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STOCK ASSESSMENT AND ESTIMATION OF OPTIMUM YIELD FOR THE TILAPIA STOCK (*OREOCHROMIS NILOTICUS*) OF LAKE HAWASSA, ETHIOPIA

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Abstract

This study was conducted on Lake Hawassa, one of the series of Ethiopian rift valley lakes. Data were collected on a daily basis for 514 days (from 27-12-2003 to 24-05-2005) from the area where fish were landed at one major landing site called fish market, locally known as Amora Gedel. The sampling regime falls into two periods, namely prior to reduction of the fishing efforts on the lake (i.e., 27-12-2003 to 08-04-2004) and after reduction of the fish efforts (i.e., 10-04-2004 to 24-05-2005). Length composition of Tilapia caught by the fishery, total Tilapia yield and fishing effort expanded were the basic information collected from the site. The aim of the study was to estimate the population number of Tilapia and fishing mortality coefficient by length group as well as predict the maximum sustainable fish yield and biologically optimum level of fishing pressure for the Tilapia stock of the lake. Jones length based cohort analysis model and length-based Thompson and Bell yield prediction model were employed to estimate the maximum sustainable yield with the corresponding biologically optimum fishing effort level. The estimated current annual yields before and after reduction of fishing effort on the lake were 526.8 tons and 441.6 tons/year of Tilapia, respectively. Based on data collected before and after reduction of the fishing pressure on Lake Hawassa, the predicted values of Optimum Sustainable Yield were 514.5 tons/yr and 441.6 tons/yr, respectively, and these are obtained at fishing mortality factor of 0.5 and 1.0, respectively. Hence, the fishing effort expanded before reduction of the fishing effort (i.e., 1954 nets/day) was very high and it should be reduced by a factor of at least 0.5. Accordingly, the measure taken to reduce the fishing effort to below 800 nets/day was appropriate. The analysis on data collected after reduction of the fishing effort indicated that the recommended safe level of exploitation is at an F-factor of 1 and the effort can be maintained at its current level of 696 nets/day.

Keywords: Analytical yield prediction model, Fishery management, MSY, Optimum fishing effort, Stock assessment, Virtual population analysis.

1. Introduction

Global oceans 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, thus yielding 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 majorly-fished lakes in Ethiopia, the harvest exceeds the potential in nine, and this includes Lake Hawassa. It is only in Lake Tana that the harvest is estimated to be much less than the potential (15%). In the past few years, Lake Hawassa has been clearly over fished. Production peaked between 1992 and 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. 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 (*Oreochromis niloticus*), Catfish (*Clarias gariepinus*) and Barbus (*Labeobarbus intermedius*), Tilapia accounts to about 90% by weight of the total annual landings. As a result, the Tilapia stock has already shown signs of overfishing (LFDP, 1997). Hence to take sound management measures, it is inevitable to get adequate information on the existing status of the stocks as well as predict the exploitable potentials and the corresponding biologically optimum effort level to be expanded on the stocks.

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 were used to estimate the maximum sustainable yield of the major 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 to provide those responsible bodies for the management of the fishery, using predictive models, with information on the biologically optimum level of exploitation of the majorly fished stock, Tilapia.

2. Methodology

2.1. Site description

Lake Hawassa is the smallest of the eight 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°33′–7°33′ N and 38°22′–38°29′ E at an altitude of 1680 m asl. 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. 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*) make up 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 amongst of which the most important commercial species is Tilapia (*Oreochromis niloticus*), but there are also some populations of catfish (*Clarias gariepinus*) and Barbus (*Labeobarbus intermedius*) that account to the fishery of the lake. Tilapia constitutes about 90% of the total production, while catfish and Barbus contribute only about 7% and 2-3%, respectively, of the total annual production (Reyntijen and Tesfaye Wudneh, 1998). Tilapia and Barbus are caught exclusively by gill nets while catfish is caught both by gill nets and also long lines. The other three species are not fished because of their small size and these include *Barbus paludinosis*, *Aplocheilchthys antinori* and *Gara quadrimaculata* (LFDP, 1997).

