Prediction of Maximum Sustainable Yield and Optimum Fishing Effort for the Nile Perch (*Lates niloticus* L.) in Lake Chamo, Ethiopia

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Abstract: *The study was conducted to assess the current status and determine the maximum sustainable yield level of exploitation for the Nile perch (Lates niloticus L., 1758) a 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 L. niloticus caught by the fishers and the fishing efforts were the basic information collected from these sites. Totally, 544 L. niloticus samples were collected in 120 days. Jones length based cohort analysis model and length-based Thompson and Bell yield prediction models were employed to estimate the maximum sustainable yield. Overall about 0.25 million L. niloticus populations were estimated to exist in the lake. The estimated current annual yield was 102.4 tons per year. However, the predicted value of MSY was 74 tons obtained at f_{MSY} of 9,007 nets. The maturity length (L_{50}) was 100 cm and out of the total annual catches 87.9% of L. niloticus were below their respective size of maturity. Thus, the reduction of yield was due to experiencing both growth and recruitment overfishing with increased effort and reduced mesh size. Lates niloticus of Lake Chamo is overfished. Therefore, conservation and rehabilitation as well as co-management practices are required for sustainable utilization of the resource.*

Keywords: Jones length based cohort analysis model, Lake Chamo, stock assessment, yield prediction

1. Introduction

In Ethiopia, water bodies have an estimated surface area of 7,334 km² of major lakes and reservoirs, and 275 km² of small water bodies, with 7,185 km of rivers (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; the Nile perch (*Lates niloticus*) stock is clearly being over-exploited as seen from the overall catch composition from the lake (Ward and Wakayo, 2013; Mulugeta and Mereke, 2016).

L. niloticus is widely accepted fish species as a food commodity and are economically important for the fishing societies in Lake Chamo. Nowadays, *L. nilotcus* is the most target fish species of Lake Chamo fisheries due to its high price value in the market. To get high income, irresponsible fishing practices are taking place that may cause depletion of the resource. To save the resources from depletion, determining the optimum level of exploitation is important and the primary goal of this study was searching for the optimum level of exploitation. The finding of this study would serve as an essential input for decision-makers in recommending proper fish resource utilization and management.

2. Materials and Methods

2.1. Description of the study areas

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 enter Lake Chamo through River Kulfo, and an overflow from Lake Chamo through Metenafesha joins Sermale River in Amaro Woreda (Bekele, 2006). Earlier studies stated that, Lake Chamo has a surface area of 551 km^2 and a maximum depth of 16m (Belay and Wood, 1982). However, according to Bekele (2006), the surface area of the lake declined to about 335 km^2. The high rate of evaporation of water and the diversion of the feeder river, Kulfo, for agricultural activities are the reasons for the decline in the surface area of the lake (Kebede, 1996).

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. The gill nets 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.

2.2. Methods of sampling and data collection

In Lake Chamo, there are five legal fishers' co-operatives who are landing their fish catches on 31 major landing sites (from fishers' co-operatives). Of these, eight major landing sites (Bole, Ashewa, Gentafora, Bedena 1, Chika, Mehal, Wedeb and Girawa) were selected randomly and used as sampling sites. Due to differences in the number of nets deployed in 31 landing 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 *L. niloticus* was measured to the nearest 1 mm by using a measuring board, sample weights and total weights of fish from each boat was measured to the nearest 1 g and 100 g, respectively by using electronic and hanging scale balances. In addition 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. *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:

I. Length measurements recorded were grouped into 7cm length intervals to prepare a table of the length frequency. The interval was 7 cm because it was the least interval between the consecutive length groups in the sample.
II. Estimating the total number of fish caught during 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.

2.3.2. *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:

$\Delta t = 1/k * Ln[(L\infty - L_1)/[(L\infty - L_2)]$ [1]
$t\ (L_1+L_2)/2 = -1/k\{Ln[(1-(L_1+L_2)/2/(L\infty)]$ [2]
$Ln\{[C(L_1,L_2)]/[\Delta t(L_1,L_2)]\} = a - Z*t(L_1+L_2)/2$ [3]

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)
$Ln\{[C(L_1,L_2)]/[\Delta t(L_1,L_2)]\}$ = Y variable

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

Total mortality (Z) = fishing mortality (F) + natural mortality (M) [4]

The natural mortality coefficient (M) was estimated using Pauly's (1980) empirical formula as follows:
$Log_{10} M = - 0.0066 - 0.279 Log_{10} L_\infty + 0.65443 Log_{10} K + 0.4634 Log_{10} T$ [5]

Where,

M = is natural mortality coefficient
$L\infty$ = 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.

