Received: 10 February 2021 | Revised: 26 July 2021 | Accepted: 2 August 2021

DOI: 10.1111/lre.12375

ORIGINAL ARTICLE

Lakes & Reservoirs WILEY

Growth and status of Nile tilapia (*Oreochromis niloticus* L.) stock in Lake Chamo, Ethiopia

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Funding information
Austrian Development Cooperation; Hawassa University

Correction added on 4th, September, after first online publication: Figures 2, 3, 4 and 5 have been moved to more appropriate positions

Abstract

Global inland freshwater fisheries support livelihoods for several million people. These important resources, however, are suffering from excessive overfishing as a result of increasing fishing pressures attributable to an increased human population and subsequent demand for food and economic livelihoods. To this end, very little is known about the vital population parameters and stock status of Nile tilapia (*Oreochromis niloticus*) in Lake Chamo in Ethiopia. Thus, the present study focused on determining the Nile tilapia population parameters and assessing their stock status in Lake Chamo, using length-frequency and catch-effort data collected between February 2018 and January 2019 from commercial fish catches from 10 major fish landing sites. The TropFishR software package was used to determine von Bertalanffy growth parameters, and length-converted catch curve and empirical models were used to calculate mortality parameters. The maximum sustainable yield (MSY) and its corresponding level of effort (f_{MSY}) were determined using the length-based Thompson & Bell yield prediction model. The growth parameters L_∞, K and Φ' of the Nile tilapia stock were found to be 59.4-cm, 0.41/year and 3.16, respectively. The annual rate of total (Z), natural (M) and fishing mortality (F) were estimated to be 2.442, 0.558 and 1.884/year, respectively. The calculated current yield (711 *t*/year) is lower than the predicted values of MSY (771 *t*/year). The present level of fishing effort (2564 nets/day) is more than twice higher than the optimum level of fishing effort (1026 nets/day), clearly indicating overfishing of the Nile tilapia stock in the lake. This finding is also substantiated by the high level of exploitation rate ($E = 0.771$). Thus, a recommendation based on the results of the present study is a 60% reduction in the fishing effort (1538 nets/day), which will also provide a higher fish yield. The results of the present study also are useful facilitate development of appropriate management strategies for the Nile tilapia fishery in Lake Chamo.

KEYWORDS
cohort analysis, exploitation rate, MSY, overfishing, stock assessment, Thompson and Bell model

1 | INTRODUCTION

Inland fisheries contribute significantly to the worldwide fisheries, being a means of livelihoods for millions of people, predominantly in less-developed countries with limited income alternatives (Hicks & McClanahan, 2012; Pauly et al., 1998; Tesfaye & Wolff, 2015). It comprises more than 60% of Africa's fishery production, with 10 million Africans relying on it as their primary livelihood, and a further 90 million farmers and resource-poor dependent on fishing as a component of a diversified livelihood strategy (Béné, 2006).

However, inland water resources in these countries face multi-dimensional challenges, including overfishing, pollution, eutrophication and climate change, attributable mainly to unsustainable use of aquatic resources by humans (Tesfaye, 2016).

According to Lorenzen et al. (2016), various freshwater fisheries lack stock assessment, even where the capacity for data collection and analysis exists. Thus, accurate assessment and management based on credible scientific evidence are indispensable for safeguarding the sustainability of fishery resources at levels reflecting their ideal utilization and also conserving their sustained availability for current and coming generations (Tesfaye & Wolff, 2015).

Knowledge of current fishing pressures and stock biomass regarding biological reference levels supports the need for development of management strategies for sustainable fishery harvests. For management purposes, single-species stock assessment models are mainly used to derive these reference levels (Mildenberger et al., 2017). Of several fish stock assessment models, two analytical prediction models are widely applied, including the Beverton and Holt yield-per-recruit model (Beverton & Holt, 1957) and the Thompson and Bell model (Thompson & Bell, 1934). These two prediction models have dissimilar data stipulation approaches. The latter model demands more data regarding preconditions. At the same time, it permits the integration of a third magnitude; namely prices (i.e. the worth of the fish catch), thereby allowing evaluation of the economic relevance of the catch under different fishing pressures (Kuriakose et al., 2017).

Lake Chamo is the most productive lake in Ethiopia, contributing about 3500 *t* fish/year to Ethiopian fisheries, particularly in regard to riparian communities (Tesfaye & Wolff, 2014). Nile Perch was previously the most commercially important species in the Lake Chamo fishery. However, following the introduction of 'Gancho' nets' (a dragging trammel net with a wide mesh size and very strong twine made of several monofilament or multifilament nylon, three or four gillnets combined together to make it stronger and bond to each other), in March 1986 the catch rates of the 'big old fish' increased dramatically from a monthly level of 10–20 *t* to 190 *t* in October 1987 (LFDP, 1997). Since then the total catch dropped sharply (LFDP, 1997). Much of the current catch has been contributed by Nile tilapia (*Oreochromis niloticus*), followed by Nile perch (*Lates niloticus*), African catfish (*Clarias gariepinus*) and *Bagrus dockmak*. Nile tilapia contributes about 85% of the annual catch of Lake Chamo and 49% of per annum total fish landing from Ethiopian lakes (Mereke & Mulugeta, 2016; Tesfaye & Wolff, 2014).

