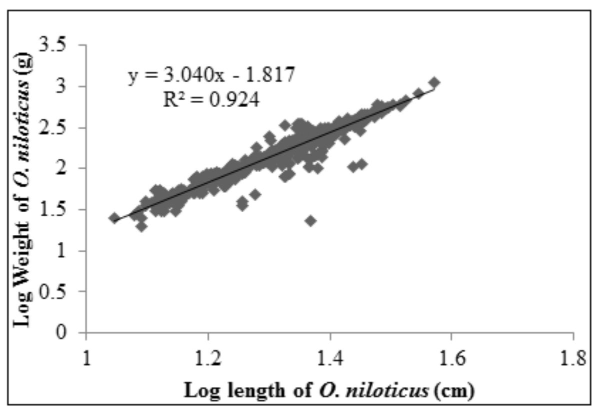

Figure 6b: Log$_{10}$transformed length-weight relationship of *O. niloticus.*

Mortality and Exploitation rate

There was variation between the years from 2009 to 2011 in total mortality (Z) did not follow any particular trend as it rose from 1.85 year^{-1} in 2009 to 2.11 year^{-1} in 2010 and declined to 1.57 year^{-1} in 2011), natural mortality (M) and fishing mortality (F) (Table

4). The mean values for Z, M, F and E for the three years were 1.84 $year^{-1}$, 0.81 $year^{-1}$, 1.04 $year^{-1}$ and 0.58 $year^{-1}$ respectively. The values were computed from the Length Converted Catch Curves.

Table 4: Summary of the growth and mortality parameters of *O. niloticus* in Lake Chivero from 2009-2011

Year	2009	2010	2011	Mean (2009 - 2011)
L_∞ (cm)	42.5	40.4	35.2	39.4
K ($year^{-1}$)	0.47	0.39	0.37	0.41
(ø)	2.9	2.8	2.7	2.8
Lm_{50} (cm)	25	23	22	23.3
Lc_{50} (cm)	22.9	22.9	22	22.6
Z ($year^{-1}$)	1.85	2.11	1.57	1.84
M @ 21°C ($year^{-1}$)	0.87	0.78	0.79	0.81
F ($year^{-1}$)	0.99	1.33	0.79	1.04
E ($year^{-1}$)	0.53	0.63	0.5	0.58

Total Length – Anterior Scale Radius Relationship

The anterior scale radius of *O. niloticus* was linearly related to total length and can be described by the following relationship:

$$TL = 4.627S + 4.794 \; (R^2 = 0.756)$$

where S = scale radius in mm.

There was strong linear correlation (R^2 = 0.76) between total length and anterior scale radius. This high linear correlation indicated that scale growth was proportional to fish growth and demonstrates the validity of using scales for estimating the age and past history of *O. niloticus*. The Y intercept in this study was 5 cm TL.

Based on edge analysis and prevalence of code 1 in a year, an opaque zone was deposited in winter between May and July, and another in the last quarter (October to December) represented by the maxima in a bimodal plot. The periods of opaque zone deposition coincided with late winter and the early rainy seasons. Validation of the fish scales using edge analysis confirmed that the checks occur twice per annum and this was a genuine annual cyclic event. The comparison of length-at-age groups using the Bhattacharya method and scale-aging method are presented in Table 5. The Paired *t*-test was used to compare the two methods and concluded that there was no significant difference between the two methods, and thus validated the age readings and confirmed the hypothesis that there was no difference between the ages at length determined by the two methods (Paired t-test, $p > 0.05$).

The Bhattacharya plot showed four age groups which represented 2, 3, 4 and 5 year old fish (Figure 7). Increase in SD shows more deviation with increase in age towards asymptote. The separation index (SI) values > 2 show acceptable separation between peaks used to assign cohorts. The age statistics of *O. niloticus* in Lake Chivero (2009-2011) are presented in Table 5.