2.3.3. ***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 *L. niloticus* by length groups. This was done in three steps as follows:

i). 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) [6]

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
$C(L_1,L_2)$ = the catch of the length groups of $N(L_1)$

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

This was done using the equation as follows:

$N(L_1) = [N(L_2) * H(L_1,L_2) + C(L_1,L_2)] * H(L_1,L_2)$ [7]

Where,
$N(L_1)$ = The population number of L_1 (younger) fish
$N(L_2)$ = The population number of L_2(older) fish
$H(L_1,L_2)$ = the fraction of $N(L_1)$ fish that survived natural death as it grows from length L_1 to L_2 and computed as the following equation (Jones, 1984).

$H(L_1,L_2) = [(L\infty - L_1)/ (L\infty - L_2)]^{(M/2K)}$ [8]

Where,

$L\infty$= the asymptotic length (cm) of *L. 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 *L. niloticus* stock of Lake Chamo

iii). Estimating the fishing mortality rate of the respective length groups

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

$F(L_1,L_2) = (1/\Delta t) * ln[N(L_1)/N(L_2)] – M$ [9]

Where,

$F(L_1,L_2)$ = Fishing mortality coefficient pertaining to the respective length group
$N(L_1)$, $N(L_2)$ 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).

2.3.4. ***Predicting maximum sustainable yield and optimum fishing efforts***

Input data and parameters required were:

i) Total number of fish caught per year structured by length groups
ii) Estimates of population number and fishing mortality coefficient (F) by length group (obtained from Jones length based cohort analysis)
iii) Values of the von Bertalanffy growth parameters ($L\infty$ and K) and natural mortality coefficient (M)
iv) 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

i) Estimating the yield obtained per year from each length group
   - Yield from each length group obtained per year ($Y(L_1,L_2)$ - was catch in number per length group per year ($C(L_1,L_2)$ multiplied by the average weight of each length group i.e.,

$$Y(L_1, L_2) = C(L_1, L_2) * W(L_1, L_2) \quad [10]$$

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

$$W(g) = a* L^b \quad [11]$$

Where,

W(g) 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

ii) Estimating yield obtained from all length groups per year

Adding up the contribution of each length group gives the total yield obtained 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

$$F = q*f \quad [12]$$

Where,

F= fishing mortality,
q = catchability coefficient and f= fishing effort

Procedures of predicting yield under the doubled F:

i) Calculating the changed fishing mortality
   - The new fishing mortality values under the changed F was calculated by multiplying the current F by the raising factor (X)

$$F(New) = F(current)* X, \quad [13]$$

Where,
F(new) = the changed F

ii) Calculating the changed total mortality rate under the changed F

$$Z(new) = F(new) +M \quad [14]$$

Where,

F(new) is the changed fishing mortality coefficient of each length group. M is the natural mortality coefficient estimated by equation 5 above.

iii) 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).

$$N(L_2) = N(L_1) * e^{-Z(new)*\Delta t(L1,L2)} \quad [15]$$

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
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 1.
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 14.

iv) 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).

$$C(L_1, L_2) = F(L_1,L_2)/Z(L_1,L_2) * D(L_1,L_2) \quad [16]$$

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 10. 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 Discussion

3.1. Status of Lake Chamo *L. niloticus* fishery

Overall there were five fishers' co-operatives and 300 registered co-operative member of fishermen operating in the lake during the time of sampling (Table 1). The fishing nets of Lake Chamo fishers are constructed differently considering the size of the target fish and set differently. These fishers own 60 boats and on average 49 nets for *L. niloticus,* which were set daily in the lake. Each fisher on average owns 0.16 *L. niloticus* nets and about 0.82 nets were set per boat daily. The total annual estimated nets were 17,885 during the year of investigation (365 days). With this level of fishing efforts, an estimated total annual catch were 15,868 and weighed about 102.4 tons per year. The estimated average catch per net per day was 1 fish and weighed 5.73 kg/net/day.