In view of the socio-economic and ecological importance of the Nile tilapia fishery, several investigators investigated their food and feeding habits (Assefa & Getahun, 2015; Engdaw et al., 2013; Tadesse, 1999; Tefera, 1993; Teferi et al., 2000; Wudneh, 1998), reproductive biology (Abera, 2013; Admassu, 1996; Degefu et al., 2012; Tadesse, 1997; Temesgen, 2017), and length and weight relationship (Degefu et al., 2012; Tadesse, 1997; Tesfaye & Tadesse, 2008). some significant contributions on the population dynamics of Nile tilapia were also provided by Admassu (1998), Wudneh (1998), Admassu and Ahlgren (2000), Tekle-Giorgis (2002), Tesfaye and Wolff (2015), Tekle-Giorgis et al. (2017). However, they were inadequate with their application restricted to the study sites. Virtually, no information is currently available on the growth, mortality, stock status and utilization rate of Nile tilapia fishery in Lake Chamo. Accordingly, the present study focuses on determining the growth and current stock status of Nile tilapia in Lake Chamo as a means of providing essential information for better management of this commercially important fish stock.

2 | METHODS AND MATERIALS

2.1 | Study area

The Abaya-Chamo drainage basin is a sub-basin in the southern Ethiopian Rift Valley, which is part of the Great East African Rift System extending from the Afar triple junction southward across eastern Africa to Mozambique. Lake Chamo (5°42′–5°58′N; 37°27′–37°38′E; Figure 1) is located about 515 km south of the capital city of Addis Ababa, lying at an altitude of 1108 m above mean sea level (Teferi & Admassu, 2002). It is the southward passage of Lake Abaya and the city of Arba Minch and is east of the Guge hills. The lake's northern tip lies in the Nechisar National Park. The lake is 26 km in length, with a width of 22 km, a pick depth of 10 m and a surface area of 551 km^2 (Dadebo et al., 2005; Gerenfes, 2017). The major inflowing tributaries include the Argoba, Sile, Sego and Wezeka rivers. The lake also receives runoff from Lake Abaya, which concourses with the Kulfo River and ultimately flowing to Lake Chamo (Gerenfes, 2017).

The phytoplankton community is dominated by different species of Cyanophyceae, Chlorophyceae and Bacillariophyceae, while dominant Zooplankton groups include the genera *Thermocyclops*, *Mesocyclops* and *Moina* (Dadebo et al., 2005; Utaile & Sulaiman, 2016).

Lake Chamo is believed to be a part of the much larger drainage basin extending further south up to Lake Chew Bahir and Lake Turkana (Beadle, 1974). Intermittent river flows in the past have linked Lakes Abaya, Chamo and Chew Bahir to Lake Turkana and then to the White Nile system. As a result, the ichthyofauna of Lake Chamo and Lake Abaya primarily comprises Nilo-Sudanic species, being the most diversified than other Rift Valley lakes, being composed of more than 20 species. Of these species, *O. niloticus*,