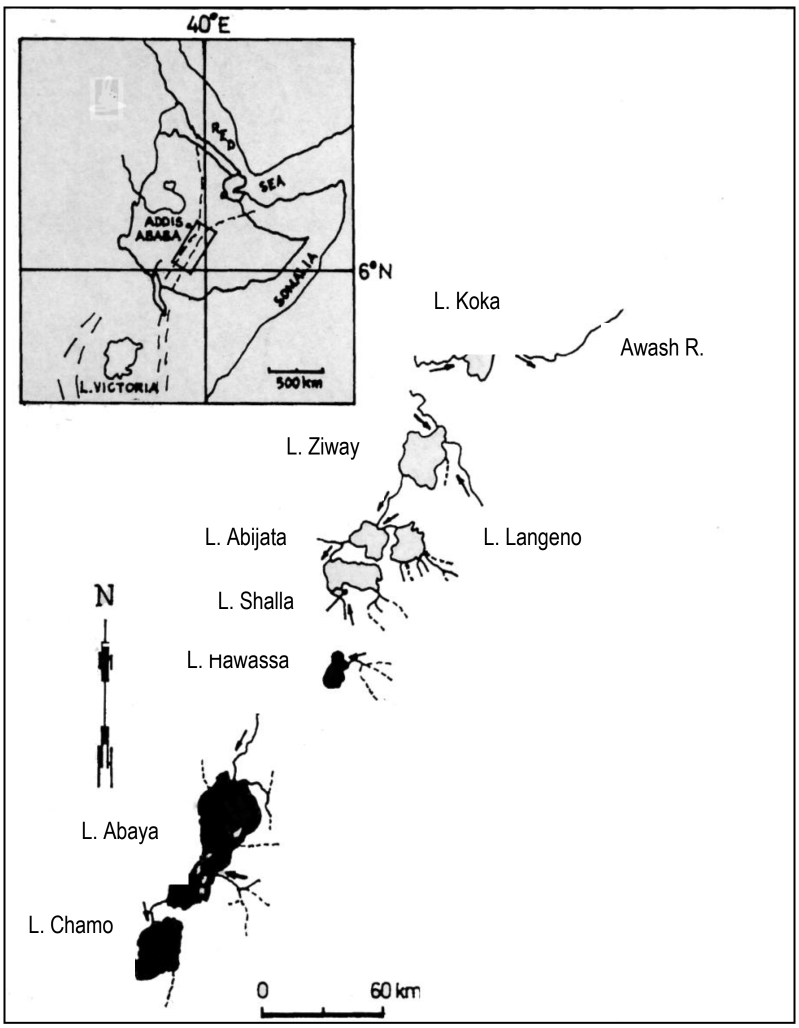

Fig. 1. Location of Lake Hawassa in the Ethiopian part of the Eastern Great Rift of Africa. Inset: map of East Africa showing the northeastern section of the Great Rift.

2.2. Sampling regime and data collection

Data were collected from the cooperative fishermen landing site called fish market, locally known as 'Amora gedel'. The data mainly constituted information on the Tilapia 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 Tilapia caught by the fishery, ii) Total Tilapia yield, iii) Fishing effort expanded, iv) Number of fishermen in operation and v) Fishing site.

During each day of sampling, random samples of 30 upto 50 Tilapia 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 Tilapia caught by the respective fisherman.

The daily catch and yield data were collected from fishermen for 514 days. Accordingly, the lake was visited on a daily basis from 27-12-2003 to 24-05-2005. These sampling days fall into two sampling regimes. 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) on the Tilapia fishery of Lake Hawassa. Moreover, the sampling days encompassed both fasting and non-fasting periods of the Ethiopian Orthodox church and this enabled to get representative catch record data during the time when the lake was lightly as well as intensively fished.

