Assessment of Sustainable Yield and Optimum Fishing Effort for the Tilapia (*Oreochromis niloticus* L. 1758) Stock of Lake Hawassa, Ethiopia

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ABSTRACT

The tilapia (*Oreochromis niloticus*, L. 1758) stock of Lake Hawassa, Ethiopia, was assessed to estimate sustainable yield (MSY) and optimum fishing effort (f_{opt}) using length-based analytical models (Jone's cohort analysis and Thompson and Bell). Pertinent data (length, weight, catch, effort, etc.) were collected on a daily basis for 514 days during 27-12-2003 to 24-05-2005 at the major landing site known as *Fish market* or *AmoraGedel*. The sampling days fell into two periods demarcated by the date (08-04-2004) when a management action was implemented, which reduced fishing effort by half (from1954 gillnets/day to below 800 nets/day). Thus, data obtained during 27-12-2003 to 08-04-2004 pertained to the period prior to effort reduction whereas the rest pertained to the period after the reduction. The two data sets were analyzed separately to get a basis to evaluate the effect of the management action of effort reduction. The assessment gave an estimate of current yield of 526.8 t/year for the period before effort reduction whereas 441.6 t/year afterward. The predicted MSY was 514.5 t/year and 441.6 t/year for the period before and after effort reduction, respectively. The respective F-factor is estimated to be 0.5 and 1.0.This suggested that the fishing effort before the reduction of effort (1954nets/day) was very high and, as already implemented, should have been reduced by half(i.e., an F-factor of 0.5).Therefore, the implemented management measure to reduce effort below 800 nets/day is appropriate. Likewise, since the estimated MSY of441.6 t/year for the period after the reduction would be obtained at an F-factor of 1.0, it was concluded that the current level of fishing effort of 696 gillnets/day can be maintained as f_{opt} for sustainable exploitation of the stock.

Keywords: Stock assessment, MSY, Optimum fishing effort, Analytical yield prediction model, Lake Hawassa, *O.niloticus,* Ethiopia.

1. INTRODUCTION

Global Ocean and inland water bodies are suffering from excessive overfishing exerted by an increasing demand of human population. This strong demand, which was not controlled through appropriate management of fishing capacities, had led to a generalized fleet overcapacity and to overfishing, highlighted by declining catches worldwide (FAO, 2009a).In 2007, most of the stocks were either overexploited or depleted and thus yielded less than their maximum potential owing to excessive fishing pressure (FAO, 2009b).The general view seems to be that most of Ethiopian lakes are also heavily exploited. Among the ten most fished lakes in Ethiopia, the harvest exceeds the potential in nine of them and this includes Lake Hawassa (LFDP, 1997). In the past few years, Lake Hawassa has been clearly over fished. Production peaked between 1992and 1994 at around 900 tons per year. However, after a decade it is only just over half that figure while the effort has not declined by nearly as much (LFDP, 1997). This proves that the lake was over fished in the past years. According to LFDP (1997), it is in critical condition compared to the other Ethiopian lakes.

The impact of this alarming rate of fishing pressure is further worsened because of the disproportionate exploitation of the fish species in Lake Hawassa. Among the three commercially exploited species in the lake, tilapia (*O.niloticus*), catfish (*Clarias gariepinus*, B. 1822) and barbus (*Labeobarbus intermedius*, R. 1836), tilapia accounts to about 90% by weight of the total annual landings (Yosef Tekle-Giorgis, 2002). As a result, the tilapia stock has already shown signs of over fishing (LFDP, 1997). Hence to take sound management measures, it is inevitable to get adequate information on the status of the stocks as well as predict the exploitable potentials and the corresponding biologically optimum effort level that can be expanded on the stocks.

Reliable yield estimates are obtained from the use analytical type stock assessment models and the basic input data for these types of models comprise the age and/or length composition of the total annual landings of the fishery (Thompson and Bell, 1934; Jones, 1984). Particularly, the length based models are suitable for tropical fish stock assessment work as they do not require the tedious procedure of age determination, which is frequently difficult for tropical fish stocks. Unfortunately, the catch statistics data collection system practiced in Lake Hawassa (also in other lakes of the country as well) has not been geared towards generating age and/or length structured catch data. Hence lack of such data has mainly limited the application of analytical type models. Thus, little is known about the potential yield of the exploited fish species and even the limited information available on potential yield estimates are derived from empirical models.

Generally, in order to protect the fish stocks from damage, conducting rigorous stock assessment work should be a timely question for proper management of the lake. Therefore, in this study analytical stock assessment models have been used to estimate the maximum sustainable yield of the most fished stock, tilapia, as well as to estimate the biologically optimum fishing pressure to be exerted on the stock. Thus, the main purpose of the study was to provide information on current status of the tilapia stock as well as using predictive models, to provide those responsible bodies for the management of the fishery with information on the biologically optimum level of exploitation of the most fished stock, tilapia.