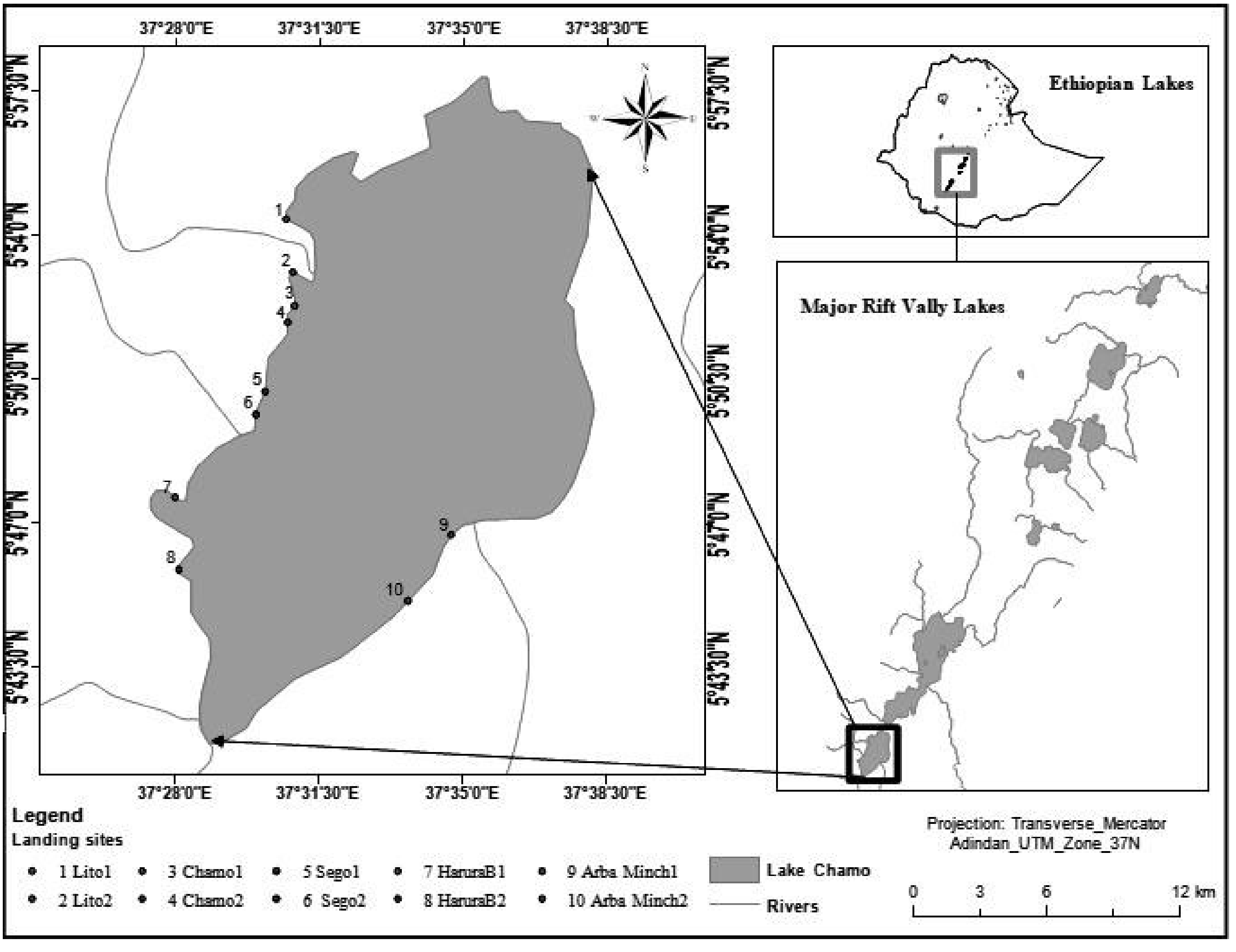


FIGURE 1 Map of Ethiopian lakes, major Rift Valley lakes and Lake Chamo with landing sites

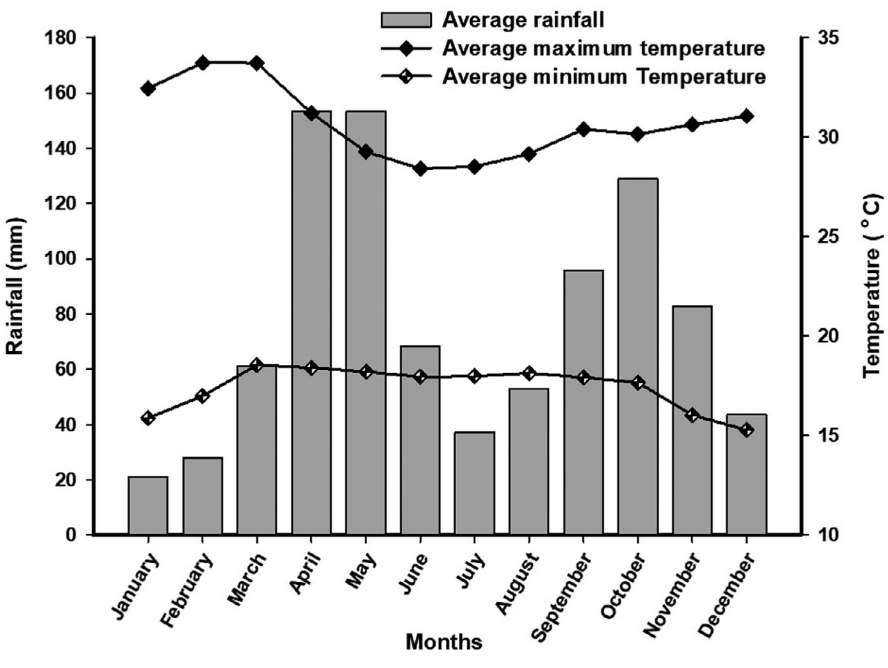


FIGURE 2 Temporal variations in mean monthly rainfall (2000–2018 G.C) and mean monthly air temperature (maximum and minimum) for Lake Chamo

L. niloticus, *C. gariepinus* and *Bagrus docmac* are of great economic importance to the Lake Chamo fishery (LFDP, 1997).

Temporal variations in meteorological variables (mean monthly rainfall; mean monthly air temperature) for Lake Chamo were obtained from the Arba Minch station of the National Meteorological Services (Figure 2). The area receives about 21.02–153.9 mm of rainfall per annum, occurring mostly in April and October, with peaks in April and May. The average monthly temperature over 18 years indicates temperatures reach their peak in January, February and March, being lowest in June and December (Figure 2). [Correction added on 4th, September after first online publication: The citation is corrected from Figure 3 to Figure 2 in the previous line.]

2.2 | Data collection

Data were collected from five well-organized fishery cooperatives (Sego; Arba Minch; Lito; Harura Boche; and Chamo) from 10 major landing sites (Figure 1) three times a week for 12 consecutive months (February to January 2019). The data predominantly comprised details on the Nile tilapia fishery of the lake, which are useful to determine the growth parameters and estimate MSYs with corresponding optimum levels of fishing effort.

2.2.1 | Catch-effort data

The catch and effort data were summarized in the approach required for length-based Jones cohort analysis (CA) and the Thompson and Bell yield prediction model (Sparre & Venema, 1998; Thompson & Bell, 1934). This was achieved with the following sequence of step. First, the length frequencies of sampled fish catch were classified into two-cm length classes to develop the length-frequency table for *O. niloticus* sampled during the sampling occasions. The overall number of fish collected daily at respective landing sites was then estimated by multiplying the number of length measured fish by a conversion coefficient. Thus, fish concurrently counted and weighed are adjusted to ascertain a proper raising factor to transform records of the daily weight of the catch of corresponding fishermen into numbers. The second step involved determining the length composition of the whole daily catch by duplicating the overall number of fish caught per day by the relative recurrence of each length group in the sampling days. The whole length recurrence of fish landed within the sampling periods (156 days) was then determined by summing the individual length groups. The third step was estimating the whole number of *O. niloticus* caught during the un-sampled days (209 days) from the inspected days. The catch and effort extended varied during the fasting days in February, March and August, and the non-fasting days of the Ethiopian Orthodox Christians. Accordingly, the average catch of the inspected days during February, March and August was used to estimate the un-sampled days during these months. Likewise, the average catch of the sampled days during the non-fasting months was used to estimate the un-sampled days during the same period. Finally, the total length composition of landed fish of sampled months was projected by multiplying the length frequency of the inspected days catch by a proper conversion coefficient calculated as C/c, where C refers to the total catch of fish throughout the entire year, and c represents the overall catch of fish throughout the sampled days.