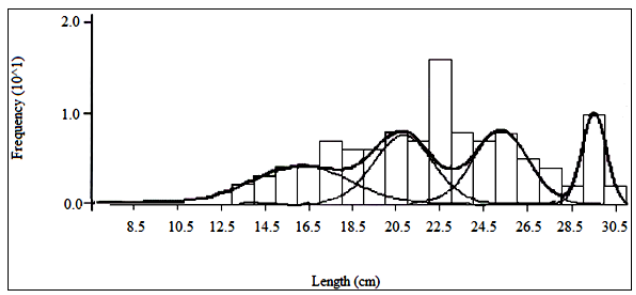

Figure 7: Length frequency composite distribution used for age determination of *O. niloticus* using the Bhattacharya method.

Table 5: Mean length (cm) at age estimated from direct age reading and from length frequency distribution (Bhattacharya, 1967)

Age Reading using scales			Bhattacharya Method		
Age	No of fish	Mean length	No of fish	Mean length	SI
2	25	14.37 ±0.386	19	14.40 ± 0.93	-
3	102	18.24 ± 1.50	30	18.73 ± 1.33	2.270
4	178	21.49 ± 1.16	60	21.70 ± 0.85	2.080
5	158	24.22 ± 1.17	37	27.00 ± 1,30	2.280
6	52	27.19 ± 2.13	-	-	-

***Length at first capture* (L_c)**

Analysis of the fish caught by the various net sizes showed that the largest percentage of fish was caught by mesh size 3 inch, with fish averaging 21.2 cm TL. The length at first capture was 22.9 cm TL, which was close to the mean length of 21.2 cm TL of fish caught by the legal minimum mesh size used in Lake Chivero.

***Length at sexual maturity* (L_m)**

The length-at-first maturity was determined for the three consecutive years (2009, 2010 and 2011) by plotting the maturation curves for the same years (Figure 8). The Lm_{50} was estimated to be 22 cm TL for females with a correlation coefficient (R^2 = 0.979) in 2011. The Lm_{50} for the years 2009 & 2010 were also computed for comparison and registered 25 cm and 23 cm total length, respectively. The minimum length to register sexual maturity was 11.5 cm median length for males and 14.5 for females, respectively. There was a decline of length-at-first maturity (Lm_{50}) over the three years from 2009 to 2011.

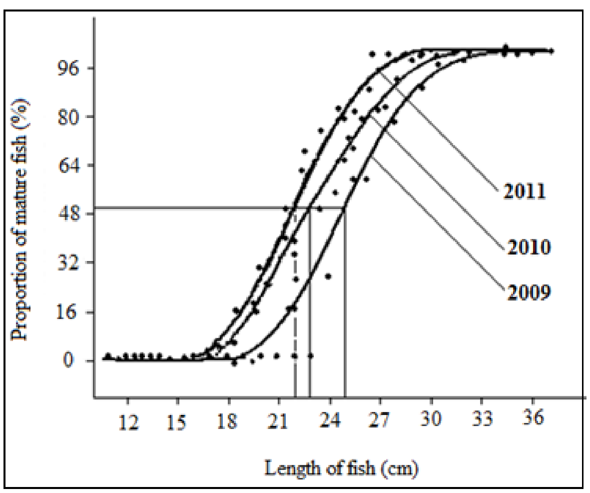

Figure 8: Length at sexual maturity for *O. niloticus* (females) in Lake Chivero (2009-2011), showing the decline in age at sexual maturity within this period.

Relative Yield per Recruit and Biomass per Recruit

The relative yield per recruit and biomass per recruit of *O. niloticus* were first determined with the current fishing rate (F and E), using the legal mesh size where L_c is 21.2 cm TL. Both values obtained for L_c by the two methods (net selection and catch curves) were not significantly different (χ^2 = 0.01375; $p > 0.05$), but they were less than the L_m. The other determinations of relative yield per recruit and relative biomass per recruit included deliberately manipulating the L_c or net selectivity so that the values of Lc_{50} that were used are higher than the length at maturity Lm_{50}.

The net sizes used for the prediction were 3.5 inches and 4 inches mesh sizes which have a mean capture size of 24 cm TL. The results also show the determination of the best exploitation rate that gives the biggest yield per recruit. There was a gain in biomass per recruit and a decline in yield per recruit. The decline in yield (number) with an increase in mesh size was compensated for by an increase in biomass as the fish caught by the larger meshes would be larger. This puts a premium on increasing mesh size in order to catch larger fish.

