Assessment of Maximum Sustainable Yield and Optimum Fishing Effort for the Nile Tilapia (*Oreochromis niloticus L.*) in Lake Chamo, Ethiopia

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Abstract: *The study was conducted to estimate the maximum sustainable yield (MSY) and optimum level of fishing effort for Nile tilapia (Oreochromis niloticus) stock in Lake Chamo, Ethiopia. Data were collected from eight major landing sites of Lake Chamo for three days in a week for ten months (February to November, 2018). The total length, sample weight and total weight of O. niloticus caught by the fishermen and the fishing effort were the basic information collected from these sites. Totally, 7,570 O. niloticus samples were collected in 120 days. The FiSAT software was used to determine von Bertalanffy growth and mortality parameters. Jones length based cohort analysis model and length-based Thompson and Bell yield prediction models were employed to estimate the maximum sustainable yield. The estimated growth parameters; asymptotic length that the fish attains at an older age(L∞) and growth constant(k)of O. niloticus were 55 cm and 0.37 yr^{-1}, respectively. Overall about 11 million O. niloticus populations were estimated to exist in the lake. The estimated current annual yield was 290.1 tons per year for O. niloticus fisheries of the lake. However, the predicted value of MSY was 313 tons per year obtained at f_{MSY} of 136,249 nets. The length at first maturity (L_{50}) was 39.6 and out of the total annual catch 93.1% were below their respective size of maturity. Thus, the current yield reduction might be due to growth overfishing with reduced mesh sizes. As reported in the earlier studies and according to the finding of this investigation, the catch and yield of Lake Chamo is in the state of reduction through year. Unless the lake is properly managed, the future yields of Lake Chamo will be declining that may lead the resources depletion. Co-management practices, using the recommended mesh size and level of effort (number of nets) should be considered for the sustainability of the resources.*

Keywords: *Fish stock assessment, fish yield prediction model, Jones length based cohort analysis model*

1. Introduction

Fish stock assessment may be described as the search for the exploitation level, which in the long run gives the maximum sustainable bio-economic yield from fishery (MacLean and Evans, 1981). Ethiopia has a remarkable diversity of lakes which differs considerably in size, shape, depth, permanency in stratification and biotic diversity (Yilma and Geheb, 2003; FAO, 2003).

The Ethiopian Rift Valley Lakes belong to a group of lakes formed by the East African Rift, running from north to south on the eastern side of the African continent. Most lakes are highly productive and well known for their aquatic diversity and indigenous populations of edible fish species (Tudorancea and Taylor, 2002; Ayenew and Legesse, 2007). Lake Chamo is one of the Rift Valley Lakes in Ethiopia and due to the combined effect of an increasing number of fishing nets and vessels; there has been a steady decline of fish landings in Lake Chamo (Ward and Wakayo, 2013).

O. niloticus is one of the edible fish species in Lake Chamo and are economically important as well as highly acceptable by the consumers in Ethiopia particularly in Rift Valley areas where fish production is very high. Nowadays, *O. nilotcus* is the most target fish species of Lake Chamo fisheries due to high demand in the market. The sustainable exploitation level was not determined for this important fish species. The aim of this study was searching for the optimum level of exploitation for *O. niloticus* stocks of Lake Chamo. The finding of this study would serve as an essential input for decision-makers in recommending proper fish resource utilization and management measures considering the potential of the lake in order to maximize the long-term benefits for fishermen and other societies.

2. Materials and Methods

2.1. Description of the study area

Lake Chamo is geographically located at 5°42'– 5°58' N Latitude and 37°27'– 37°38' E Longitude and it is one of Ethiopian Rift Valley lakes with an area of 551 km^2 and a maximum depth of 16 m (Belay and Wood, 1982). The lake is located at an altitude of 1108 m and about 515 km south of the capital city Addis Ababa (Dadebo *et al.*, 2005). Lake Chamo is part of the Ethiopian Rift Valley Lakes Basin (ERVLB) in the Abaya–Chamo Drainage Sub-basin (ACB). The ERVLB comprises eight natural lakes and their tributaries. The ACB comprises Lake Chamo and Lake Abaya, and rivers and streams entering the lakes. The two lakes are connected via surface hydrology. Outflow from Lake Abaya enters Lake Chamo through River Kulfo, and an overflow from Lake Chamo through Metenafesha joins Sermale stream and subsequently the Segen River (Bekele, 2006).

The fishery on Lake Chamo is almost exclusively conducted with a surface gillnet, although long–lines are also used to some extent to African catfish (*Clarias gariepinus)* and *Bagrus docmak.* The nets are prepared locally by fishers themselves or by some other people involved in fishing gear making activity. Gillnets are the most important fishing gears and are typically set in the afternoon and hauled early in the morning. They are removed only to change the fishing ground or when maintenance is necessary. *Lates niloticus* is used to be the major target species. However, because of low catch rates, the fishing effort has been shifted to *O. niloticus* which may result to reduction of the stock of this fish species.

2.2. Methods of sampling and data collection

In Lake Chamo, there were five legal fishers' co-operatives who are landing their fish catches on 31 major landing sites. Of these, eight major landing sites (Bole, Ashewa, Gentafora, Bedena 1, Chika, Mehal, Wedeb and Girawa) were selected and used as sampling sites. The estimated total annual catch from 31 landing sites were obtained by multiplying the annual estimated catch from 8 landing sites by the fraction of **(**total estimated nets from 31 landing sites**)/(**total estimated nets from 8 sample landing**)** sites with the catch of respective length groups.