2.2.2 | Length–weight relationship

The total length and body weight of 13,620 Nile tilapia specimens were measured to the closest centimetre (cm) and gram (g), respectively. The length–weight relationship (LWR) was then derived for the unsexed population, using the power function of Le Cren (1951) as follows:

$$W = aL^b \tag{1}$$

where W = body weight (g); L = total length (cm); 'a' = a coefficient related to body form; and 'b' = an exponent (slope) indicating either isometric or allometric growth. The data analysis was carried out with non-linear regression analysis using R software.

2.2.3 | Growth parameters

Length-frequency data are commonly used for stock assessment models to assess the fish stocks in tropical countries (e.g. Ethiopia), in contrast to length-at-age data in temperate countries. Thus, the models developed for tropics are called length-oriented fish stock assessment models (Sparre & Venema, 1998). With Lake Chamo being a tropical lake, length-based fish stock assessment methods were used to assess the growth, mortality and stock status of *O. niloticus*.

The growth of *O. niloticus* in Lake Chamo was expected to follow the von Bertalanffy growth function (VBGF) as follows:

$$L_t = L_\infty \cdot \left(1 - exp^{-K(t - t_o)}\right) \tag{2}$$

where L_t = length at a specific given time t; K = rate at which length approaches the asymptote; L_∞ = asymptotic length of fish (cm); t = time (age of fish); and t_o = hypothetical age at which the fish would have had at zero length.

An initial estimate of the VBGF parameters (L_∞ and K) was determined with a Powell–Wetherall method using the 'TropFishR' package in R software (Mildenberger et al., 2017), the latest computer program bundle developed principally for examining length-frequency data. Initial gauges of L_∞ and K, determined with the Powell–Wetherall method, were entered into the Electronic LEength Frequency ANalaysis—Simulated Annealing (ELEFAN-SA) and Electronic LEength Frequency ANalaysis—Genetic Algorithm (ELEFAN-GA) (details of these approaches are provided by Mildenberger et al. (2017)) to plot the growth curve that 'best' fit a group of length-frequency data, utilizing the esteem of the goodness-of-fit list (Rn) as a measure. L_∞ and K values with the most elevated Rn values were then considered as 'best' gauges.

The 3rd VBGF parameter, age at zero length (t_0), was estimated following the approach of Pauly (1979) as follows:

$$\log\left(-t_o\right) = -0.3922 - 0.275 \cdot \log L_\infty - 1.038 \cdot \log K \quad (3)$$

where L_∞ is expressed in cm and K is expressed in per year.

The Phi prime index (Ø′) of the VBGF parameters (Munro & Pauly, 1983) was utilized to ascertain the growth performance of the fish in length, which is characterized as:

$$\varnothing' = \log K + 2 \cdot \log L_\infty . \quad (4)$$

2.2.4 | Mortality rates

The length-regenerated catch curve was used to estimate the total instantaneous mortality rate. A regression was fitted to the points of the catch beyond which L' is the first point of the curve used for the regression analysis, representing the smallest length at which the probability of capture is 1 and the slope of the relapse line represents the estimate of the overall mortality rate, as depicted by Pauly (1984) and Gayanilo et al. (2005) as follows:

$$\ln\left(\frac{N_i}{\Delta t}\right) = a + b \cdot t_i \quad (5)$$

where Δt = time required for the fish to grow through length group i; N_i = the number of fish in length group; t_i = age (or relative age) with respect to the mid-length of class i and b (with sign changed) = an estimate of Z. Further

$$\Delta t = -\left(\frac{1}{K}\right) \cdot \ln\left[\frac{(L_\infty - L_{i+1})}{(L_\infty - L_i)}\right] \pi r^2 \quad (6)$$

and

$$t_i = \left(\frac{1}{K}\right) \cdot \ln\left(1 - \frac{L_i}{L_\infty}\right) + t_o \quad (7)$$

where t_o = theoretical age at which fish would be at zero length and L_i = middle point of length classes i.

The natural mortality constant (M) for the *O. niloticus* stock in Lake Chamo was foreseeable from the updated version of the Pauly (1980) formula, excluding the effect of temperature (T), which was fitted to a dataset of 218 species using non-linear least square fitting described by Then et al. (2015) as follows:

$$M = 4.118 K^{0.73} \cdot L_\infty^{-0.331} \quad (8)$$

where L_∞ and K are as illustrated above for *O. niloticus* stock. The fishing mortality (F) was then acquired by deducting M from Z.

2.2.5 | Cohort analysis

A Jones length-oriented CA was carried out to determine the fishing mortality constant and population abundance for each length group of *O. niloticus*. The analysis was conducted using (C (L_1, L_2)) as the basic input data. The population number of the largest length class in the catch was then estimated as follows:

$$N_{\text{terminal}} = C_{\text{terminal}} \cdot \left(\frac{Z}{F}\right) \text{terminal} \quad (9)$$

where N_{terminal} = population of largest length fish group; C_{terminal} = catch of the largest length group; and $(Z/F)_{\text{terminal}}$ = proportion of total mortality to fishing mortality of largest length group in the fish catch.

After obtaining the N_{terminal} value for the largest length fish group, the population numbers of sequential younger length classes in the catch were calculated as follows:

$$N(L_i) = \left[(N(L_{i+1}) . H(L_i, L_{i+1})) + C(L_i, L_{i+1})\right] . H(L_i, L_{i+1}) \quad (10)$$

where $N(L_i)$ = population number of L_i (younger) fish; $N(L_{i+1})$ = population number of L_{i+1} (older) fish; $C(L_i, L_{i+1})$ = overall yearly catch in number of fish caught between lengths L_i and L_{i+1}, and $H(L_i, L_{i+1})$ = the natural mortality factor.