Discussion

Fish catches in Lake Chivero have declined steadily since 2008 despite the fact that effort has remained high and constant over the last four years (ZNPWMA Fisheries Statistics Report, 2011. Results show overall catch per unit effort has fallen, while there has been a decline of length at maturity and the asymptotic length has also declined and juvenile fish now comprise most of the catch. These observations are consistent with an overfished fishery (Cowx *et al*., 2003; Njiru *et al*., 2003). The sex ratio of *O. niloticus* in Lake Chivero was biased in favour of males at 1.23:1. This is a common phenomenon recorded elsewhere for *O. niloticus*. For example, in Lake Kariba males dominated at 63% of the catch (Chifamba 1998), while a catch ratio of 1.3:1 males to females was recorded in the Albert Nile (Uganda) (Nyakuni, 2009). The difference in sex ratio in this study might have occurred because males spend more time in the fishing areas than females. Once mating is concluded, males probably move away from the spawning areas to feeding areas in deeper water where they were more likely to be captured in gillnets (Gomez-Marquez *et al.*, 2003).

The coefficient of determination for the length-weight relationship (***b*** = 3.04) indicated isometric growth of the fish and was within the expected range of 2.5 - 3.5 King, 1995). Any value of ***b*** less than 2.5 or greater than 3.5 shows allometric growth which is either negative (less than 2.5) or positive (greater than 3) (King, 1995). In majority of the fishes the shape and density change with increasing age, which often causes the regression coefficient of weight of length, to depart from 3. Studies done elsewhere on *O. niloticus* have found different outcomes for the **b** value. For example, in India, Marx et al. (2014) observed ***b*** values of 2.31 which were much lower than 3.0. Similarly, in a comparative study on length-weight relationships of *O. niloticus* and *O. aureus* in polluted and non-polluted parts of Lake Ariat (Egypt). Bakhoum (1994) reported that there were highly significant variations of length-weight relationships of both species in polluted and non-polluted parts of the lake. Also in Egypt, Khallaf et al. (2003) reported differences in length-weight relationships of *O. niloticus* in a polluted canal compared with those of other localities and times and found ***b*** values consistently less than 3. These differences were attributed to the effect of eutrophication and pollution on growth and other biological aspects of *O. niloticus*. In Lake Tana (Ethiopia), Tadesse (1997) reported ***b*** values of less than 3.0 indicating allometric growth. In Kenya, Njiru et al. (2006) also found that *O. niloticus* growth was allometric and was significantly different and greater than the expected value of 3.0.

The length and weight of the fish were also typically highly correlated. The condition factor for the various age classes varied within narrow limits of 1.5 - 2.0. Condition factor remained the same for fish within the 10 cm – 35 cm TL size range. Condition factor compares the overall well-being of fish and is based on the hypothesis that the more a fish weighs for a given length, the better its condition than lighter fish of the same length (King, 1995). It would have been expected that there would be a dip around 22 cm TL which coincides with the length at maturity, but this was not the case. This is because during the reproductive stages much energy is directed towards gonad development and spawning, and this has been associated with a decline in weight and thus condition (Le Cren, 1951). In Lake Kariba, fish condition declined during the months when there is lower food availability (Mhlanga, 1998). In this study, a corresponding decline was not observed with onset of reproduction because Lake Chivero is highly enriched and there should be no limitation in food availability throughout the year.

Age determinations

Age determinations were done using scales and this was validated also using data from length frequency analysis. A distinct growth check (Code 1) appeared on the margin of the scale in May, June and July and another appeared in October, November and December. The formation of the first growth check usually occurs due to an interruption in growth in winter months, while the second growth check occurs at the onset of the summer rains (Falconer *et al*., 1970). Low temperatures in winter results in reduced growth, while in summer reproductive activity ensures high expenditure of energy towards reproduction (LeCren, 1951). The effect of reproductive activity on growth was observed in the Abu-Zabal lakes (Egypt), where poor feeding activity coincided with spawning season of *O. niloticus* (Shalloof and Khalifa, 2009).