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

Operation measurements	Value
Total number of fishers in operation	300
Average number of boat operated per day	60
Average nets set per day	49
Total number of nets set per year	17,885
Total number of fish caught per year	15,868
Total weight of catch (kg) per year	102,400
Catch per net (no./net/day)	1.0
Weight of catch per net (kg/net/day)	5.73

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

Totally, 544 samples of *L. niloticus* were measured during the study period and the measured total length (TL) compositions were ranged from 35 to 126 cm with an average length of 80.5 cm (Table 2). From 544 fish measured, only 66 were greater than the maturity length (L_{50}) of 100 cm which was reported by Dadebo *et al*. (2005). Thus, 12.1% of the fish caught were above L_{50} and the remaining 87.9% were below L_{50}.

A similar result was reported by Dejene (2008), who estimated the proportion of immature *L. niloticus* as 94.3%. As observed during the data collection, the mesh sizes of nets used to catch the fish were found to be 20 cm which was narrower than the recommended minimum mesh size as 28 cm (LFDP, 1997).Out of the total annual catch, over 95.61% of the catch was ranged from 42 cm to 112 cm in total length. More importantly, the length groups ranged from 49 cm to105 cm was about 88.76% of the total catch and had a high contribution in fish yield Table 2 (column 4, rows 5-12). Thus, large numbers of *L. niloticus* of Lake Chamo are being removed before they grow and replace their population.

Table 2: Nile perch caught during the sampled days and estimated total annual catch by length group in 2018

Length group **L1-L2**	Samples/120 days C (L_1,L_2)	Estimated annual catch (number)	Proportion of length group composition from the total catch (%)
35-42	7	204	1.3
42-49	17	496	3.13
49-56	37	1079	6.79
56-63	67	1954	12.32
63-70	80	2334	14.70
70-77	82	2392	15.07
77-84	73	2129	13.43
84-91	64	1867	11.77
91-98	51	1488	9.38
98-105	29	846	5.34
105-112	20	583	3.68
112-119	11	321	2.02
119-126	6	175	1.11
Total	544	15,868	100

3.3. Growth and total mortality coefficient of *L. niloticus*

The von Bertalanffy growth parameters used for mortality estimation were obtained from previous age-based analysis as $L\infty = 164$ cm and $k = 0.12$ yr^{-1} (Tekle-Giorgis, 2002). *L. niloticus* in Lake Chamo becomes liable to the fishing gears at the length of 35 cm and this length is said to be the length at first recruitment (Tr) (Table 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).

The *L. Niloticus* of Lake Chamo started to be caught considerably at the length of 49 cm and 49 cm is the age at first capture (Tc).Because starting 49 cm in Lake Chamo are readily captured if they encounter the nets Table 3 (column 2, row 5). 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 *L. niloticus* for length-based catch curve analysis in 2018

Length group	Catch			X	Y
L_1-L_2	$C(L_1,L_2)$	$\Delta t\ (L_1,L_2)$	$(L_1+L_2)/2$	$t(L_1+L_2)/2$	$Ln(C(L_1,L_2)/\Delta t)$
35-42	204	0.465	38.5	2.230	6.08
42-49	496	0.492	45.5	2.708	6.91
49-56	1079	0.523	52.5	3.215	7.63
56-63	1954	0.558	59.5	3.756	8.16
63-70	2334	0.599	66.5	4.333	8.27
70-77	2392	0.645	73.5	4.954	8.22
77-84	2129	0.699	80.5	5.625	8.02
84-91	1867	0.763	87.5	6.355	7.80
91-98	1488	0.840	94.5	7.154	7.48
98-105	846	0.934	101.5	8.039	6.81
105-112	583	1.052	108.5	9.029	6.32
112-119	321	1.205	115.5	10.152	5.58
119-126	175	1.409	122.5	11.451	4.82

Using the 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).