2.3. Data summarization and analysis

The catch statistics data were summarized in a manner useful for stock assessment work using Jones length-based cohort analysis model and length-based Thompson and Bell yield prediction model. The catch statistics 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 Tilapia were summarized to prepare a table of the average total annual catch of Tilapia distributed by length groups. This was done as follows (Pauly, 1984; Sparre and Venema, 1992).

i. 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 Tilapia sampled each day during the sampling occasions. A total of 5,787 fish were length and weight measured during the 21 days of sampling before reduction of the fishing effort. Also, 20,509 fish were length and weight measured during the 115 days of sampling after reduction of fishing effort. Overall 26,296 fish were length and weight measured during the 136 days of sampling and the length frequency produced using such a large sample size was considered adequate to give a good picture of the length frequency of the catch of Tilapia in the lake.

ii. 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 into numbers.

iii. 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 'i' above. The total length frequency of fish landed during the sampled day was then determined by summing the frequencies of respective length groups.

iv. Estimating the total number of Tilapia caught during the unsampled 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 1st and 16th day of August). Accordingly, the average catch of the sampled non-fasting days was used to estimate the catch of the unsampled non-fasting days. Similarly, the average catch during the sampled Wednesdays and Fridays was used to estimate the catch of the unsampled Wednesdays and Fridays. Likewise, the average daily catch of the sampled major fasting days was used to estimate the catch of the unsampled major fasting days. In a similar manner, the total weight of the catch (yield) and effort expanded were estimated for the unsampled days of the year, categorizing the dates into three categories as explained above.

v. Estimating the annual total length composition of fish landed

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 of Tilapia and fishing mortality coefficient by length group. To get started with the analysis, the total annual catch distributed by length group (C(L1,L2)) was used as the basic input data. This was done in three steps as follows:

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

The following equation was employed:

$N_{terminal} = C_{terminal} * (Z/F)_{terminal}$ ------------------------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

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

This was done using the following equation:

$N(L_1) =\{[N(L_2) * H(L_1,L_2)] + C(L_1,L_2)\} * H(L_1,L_2)$ ---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)

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

Where

L_∞ = the asymptotic length (cm) of Tilapia attained at mature size

L_1 and L_2 are consecutive length groups of fish that accounted to the fishery

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

M = the rate of natural mortality coefficient for the Tilapia stock of Lake Hawassa.

c. Estimating the fishing mortality rate of the respective length groups

Fishing mortality values for each length group was estimated using equation 4 as follows.

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

Where

$F(L_1,L_2)$ = Fishing 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 namely, L_∞ and K values for the Tilapia stock of Lake Hawassa were obtained from previous age determination work as L_∞ = 35 cm and K = 0.28 yr^{-1} (Yosef, 1990; 2002; Demeke 1998).

iii) Thirdly, an estimate of the natural mortality coefficient (M) for the Tilapia 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 the Tilapia stock and T is the mean annual surface water temperature of Lake Hawassa recorded during the study period, which was equal to 21°C.

2.5 Predicting sustainable fish yield and optimum fishing efforts

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:

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

b. 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.

c. An average estimate of natural mortality coefficient (M), and the Von Bertalanffy growth parameters (L_∞ and K). Same values as discussed earlier have been used.

d. 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 Tilapia 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 yield model consisted of two main stages as described below.

2.5.1. Estimating fish yield under current level of effort

First the yield of fish under the level of fishing efforts 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 is 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 the Tilapia stock at the time of sampling.

2.5.2. Yield predictions under different levels of fishing efforts

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 are as follows:

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

Since a change in fishing mortality obviously result 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).

$N(L_2) = N(L_1) * e^{-z(L_1, L_2) * \Delta t(L_1, L_2)}$ ------------------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.,

$Z (L_1, L_2) = F\ new\ (L_1, L_2) + M$--------------------------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 ($C(L_1, L_2)$) is 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 under the changed level of fishing. 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. In due regard, the total annual yield to be expected under the new level of fishing effort was 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 stocks.