The natural mortality factor was calculated as follows:

$$H(L_i, L_{i+1}) = \left[\frac{(L_\infty - L_i)}{(L_\infty - L_{i+1})}\right] \frac{M}{2K} . \quad (11)$$

The next step was to project the fishing mortality rate of the corresponding length groups by utilizing F_{terminal} as an initial value. This was calculated by subtracting Z (obtained from catch curve analysis) from M (Equation 8) as follows:

$$F(L_i, L_{i+1}) = \left\{\left(\frac{1}{\Delta t}\right) \cdot \text{Ln}\left(\frac{N(L_i)}{N(L_{i+1})}\right)\right\} - M \quad (12)$$

where $F(L_i, L_{i+1})$ = fishing mortality coefficient pertaining to the respective length group; $N(L_i)$ and $N(L_{i+1})$ = population numbers of consecutive length groups (Equations 9 and 10); M as defined in Equation (8), and Δt = time needed for the fish to grow through length class i (Equation 6).

2.2.6 | Prediction of fish yield and stock biomass

The results of the length-based cohort investigation procedures were employed as intake data for forecasting the sustainable fish yield and biomass at different levels of fishing mortalities using the Thompson and Bell yield prediction model (Sparre & Venema, 1998; Thompson & Bell, 1934). In addition, the Von Bertalanffy growth parameters (L_∞ and K), LWR parameters were as previously described in Equation (1).

The yield in weight per year from the corresponding length class of fish was calculated by multiplying the overall yearly catch in numbers of each length class by the mean weight of the corresponding length class as follows:

$$Y\left(L_i, L_{i+1}\right) = C\left(L_i, L_{i+1}\right).W\left(L_i, L_{i+1}\right) \tag{13}$$

where $Y(L_i, L_{i+1})$ = yield (weight) of fish obtained per year from respective length group; $C\ (L_i, L_{i+}\ 1)$ = total annual catch of fish obtained from respective length group; and $W\ (L_i, L_{i+1})$ = mean weight of each length group estimated with Equation (1).

Further, the mean biomass for each length group $B\ (L_i, L_{i+1})$ was calculated as follows:

$$B\left(L_i, L_{i+1}\right) = \frac{Y\left(L_i, L_{i+1}\right)}{F\left(L_i, L_{i+1}\right)} \tag{14}$$

where $Y\ (L_i, L_{i+1})$ = yield of each length group estimated using Equation (13) and $F\ (L_i, L_{i+1})$ = fishing mortality of respective length group as calculated using Equation (12).

Adding up the individual contributions of each length class yield and biomass provide estimates of the annual total yield and biomass of the fish acquired under the existing level of fishing efforts prolonged on the stock.

The next step of the Thompson and Bell yield projection techniques includes appraisal of the impacts of changes within current fishing levels. This was done by anticipating fish yields at different levels of fishing mortality factor relating to the respective length classes. The predicted values of the current fishing mortality to each length class were used as a reference, being expanded and/or diminished by certain raising coefficients (*F*-factor) to foresee new yield values with respect to the transformed fishing mortalities as follows:

$$N\left(L_{i+1}\right) = N\left(L_i\right) \cdot e^{-Z\left(L_i, L_{i+1}\right)\cdot \Delta t\left(L_i, L_{i+1}\right)} \tag{15}$$

where $N(L_{i+1})$ = population number of length L_{i+1} fish; $N\ (L_i)$ = population number of length L_i fish; $\Delta t\ (L_i, L_{i+1})$ = the time it takes for an average fish to grow from length L_i to length L_{i+1} (as defined with Equation 6). $Z\ (L_i, L_{i+1})$ is the total mortality under the changed fishing level, being was equal to the sum of the changed fishing mortality and natural mortality coefficient as follows:

$$Z\left(L_i, L_{i+1}\right) = F_{new}\left(L_i, L_{i+1}\right) + M \tag{16}$$

where $F_{new}\ (L_i, L_{i+1})$ = transformed fishing mortality factor of each length class and M = natural mortality factor foreseen using Equation (8).

The catch $C(L_i, L_{i+1})$ of respective length groups under the transformed level of fishing mortality was estimated as follows:

$$C\left(L_i, L_{i+1}\right) = \left[N(L_i) - N\left(L_{i+1}\right)\right] \cdot \frac{F_{new}}{Z_{new}} \tag{17}$$

where Z_{new} and F_{new} = the overall mortality and fishing mortality factor, respectively, under the transformed level of fishing pressure. To estimate the predictable yield obtained from respective length groups annually $Y(L_i, L_{i+1})$ under the transformed fishing mortality, the expected catch in number under the transformed fishing level was multiplied by the mean weight of each length group as determined earlier. The overall yearly fish yield to be expected under the changed level of fishing mortality was predicted by adding the contributions of each length class. Similarly, the mean stock biomass under changed fishing mortalities of respective length groups was calculated and summed up.

To determine the maximum optimum fishing effort and sustainable yield, different values of fishing mortalities were assessed, and by examining the complete range of the impact of changing fishing mortalities on the stock (which has a direct relationship with fishing effort), the MSY was recommended.

3 | RESULTS

3.1 | Growth parameters

The length-frequency data of *O. niloticus* used for determination of growth parameters by ELEFAN_SA and ELEFAN_GA comprises sizes ranging from −18 to 56 cm TL for Lake Chamo. Using the 'automatic search routine' within ELEFAN_SA and ELEFAN_GA, it was possible to achieve the best fit for the growth curve from length-frequency data (Table 1).