The length-age plots as well as the scale radius-age plots, all showed a high variation of length per age for *O. niloticus*, which was an indication of a large individual variation in growth. This is why it is advisable to use younger fish for aging because then the length is highly linearly correlated to its age, and there will be less variation in the age-at-length. Thus age determination is more accurate (Pauly and Gayanilo, 1997). Of the 1260 fish sampled, only 8 fish were above 8 years, thus there were very few old fish captured in this study. The length-frequency method showed a relative age of 8 years as the maximum but the Bhattacharya method failed to distinguish this age group (cohort) perhaps because the separation index (SI) was below 2. Cohorts also tend to merge more with age due to the slowing down of growth. Pooled samples were used and the contribution of sex differences could not be investigated. In future studies the analysis should be done for the separate sexes.

Comparison of the length frequency (Bhattacharya) age groups with the age data obtained from scales shows that the Bhattacharya age groups started from age 2 years to 5 years. The 1 year old fish which should have a mean length of 10 cm TL were not represented in the length frequencies but were accounted for in scale aging. The Bhattacharya plot shows an empty area before 14 cm TL, which ideally should have the 1 year olds had the method been sensitive enough or the gear selective for all the fish sizes in the lake. Without the age-at-length data derived from scales, the length frequency aging would have certainly under-aged the fish by at least one year. The mean estimated length-at-age indicates fast growth in the $1^{st}$and 2^{nd} year of life with the fish reaching about 50% of L_∞ in this time, and then growth subsequently slows down. The two approaches to aging fish used in this study showed that there were no significant differences in age-at-length of the fish.

Length at maturity; Length at first capture and Net selectivity

The length at maturity results showed that the males mature after the females at 24 cm and 22 cm TL respectively. It was clear from the values of length at maturity (Lm_{50}) and length at first capture (Lc_{50}) that the fish in Lake Chivero are not being given the chance to reach their age of maturity before being exploited. The age at first maturity for the Lake Chivero *O. niloticus* population at 23.33cm is higher than Lc_{50} implying that fish are being captured before their age of maturity. The minimum mesh size in Lake Chivero is therefore not sustainable for harvesting fish. Most fish on average do not have the opportunity to reproduce at least once before being recruited into the fishery. Recruitment overfishing might be taking place and is therefore a problem. To ensure a sustainable fishery, the Lc_{50} value should be above the Lm_{50} to give a fish the chance to breed at least once before capture.

According to Trewavas (1983), the maturation size of *O. niloticus* was 24 cm TL in Lakes George and Victoria, 25 cm TL in Lake Edward and 28 cm TL in Lake Albert. Similarly, Balirwa (1998) found that the length at first maturity of Nile tilapia in the littoral habitats of Lake Victoria was 24 cm TL for both sexes, and in Lake Kyoga it was 23 cm and 36 cm TL for males and females respectively. In Lake Nabugabo (Uganda), Bwanika et al. (2007) observed that *O. niloticus* males matured at 25.7 cm TL, while females matured later at 27.5 cm TL. In analyzing net selectivity, the minimum mesh size caught fish of 21.21 cm TL, which was obviously close to the length-at-first capture which was 21.98 cm for 2011. The combined mean length of fish caught by gillnets of mesh sizes 3 and 4 inches which are used exclusively in the fishery was 22.60 cm TL, and this was also below the Lm_{50}.

The lake Chivero fishery has evolved since the 1950s when the 3 inch net was determined and designated as minimum. In the past, the fishery was based on the smaller cichlids, *O. mossambicus*, *Tilapia rendalli* and *O. macrochir*. Sexual maturity in tilapia is a function of age, size and environmental condition and it is known that for example, *O. mossambicus* reaches sexual maturity at a smaller size and younger age than *O. niloticus* (Daget, 1956). Now, the fishery has become almost a single species fishery dominated by the relatively larger cichlid, *O. niloticus* which has nearly replaced the other species. The legal mesh sizes as currently stipulated (Zimbabwe Parks and Wildlife Act: Chapter 20; 14 (1996) as amended in 2001) for both gillnets and seine nets are not suitable anymore for the fishery if recruitment overfishing is to be avoided.