3. Results and Discussion

3.1. Status of Lake Hawassa fishery

3.1.1. Fishing status of the lake

There were overall 72 registered cooperative member fishermen operating on the lake during the 104 days of sampling before reduction of fishing effort (between 27-12-2003 to 08-04-2004) (Table 1). These fishermen set on average 1954 nets daily on the lake. The nets were basically set to catch Tilapia but these nets also caught some catfish (*C. gariepinus*) and rarely Barbus (*B. intermedius*). Each net was on average 80 m long and 2.5 m wide and it had an average mesh width of 6-8 cm stretched mesh. Each fisherman on average owned 27 nets. Overall an estimated number of 713,063 nets were operated per year prior to reduction of the fishing effort. With this level of fishing effort, an estimated total number of 2, 658, 906 Tilapia were caught during the year that weighed about 526.76 tons. The estimated catch per net per day was 3.7 Tilapia and it weighed about 0.74 kg/net/day (Table 1).

There were overall 66 registered cooperative member fishermen operating on the lake during the 410 days of sampling after reduction of fishing effort (between 10-04-2004 to 24-05-2005) (Table 2). These fishermen set on average 696 nets daily on the lake i.e., each fisherman on average owned 10.6 nets. The specification of the nets after reduction of fishing efforts was the same as before reduction of efforts, i.e., each net was on average 80 m long and 2.5 m wide and it had an average mesh width of 6-8 cm stretched mesh. Overall an estimated number of 253,956 nets were operated per year after reduction of the fishing effort. With this level of fishing effort, an estimated total number of 2,046,077 Tilapia were caught during the year that weighed about 441.6 tons. The estimated catch per net per day was 8.1 Tilapia and it weighed about 1.74 kg/net/day (Table 2).

Table 1. Statistics of Tilapia fishery of Lake Hawassa during the sampled 104 days before reduction of fishing effort (between 27-12-2003 to 08-04-2004).

Operation measurements	**Value**
Total nets set /104 days	203174
Total fishermen operated/104 days	7524
Total weight of fish caught/104 days (tons)	150
Total catch/104 days (number)	757606
Average number of fishermen/day	72
Total nets set/year	713063
Average nets set/day	**1954**
Catch/ day (number)	7284
Weight of catch/day (kg)	1443
Total number of fish caught/year (number/yr)	2658906
Total weight of the catch/yr (ton/yr)	526.76
Catch/net/day (number)	3.7
Wt of catch/net/day (kg)	0.74

After measures were taken to reduce the fishing efforts (i.e., after 10-04-2004), the number of nets set per day were drastically reduced by nearly 2.8 times, i.e., from close to 2000 nets that were set per day prior to reduction of the effort 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) increased by more than two fold from an average catch of 3.7 Tilapia per net to 8.1 Tilapia per net. As a result, increase in catch per unit effort, the total catch per year which was 2,658,906 Tilapia per year (526.76 tons/yr) prior to reduction of the effort did not appreciably decrease after reduction of the fishing effort (2,046,077 Tilapia/year and 441.6 tons/year, see Table 2). This indicates that the fishing effort prior to reduction was way beyond the capacity of the stock and the measure taken was quite appropriate.

Table 2. Statistics of Tilapia fishery of Lake Hawassa during the 410 days of sampling after reduction of fishing effort (between 10-04-2004 to 24-05-2005).