Using the value of the goodness of fit index (Rn) as a criterion (Gayanilo et al., 2005), it was possible to identify the growth curve that 'best' fits a set of length-frequency data. Accordingly, the growth parameters estimated using ELEFAN-SA were considered as the best fit for the length-frequency *O. niloticus* dataset for Lake Chamo, with estimated L_∞ and K values of 59.41 cm and 0.41/year, respectively, since the value of the goodness of fit index (Rn) 0.27 was higher (Table 1). The length-frequency distribution and computed growth curve produced with those parameters are illustrated over its restructured length distribution (Figure 3). The third parameter of VBGF (t_0) was estimated to be −0.48/year. The Φ' and t_{max} values were 3.24 and 7.32/year, respectively. Using the growth parameters (L_∞, K, and t_0), growth in length at a time (t) was expressed in (Figure 3). [Correction added on 4th September, after first online publication: The citation in "...its restructured length distribution (Figure 2)." is amended to "Figure 3":]

$$L_t = 59.413\left(1 - e^{-0.41(-t(-0.48))}\right).$$

TABLE 1 Estimate of growth parameters using ELEFAN-SA and ELEFAN-GA

Method	L_∞ (cm)	K (year^{-1})	Φ'	Rn
ELEFAN-SA	59.41	0.41	3.24	0.27
ELEFAN-GA	57.80	0.43	3.15	0.20

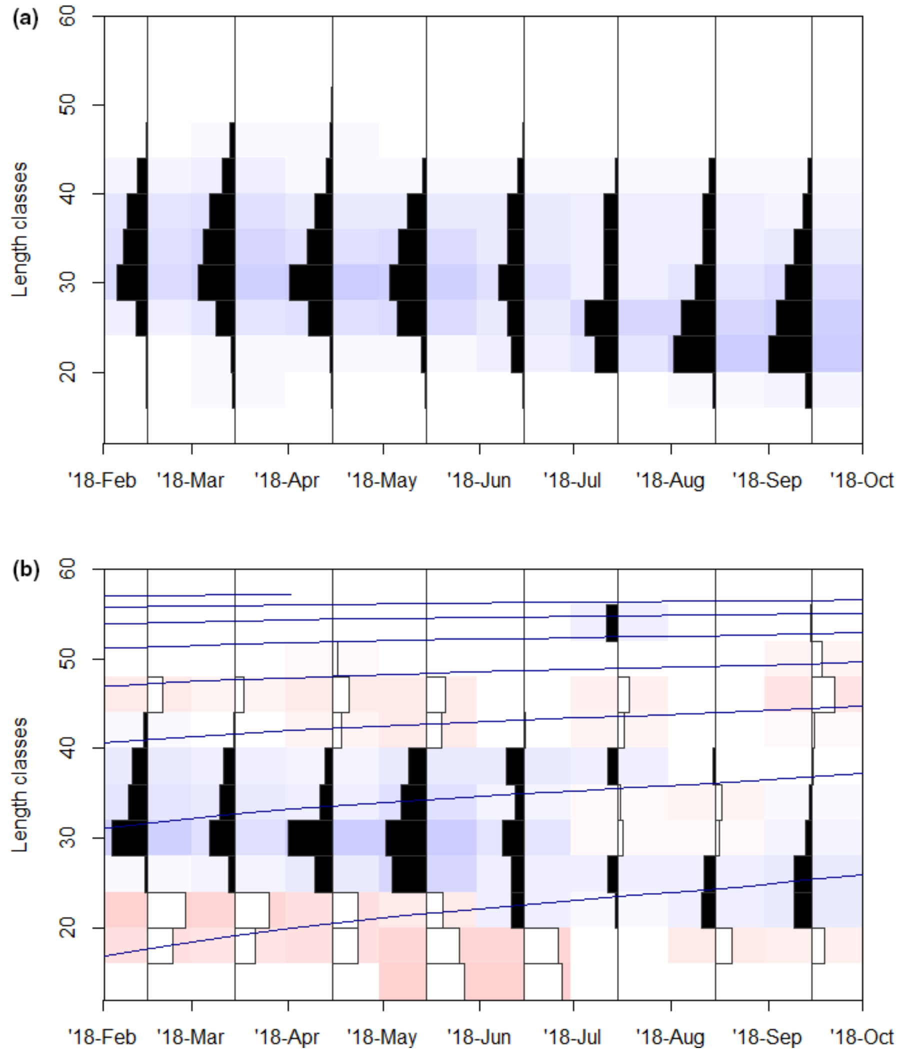


FIGURE 3 Length-frequency distribution and growth curves (LFQ data visualized in terms of (a) catch and (b) restructured data, with moving average setting of MA = 5; line indicates fitted growth curves)

3.2 | Mortality and exploitation rates

The length-converted catch curve with corresponding linear regression was used to estimate the instantaneous total mortality rate (*Z*; Figure 4). Points (ascending left) deviating broadly from the straight regression line were not included in the regression analysis because they were too small to be vulnerable to the fishing gear. The point on the right side of the graph (represented by a green dot) was also not used for the regression analysis because it is considered close to the asymptotic length. Those in the middle part represent size/age groups fully vulnerable to the fishing gear, therefore, being used for the regression analysis.

Accordingly, the estimated instantaneous total mortality rate (*Z*) was 2.442/year, with the correlation coefficient for the regression being 0.96. Using the updated Pauly formula, the natural mortality rate (*M*) was calculated to be 0.558/year. The fishing mortality rate (*F*) was subsequently calculated by subtracting *M* from *Z* and appeared to be 1.884/year during the study period.