Growth, Mortality and Exploitation Rate

There was a decline in the $L\infty$ values in Lake Chivero from 2009 to 2011. The slope factors, K which the rate at which the fish approach asymptote, had also declined since 2009. This fall in K coefficients indicated that the fish were approaching asymptote more slowly (Sparre and Venema, 1992). At the same time, the growth performance (ø) decreased in the same period which meant that there had been an overall decline in growth in Lake Chivero. Factors such as diet, exploitation and genetic makeup determine growth potential of a species (Ssentongo and Welcomme, 1985), and these factors may also have played a part in the decrease of growth observed. The overall pattern of decline in all these growth parameters were consistent with an overexploited fish population.

The fishing mortality remained above the natural mortality in all the three years that were studied. Exploitation rate was accordingly above 0.5 $year^{-1}$ which confirms that overfishing is occurring in Lake Chivero. Examination of the length converted catch curves showed that the fish are recruited into the fishery quickly after two years of age. This means that the effect of the heavy fishing seen in 2010, occurred when the age classes of 2007/8 were recruited into the fishery 2-3 years afterwards. Therefore fish are getting vulnerable to the fishing gear very early in their lives. The reliability of the estimated natural mortality rate was ascertained using the M/K ratio, and for most fishes this ratio lies in the range of 1.12-2.5 (Beverton and Holt, 1957). The M/K ratio of *O. niloticus* in Lake Chivero for 2011 was 2.11.

There have been several studies in other parts of the world on *O. niloticus* fisheries. In Lake Manzalah (Egypt), El-Bokhty (2010) found that *O. niloticus* grew to $L\infty$ 22.60 cm with a growth constant (K) of 1.1 $year^{-1}$; natural mortality of 2.54; fishing mortality of 1.04; and exploitation of 0.59. In Kaptai reservoir (Bangladesh), *O. niloticus* grew faster and larger to 55.59 cm at a growth rate of 0.39 $year^{-1}$ respectively (Ahmed *et al*., 2003). Natural and fishing mortality were 0.80 and 0.59 respectively. In Nyanza Gulf Lake Victoria, Kenya, Njiru et al. (2003) found that *O. niloticus* grew to 58.78 cm at 0.59 $year^{-1}$ with fishing and natural mortalities at 1.12 and 1.00 respectively. Growth performance index was 3.31. Gomez-Marquez et al. (2008) recorded *O. niloticus* growth to 17.88 cm at K = 0.3409 in Mexico. The growth parameters of *O. niloticus* estimated by Getabu (1991) where $L\infty$ = 64.6 cm, growth constant (K) = 0.254 yr^{-1} and the instantaneous rate of total mortality = 0.818 yr^{-1}. According to Getabu (1991), the longevity of *O. niloticus* was estimated at 11 years. It is evident that different populations of *O. niloticus* have different population growth and mortality characteristics. Reasons for these differences can be varied as these waterbodies all differ in their ecological characteristics such as productivity, as well as the management of the fisheries. It is therefore difficult to make any useful comparisons for population growth characteristics.

Relative Yield and Biomass per Recruit Analysis

The exploitation rate E gave a maximum (Y'/R) estimate of 0.79 year^{-1}, while the exploitation level which maintains the spawning stock biomass at 50% of the virgin spawning biomass ($E_{0.5}$) was estimated at 0.38 year^{-1}. At 0.38 year^{-1}, exploitation of the fishery replenishes the fish lost to fishing and thus ensures sustainability. This indicates that the current mean E value of 0.58 is higher than that which maintains 50% of the unexploited stock biomass which should be 0.38 year^{-1}. The current exploitation level which is 0.58 year^{-1} is however below that which gives the maximum yield per recruit E_{max} of 0.79 year^{-1}. This theoretically means that rate of exploitation can still be raised by 32% to bring the exploitation level to the maximum allowable limit (maximum Y'/R). However, this exploitation level which gives maximum yield per recruit is not the sustainable level of exploitation.

Increasing the length-at-first capture resulted in a decrease in relative yield per recruit as expected, and a gain in biomass per recruit at the existing exploitation rate (E) of 0.58 year^{-1}. The biomass per recruit increase occurred because fish gained body mass through somatic growth. However, this meant that fewer fish grew to a larger size due to natural mortality. Using a larger mesh size for gillnets will allow a larger size-at-first-capture by postponement of their capture. The use of larger mesh sizes will reduce the possibility of stock collapse through a long term increase of the spawning stock size, and also preventing of recruitment overfishing.