Sixteen data collectors (two from each landing sites) were trained to collect data from the commercial fish catches. The catch data were collected for ten months (February to November 2018). Data were collected from randomly selected boats in randomly selected 3 days in a week. During each day of sampling, the total lengths (TL) of randomly selected samples of *O. niloticus* was measured to the nearest 1mm by using a measuring board, sample weights and total weights of fish from each boat was measured to the nearest 1g and 100g, respectively by using electronic and hanging scale balances. Also sample nets and total number of nets deployed into the lake per day were recorded.

2.3 Data summarization and analysis

The catch statistics data was summarized in a manner useful for Jones length-based cohort analysis and length-based Thompson and Bell yield prediction model. The summarization and analysis were done by using Microsoft Office Excel (2010) software.

2.3.1. Estimating growth parameters

Asymptotic length (L∞) and growth rate (K) were computed by FAO-ICLARM Stock Assessment Tools (FISAT-II) software. These two growth parameters are important for mortality estimation and the third parameter (t_o) refer to theoretical age at length zero. An estimate of t_o be calculated using Pauly (1979) empirical equation:

$$\text{Log}(-t_o) = -0.3922 - 0.275*\log L\infty - 1.038*\log K \quad [1]$$

Where

t_o is the theoretical age at which fish would have at zero length.

2.3.2. Arrangement of length composition data

The length composition of catch data were summarized as a table of the average total annual catch distributed by length groups. This was done as follows:

- Length measurements recorded were grouped into 2 cm length intervals to prepare a table of the length frequency of *O. niloticus* sampled during the sampling occasions.
- Estimating the total number of fish caught during the un-sampled days of the year was done by multiplying the average catch per day of the sampled 120 days of catch by the number of un-sampled days during the year.

Estimating the annual total length composition of fish landed

This was done by raising the length frequency of the sampled 120 days of catch by an appropriate raising factor which is equal to C/c, in which 'C'- the estimated total catch of fish during the whole twelve months and 'c'- the total catch of fish during the 120 days of sampling.

2.3.3 Estimating mortality parameters based on length composition data

For the estimation of total mortality rates, linearized length converted catch curve method was applied. Required input data was length structured catch data randomly sampled from the commercial fishery and the relative age of the fish that corresponds to the mid-length of the size groups, which was calculated by the following formula:

$$\Delta t = 1/k * Ln\ [(L\infty - L_1) / [(L\infty - L_2)] \quad [2]$$

$$t\ (L_1+L_2)/2 = -1/k\ \{Ln\ [(1-(L_1+L_2)/2/(L\infty)] \quad [3]$$

$$Ln\ \{[C\ (L_1, L2)]/[\Delta t\ (L_1, L2)]\} = a - Z * t\ (L_1+L_2)/2 \quad [4]$$

Where

Δt = is age interval between L_1 and L_2 or the time taken by L_1 to reach L_2

$t\ (L_1+L_2)/2$ = age of the average consecutive length groups (X variable)

$Ln\ \{[C\ (L_1, L2)]/[\Delta t\ (L_1, L2)]\}$ = Y variable

To obtain total mortality, regression analysis was conducted between X and Y variables.

Total mortality (Z) = fishing mortality (F) + natural mortality (M) [5]

The natural mortality coefficient (M) was estimated using Paul's (1980) empirical formula as follows:

$$Ln\ (M) = -0.00152 - 0.279 * ln\ (L\infty) + 0.6543 * ln\ (k) + 0.463 * ln\ (T) \quad [6]$$

Where

M = is natural mortality coefficient

L∞ = asymptotic length

K = growth constant

T = mean annual surface water temperature of the lake

Then, the fishing mortality rate (F) was calculated by subtracting *M* from *Z*.

2.3.4. Estimating population sizes and fishing mortalities by length group (Jones, 1984)

Jones length-based cohort analysis model was used to estimate the population size and fishing mortality coefficient of *O. niloticus* by length groups. This was done in three steps as follows:

1. Estimating the population number of the largest length group in the catch. This was done as follows:

N (largest L) = C (Largest L)*(Z Largest L/F Largest L) [7]

Where

N (largest L) = the population of the largest length group in the catch

C (largest L) = the catch of the largest length group

Z (largest L) = the total mortality rate of the largest length group in the catch

F (largest L) = the fishing mortality rate of the largest length group in the catch

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

This was done using the equation as follows:

$$N\ (L_1) = [N\ (L_2) * H\ (L_1, L2) + C\ (L_1, L2)] * H\ (L_1, L2) \quad [8]$$

Where

N (L1) = The population number of L1 (younger) fish

N (L2) = The population number of L2 (older) fish

H (L1, L2) = the fraction of N(L1) fish that survived natural death as it grows from length L1 to L2 and computed as the following equation (Jones, 1984).

$$H\ (L_1, L_2) = [(L\infty - L_1)/(L\infty - L_2)]^{(M/2K)} \quad [9]$$

Where

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

L1 and L2= 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 Chamo.

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

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

$$F(L_1, L_2) = (1/\Delta t) * \ln [N(L_1)/N(L_2)] - M \quad [10]$$

Where
F (L1, L2) = Fishing mortality coefficient pertaining to the respective length group
N (L1), N (L2) and M are as defined above.

To know the status of the stock, the exploitation rate (E) was estimated from mortality parameters as: E = F/Z. The exploitation rate (E) equal to 0.5 is considered as optimum level of exploitation; whereas less than 0.5 refers to under exploitation and greater than 0.5 refers to overexploitation (Gulland, 1971).