2. MATERIALS AND METHODS

2.1. Site Description

Lake Hawassa is the smallest of the seven natural lakes in the rift valley of Ethiopia (Fig 1). It is located in southern Ethiopia bordering the eastern side of Hawassa city, which is located 275 km south of Addis Ababa. Geographically, the lake lies between $6^0$33'–$7^0$33' N and $38^0$22'–$38^0$29' E at an altitude of 1680 m above sea level. The lake has a surface area of 90 km^2, a mean depth of 11 m, a volume of $1.036x10^9$ m^3 and a drainage area of 1,250 km^2 (LFDP, 1997). It is a terminal lake with no surface out flow and receives surface inflow through Tikur-Wuha River (LFDP, 1997).Lake Hawassa is productive and one of the most fished lake in the country. It has the most diversified phytoplankton community (i.e., over 70 species) in the rift system, and amongst of which Cyanophytes (mainly *Microcystis*) makeup over 75 % of the total algal biomass (Elizabeth Kebede, 1996). The zooplankton community comprises mainly Copepoda (*Mesocyclops* and *Thermocyclops*) and Cladocera (*Diaphanosoma*) (Seyoum Mengistou and Fernando, 1991). Dominant groups of benthic invertebrates in this lake are Ostracoda (comprising>50 % of numerical abundance) followed by Oligocheata and nematoda (Tudorancea et al., 1989).

There are six fish species in the lake of which the Nile tilapia (*O.niloticus*) is commercially the most important as it contributes about 90 % of the annual catch (Reyntjens and Tesfaye Wudneh, 1998). There are also some populations of the African catfish (*C.gariepinus*) and the African big barb *(L. intermedius*), which contribute about 7% and 2-3%, respectively, of the total annual catch (Reyntjens and Tesfaye Wudneh, 1998). *O.niloticus* and *L. intermedius* are caught exclusively by gillnets while *C.gariepinus* is caught both by gillnets and also long lines. The other three species are not fished because of their small size and these include the straightfin barb (*Barbus paludinosis*, P.1852), the black lampeye (*Aplocheilichthys antinorii*,V. 1883)and the stone lapping minnow (*Gara quadrimaculata*, R.1835) (Elias Dadebo, 2000).

Since there was excessive fishing effort expanded on the lake, the management bodies reduced the fishing effort expanded (i.e., number of nets set) since April 08, 2004 from an average of 1954 nets/day to below 800 nets /day.

2.2. Sampling regime and data collection

Data were collected from the cooperative fishermen landing site, locally known as '*Amora-Gedel Asa Gebeya*', where fishermen retail their catch. Since all the fish landed were brought to *Amora-Gedel* for retail, sampling only from this site was considered as sufficient to obtain representative sample. The data mainly constituted information on the *O.niloticus* fishery of the lake that are useful to assess the stock and estimate maximum sustainable yield and biologically optimum level of fishing effort. Specifically the basic information collected included i) the length composition of *O.niloticus* caught by the fishery, ii) total *O.niloticus* yield, iii) fishing effort expanded, iv) number of fishermen in operation and v) fishing site.

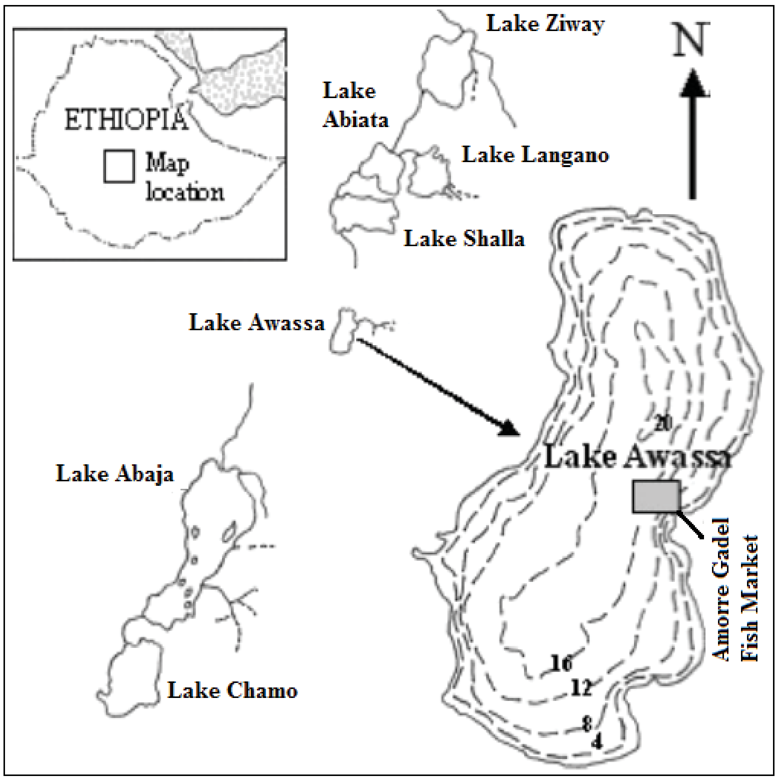

Figure 1. Location of Lake Hawassa in the Ethiopian part of the Eastern Great Rift of Africa. Contour lines are bathymetric lines at 4 meters depth interval. Inset: map of Ethiopia showing the northeastern section of the Great Rift (Elizabeth Kebede, 1996).