Operation measurements	**Value**
Total nets set /410 days	285266
Total fishermen operated/410 days	26939
Total weight of the catch/410 days (tons)	496.05
Total catch/410 days (number)	2298333
Average No of fishermen/day	66
Total nets set/year	253956
Average nets set/day	**696**
Catch/ day (number)	5606
Weight of catch/day (kg)	1210
Total number of fish caught/year (number)	2046077
Total weight of the catch/yr (ton/yr)	441.6
Catch/net/day (number/net)	8.1
Wt of catch/net/day (kg)	1.74

3.1.2. Length composition of the sampled catch and estimated annual catch

Tables 3 and 4, respectively, show the length frequency of Tilapia in the sampled catch as well as in the estimated annual catch for the sampling periods prior to and after reduction of the fishing effort. As shown by column 2 of Table 3, a total of 5,787 Tilapia were length and weight measured during the 21 days of sampling before reduction of the fishing efforts. Similarly, a total of 20,509 Tilapia were length and weight measured during the 115 days of sampling after reduction of the fishing efforts (column 2, Table 4). Thus, the length frequency of fairly large sample was used to estimate the length distribution of the total annual catch of Tilapia shown in column 3 of the respective tables.

Table 3. Length measured fish during the sampled 21 days conducted prior to reduction of fishing efforts (between December 27, 2003 and April 08, 2004) and estimated total annual catch by length group.

Length group	**Length measured fish during the sampled 21 days (number)**	**Estimated annual catch (number)**	**The contribution of the catch in each length group to the total catch (%)**
14-16	11	67317	2.53
16-18	150	124992	4.70
18-20	966	519703	**19.55**
20-22	1948	928990	**34.94**
22-24	1599	688096	**25.88**
24-26	656	250673	9.43
26-28	200	63783	2.40
28-30	86	13716	0.52
30-32	82	1511	0.06
32-34	58	59	0.002
34 & above	31	65	0.002
Total	**5,787**	**2,658,906**	**100**

Tilapia 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 the length composition of Tilapia was similar during both sampling periods. About 80% of the catch ranged between 18 to 24 cm and about 90% ranged between 18 to 26 cm TL (Tables 3 and 4).

Table 4. Length measured fish during the sampled 115 days conducted after reduction of the fishing efforts (between April 10, 2004 and May 24, 2005) and estimated total annual catch by length group.

Length group	**Length measured fish during the sampled 115 days (number)**	**Estimated annual catch (number)**	**The contribution of the catch in each length group to the total catch (%)**
14-16	6	4087	0.20
16-18	419	44381	2.17
18-20	3147	347119	16.97
20-22	7663	701358	34.28
22-24	5788	584494	28.57
24-26	2104	252674	12.35
26-28	842	80828	3.95
28-30	287	23511	1.15
30-32	160	6128	0.30
32-34	67	1390	0.07
34 & above	26	106	0.01
Total	**20,509**	**2,046,077**	**100**

The length composition of Tilapia in the catch did not appreciably change since the last 15 years. For instance, according to LFDP (1997) report, Tilapia measuring in TL between 18 to 28 cm composed about 97% of the catch and those between 20 to 26 cm TL accounted for 88% of the catch. Similarly 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, unpublished data). 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, focus group discussion with fishermen of the lake indicated that some two to three decades ago, Tilapia measuring up to 35 to 40 cm TL were very common in the fishermen catch and the average catch size of Tilapia was 25 to 30 cm TL. This was the time when the fishing pressure was quite low.

According to Yosef (2002), the length at first maturity of Tilapia in Lake Hawassa was about 20 cm TL. In the present result, fish below 20 cm composed about 20% or more of the total catch (Tables 3 and 4). This indicates that considerable portion of the fishermen's catch composed immature Tilapia that have not yet reproduced at least once in their lifespan. Thus, it seems reasonable to slightly increase the width of the mesh of nets used by fishermen. To be fair, nets below 8 cm mesh width should be totally prohibited from being used by fishermen.

The total annual catch of Tilapia during the sampled year prior to reduction of the fishing pressure was estimated to be 2,658,906 fish (Table 3) and this is fairly comparable to the total annual catch even after reducing the fishing pressure by almost three times, i.e., 2,046,077 Tilapia/year (Table 4). This indicated that the fishing pressure prior to reduction of the effort was excessive and that the catch per net was nil.