2.3.5. Predicting maximum sustainable yield and optimum fishing efforts

Input data and parameters required were:

- Total number of fish caught per year structured by length groups
- Estimates of population number and fishing mortality coefficient (F) by length group (obtained from Jones length based cohort analysis)
- Values of the von Bertalanffy growth parameters (L∞ and K) and natural mortality coefficient (M)
- Mean weight of fish for each length group obtained as described above for cohort analysis

Thompson and Bell (1934) yield prediction procedure

Step 1: Estimating the total annual yield obtained under the current level of fishing

1. Estimating the yield obtained per year from each length group

Yield from each length group obtained per year Y (L_1, L2) - was catch in number per length group per year C (L_1, L2) multiplied by the average weight of each length group i.e.

$$Y(L_1, L_2) = C(L_1, L_2) * W(L_1, L_2) \quad 11]$$

Where
Y (L1, L2) = the yield (weight) of fish obtained per year from respective length group
C (L1, L2) = total annual catch of fish obtained from respective length group
W (L1, L2) = the mean weight of each length group estimated using equation

$$W(g) = a * L^b \quad [12]$$

Where
W (g) is the average weight of each length group, L = the average length (cm) of each length group i.e., L = (L1+L2)/2 in which L1 and L2 are the length intervals of consecutive length groups. ‘a’ and ‘b’ are values of the regression coefficients.

2. Estimating yield obtained from all length groups per year

The total estimated yield was obtained by adding up the contribution of each length group from the stock per year.

Step 2: Predicting yield obtained under different levels of fishing pressure

If the fishing pressure exerted on the stock changes, obviously the yield also changes (increases or decreases). Hence the yield obtained under different levels of fishing pressure was predicted by changing the current level of fishing pressure by a certain factor. In due regard the fishing level that gives the maximum yield is assumed to be optimum fishing level and is recommend to the management for sustainable fishing.

Step 3: Yield prediction under doubling of the fishing effort

Doubling the fishing effort also doubles the fishing mortality rate. Fishing mortality and fishing effort are related as follows:

$$F = q*f \quad [13]$$

Where
F = Fishing mortality,
Q = Catch-ability coefficient
f = Fishing effort

Procedures of predicting yield under the doubled F:

1. Calculating the changed fishing mortality

The new fishing mortality value under the changed F was calculated by multiplying the current F by the raising factor (X).

F (New) = F (current)* X [14]

Where

F (new) = the changed F

2. Calculating the changed total mortality rate under the changed F

Z (new) = F (new) +M [15]

Where

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

3. Predicting the population number of fish under the changed 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).

$$\mathbf{N (L_2) = N (L_1) * e^{-Z (new)*\Delta t (L_1, L2)}} \quad [16]$$

Where,

N (L_1) is the population number of length L_1 fish

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 2. Z (new) is the total mortality under the changed level of fishing and it is equal to the sum of the changed fishing mortality as defined above by equation 15.

4. 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).

$$C (L_1, L_2) = F (L_1, L2)/Z (L_1, L2) * D (L_1, L2) \quad [17]$$

Where

F (L_1, L_2) and Z (L_1, L_2) 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 11. 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 and Discussions

3.1 Status of Lake Chamo *O. niloticus* fishery

Overall, there were five fishers' co-operatives and 300 registered co-operative members of fishers operating in the lake during the time of sampling (Table 1). The fishing nets of Lake Chamo fishers are constructed and set differently considering the size of the target fish. These fishers own 60 boats and on average 207 nets which, were set daily in the lake. Each fisher on average owns 0.69 nets and about 3.45 nets were set per boat daily for the fishery. Overall, the total annual estimated nets were 75,555 during the year of investigation (365 days). The fishing activity takes place throughout the year and with this level of fishing effort, an estimated total number of 538,265 *O. niloticus* were caught during the year that weighed about 290.1 tons. The estimated average catch per net per day was 7 fish and it weighed about 3.84 kg/net/day.

Table 1: Catch statistics of *O. niloticus* fishery of Lake Chamo in 2018

Operation measurements	Value
Total number of fishers in operation	300
Average number of boats operated per day	60
Average nets set per day	207
Total number of nets set per year	75,555
Total number of fish caught per year	538,265
Total weight of catch (kg) per year	290,127
Catch per net (no./net/day)	7
Weight of catch per net (kg/net/day)	3.84

3.2 The length composition of sampled catch and estimated annual catch of *O. niloticus*

Totally 7,570 samples of *O. niloticus* were measured during the study period and the measured TL composition ranges from 15.0 cm to 53.4 cm with an average of 34.2 cm that composed the catch of the fishers during the time of sampling (Table 2). The maturity length (L_{50}) of *O. niloticus* was 39.6 cm as reported by Teferi (1997). The (L_{50}) here is too old but used due to the absence of recent study on the maturity length in Lake Chamo.

From the total of 7,570 *O. niloticus* measured, only 6.9% were above the L_{50} and 93.1% were below it, indicating that 93.1% of the caught fish were immature. As observed during the data collection, the main cause for catch of immature fish were the reduction of mesh sizes (11 cm) which was narrower than the recommended minimum mesh size of 18 cm (LFDP, 1997). Thus, a large numbers of *O. niloticus* were being removed before they grow and replace their populations. Out of the total estimated annual catch, over 95% of *O. niloticus* catch ranged in length between 19 to 41 cm and more importantly, the length groups' 25 to 37 cm total length composed about 63% of the total catch (Table 2).