During each sampling day, random samples of 30 up to 50 *O. niloticus* were taken from the catch of each fisherman and their length was measured to the nearest mm. Also the total weight of the length measured fish was recorded (to the nearest gm) as well as the total catch of each fisherman was weighed. The latter data was then used to estimate the total number of *O.niloticus* caught by the respective fisherman.

The daily catch and yield data were collected from fishermen for 514 days. i.e., the lake was visited on a daily basis, from 27-12-2003 to 24-05-2005.The sampling days fell into two sampling periods. These were before reduction of fishing effort (between 27-12-2003 to 08-04-2004) and after reduction of fishing effort (between 10-04-2004 to 24-05 2005). Furthermore, the sampling days encompassed both fasting and non-fasting periods of the Ethiopian Orthodox Church and this enabled to get representative catch data during the time when the lake was lightly as well as intensively fished.

2.3. Data summarization and analysis

The catch data were summarized in a manner useful for stock assessment using Jones length based cohort analysis model (Jones, 1984) and length-based Thompson and Bell yield prediction model (Thompson and Bell, 1934; Sparre and Venema, 1992).The catch data collected before and after reduction of the fishing pressure were separately analyzed and interpreted. The summarization and analysis were done by using Microsoft Office Excel 2007 software. Accordingly, the length composition catch data of *O. niloticus* were summarized to prepare a table of the length composition of total annual catch of fish and this was done as follows (Pauly, 1984; Sparre and Venema, 1992).

2.3.1. Preparing length frequency of the sample catch

Length measurements recorded daily were grouped into two cm length intervals to prepare a table of the length frequency of *O.niloticus* sampled each day during the sampling occasions. The length and weight of a total of 5,787 fish were measured during the 104 days of sampling before reduction of the fishing effort. Also, the length and weight of 20,509 fish were measured during the 410 days of sampling after reduction of fishing effort. Overall, 26,296 fish were measured during the 514 days of sampling and the length frequency produced using such a large sample size was considered as adequate to give a good picture (Sparre and Venema, 1992) of the length frequency of the catch of *O.niloticus* in the lake.

2.3.2. Estimating the total number of fish landed per day by each fisherman

This was estimated by multiplying the number of length measured fish by a conversion factor (W/w) where W= the total weight of the catch of respective fisherman and w = sample weight of the length measured fish. Thus fish that were simultaneously counted and weighed were used to determine appropriate raising factor to convert records of the daily weight of the catch of respective fishermen into numbers.

2.3.3. Estimating the length composition of the total daily catch

This was achieved by multiplying the total numbers caught per day by the relative frequency of each length group in the daily sample obtained under item ‘2.3.1’ above. The total length frequency of fish landed during the sampled days was then determined by summing the frequencies of respective length groups.

2.3.4. Estimating total number of O.niloticus caught during theun-sampled days of the year

Since the catch and effort expanded differed during the fasting and non-fasting days of the Ethiopian Orthodox Christians, the days of the year were divided into three categories as non-fasting days of the week (i.e., days other than Wednesdays and Fridays), common fasting days of the week (Wednesday and Friday), and major fasting seasons (‘*Hudade*’, i.e., 55 days between February and April as well as ‘*Felseta*’, i.e., 15 days between the 1^{st} and 16^{th} day of August). Accordingly, the average catch of the sampled non-fasting days was used to estimate the catch of the un-sampled non-fasting days. Similarly, the average catch during the sampled Wednesdays and Fridays was used to estimate the catch of the un-sampled Wednesdays and Fridays. Likewise, the average daily catch of the sampled major fasting days was used to estimate the catch of the un-sampled major fasting days. In a similar manner, the total weight of the catch (yield) and effort expanded were estimated for the un-sampled days of the year, categorizing the dates into three categories as explained above.

2.3.5. Estimating the annual total length composition of landed fish

This was done by multiplying the length frequency of the sampled days catch by an appropriate conversion factor which was equal to **C/c**, in which **‘C’** =the estimated total catch of fish during the whole year and **‘c’** = the total catch of fish during the sampled days.

2.4. Estimating population size and fishing mortalities using Jones length based cohort analysis

The Jones length based cohort analysis model (Jones, 1984) was used to estimate the population abundance and fishing mortality coefficient by length group of *O.niloticus*. To get started with the analysis, the total annual catch in each length group $[C(L_1,L_2)]$was used as the basic input data. This was done in three steps as follows:

2.4.1. Estimating the population number of the largest length group in the catch

The following equation was employed (Jones, 1984;Sparre and Venema, 1992)

$$N_{terminal} = C_{terminal} * (Z/F)_{Terminal} \quad \text{Equation 1}$$

Where,

$N_{terminal}$ = the population of the largest length group in the catch

$C_{terminal}$ = the catch of the largest length group and

$(Z/F)_{Terminal}$ = the proportion of total mortality to fishing mortality of the largest length group in the catch. A value of Z/F = 0.5 have been used as the starting value based on the recommendation by Sparre and Venema (1992).