The L_c values of 24.00 cm and 25.00 cm TL would predict masses of 235.47g and 266.58g respectively as opposed to the current mean length Lc_{50} of 22.60cm TL which weighs 196.15g. The gain in body mass which would be achieved by assigning a 24cm or 25cm length-at-first-capture would be in the order of 39.32g and 70.42 gm, respectively. This change would increase the catch based on the criterion of gaining extra weight from individual growth in size mentioned earlier and realize more economic returns. The current situation in the Lake Chivero fishery is that eumetric fishing is occurring, where fishing mortality is high and the relative size of fish caught has declined (Beverton and Holt, 1964).

In conclusion, results of this study have shown that immature individuals are presently the target of the fishery and the stock dynamics of this species are likely to be adversely affected. Thus, the protection of immature fish is probably the key for the sustainability of the resource. The establishment of a closed season and restricting access to breeding areas is worth considering. This may be achieved through protecting breeding areas such as inshore areas from seine netting and gill netting. A detailed map of the spawning and nursery grounds of *O. niloticus* should be prepared based on sound biological research. The direct reduction of effort to reduce overfishing is presently not acceptable in the current economic, political and social environment. However, the adjustment of mesh sizes is practical and is therefore recommended. The use of monofilament twine fishing nets should be discontinued immediately, as fishermen can now illegally fish during the day thereby negatively affecting other uses of the lake such as boating safaris and recreational fishing.

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References

Ahmed, K.K.U., Amin, S.M.N., Haldar, G.C., and S. Dewan. (2003). Population dynamics and stock assessment of *Oreochromis niloticus* (Linnaeus) in the Kaptai Reservoir, Bangladesh. *Indian Journal of Fisheries* **50**: 47-52.

Bagenal, T.B. and Braum, E. (1968). Eggs and early life history. In: *Methods for assessment of fish production in fresh waters.* Ricker, W.E. (Ed). IBP Handbook 3, Blackwell Scientific Publications, Oxford, pp. 162-167.

Balirwa, J.S. (1998). Lake Victoria wetlands and the ecology of Nile tilapia *Oreochromis niloticus*. PhD Thesis, University of Wageningen, Rotterdam, pp 83-88.

Bakhoum, S.A. (1994). Comparative study on length-weight relationship and condition factors of the Oreochromis in polluted and non-polluted parts of Lake Mariut, Egypt. *Bulletin of the National Institute of Oceanography and Fisheries (Egypt)* **20**: 201-210

Beverton, R.J.H., and S.J. Holt. (1964). Tables of yield functions for fishery management. *FAO Fisheries Technical Paper* **38**: 49.

Beverton, R.J.H., and S.J. Holt. (1957). On the dynamics of exploited fish populations. *Fisheries Investigation Series* II **19**: 1-533.

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

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

Chifamba, P.C. (1998). Status of *Oreochromis niloticus* in Lake Kariba, Zimbabwe, following its escape from fish farms. In: I.G. Cowx (Ed), Stocking and Introduction of Fish. Fishing News Books, pp. 267-273.

Cowx, I.G., van der Knaap, M., Muhoozi, L.I., and R. Othina. (2003). Improving fisheries catch statistics for Lake Victoria. *Aquatic Ecosystem Health & Management* **6**: 299-310.

Daget, P. (1956). River Fisheries. FAO Corporate document repository, Rome. http://www.scielo.br/pdt/rbo/v60n (viewed on 10/11/2011).

El-Bokhty, E.B.B. (2010). Fisheries management of *Oreochromis niloticus* and *Oreochromis aureus* caught by trammel nets and basket traps in Lake Manzalah, Egypt. *World Journal of Fish and Marine Sciences* **2**: 51-58.

Falconer, A., Marshall, B.E. and D.S. Mitchell. (1970). Hydrobiological research in Lake McIlwaine-1968-69. Department of Parks and Wildlife Management publication.

FAO. (1990). Source Book for the Inland Fishery Resources of Africa. Vol. 1: Rome.