Table 2: Sample catch and estimated total annual catch of *O. niloticus* by length group in 2018

Length group L1-L2	Total sample caught/120 days (number)	Estimated annual catch (number)	Proportion of length group composition from the total catch (%)
15-17	9	640	0.12
17-19	114	8106	1.51
19-21	569	40459	7.52
21-23	576	40956	7.6
23-25	586	41668	7.74
25-27	868	61719	11.46
27-29	872	62004	11.52
29-31	908	64563	11.99
31-33	713	50698	9.42
33-35	709	50413	9.37
35-37	668	47498	8.82
37-39	456	32424	6.01
39-41	271	19269	3.60
41-43	149	10595	1.96
43-45	63	4480	0.84
45-47	26	1849	0.34
47-49	8	569	0.1
49-51	3	213	0.04
51-53.4	2	142	0.03
Total	7,570	538,265	100

3.3 Growth and total mortality coefficient of O. niloticus

The estimated von Bertalanffy growth parameters for O. niloticus were $L\infty$ =55 cm, K=0.37 per year and t_o = -0.467 with the goodness of fit index (Rn) value of 0.203. The O. niloticus in Lake Chamo becomes liable to the fishing gears at the length of 15 cm and this length is the length at first recruitment (Tr) for O. niloticus of Lake Chamo (Tr = 15 cm) Table 3 (column 2, row 3). At a certain age (sayTr), the fish become liable to encounter the gears because they start migrating to the fishing grounds and this age is referred as the age of recruitment to the fishery (Sparre and Venema, 1992).

In Lake Chamo, O. niloticus started to be caught considerably at the length of 18 cm and 18 cm is the age at first capture (Tc).Because starting 18 cm in Lake Chamo are readily captured if they encounter the nets Table 3 (column 2, row 4). After the age of Tr, the vulnerability of the fish to the fishing net increases when they attain a certain age commonly referred as the age of first capture (Tc) (Schnute, 1987).

A length composition data prepared for a linear regression analysis was established between X and Y variables for total mortality estimation (Table 3).

Table 3: Length composition data of *O. niloticus* for length-based catch curve analysis in 2018

Length group	Catch			X	Y
L1-L2	C(L1,L2)	Δt (L1,L2)	(L1+L2)/2	t(L1+L2)/2	Ln(C(L1,L2)/Δt)
15-17	640	0.139	16	0.93	8.4
17-19	8106	0.146	18	1.07	10.9
19-21	40459	0.154	20	1.22	12.5
21-23	40956	0.164	22	1.38	12.4
23-25	41668	0.174	24	1.55	12.4
25-27	61719	0.186	26	1.73	12.7
27-29	62004	0.200	28	1.92	12.6
29-31	64563	0.216	30	2.13	12.6
31-33	50698	0.235	32	2.36	12.3
33-35	50413	0.258	34	2.60	12.2
35-37	47498	0.285	36	2.87	12.0
37-39	32424	0.318	38	3.17	11.5
39-41	19269	0.361	40	3.51	10.9
41-43	10595	0.417	42	3.90	10.1
43-45	4480	0.493	44	4.35	9.1
45-47	1849	0.603	46	4.89	8.0
47-49	569	0.778	48	5.57	6.6
49-51	213	1.096	50	6.48	5.3
51-53	142	1.873	52	7.86	4.3

Using the estimated von Bertalanffy growth parameters and the annual length-frequency data, the total catch curve was estimated by applying the length converted catch curve analysis (Figure 1).