2.4.2. Estimating the population numbers of consecutively younger length groups in the catch

This was done using the following equation:

$$N(L_1) =\{[N(L_2) * H(L_1,L_2)] + C(L_1,L_2)\} * H(L_1,L_2) \quad \text{Equation 2}$$

Where,

$N(L_1)$ = the population of fish in the water that attained length L_1

$N(L_2)$ = the population of fish in the water that attained length L_2

$C(L_1,L_2)$ = the total annual catch in number of fish caught between lengths L_1 and L_2

$H(L_1,L_2)$ = the fraction of $N(L_1)$ fish that survived natural deaths as it grows from length L_1 to L_2 and it is computed by the following equation (Jones, 1984)

$$H(L_1,L_2) = [(L_\infty - L_1)/ (L_\infty - L_2)]^{m/2k} \quad \text{Equation 3}$$

Where,

L_∞ = the asymptotic length (cm) of *O.niloticus* attained at mature size

L_1 and L_2= consecutive length groups of fish (cm) that contributed to the fishery

K = Von Bertalanffy growth rate constant (yr^{-1})

M = the rate of natural mortality coefficient for *O.niloticus* stock of Lake Hawassa.

2.4.3. Estimating the fishing mortality rate for the respective length groups

Fishing mortality values for each length group was estimated using the following equation.

$$F(L_1,L_2) = \{(1/\Delta t) * Ln[N(L_1)/N(L_2)]\} - M \quad \text{Equation 4}$$

Where,

$F(L_1,L_2)$ = Fising mortality coeffecient pertaining to the respective length group

$N(L_1)$, $N(L_2)$ and M are as defined above.

Δt = the time, required for fish of length L_1 to grow to length L_2 and it is defined by the following equation (Jones, 1984; Pauly and Morgan, 1987; Gulland and Rosenberg, 1992).

$\Delta t = 1/k * Ln[(L_\infty - L_1)/(L_\infty - L_2)]$ -- Equation 5

The terms are as defined above.

To use equations 2, 3, 4 and 5, the following input data and parameters were prepared in advance.

i) First a table of the total annual catch distributed by length group was prepared as described earlier.

ii) Secondly, estimates of the Von Bertalanffy growth parameters (L_∞ and K) for *O.niloticus* stock of Lake Hawassa were obtained from previous age determination work as L_∞ = 35 cm and K = 0.28 yr^{-1} (Yosef Tekle-Giorgis and Casselman, 1995; Demeke Admassu, 1998; Yosef Tekle-Giorgis, 2002).

iii) Thirdly, an estimate of the natural mortality coefficient (M) for *O.niloticus* stock of Lake Hawassa, which is equal to 0.35 yr^{-1}, was estimated using Pauly's empirical formula as follows (Pauly, 1984).

$Ln M = -0.00152 - 0.279 * Ln L_\infty + 0.6543 * Ln K + 0.463 * Ln T$ ----------Equation 6

Where values of L_∞ and K are as described above for *O.niloticus* stock and T is the mean annual surface water temperature of Lake Hawass arecorded during the study period, which was 21 ^oC.

2.5. Predicting sustainable fish yield and optimum fishing effort

The outputs of the above cohort analysis procedures were used as input data for the Thompson and Bell yield prediction model to predict sustainable fish yield at different levels of fishing mortalities (Thompson and Bell, 1934; Pauly and Morgan, 1987; Schnute, 1987; Sparre and Venema, 1992).

For the length based Thompson and Bell model, input data and sources comprised the following

i. Length composition of the annual total number of fish landed by the fishery. This was obtained from field data collection (catch statistics data) as described earlier.

ii. Estimates of population numbers of fish and fishing mortality coefficient (F) by length group. Source: results of the Jones length based cohort analysis described earlier.

iii. An average estimate of natural mortality coefficient (M) and the Von Bertalanffy growth parameters (L_∞ and K). The same values discussed earlier have been used.

iv. Mean weight of the landings per length group. This was estimated by using the mean length of each length group and the length-weight relationship formula expressed as follows:

Wt (gm) = $a * L^b$ --- Equation 7

Where,

Wt (gm) is the average weight of each length group, L = the average length (cm) of each length group i.e., $L = (L_1+L_2)/2$ in which L_1 and L_2 are the length intervals of consecutive length groups. 'a' and 'b' are values of the regression coefficients.

To establish the above length-weight regression relationship, a random sample of 1000 *O.niloticus* that encompassed a wide range of length groups were length and weight measured. In due regard, the total weight of fish landed per year in each length group was estimated by multiplying the average weights of each length group by the corresponding total annual catch of respective length group. The computation procedures of the Thompson and Bell (1934) yield model consisted of two main stages as described below.