Froese, R. and D. Pauly (Eds). (2016). FishBase. World Wide Web electronic publication. www.fishbase.org, version (01/2016).

Fryer, G. and T.D. Iles. (1972). The Cichlid Fishes of the Great Lakes of Africa. Oliver and Boyd, Edinburgh.

Gayanilo, F.C.Jr, Sparre, P. and D. Pauly. (2005). FAO ICLARM Stock Assessment Tools. (FiSAT) User Manual. Revised version. FAO Computer Information Series, (Fisheries), Rome No. 8.

Getabu, A. (1991). Mortality Rate, Exploitation and Recruitment in *Oreochromis niloticus* (Linnaeus) in Nyanza Gulf of Lake Victoria, Kenya. In: E. Okemwa, E.O. Wakwambi and A. Getabu (eds). Recent Trends in Research on Lake Victoria Fisheries. Kenya Marine and Fisheries Institute (KMFRI). ICIPE Science Press.

Gomez-Marquez, J., Pena-Mandoza, L., Salgado Ugarte, I.H. and G. Arroyo. (2003). Reproductive aspects of *Oreochromis niloticus* (Perciformes: Cichlidae) at Coatetelco Lake, Morelos, Mexico. *Revised Tropical Biology* **51**: 221-228.

Gomez-Marquez, J., Pena-Mendoza,L., Salgado Ugarte, I.H. and J.L. Arredondo-Figueroa. (2008). Age and growth of the tilapia *Oreochromis niloticus* (Perciformes: Cichlidae) from a tropical shallow Lake in

Mexico. *Revised Tropical Biology* **56**: 875-884.
Goudswaard, P.C., Witte, F. and F.B. Katunzi. (2002). The tilapiine fish stock of Lake Victoria before and after the Nile perch upsurge. *Journal of Fish Biology* **60**: 838-858.
Khallaf, E.A., M. Galal and M. Authman, 2003. The biology of *Oreochromis niloticus* in a polluted: Canal. *Ecotoxicology* **12**: 405-416.
King, M. (1995). Fisheries Biology, Assessment and Management. Fishing News Books, London.
Lake Chivero Fisheries Statistical Report. (2011). Zimbabwe Parks and Wildlife Management Authority Publication.
LeCren, E.D. (1951). The length weight relationship and seasonal cycle in gonad weight and condition in perch *Perca fluviatilis*. *Journal of Animal Ecology* **20**: 201-219.
Marshall, B.E. and C.A. Lockett. (1976). Juvenile fish populations in the marginal areas of Lake McIlwaine, Rhodesia. *Journal of the Limnological Society of Southern Africa* **2**: 37–42.
Marshal, B.E. (1982). The fish of Lake Mcllwaine. In Thornton, J. A. (ed.) Lake Mcllwaine: the eutrophication and recovery of a tropical African lake. The Hague: Dr W Junk Publishers, pp156-188.
Marshall, B.E. (1997). Lake Chivero after forty years: The impact of eutrophication. In: N.A.G.
Morales, D.A. (1991). La tilapia en México. A.G.T., México D.F., México.
Marx, K.K., Vaitheeswaran T., Chidambaram P., Sankarram S. and Karthiga P. (2014). Length weight relationship of Nile tilapia of *Oreochromis niloticus* (Linnaeus, 1758) (Family: Cichlidae *). Indian Journal of Veterinary & Animal Sciences Res.* **43**: 33 – 39.
Mhlanga, W. (1998). Observation on gillnet catches of Kariba tilapia, *Oreochromis mortimeri*, from Bumi Basin of Lake Kariba, Zimbabwe. *Naga* **21**:57-60.
Moyo, N.A.G. (1997). Causes of massive fish death in Lake Chivero. In: N.A.G. Moyo (Ed), Lake Chivero, a polluted lake. University of Zimbabwe Publications.
Njiru, M., Okeyo-Owuor, J.B., Muchiri, M., Cowx, I.G. and M. van der Knaap. (2003). Changes in population characteristics of Nile tilapia *Oreochromis niloticus* (L.) from Nyanza Gulf of Lake Victoria, Kenya: What are the Management Options? *Aquatic Ecosystem Health & Management* **10**: 434-442.
Njiru, M., Okeyo-Owuor, J. B, Muchiri, M. & I. G. Cowx. (2004). Shift in feeding ecology of Nile tilapia in Lake Victoria, Kenya. *African Journal of Ecology* **42:** 163-170.
Njiru, M., Ojuok J.E., Okeyo-Owuor J.B., Muchiri M., Ntiba M.J. and Cowx I.G. (2006). Some biological aspects and life history strategies of Nile tilapia *Oreochromis niloticus* (L.) in Lake Victoria, Kenya. *African Journal of Ecology* **44**: 30–37
Nyakuni, L. (2009). Habitat utilization and reproductive biology of Nile tilapia (*Oreochromis niloticus*) in Albert Nile, M.Sc. Thesis. Department of Zoology, Makerere University, Uganda.
Pauly, D. (1979). Gill size and temperature as governing factors in fish growth: a generalization of von Bertalanffy's growth formula, *Berichte des Instituts fur Meerskunde an der Univ*, *Kiel*, No 63. 156p.
Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *ICES Journal of Marine Science* **39**, 175–192.
Pauly, D. (1984). Length converted catch curves: a powerful tool for fisheries research in the tropics (Part II). *ICLARM Fishbyte* **2**: 17-19.
Pauly, D. and J.L. Munro. (1984). Once more on the comparison of growth in fish and invertebrates. *ICLARM Fishbyte* **2**: 21.
Pauly, D., and F.C. Gayalino. (1997). FAO-ICLARM stock assessment tools. Reference