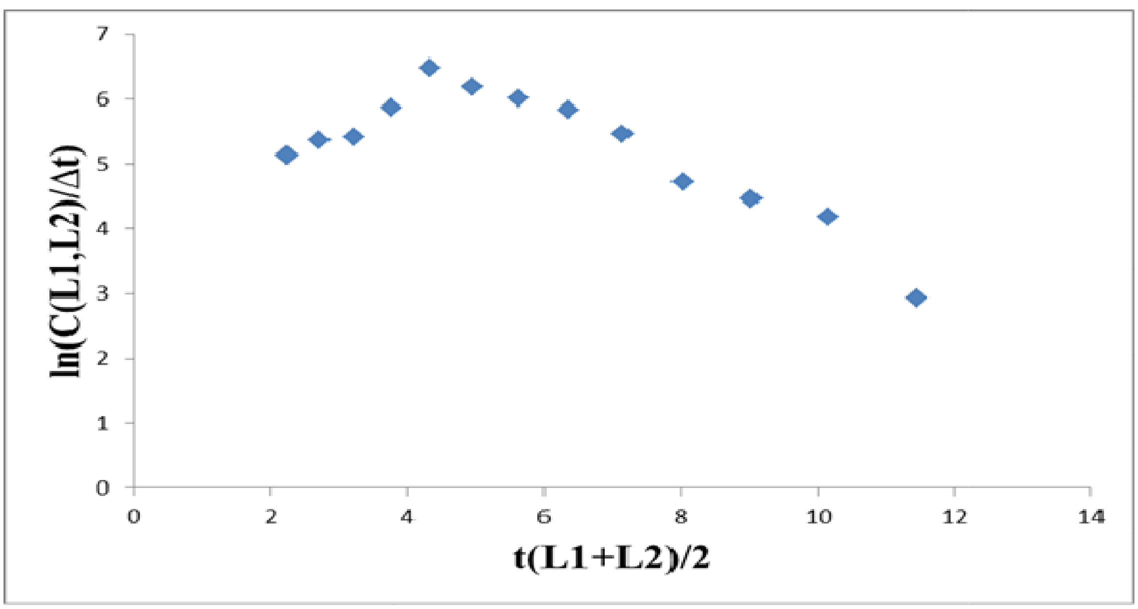

Figure 1: Length-based total catch curve of *L. niloticus* from Lake Chamo

For total mortality (Z) estimation, the data points that did not fall on straight line were the data of the youngest age groups and them were excluded as they had not yet attained the age of full exploitation (Figure 2). The slope of the regression line (b) is -0.5674 and hence, the estimated total mortality (Z) was 0.5674 yr^{-1} and it was low due to exclusion of youngest age groups as they did not fall on straight line. Of the total mortality, natural mortality (M) and fishing mortality (F) was 0.28 yr^{-1} and 0.29 yr^{-1}, respectively. Using these mortality estimates, the exploitation rate (*E*) was computed as 0.51 and indicates slightly overexploitation. 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).