3.2. Estimates of population number and fishing mortality coefficient by length group of Tilapia in Lake Hawassa

Tables 5 and 6 below give estimates of population number and fishing mortality coefficient by length group of Tilapia that composed the fishery for the periods before and after reduction of the fishing pressure, respectively. The estimates were made using Jones length-based cohort analysis model (Jones, 1984). In both tables, the second column is the total number of fish caught per year in each length group and it is estimated based on catch statistics records as explained earlier. Estimates of population numbers ($N(L_1)$) and Fishing mortality coeffecients ($F(L_1, L_2)$) shown by columns 3 and 4, respectively are direct outputs of the Jones length-based cohort analysis computed using equations 2 and 4, respectively.

Table 5. Estimates of total annual catch, population number and fishing mortalities by length group estimated based on data collected before reduction of fishing effort (between December 27, 2003 and April 08, 2004). Values are calculated using Jones length-based cohort analysis.

Length group (cm) L_1 , L_2	**Total annual catch (number) $C(L_1, L_2)$**	**Population number $N(L_1)$**	**Fishing mortality (yr^{-1}) $F(L_1, L_2)$**
14-16	67317	4762201	0.04
16-18	124992	4139006	0.08
18-20	519703	3485304	0.39
20-22	928990	2501519	1.01
22-24	688096	1249861	1.54
24-26	250673	405185	1.60
26-28	63783	99836	1.42
28-30	13716	20352	1.28
30-32	1511	2879	0.61
32-34	59	500	0.06
34 & above	65	100	0.65
Total	**2,658,906**	**16,666,742**	

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During the period prior to reduction of the fishing pressure, a population of over 16.6 million Tilapia 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 3 (Table 5). This estimate for the period after reduction of the fishing pressure was over 14.6 million as shown by column 3 of Table 6. Both of these estimates were fairly comparable. Also both estimates pertain to the population of the whole area of the lake where the fishery was active. As explained above, the sampled fishery, which was run by the fishermen cooperatives operated in the whole area of lake. According to Yosef (unpublished data), the total population number of Tilapia that composed the fishery estimated in 2002 was some 20 million fish, which was not too far from the estimates obtained in the present study. Similarly, Sintayehu Adissu (2012) estimated the population of Tilapia as 7 million fish. Since his study was based on data collected from one-third part of the lake, tripling this figure gives an estimate close to the present study.

Length group(cm) L_1 , L_2	**Total annual catch (number) $C(L_1, L_2)$**	**Population number $N(L_1)$**	**Fishing mortality (yr^{-1}) $F(L_1, L_2)$**
14-16	4087	3955453	0.003
16-18	44381	3486474	0.03
18-20	347119	2992570	0.30
20-22	701358	2239043	0.81
22-24	584494	1235744	1.22
24-26	252674	483808	1.21
26-28	80828	158089	0.97
28-30	23511	48198	0.72
30-32	6128	13291	0.50
32-34	1390	2839	0.38
34 & above	106	163	0.65
Total	**2,046,077**	**14,615,670**	

Table 6. Estimates of total annual catch, population number and fishing mortalities by length group estimated based on data collected after reduction of fishing effort (between April 10, 2004 and May 24, 2005). Values are calculated using Jones length-based cohort analysis.

As shown in column 4 of Table 5, the length groups 20 to 30 cm fish shouldered heavy fishing mortality rate bearing a mortality of above 1.0 per year. Similarly, after reduction of the fishing pressure, the same length group accounted to most of the catch (column 4 of Table 6).