manual. FAO computerized information series (Fisheries) Rome.

Ruiz-Dura, M.F., Orijel-Arenas, Y. and G. Rodríguez-Hernández. (1970). Líneas de crecimiento en escamas de algunos peces de México, Instituto Nacional de Investigaciones BiológicoPesqueras, Serie Investigación Pesquera Estudio No. 2: 97 p.

Shalloof, K.A.S. and N. Khalifa. (2009). Stomach contents and feeding habits of *Oreochromis niloticus* from Abu-Zabal Lakes, Egypt. *World Applied Science Journal* **6**: 1-5.

Sparre, P. and S.C. Venema. (1998). Introduction to tropical fish stock assessment, FAO Fisheries technical paper, Roma, 450 pp.

Sparre, P. and S.C. Venema. (1992). Introduction to tropical fish stock assessment. Part I and II. FAO/UN.

Ssentongo, G.W. and R.L. Welcomme. (1985). Past history and current trends in the fisheries of Lake Victoria. CIFA report of the third session of the sub-committee for the development and Management of the fisheries of Lake Victoria, Jinja, Uganda. *FAO Fisheries Report* 335: 123-138.

Tadesse, Z. (1997). Breeding season, fecundity, length-weight relationship and condition factor of *Oreochromis niloticus* L. (Pisces: Cichlidae) in Lake Tana, Ethiopia. *Ethiopia Journal of Science* **20**: 31 – 47.

Tesch, F.W. (1968). Age and growth. In: W.R. Ricker (Ed.), *Methods for the assessment of fish production in freshwater*, IBP Hand Book. No. 3.pp. 98-130.

Tesfaye, W. (1998). Biology and management of fish stocks in Bahir Dar Gulf, Lake Tana, Ethiopia PhD Thesis.

Trewavas, E. (1983). Tilapiine fishes of the genera *Sarotherodon*, *Oreochromis* and *Danakilia*. London, UK: British Museum of Natural History, 583 pp.

Yamaguchi, Y., Hirayama, N., Koike, A. and H.A. Adam. (1990). Age determination and growth of *Oreochromis niloticus* and *Sarotherodon galilaeus* in High Dam Lake, Egypt. *Nippon Suisan Gakkaishi* **56**: 437-443.

Zambrano, L., Martínez-Meyer, E., Menezes, N. and A. Townsend-Peterson. (2006). Invasive potential of common carp (*Cyprinus carpio*) and Nile tilapia (*Oreochromis niloticus*) in American freshwater systems. *Canadian Journal of Fisheries and Aquatic Sciences* **63**: 1903 - 1910.