The current exploitation rate (*E*) corresponding to fishing mortality (*F*) was estimated to be 0.77. It appears the stock of *O. niloticus* in Lake Chamo exceeds the maximum fishing pressure and the

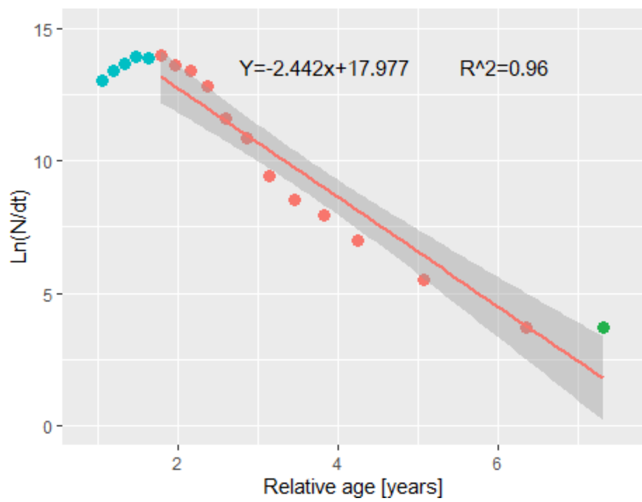


FIGURE 4 Linearized length converted catch curve for *Oreochromis niloticus* in Lake Chamo. (light blue dots represent individuals not fully recruited; green dot on right side is considered to be close to the asymptotic length; red dots in middle represent individuals fully vulnerable to fishing ground)

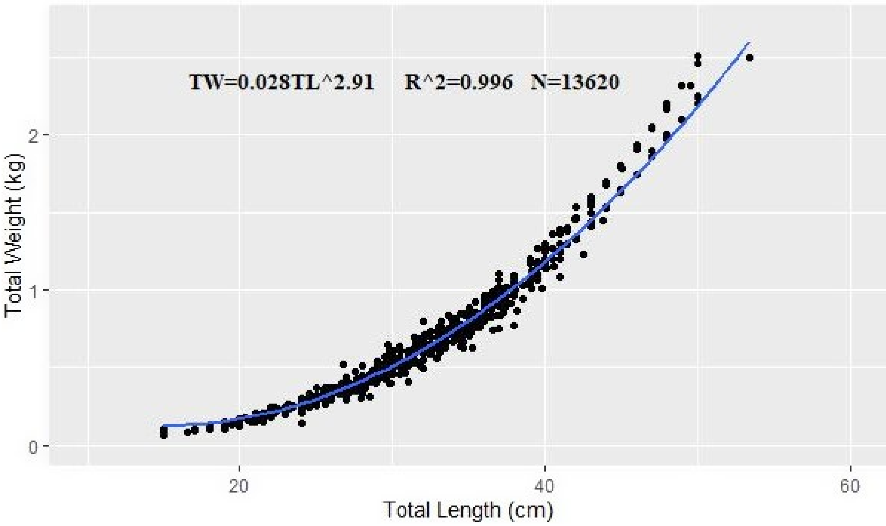


FIGURE 5 Length–weight relationship of Oreochromis niloticus in Lake Chamo

fishing mortality appears to be higher than the optimum pressure. 13,620 specimens were collected throughout the study period. The total length and total weight measurements ranged from 18 to 56 cm and 0.144 to 2.7 kg, respectively. The smallest individual (18-cm TL) was found in June, and the largest one (56-cm TL) was found in July. On the other hand, the smallest weighting tilapia (0.144-kg) was found in June and August, whereas the largest one (2.7-kg) was caught in July. The relationship between the total length and total weight of *O. niloticus* in Lake Chamo was curvilinear and statistically significant ($R^2 = 0.996$, $p < .05$; Figure 5). The regression equation for the unsexed population ($n = 13{,}620$) was $TW = 0.0281\ TL^{2.91}$ (Figure 4). [Correction added on 4th September, after first online publication: The citation for Figure 4 is added in the previous line.]

The coefficient of determination (R^2) value for the relationship was .996, indicating the estimated total weight for the respective length group is 99.6%, related to the measured weight of each length group.

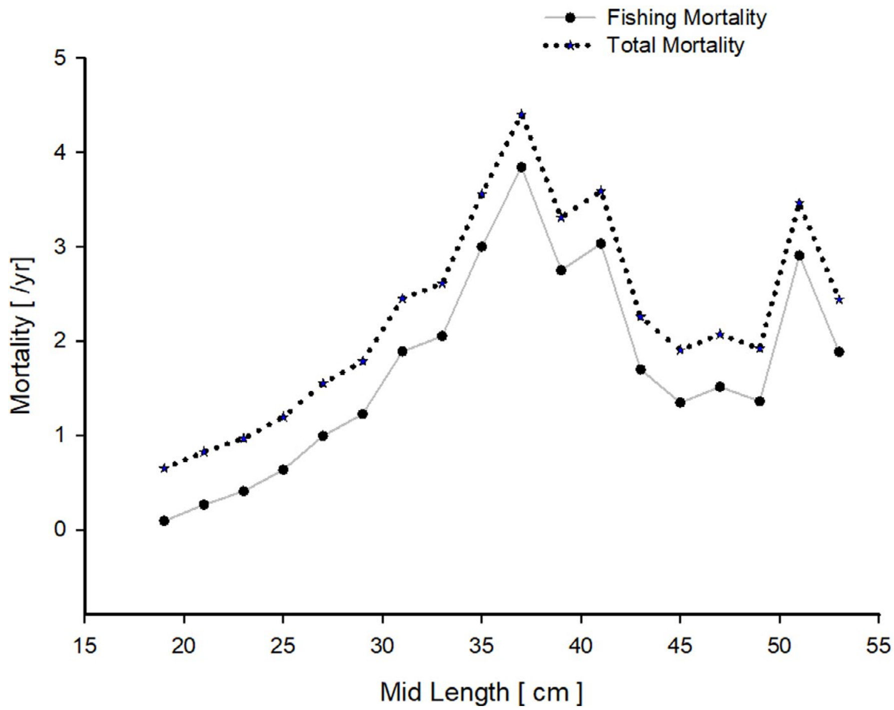
3.3 | Cohort analysis

The population number and fishing mortality coefficient by length group were estimated using the Jones length-based CA. The total