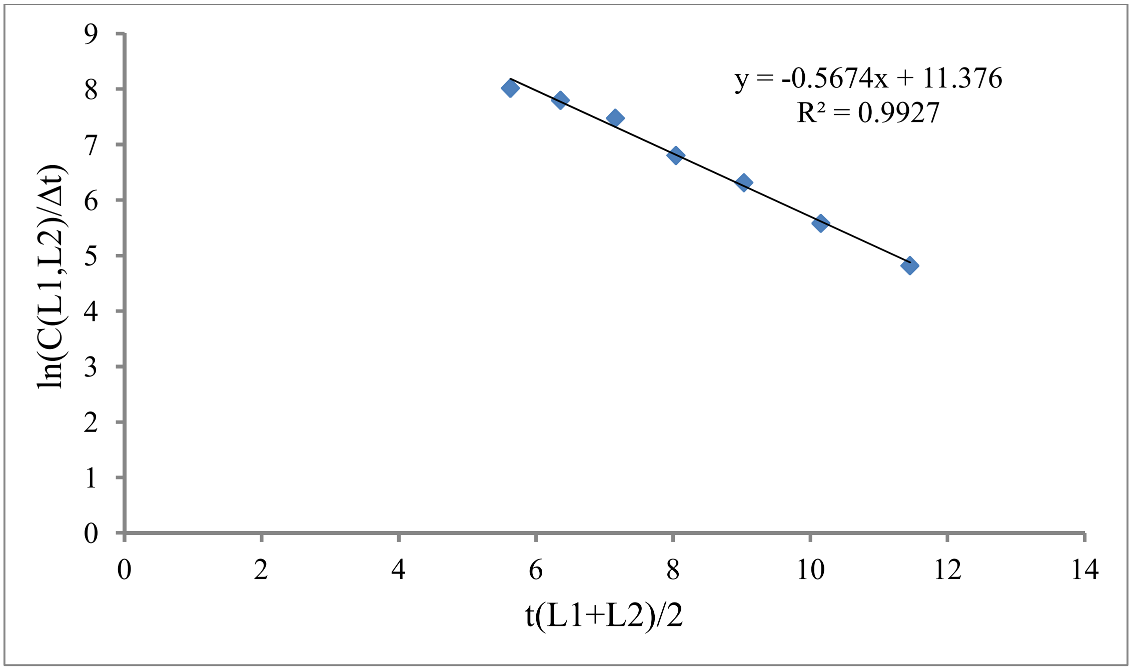

Figure 2: Linearized length-based catch curve of *L. niloticus* from Lake Chamo

3.4. Estimated population sizes and fishing mortalities

The estimated population number and fishing mortality coefficient by length group is indicated in Table 4. The estimated annual recruitment of *L. niloticus* in Lake Chamo was about 50,000 as indicated in Table 4 (column 9; row 3). Overall, about 0.25 million *L. 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 Table 4 (column 9). This estimate belongs to the population of fish excluding the area of the lake protected for fish breeding. Even if it is said to be there is a protected area for breeding, there is a problem of illegal fishing practices taking place in the area. As shown in Table 4 (column 4), the length groups' 35 cm to 70 cm fish shouldered heavy fishing mortality rate bearing above 0.5 fishing mortality per year. This indicates that, the *L. niloticus* stock of Lake Chamo is heavily exploited and removed before their age of maturity.

Table 4: Estimated population numbers, fishing mortalities and other parameters by length groups for the *L. niloticus* in 2018

Length group (L1-L2)	Catch C(L1,L2)	F(L1,L2)	H	Δt (L1,L2)	(L1+L2)/2	X t(L1+L2)/2	Y Ln(C(L1,L2)/Δt)	N(L1)
35-42	204	0.62	1.067	0.465	38.5	2.23	6.08	50806
42-49	496	0.58	1.071	0.492	45.5	2.71	6.91	44468
49-56	1079	0.55	1.075	0.523	52.5	3.22	7.63	38329
56-63	1954	0.53	1.081	0.558	59.5	3.76	8.16	32147
63-70	2334	0.51	1.087	0.599	66.5	4.33	8.27	25726
70-77	2392	0.48	1.094	0.645	73.5	4.95	8.22	19644
77-84	2129	0.45	1.102	0.699	80.5	5.63	8.02	14239
84-91	1867	0.44	1.112	0.763	87.5	6.36	7.80	9797
91-98	1488	0.44	1.124	0.840	94.5	7.15	7.48	6249
98-105	846	0.36	1.138	0.934	101.5	8.04	6.81	3627
105-112	583	0.36	1.157	1.052	108.5	9.03	6.32	2056
112-119	321	0.33	1.182	1.205	115.5	10.15	5.58	1031
119-126	175	0.15	1.216	1.409	122.5	11.45	4.82	467
Total								0.25 million

3.5. Predicting maximum sustainable yield and optimum fishing efforts

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

The estimated total annual yield is presented in Table 5 and the current total yield (102.4t) pertaining to the respective length group was obtained by multiplying the total catch of the respective length group by the corresponding mean weight values. To obtain this amount of yield (102.4 t), 17,885 nets were applied annually in the lake. In the current investigation, the fishing effort was greater than f_{MSY}(9007) which indicates a state of over fishing.