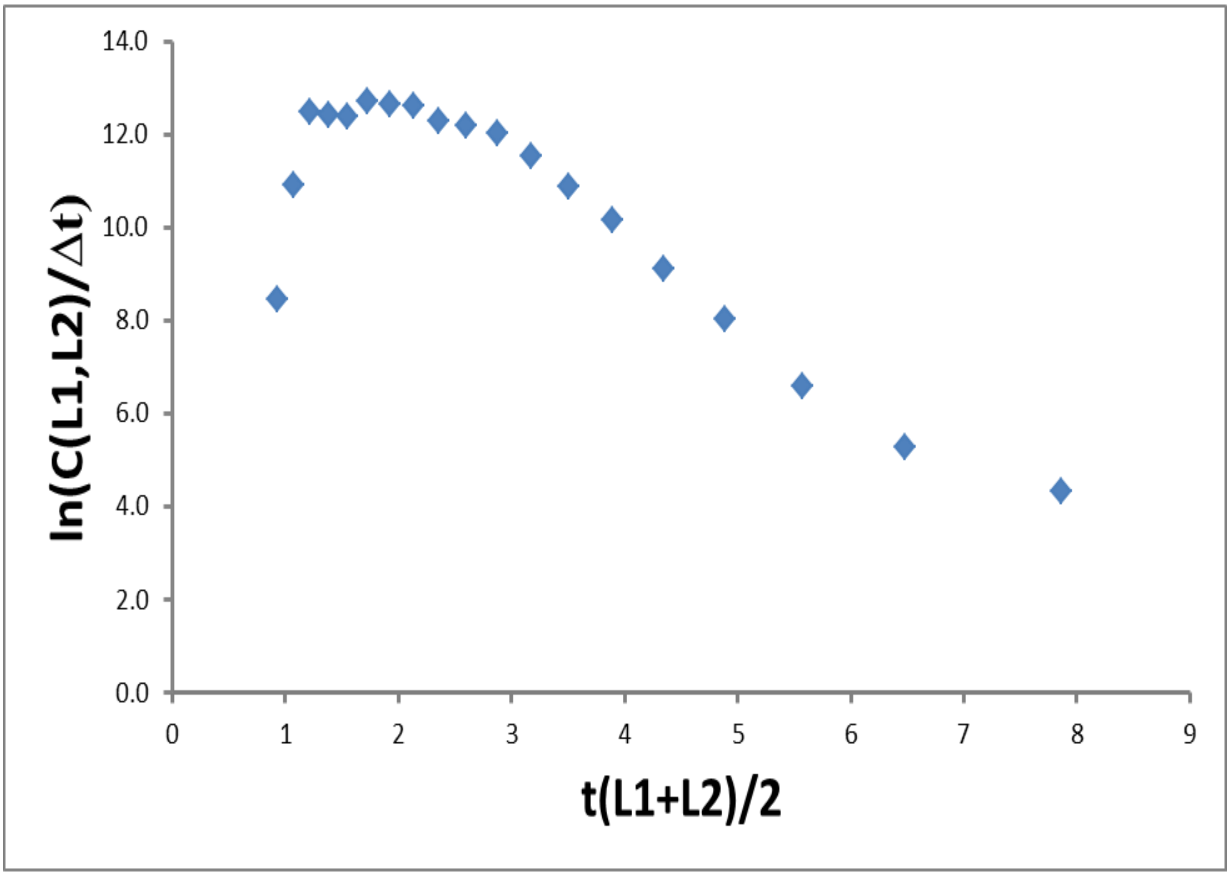

Figure 1: Length-based total catch curve of *O. niloticus* from Lake Chamo

For the total mortality (Z) estimation, the data points that did not fall on straight line were the data of the youngest age groups and were excluded as they had not yet attained the age of full exploitation (Figure 2). The slope of the regression line (b) was -1.5093 and hence, the total mortality rate (Z = 1.5093 yr^{-1}). Of the total mortality, natural mortality rate (M) and fishing mortality rate (F) was 0.79 yr^{-1} and 0.72 yr^{-1}, respectively. Using these mortality estimates, the exploitation rate (*E*) was (computed as 0.48) and indicates slightly under exploitation. The exploitation rate (*E*) equal to 0.5 is considered as an optimum level of exploitation; whereas less than 0.5 refers to under exploitation and greater than 0.5 refers to overexploitation (Gulland, 1971).