2.5.1 Estimating fish yield under the current level of effort

The yield of fish under the level of fishing effort expanded on the stock was estimated using annual catch data of each length group and the average weight of fish of respective length group. For this, first the yield in weight obtained per year from the respective length group of fish was calculated by multiplying the total annual catch in numbers of each length group by the mean weight of the respective length group. i.e.,

$Y (L_1, L_2) = C(L_1, L_2) * W(L_1, L_2)$ -- Equation 8

Where,

$Y (L_1, L_2)$ = The yield (weight) of fish obtained per year from respective length group

$C(L_1, L_2)$ = Total annual catch of fish obtained from respective length group

$W(L_1, L_2)$ = The mean weight of each length group estimated using equation 7

Summing the individual contribution of each length group gave estimates of the annual total yield of fish obtained under the level of fishing efforts expanded on the stock. i.e., these estimates pertained to the fishing mortalities that corresponded to the level of fishing effort exerted on *O.niloticus* stock at the time of sampling.

2.5.2 Yield predictions under different levels of fishing effort

The second step of the Thompson and Bell yield prediction procedure involved assessment of the effects of changes in the current level of fishing effort (and hence that of fishing mortalities) on fish yield. This was done by predicting fish yield at higher and/or lower levels of fishing mortality coefficients pertaining to the respective length groups (F-at-length-array). i.e., the current fishing mortality values of the respective length groups estimated following the Jones length based cohort analysis were used as reference and these were increased and/or decreased by certain raising factors (F-factor) to predict new values of yield corresponding to the changed fishing mortalities (Venema et al., 1988; Spare and Venema, 1992).Details of the procedure were as follows.

i) Estimating population abundance under the changed level of fishing mortality

Since a change in fishing mortality obviously results in a change in population number of fish in the water, new estimates of population numbers in each length group need to be predicted under the changed fishing mortality condition. Thus the population numbers under the changed fishing mortality were calculated from the following exponential decay relationship (Schnute, 1987; Sparre and Venema, 1992).

$$N(L_2) = N(L_1) * e^{-Z(L1,L2) * \Delta t (L1, L2)} \text{ --- Equation 9}$$

Where,

$N(L_1)$ is the population number of length L_1 fish and $N(L_2)$ is the population number of length L_2 fish. Also Δt (L_1, L_2) is the time it takes for an average fish to grow from length L_1 to length L_2 and it is defined earlier by equation 5. $Z(L_1,L_2)$ is the total mortality under the changed level of fishing and it is equal to the sum of the changed fishing mortality and natural mortality coefficient i.e.,

$$Z (L_1, L_2) = F \text{ new } (L_1, L_2) + M \text{ -- Equation 10}$$

Where,

F new (L_1, L_2) is the changed (new) fishing mortality coefficient of each length group. M is the natural mortality coefficient estimated by equation 6 above.

ii) Estimating the total death and catch in each length group under the changed fishing level

The total number of deaths expected while the fish grew from length L_1 to length L_2, i.e., $D(L_1, L_2)$ under the changed fishing level is equal to $N(L_1) – N(L_2)$. From this total death, the fraction died due to fishing make up the total catch. Accordingly, the catch per length interval corresponding to the changed fishing mortality[$C(L_1, L_2)$]was calculated from the following relationship (Wetherall et al., 1987).

$C(L_1, L_2) = [N(L_1) – N(L_2)] * F(new)/Z(new)$ ---------------------------------Equation 11

Where,

F (new) and Z (new) are the fishing and total mortality coefficients, respectively, under the changed level of fishing effort. Then, to estimate the expected yield obtained from respective length groups annually ($Y(L_1,L_2)$) under the changed fishing mortality, the expected catch in number under the changed fishing level was multiplied by the mean weight of each length group as illustrated by equation 8. The total annual yield to be expected under the new level of fishing effort was then predicted by summing up the contributions of each length group.

Such predictions were evaluated for different values of fishing mortalities so as to see the full spectrum of the effect of changing fishing effort on the stock. According to the above analysis, the level of fishing mortality that gave maximum sustainable yield was considered as the biologically optimum level of fishing mortality. Since there is a one to one correspondence between fishing mortality (F) and fishing effort (f), the value of F-factor chosen as optimum was used to recommend how much the current level of fishing effort need to be increased or decreased to get the maximum sustainable yield from the stock (Sparre and Venema, 1992).

3. RESULTS

3.1. Status of the tilapia fishery of Lake Hawassa

There were overall 72 and 66cooperative member fishermen operating daily on the lake during the period before and after reduction of fishing effort, respectively (Table 1). These fishermen set on average 1,954 and 696 nets daily on the lake before and after reduction of effort, respectively. Each fisherman on average owned 27 nets prior to reduction of efforts but after reduction of efforts each fisherman on average owned 10.6 nets. The nets were basically set to catch *O.niloticus* but these nets also caught some *C.gariepinus* and rarely *L. intermedius*. The nets used were similar during the two periods. Each net was on average 80 m long and 2.5 m deep and it had an average stretched mesh size of 6-8 cm. Overall, an estimated number of 713,063 nets were operated per year prior to reduction of the fishing effort and after reduction of the fishing efforts, the total number of nets set per year was 253,956.With these levels of fishing effort, an estimated total number of 2,658,906and 2,046, 077 *O. niloticus* were caught per year before and after reduction of fishing effort, respectively. Accordingly, the total yield before and after reduction of the fishing efforts were estimated at 526.76 and 441.6 t/year, respectively (Table 1).