As estimated by the model, over 4.7 million Tilapia measuring 14 to 16 cm were recruited to the fishery every year prior to reduction of the fishing pressure (Table 5). Based on data collected after reduction of the fishing pressure, the estimated number of Tilapia recruited to the fishery attaining a length of 14 to 16 cm was close to 4 million fish (Table 6). Accordingly both estimates were fairly comparable. Based on data collected in 2002, Yosef (unpublished report) estimated that an average number of about 5 million Tilapia recruits annually to the fishery in the whole lake attaining a length of 15 to 16 cm. Also, according to Reyintijens and Tesfaye Wudineh (1998), an average number of about 5.6 million Tilapia 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 with the previous estimates.

3.3. Fish yield under current level of effort

Tables 7 and 8 below give estimates of total annual yield of Tilapia (tons). Values in columns 2 are the annual catch of the respective length group of fish displayed in previous tables and they are shown here to illustrate the intermediary calculation steps. The mean weight of fish (kg) shown by column 3 are the average weights of each length group of Tilapia estimated using the length-weight relationship expressed by the following equation:

$$Wt\ (gm) = 0.0184 * L^{3.0197}$$

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% valid as the measured weight of each length group.

The current total yield per year pertaining to the respective length group (column 4 in both tables) was 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 Tilapia during the sampled year prior to reduction of the fishing efforts was 526.8 tons/year (Table 7). Similarly, the estimated annual yield after reduction of the fishing pressure was 441.6 ton/year (Table 8). There is a yield difference of about 85 tons/year between the two periods but given that there was fishing pressure differences, the observed yield difference is insignificant.

Reyintijens and Tesfaye Wudineh (1998) estimated a total annual yield of 520 tons of Tilapia/year as harvested by the fishermen cooperatives of Lake Hawassa. The estimate in 2002 was about 540 tons/year (Yosef, unpublished data) and the estimate in 2012 for one-third of the lake was about 192 tons/year (Sintayehu Adissu, 2012), which when tripled becomes comparable to the current yield estimate.

Table 7. Estimates of annual catch and total yield of Tilapia obtained from each length group under the level of fishing effort expanded prior to reduction of the fishing pressure on Lake Hawassa.

Length group (cm)	Current annual catch (number)	Mean weight (kg)	Current yield (tons/year)
14-16	67317	0.07	4.41
16-18	124992	0.10	11.95
18-20	519703	0.13	69.51
20-22	928990	0.18	168.09
22-24	688096	0.24	163.86
24-26	250673	0.31	76.79
26-28	63783	0.39	24.65
28-30	13716	0.48	6.58
30-32	1511	0.59	0.89
32-34	59	0.71	0.04
34 & above	65	0.85	0.05
Total	**2,658,906**		**526.8 ton/yr**

Table 8. Estimates of annual catch and total yield of Tilapia obtained from each length group under the level of fishing effort expanded after reduction of the fishing pressure on Lake Hawassa.

Length group (cm)	**Current annual catch (number)**	**Mean weight (kg)**	**Current yield (tons/year)**
14-16	4087	0.07	0.27
16-18	44381	0.10	4.24
18-20	347119	0.13	46.42
20-22	701358	0.18	126.90
22-24	584494	0.24	139.19
24-26	252674	0.31	77.40
26-28	80828	0.39	31.24
28-30	23511	0.48	11.27
30-32	6128	0.59	3.59
32-34	1390	0.71	0.99
34 & above	106	0.85	0.09
Total	**2,046,077**		**441.6 ton/yr**

3.4. Predicting yield obtained from the fishery

Tables 9 and 10 show summary of predicted yield using values of F-factors ranging from 0 to 2. Predictions were made based on the length-based Thompson and Bell model following the procedures depicted under sub section 2.5.2. The reference F-array is shown in column 4 of Tables 5 and 6. It has been multiplied by each value of F-factor shown in column 1 of Tables 9 and 10 to produce the new fishing mortality coefficient for each length group. Then values of yield were predicted using the new F-array. In due regard, column 2 (Tables 9 and 10) show expected value of total yield for each of the F-factors. Note that the total yield values corresponding to the F-factor 1 in Tables 9 and 10 are same as in Tables 7 and 8, respectively, because no change has been done to the reference F-array.