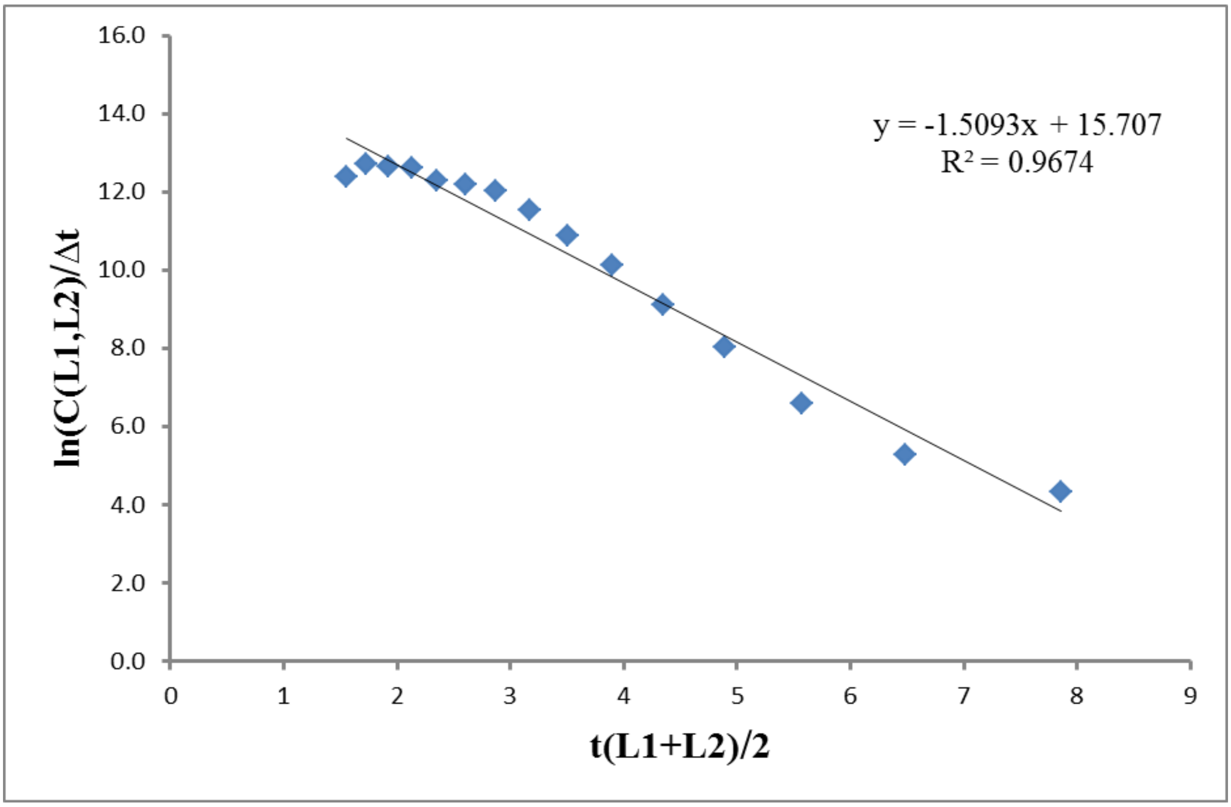

Figure 2: Linearized length-based catch curve of *O. niloticus* from Lake Chamo

3.4. Estimated population sizes and fishing mortalities

The estimated population number and fishing mortality coefficient by length group of *O. niloticus* are given in Table 4. The annual recruitment of *O. niloticus* in Lake Chamo was 1.92 million as indicated in Table 4 (column 9, row 3). Lake Chamo is known as the most productive lake in the country and its catch contribution is 29%, while Lake Hawassa contributes 7% (Tesfaye and Wollf, 2014). *O. niloticus* contributed on average more than 6600 tons annually for the country's fish supply, which is about 50% of the annual average catch for the period 1998-2010 (Tesfaye and Wollf, 2014).

According to Tekle-Giorgis *et al.* (2017), the annual recruitment of *O. niloticus* in Lake Hawassa is 3.95 million. This is about twice greater than the recruitment of *O. niloticus* in Lake Chamo, while the catch contribution of Lake Hawassa is very much less than Lake Chamo. This difference might be attributed to the difference in the fishing activities taking place on the lakes during the year and the number of nets as well as mesh size of the net that the fishers deployed in the two lakes.

Overall, about 11 million *O. niloticus* population were 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 given in Table 4 (column 9). This estimate belonged to the population of fish excluding the area of the lake protected for fish breeding. Even if it is said to be there is protected area for breeding, there was a problem of illegal fishing practices taking place in the area. As shown in Table 4 (column 9) the length groups' 29 to 47 cm fish shouldered heavy fishing mortality rate, bearing above 0.5 fishing mortality (F) per year. Although *O. niloticus* encountered the fishery ranging from 15 to 53.4 cm, most of the fishing pressure relied up on length groups starting from 27 cm to 49 cm.

Table 4: Estimated population, fishing mortalities and other parameters by length group *O. niloticus* in 2018

Length group	Catch				X	Y		
L1-L2	C (L1,L2)	F (L1,L2)	Δt (L1,L2)	(L1+L2) /2	T (L1+L2)/2	Ln(C(L1, L2) /Δt)	H(L1,L2)	N(L1)
15-17	640	0.003	0.139	16	0.93	8.4	1.06	1922271
17-19	8106	0.034	0.146	18	1.07	10.9	1.06	1723215
19-21	40459	0.185	0.154	20	1.22	12.5	1.06	1528583
21-23	40956	0.206	0.164	22	1.38	12.4	1.07	1315728
23-25	41668	0.233	0.174	24	1.55	12.4	1.07	1118336
25-27	61719	0.395	0.186	26	1.73	12.7	1.08	936150
27-29	62004	0.467	0.200	28	1.92	12.6	1.08	751168
29-31	64563	0.592	0.216	30	2.13	12.6	1.09	584441
31-33	50698	0.583	0.235	32	2.36	12.3	1.10	433753
33-35	50413	0.758	0.258	34	2.60	12.2	1.11	314329
35-37	47498	1.018	0.285	36	2.87	12.0	1.12	211156
37-39	32424	1.080	0.318	38	3.17	11.5	1.13	126342
39-41	19269	1.062	0.361	40	3.51	10.9	1.15	69763
41-43	10595	1.028	0.417	42	3.90	10.1	1.18	35812
43-45	4480	0.793	0.493	44	4.35	9.1	1.21	16817
45-47	1849	0.599	0.603	46	4.89	8.0	1.27	7726
47-49	569	0.337	0.778	48	5.57	6.6	1.36	3351
49-51	213	0.244	1.096	50	6.48	5.3	1.54	1399
51-53	142	0.36	1.873	52	7.86	4.3	2.09	453
Total (Million)								11

Note: The second column is the total number of fish caught per year in each length group estimated based on catch statistics record. Columns 3 and 4 are the time taken by (L1) to reach (L2) and mean length of fish respectively. Columns 5 and 6 are the established value of X and Y for regression analysis. Columns 7, 8 and 9 are natural mortality factors, estimated population numbers (N (L1)) and fishing mortality coefficients (F (L1, L2)), respectively.

3.5 Predicting maximum sustainable yield and optimum fishing efforts

3.5.1 Estimated total annual yield obtained under the current level of fishing

Table 5 below gives the estimated total annual yield of *O. niloticus*. Values in column 2 are the annual catch of the respective length group fish displayed in previous tables and they are shown here to illustrate the intermediary calculation steps. The current total yield (290.1 tons) pertaining to the respective length group (column 10) was obtained by multiplying the total catch of the respective length group by the corresponding mean weight values.

There was a drastic decline in the amount of catch over the period 1982-1991 (Dejene, 2008) and also the same situations were observed in this investigation. The drastic decline in catch level due to increased effort, even without a reduction in mesh size of nets, indicates the presence of recruitment overfishing (Cushing, 1982; Pauly, 1987; FAO, 1999; Israel and Banzon, 2000). According to Cushing (1982), recruitment overfishing causes a stock decline, which in turn results in the decline of catch.

However, in the current study, fishing effort was below effort of maximum sustainable yield (f_{MSY}), the decline in the catch is mainly related to growth overfishing with reduced mesh size. It is also important to consider that some natural mortality factors might be the reason as well as the mesh size reduction. Also, some other factors such as buffer zone agricultural practices, the application of monofilament nets and lack of political commitment for monitoring and evaluation could be some of the specific problems taken as a reason for the drastic decline in the amount of yield.