Table 1. Statistics of *O.niloticus* fishery of Lake Hawassa before and after reduction of fishing effort.

Operation measurements	***Sampling period***	
	Before reduction of effort (27/12/2003 – 08/04/2004)	***After reduction of effort (10/04/2004 – 24/05/2005)***
Duration of sampling (days)	104	410
Total nets set during the sampled days	203,174	285,266
Total number of fishermen operated during the sampled days	7,524	26,939
Total weight of fish caught during the sampled days (tons)	150	496.05
Total catch during the sampled days (number)	757,606	2,298,333
Average number of fishermen operated/day	72	66
Total nets set/year	713,063	253,956
Average nets set/day	1,954	696
Catch/ day (number)	7,284	5,606
Weight of catch/day (kg)	1,443	1,210
Total number of fish caught/year (number/year)	2,658,906	2,046,077
Total weight of the catch/year (ton/year)	526.76	441.6
Catch/net/day (number)	3.7	8.1
Weight of catch/net/day (kg)	0.74	1.74

Table 2 shows the length frequency of *O.niloticus* in the sampled catch as well as in the estimated annual catch for the sampling periods prior to and after reduction of fishing effort. As shown by columns 2 and 3, the length and weight of a total of 5,787and 20,509 *O.niloticus*, were measured during the sampling periods before and after reduction of fishing effort, respectively. Thus, the length frequency of fairly large sample was used to estimate the length distribution of the total annual catch of *O.niloticus* shown in columns 4 and 5.

O.niloticus measuring in length from 14 cm up to 36 cm total length (TL) composed the catch of fishermen during both periods, before and after reduction of effort. Also the length composition of *O.niloticus* was similar during both sampling periods because in both periods, about 80% of the catch was composed of fish between 18 and 24 cm TL (Table 2).

Table 2. Length measured fish and estimated total annual catch by length group during the sampling periods prior to and after reduction of fishing efforts.

Length group (cm)	***Number of fish measured***		***Estimated annual catch (number)***		***The contribution to the total catch of each length group (%)***	
	Before reduction	***After reduction***	***Before reduction***	***After reduction***	***Before reduction***	***After reduction***
14-16	11	6	67,317	4,087	2.53	0.20
16-18	150	419	124,992	44,381	4.70	2.17
18-20	966	3,147	519,703	347,119	**19.55**	**16.97**
20-22	1,948	7,663	928,990	701,358	**34.94**	**34.28**
22-24	1,599	5,788	688,096	584,494	**25.88**	**28.57**
24-26	656	2,104	250,673	252,674	9.43	12.35
26-28	200	842	63,783	80,828	2.40	3.95
28-30	86	287	13,716	23,511	0.52	1.15
30-32	82	160	1,511	6,128	0.06	0.30
32-34	58	67	59	1,390	0.002	0.07
≥34	31	26	65	106	0.002	0.01
Total	**5,787**	**20,509**	**2,658,906**	**2,046,077**	**100**	**100**

3.2. Estimates of population abundance, fishing mortality coefficient and current yield by length group of *O. niloticus* that composed the fishery

Table 3 gives estimates of population number and fishing mortality coefficient by length group of *O.niloticus* that composed the fishery for the periods before and after reduction of the fishing pressure. Estimates of population numbers ($N(L_1)$) and fishing mortality coeffecients ($F(L_1, L_2)$) are direct outputs of the Jones length based cohort analysis computed using equations 2 and 4, respectively.

During the period prior to reduction of the fishing pressure, a population of over 16.6 million *O.niloticus* has been estimated to exist in the fished part of the lake as obtained by summing the population numbers of the respective length groups that composed the fishery shown by column 2 (Table 3). This estimate for the period after reduction of the fishing pressure was over 14.6 million (Column 3) and it is failry comparable to the estimate obtained for the period before reduction of effort. Also both estimates pertain to the population of the whole area of the lake where the fishery was active as the fishermen were operating in the whole area of the lake.

As estimated by the model, over 4.7 million of *O. niloticus* measuring 14 to 16 cm were recruited to the fishery every year prior to reduction of the fishing pressure (Column 2, Table 3). Similarly, based on data collected after reduction of the fishing pressure, the estimated number of *O.niloticus* recruited to the fishery attaining a length of 14 to 16 cm was close to 4 million fish (Column 3, Table 3). Accordingly, these estimates were fairly comparable.

Table 4 gives estimates of total annual yield of *O.niloticus* (tons) obtained under the level of fishing effort exerted at the time of sampling. The mean weight of fish (kg) shown by column 2 are the average weights of each length group of *O.niloticus* estimated using the length-weight relationship expressed by the following equation.