According to Mulugeta and Mereke (2016), the estimated annual yield between the years 2011-2015 ranged from 250-397 tons per year. The total estimated annual yield obtained in the current investigation (102.4 t) was reduced by three folds than in the previous findings. The drastic decline in catch and yield might be due to the increased effort and reduction in mesh sizes of nets. Out of the annual estimated total catch 87.9% was immature or lower than $L_{50}$and might be the main causes for yield reduction.

The 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). Thus, the drastic decline in catch and yield was mainly related to recruitment and growth overfishing with increased effort and reduced mesh size. It is also important to consider that some other factors such as buffer zone agricultural practices, siltation, the application of monofilament nets, lack of co-management and lack of political consideration for monitoring and evaluation are some specified problems taken as a reason for the drastic decline in the amount of catch and yield.

Table 5: Estimated total yield obtained from *L. niloticus* by length group under the current level of fishing effort in 2018

Length group L1-L2	Catch C(L1,L2)	F(L1,L2)	(L1+L2)/2	X t(L1+L2)/2	Y Ln (C(L1,L2)/Δt)	N(L1)	Mean wt (kg) Wbar	Current Yield/yr (kg) Y(L1,L2)
35-42	204	0.62	38.5	2.23	6.08	50806	0.67	137
42-49	496	0.58	45.5	2.71	6.91	44468	1.12	554
49-56	1079	0.55	52.5	3.22	7.63	38329	1.73	1866
56-63	1954	0.53	59.5	3.76	8.16	32147	2.54	4955
63-70	2334	0.51	66.5	4.33	8.27	25726	3.56	8313
70-77	2392	0.48	73.5	4.95	8.22	19644	4.84	11571
77-84	2129	0.45	80.5	5.63	8.02	14239	6.39	13605
84-91	1867	0.44	87.5	6.35	7.80	9797	8.24	15392
91-98	1488	0.44	94.5	7.15	7.48	6249	10.43	15520
98-105	846	0.36	101.5	8.04	6.81	3627	12.98	10980
105-112	583	0.36	108.5	9.03	6.32	2056	15.92	9286
112-119	321	0.33	115.5	10.15	5.58	1031	19.27	6183
119-126	175	0.15	122.5	11.45	4.82	467	23.07	4038
Total						248,586		102.4t/yr

3.5.2. Predicted yield obtained under different levels of fishing pressure

The new F values shown in Table 6 (column 4) are 0.5 times the value of the current fishing mortalities at which the MSY obtained. The estimated MSY of *L. niloticus* in Lake Chamo was 74 tons per year (Table 6, column 9) which would be obtained with f_{MSY} of 9,007 nets per year (Figure 3). The MSY(74 t) was lower than the current yield (102.4 t) and the current yield showed 27.73% yield increments which indicates *L. niloticus* of Lake Chamo is overfished. Therefore, the current fishing effort should be reduced by 50% to keep the sustainability of *L. niloticus* in Lake Chamo. Out of the total annual catch 87.9% were immature or below L_{50}.

Table 6: The MSY obtained under length-based Thompson and Bell yield prediction model for *L. niloticus* of Lake Chamo in 2018

Length group L1-L2	Catch C(L1,L2)	Mean wt (kg) W bar	Changed F	Changed Z	Changed N	Changed death D(L1,L2)	Expected catch C(L1,L2)	Expected Yield (kg/yr
35-42	204	0.67	0.31	0.59	50806	12156	6425	4303
42-49	496	1.12	0.29	0.57	38649	9418	4813	5372
49-56	1079	1.73	0.27	0.55	29232	7316	3629	6275
56-63	1954	2.54	0.26	0.54	21916	5718	2789	7071
63-70	2334	3.56	0.25	0.53	16198	4404	2100	7482
70-77	2392	4.84	0.24	0.52	11794	3354	1561	7553
77-84	2129	6.39	0.23	0.50	8440	2509	1130	7220
84-91	1867	8.24	0.22	0.50	5931	1877	833	6870
91-98	1488	10.43	0.22	0.50	4054	1386	614	6404
98-105	846	12.98	0.18	0.46	2668	926	364	4720
105-112	583	15.92	0.18	0.46	1742	666	263	4185
112-119	321	19.27	0.16	0.44	1075	444	165	3185
119-126	175	23.07	0.075	0.35	632	632	134	3101
Total								74t/year