Table 5: Estimated total yield *O. niloticus* by length group under the current level of fishing of Lake Chamo in 2018

Length group	Catch				X	Y		Mean wt (kg)	Current Yield per year (kg)
L1-L2	C(L1,L2)	F(L1,L2)	Δt (L1,L2)	(L1+L2)/2	t(L1+L2)/2	Ln (C(L1,L2)/Δt)	N(L1)	W bar	Y(L1,L2)
15-17	640	0.003	0.139	16	0.93	8.4	1918330	0.072	46
17-19	8106	0.034	0.146	18	1.07	10.9	1719920	0.103	834
19-21	40459	0.185	0.154	20	1.22	12.5	1525869	0.142	5744
21-23	40956	0.206	0.164	22	1.38	12.4	1313530	0.190	7780
23-25	41668	0.234	0.174	24	1.55	12.4	1116589	0.248	10326
25-27	61719	0.395	0.186	26	1.73	12.7	934794	0.317	19535
27-29	62004	0.468	0.200	28	1.92	12.6	750142	0.397	24613
29-31	64563	0.593	0.216	30	2.13	12.6	583686	0.490	31645
31-33	50698	0.584	0.235	32	2.36	12.3	433217	0.597	30267
33-35	50413	0.759	0.258	34	2.60	12.2	313963	0.719	36223
35-37	47498	1.019	0.285	36	2.87	12.0	210917	0.856	40643
37-39	32424	1.081	0.318	38	3.17	11.5	126193	1.009	32729
39-41	19269	1.063	0.361	40	3.51	10.9	69674	1.181	22752
41-43	10595	1.030	0.417	42	3.90	10.1	35760	1.371	14521
43-45	4480	0.794	0.493	44	4.35	9.1	16789	1.580	7078
45-47	1849	0.600	0.603	46	4.89	8.0	7711	1.810	3346
47-49	569	0.338	0.778	48	5.57	6.6	3344	2.061	1173
49-51	213	0.244	1.096	50	6.48	5.3	1397	2.335	498
51-53	142	0.36	1.873	52	7.86	4.3	452	2.633	374
Total							11 million		290.1 (t/yr)

3.5.2 Predicted yield obtained under different levels of fishing pressure

The current fishing mortality rates of the respective length groups were considered as reference fishing mortalities and they were raised and lowered by certain factors (F-factors) to predict yield at the changed level of fishing mortalities. Table 6 shows results of predictions made under different fishing effort expanded on the *O. niloticus* stock of Lake Chamo. Thus, the new F-values are shown in Table 6 (column 3) are 1.8 times the value of the current fishing mortalities. The new F value here is the F-factor (1.8) at which the maximum sustainable yield (MSY) was obtained with its corresponding f_{MSY}. The rest of the columns had predicted values under the changed fishing mortality levels. The MSY for *O. niloticus* is 313 tons and its corresponding f_{MSY} is 136,249 nets (Figure 3). The current yield (290.1 tons) is below the MSY (313 tons) by 7.35%. The current effort (75,555 nets) is less than the f_{MSY}(136,249 nets), suggesting that the current level of effort need to be increased to f_{MSY} or it is possible to increase the current yield to the MSY by using the recommended mesh size and harvesting matured fish.

The maximum reported yield of Lake Chamo was 4,000 tons and the catch contribution of *O. niloticus* was 94% for the period of 1982-1991 (Dejene, 2008). *Oreochromis niloticus* catches have apparently declined from the recorded history of 60–80% contribution before 1998 to only about 50% in the period between 1998 and 2010, possibly due to the high fishing pressure on tilapia in some lakes (Tesfaye and Wolff, 2014). Although the *O. niloticus* production of Lake Chamo is highly reduced, the current the exploitation rate (*E*) was (computed as 0.48) which indicates the availability of a slight room to expand exploitation. Out of the total annual catch of *O. niloticus*, 93.1% were immature and thus, the reduction of yield is due to experiencing growth overfishing as well as some natural and anthropogenic factors under taking around the lake.

To avoid unexpected overfishing the target production of 2/3 f_{MSY} is always recommended and it allows a large fraction of the MSY to be harvested (80%) but reduces very much the risk of accidental over-exploitation and stock collapse (Doubleday, 1976).

Table 6: The length-based Thompson and Bell model output obtained under 1.8*current fishing pressure *O. niloticus* stock in Lake Chamo during 2018

Length group	Mean wt (kg)				Changed death	Expected catch	Expected yield
L1-L2	W bar	changed F	changed Z	changed N	D(L1,L2)	C(L1,L2)	yield (kg/yr)
15-17	0.072	0.005	0.79	1918330	198895	1152	83
17-19	0.103	0.062	0.85	1719435	200091	14567	1499
19-21	0.142	0.333	1.12	1519344	240993	71777	10190
21-23	0.190	0.372	1.16	1278352	220671	70886	13466
23-25	0.248	0.421	1.21	1057681	200627	70019	17353
25-27	0.317	0.711	1.50	857054	208667	99196	31397
27-29	0.397	0.842	1.63	648387	180300	93297	37036
29-31	0.490	1.068	1.85	468087	154560	89068	43656
31-33	0.597	1.051	1.84	313526	109952	62950	37582
33-35	0.719	1.367	2.15	203575	86624	55022	39535
35-37	0.856	1.834	2.62	116950	61472	43046	36833
37-39	1.009	1.946	2.73	55478	32218	22956	23172
39-41	1.181	1.914	2.70	23260	14477	10266	12121
41-43	1.371	1.854	2.64	8783	5858	4115	5640
43-45	1.580	1.429	2.21	2925	1943	1254	1981
45-47	1.810	1.081	1.87	983	664	384	696
47-49	2.061	0.608	1.39	319	211	92	190
4951	2.335	0.439	1.22	108	80	29	67
51-53	2.633	0.648	1.43	28	28	13	34
Total (t/year)							313