$Wt\ (gm) = 0.0184 * L^{3.0197}, \quad R^2 = 0.96$

Where, Wt (gm) is the average weight of each length group and L (cm) is the average length of respective length groups. The coefficient of determination (R^2) value for the relationship was 0.96 indicating that the estimated total weight for the respective length group is 96 % related to the measured weight of each length group.

Values in columns 3 and 4 (Table 4) are the annual catch of the respective length group of fish before and after reduction of the fishing effort and they are displayed here to illustrate the intermediary calculation steps. The current total yield per year pertaining to the respective length group (columns 5 and 6) were obtained by multiplying the total catch per year of the respective length group by the corresponding mean weight values as depicted by equation 8. The estimated annual total yield of *O.niloticus* during the sampled year prior to and after reduction of the fishing effort was 526.8 t/year and 441.6 t/year, respectively. There is a yield difference of about 85 t/year between the two periods but given that there was fishing pressure differences, the observed yield difference is not significant.

Table 3. Population number and fishing mortalities by length group estimated based on data collected before and after reduction of fishing efforts.

Length group(cm) L1 - L2	Population number N(L1)		Fishing mortality (yr^{-1}) F(L1, L2)	
	Before reduction	After reduction	Before reduction	After reduction
14-16	4,762,201	3,955,453	0.04	0.003
16-18	4,139,006	3,486,474	0.08	0.03
18-20	3,485,304	2,992,570	0.39	0.30
20-22	2,501,519	2,239,043	1.01	0.81
22-24	1,249,861	1,235,744	1.54	1.22
24-26	405,185	483,808	1.60	1.21
26-28	99,836	158,089	1.42	0.97
28-30	20,352	48,198	1.28	0.72
30-32	2,879	13,291	0.61	0.50
32-34	500	2,839	0.06	0.38
34 & above	100	163	0.65	0.65
Total	**16,666,742**	**14,615,670**		

Table 4. Estimates of total yield of *O.niloticus* obtained from each length group under the level of fishing effort expanded before and after reduction of the fishing pressure.

Length group (cm)	Mean weight (kg)	Current annual catch (number)		Current annual yield (tons/year)	
		Before reduction	After reduction	Before reduction	After reduction
14-16	0.07	67,317	4,087	4.41	0.27
16-18	0.10	124,992	44,381	11.95	4.24
18-20	0.13	519,703	347,119	69.51	46.42
20-22	0.18	928,990	701,358	168.09	126.90
22-24	0.24	688,096	584,494	163.86	139.19
24-26	0.31	250,673	252,674	76.79	77.40
26-28	0.39	63,783	80,828	24.65	31.24
28-30	0.48	13,716	23,511	6.58	11.27
30-32	0.59	1,511	6,128	0.89	3.59
32-34	0.71	59	1,390	0.04	0.99
≥34	0.85	65	106	0.05	0.09
Total		**2,658,906**	**2,046,077**	**526.8 t/year**	**441.6 t/year**

Table 5 Total annual yield (ton/year) obtained from *O. niloticus* stock of Lake Hawassa predicted using values of F-factor ranging from 0 to 2. Predictions were made using catch record data collected before and after reduction of fishing effort.

F-factor	***Predicted total annual yield (tons)***	
	Before reduction	***After reduction***
0.1	251.9	178.2
0.2	391.3	282.8
0.3	457.3	345.8
0.4	497.1	384.4
0.5	**514.5**	408.2
0.6	524.6	422.9
0.7	528.4	431.9
0.8	528.2	437.2
0.9	528.0	440.2
1.0	526.8	**441.6**
1.1	524.9	441.9
1.2	522.3	442.1
1.3	519.8	441.2
1.4	517.3	440.3
1.5	514.9	439.3
1.6	512.4	438.1
1.7	510.1	436.9
1.8	507.8	435.6
1.9	505.6	434.4
2.0	503.4	433.1

Note: Bold values refer to the maximum sustainable yield (MSY) as well as to the corresponding optimum level of F-factor.

Similarly, the analysis done on data collected after reduction of the fishing effort indicated that the predicted maximum sustainable yield of *O.niloticus* is 442.1 t/year and this is obtained at an F factor of 1.2(Table 5). It indicates that the fishery can have small room for expansion and the level of fishing effort that was exerted at the time of data collection (i.e., 696 nets/day) can be increased by 20%. i.e., it can be elevated to 835 nets/day. However, since the safe level of exploitation is to reduce the F factor that gives the maximum sustainable yield by 20 % (Pauly, 1984; Sparre and Venema, 1992), it is advisable to recommend an F factor of 1 and keep the fishing effort as it is at 696 nets/day, which corresponds to a yield of 441.6 t/year.