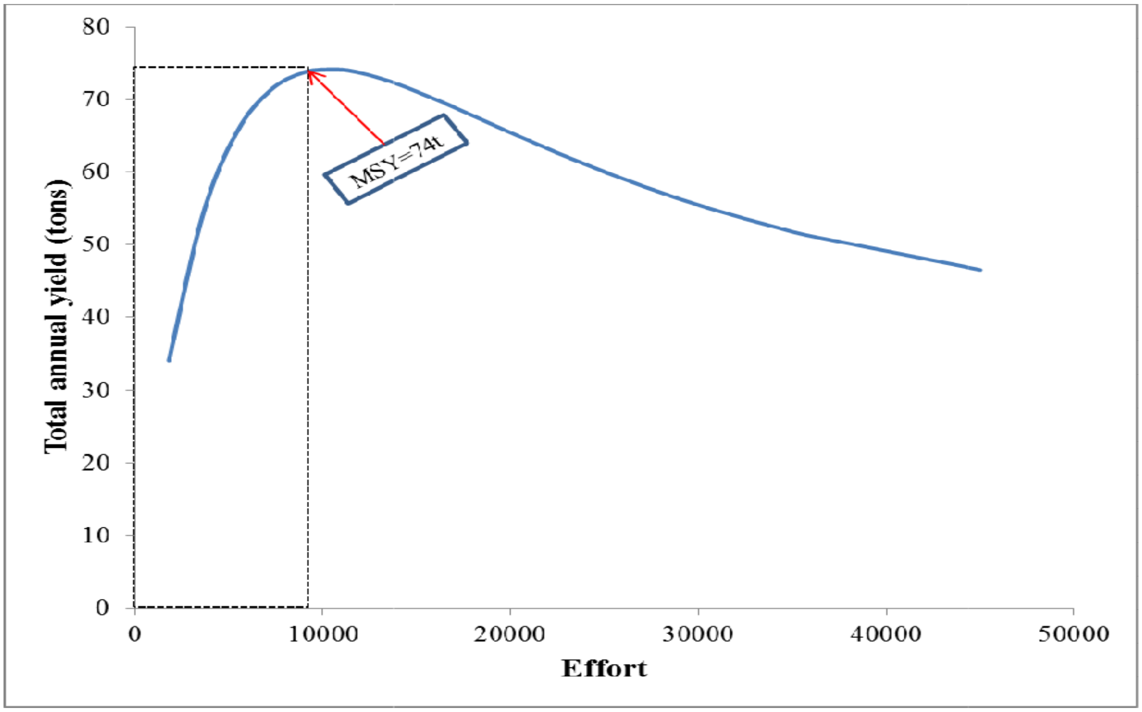

Figure 3: Maximum sustainable yield and fishing effort of *L. niloticus* in Lake Chamo

4. Conclusions and Recommendations

The *Lates niloticus* stock in Lake Chamo is under heavy fishing pressure. The current fishing effort (17,885) is twice greater than the effort of maximum sustainable yield (9,007) and also found to be narrower mesh size (20 cm) than the recommended minimum mesh size as 28 cm. Consequently, the *L. niloticus* annual catch were found to be insufficient due to heavy fishing pressure and were highly dominated by fish sizes lower than the L_{50} reported for this specie. Thus, the immature number of *L. niloticus*(87.9%) populations of Lake Chamo is exposed to heavy fishing pressure and hence, conclude that, the stocks are experiencing both growth and recruitment overfishing.

The estimated current annual yield (102.4t) was greater than the MSY (74 t) and indicates that the *L. niloticus* of Lake Chamo is overfished. In summary, the future yield status of Lake Chamo is under the status of being depleted with the respective fish species in this study and the fish resource utilization of Lake Chamo calls for urgent management action for conservation and sustainable use. To keep the sustainability of the resource, conservation, rehabilitation and co-management practices should be applied. The nets should be also enforced urgently to protect the capture of immature fish thereby minimize and eventually control growth overfishing.

Conflicts of Interest

The authors declare that there is no conflict of interest in publishing the manuscript in this journal.

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