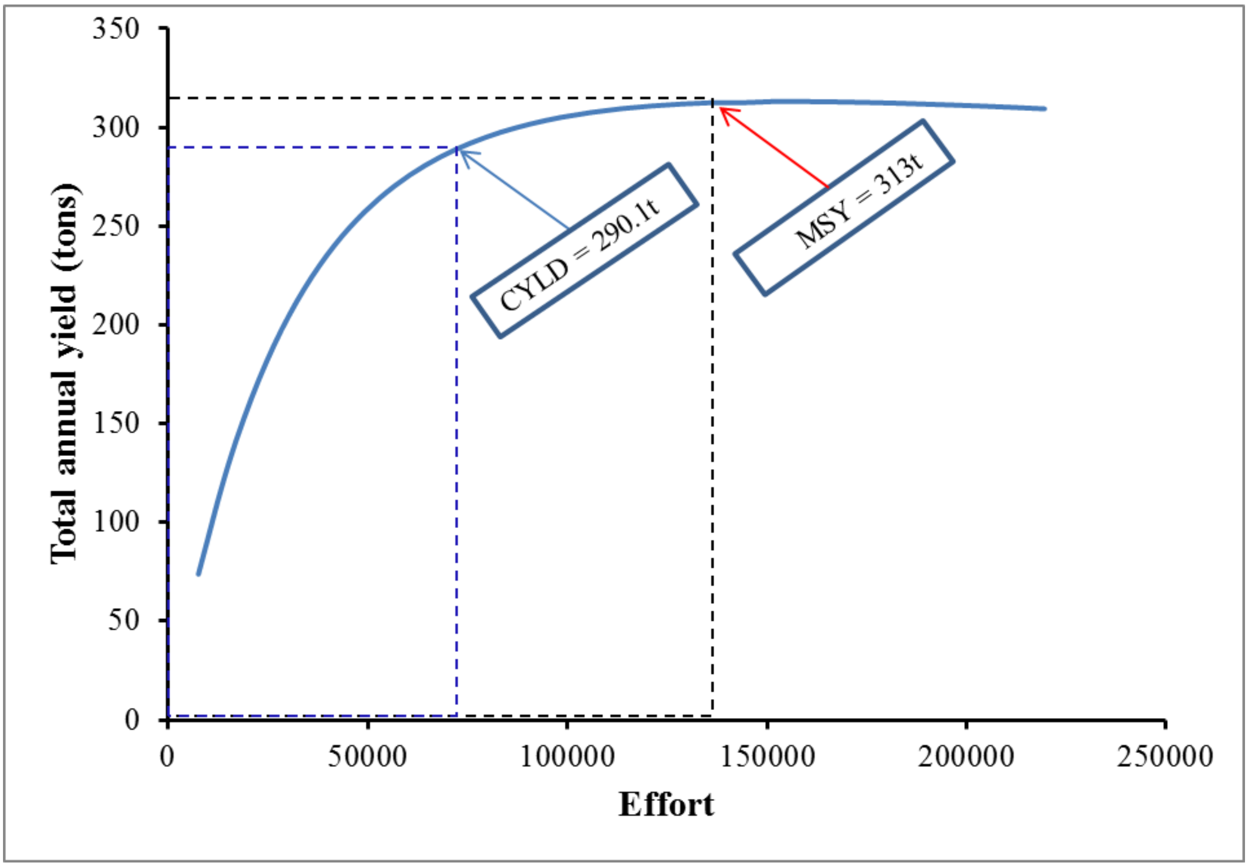

Figure 3: Maximum sustainable yield and fishing effort of *O. niloticus* in Lake Chamo

4. Conclusions and Recommendations

4.1 Conclusions

Fishers' of Lake Chamo are exploiting the fish with narrow mesh size nets. Consequently, the *O. niloticus* landed the catch were found to be highly dominated by fish whose sizes were below the L_{50} reported for this species. Thus, larger proportion of immature *O. niloticus* (93.1%) populations of Lake Chamo were exposed to heavy fishing pressure and hence, conclude that, the stocks are experiencing growth and recruitment overfishing.

The current yield (290.1 tons) is below the MSY (313 tons) and the reduction in yield is not due to overfishing but mainly related to growth overfishing with reduced mesh sizes. In summary, the future yield status of Lake Chamo is under the status of drastic reduction with the respective fish species in this study and the fish resource utilization of Lake Chamo calls for urgent management action for sustainable use.

4.2 Recommendations

Harvesting of immature fish with reduced mesh size is the major problem associated with reduced Nile Tilapia stock in Lake Chamo, which calls the use of recommended mesh size for sustainability of the resources. Therefore, management actions including multi-stakeholder participation in conservation and rehabilitation of fish resources for sustainable utilization of the natural resources in Lake Chamo are recommended. Moreover, the similar research activities for other fish species in the lake are also recommended for full information and conservation of the resources.

Conflicts of Interest

The authors declare no conflict of interest.

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