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Table 9.Total annual yield (ton/year) obtained from Tilapia stock (*O. niloticus*) of Lake Hawassa predicted using values of F-factor ranging from 0 to 2. Predictions were made using catch record data collected prior to the reduction of fishing effort when the fishery was expanding an average of 1954 gill nets/day.

F-factor	Predicted total annual yield (tons)
0.1	251.9
0.2	391.3
0.3	457.3
0.4	497.1
0.5	514.5
0.6	524.6
0.7	528.4
0.8	528.2
0.9	528.0
1.0	526.8
1.1	524.9
1.2	522.3
1.3	519.8
1.4	517.3
1.5	514.9
1.6	512.4
1.7	510.1
1.8	507.8
1.9	505.6
2	503.4

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

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Table 10. Estimated total annual yield (ton/year) obtained from Tilapia stock (*O. niloticus*) of Lake Hawassa predicted using values of F-factor ranging from 0 to 2. Predictions were made using catch record data collected after the reduction of fishing effort when the fishery was expanding an average of 696 gill nets/ day.

F-factor	**Predicted total annual yield (tons)**
0.1	178.2
0.2	282.8
0.3	345.8
0.4	384.4
0.5	408.2
0.6	422.9
0.7	431.9
0.8	437.2
0.9	440.2
1.0	441.6
1.1	441.9
1.2	442.1
1.3	441.2
1.4	440.3
1.5	439.3
1.6	438.1
1.7	436.9
1.8	435.6
1.9	434.4
2	433.1

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

Based on data collected before reduction of the fishing efforts, the predicted value of maximum sustainable yield of the Tilapia stock is 528.4 tons/year and this is obtained at an F-factor of 0.7 (Table 9). This implies that the level of fishing effort should be reduced by a factor of 0.7 to achieve the maximum sustainable yield. More importantly, Pauly (1984) and Sparre and Venema (1992) recommend that the optimum sustainable yield should be fixed at a value 20% less than the fishing pressure that gives the maximum sustainable yield. Accordingly, the biologically optimum level of fishing effort to be expanded on the Tilapia stock of Lake Hawassa should be half the level of fishing effort expanded before reducing the fishing pressure i.e., the fishing effort 1954 nets/day should be reduced by half in order to sustainably exploit the stock. In other words, the recommended level of fishing effort to be expanded on the Tilapia stock should not exceed 977 nets/day.

Similarly, the analysis done on data collected after reduction of the fishing effort indicated that the predicted maximum sustainable yield of Tilapia is 442.1 tons/year and this is obtained at an F-factor of 1.2 (Table 10). 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.

In general, the analysis done on data collected before and after reduction of the fishing pressure although do not perfectly match, they somehow corroborate each other. The estimated optimum effort level in the present study for the Tilapia stock of Lake Hawassa is similar to the recommended level of fishing estimated by Reyintijens and Tesfaye Wudineh (1998) as 700 nets per day. Similarly, Yosef (unpublished data), based on data collected in 2002 recommended a fishing effort of less than 1000 nets for the Tilapia stock of Lake Hawassa.

4. Conclusion and Recommendation

In order to manage the Tilapia fishery of Lake Hawassa sustainably, the fishing pressure exerted prior to reduction of the fishing effort should be reduced by at least half whereas the fishing pressure expanded after reduction of the fishing pressure can be maintained as it is. Thus to be on the safe side, the effort level to be exerted on the stock should not exceed 800 nets/day. Although not excessively alarming, still some 20% of the Tilapia exploited are below the length of first maturity. Therefore, it is mandatory to keep the legal mesh width above 8 mm stretched mesh. Presently, the lake is fished by two different groups of fishermen one operating at the northern part and the other one operating at the southern part. Thus, stock assessment work should be continually done on both parts of the fishery and recommendations should be given regarding safe level of exploitation for both groups of fishermen independently.

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