4. DISCUSSION

4.1. Status of the tilapia fishery of Lake Hawassa

After measures were taken to reduce the fishing efforts (i.e., after 08-04-2004), the number of nets set per day were drastically reduced by 2.8 times, i.e., from close to 2000 nets per day to about 700 nets per day. However the number of fishermen was relatively the same as the period prior to reduction of the nets. Owing to reduction of efforts, the catch per net (catch per unit effort) had increased by more than two fold from an average catch of 3.7 fish per net (0.74 kg/net/day) to 8.1 fish per net (1.74 kg/net/day). As a result of increase in catch per unit effort, the total catch per year which was 2,658,906 fish per year (526.76 t/ year) prior to reduction of the effort did not appreciably decrease after reduction of the fishing effort (2,046,077 fish, 441.6 t/ year). This indicates that the fishing effort prior to reduction was way beyond the capacity of the stock and the measure taken to reduce the fishing pressure was quite appropriate.

In the present work *O.niloticus* measuring in length from 14 cm up to 36 cm total length (TL) composed the catch of fishermen during both periods before and after reduction of efforts. Also about 80% of the catch in the present work was composed of lengths between 18 and 24 cm and this was similar to the reported length distribution of *O.niloticus* caught from Lake Hawassa during the last 15 years. For instance, according to LFDP (1997), *O.niloticus* measuring in TL between 18 and 28 cm composed about 97% of the catch and those between 20 and 26 cm TL accounted for 88 % of the catch. Similarly in the samples of fish taken from fishermen's catch in 2002, the length group 18 to 28 cm TL accounted for 95 % of the annual catch and those measuring 20 to 26 cm made up 83 % of the catch (Yosef Tekle-Giorgis, 2002). The reason for the similarity of the length composition of the catch may be because of usage of similar mesh size nets since the last 15 or so years. Unlike this however, some three decades ago, *O.niloticus* measuring up to 35 to 40 cm TL were very common in the fishermen catch and the average catch size of *O.niloticus* was 25 to 30 cm TL (LFDP, 1997). This was the time during when the fishing pressure was fairly low and that the fishermen were using mesh sizes ≥10 cm stretched width.

According to Yosef Tekle-Giorgis (2002), the length at first maturity of *O.niloticus* in Lake Hawassa was about 20 cm TL. In the present result, fish equal or below 20 cm composed about 20 % or more of the total catch (Table 2). This indicates that considerable portion of the fishermen's catch composed immature *O.niloticus* that have not yet reproduced at least once in their lifespan. Thus, it seems reasonable to slightly increase the mesh width of nets used by fishermen. To be fair, nets below 8 cm mesh width should be totally prohibited from being used by fishermen.

4.2 Estimates of population abundance, predicted yield and optimum level of fishing for *O.niloticus* stock

The estimated population aboundance of *O.niloticus* that composed the fishery of Lake Hawassa in the present study was fairly comparable to the estimates reported by Yosef Tekle-Giorgis (2002), as 20 million fish. Also Sintayehu Adissu (2012) estimated a population of *O.niloticus* as 7 million fish based on data collected from one third of the lake area where the fishery was actively operating. Thus, triplicating this figure gives an estimate close to the present study.

Similarly, estimates of annual recruitment rate of *O.niloticus* obtained in the present study were fairly comparable to the estimates reported previously by different workers. For instance, Yosef Tekle-Giorgis (2002) estimated that an average number of about 5 million *O. niloticus* had recruited annually to the fishery attaining a length of 15 to 16 cm. Also, according to Reyintjens and Tesfaye Wudineh (1998), an average number of about 5.6 million *O. niloticus* were recruited to the fishery of Lake Hawassa attaining a total length of 16 cm. Given that recruitment considerably varies from year to year, the present finding was fairly comparable to the previous estimates.

In the present study, a total yield of 526.8 t/year and 441.6 t/year of *O. niloticus* were estimated based on data collected before and after reduction of the fishing pressure, respectively, and these estimates were fairly comparable to the values reported earlier for *O.niloticus* stock of Lake Hawassa. For example, Reyintjens and Tesfaye Wudineh (1998) estimated a total annual yield of 520 tons of *O.niloticus*/year as harvested by the fishermen cooperatives of Lake Hawassa. The estimate in 2002 was about 540 t/year (Yosef Tekle-Giorgis, 2002) and the estimate in 2012 for one-third of the lake was about 192 t/year (Sintayehu Adissu, 2012), which when triplicated becomes comparable to the current yield estimate.

The analysis done on data collected prior to reduction of fishing effort indicated that the fishing effort expanded before reduction of the fishing pressure (1954 nets/day) should be reduced by half in order to sustainably exploit the stock. Again the analysis done on data collected after reduction of fishing effort indicates that the biologically optimum level of fishing efforts to be expanded on the stock is around 700 nets/day. Thus, the results obtained from both analyses, although do not exactly match, they somehow corroborate each other. In due regard, the recommended safe level of efforts to be exerted on the stock should be between 700 to 800 nets per day and measures taken to reduce the fishing efforts was appropriate. The estimated optimum effort level in the present study for *O.niloticus* stock of Lake Hawassa is similar to the recommended safe level of fishing reported by Reyintjens and Tesfaye Wudineh (1998) as 700 nets per day. Similarly, Yosef Tekle-Giorgis (2002) recommended a fishing effort close to 1000 nets for *O.niloticus* stock of Lake Hawassa.

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