TABLE 2 Estimate of population number, fishing mortalities and other parameters by length group for *Oreochromis niloticus* stock from Lake Chamo

Length group (cm) L_1, L_2	Numbers caught $C(L_1, L_2)$	Natural mortality factor $H(L_1, L_2)$	Population number $N(L_1)$	$\Delta t(L_1, L_2)$	Fishing mortality (year^{-1}) $F(L_1, L_2)$
18–20	19,448	1.0351	2,100,022	0.121	0.09
20–22	59,378	1.0370	1,941,118	0.127	0.27
22–24	86,820	1.0391	1,747,840	0.134	0.41
24–26	124,583	1.0414	1,535,334	0.142	0.64
26–28	170,392	1.0440	1,296,106	0.151	0.99
28–30	173,428	1.0470	1,025,964	0.160	1.23
30–32	202,097	1.0503	770,352	0.172	1.89
32–34	150,589	1.0543	505,864	0.185	2.05
34–36	132,630	1.0588	312,294	0.200	3.00
36–38	81,485	1.0643	153,290	0.218	3.84
38–40	26,363	1.0708	58,772	0.239	2.75
40–42	13,603	1.0788	26,638	0.265	3.03
42–44	3726	1.0888	10,280	0.298	1.70
44–46	1733	1.1018	5249	0.339	1.35
46–48	1097	1.1192	2751	0.394	1.51
48–50	499	1.1438	1216	0.470	1.36
50–52	340	1.1813	493	0.583	2.91
52-∞	324	–	66	–	1.88
Total	1,248,535		11,493,649		

FIGURE 6 Total mortality and fishing mortality



annual fish catch structured by length group was used as basic input data for the analysis (columns 1 & 2 in Table 2). An estimated population of over 11.5 million *O. niloticus* exists in the fished part of the lake, as calculated by summing the population number of the respective length groups in column 4 (Table 2). As estimated by the model, over 2.1 million of *O. niloticus* measuring 18–20 cm were recruited to the fishing ground every year (column 4 in Table 2). The estimated fishing mortality rate (*F*) for the respective length groups was also obtained from the CA (Figure 6).

The calculated F_{terminal} ($F_t = 1.884$), natural mortality ($M = 0.558$) and estimated VBGF parameters ($L_\infty = 59.4$, $K = 0.41$) were used as an input for this analysis. The resulting *F* values are quite variable, ranging from 0.09 to 3.84. Individuals with a length group of 24-∞ were overexploited with $E > 0.5$, with heavy fishing pressures observed on individuals with intermediate length groups around 32–42 (Figure 6). The results of the length-based cohort assessment for Lake Chamo, using the Jones CA of *O. niloticus*, were used as an input in the Thompson and Bell prediction model.

3.4 | Predicted yield and stock biomass

Estimates of the total annual yield and stock biomass of *O. niloticus* (*t*) obtained under the level of fishing effort exerted during the study period are presented in Table 3. The values in columns 1 and 2 are the annual catch of the respective length group of fish, being presented here to illustrate the intermediary calculation steps. Columns 3 and 4 of Table 3 highlight the estimated fishing mortality coefficients and population numbers by length group, being obtained from the Jones length-based CA. The mean weight per length group was estimated using the LWR (Figure 5). The current total yield per year pertaining to the respective length groups were obtained by multiplying the total catch per year of the respective length group by the corresponding mean weight values as depicted by Equation (13). The mean biomass for each length group B (L_i, L_{i+1}) was calculated using Equation (14). Accordingly, the results indicate a stock biomass of 525 *t*/year.

With the output based on the reference F-array (Figure 7), all the basic data were used as an input to predict the yield and stock biomass under different levels of fishing effort or fishing mortality, as well as determining the optimum fishing effort level and corresponding MSY. Different levels of fishing mortalities were evaluated to illustrate the full spectrum of the effects of changing the stock fishing effort (Figure 7). The F-array (Figure 7) was multiplied by each value of *F*-factor to produce the new fishing mortality coefficient for each length group. The yield and biomass values were then predicted using the new F-array (Figure 7). These values were obtained after going through the full procedure of the illustrated computation.

The results indicate the total annual yield increases from 711 *t* for an *F*-factor of 1 to 779-*t* for an *F*-factor of 0.4, while it decreased to 621-*t* and 570-*t* for an *F*-factor of 2 and 3, respectively. The MSY (MSY = 779 *t*) is obtained for an *F*-factor of 0.4. The total stock biomass significantly increased from 527-*t* for an *F*-factor of 1 to 1039-*t* for an *F*-factor of 0.4. The present level of fishing effort is well above the effort indicating the predicted MSY (Figure 7). This result generally indicates the stock is being overfished, with the level of fishing effort exerted at the time of data collection (i.e. 3157 nets/day) is

TABLE 3 Output from length-based Thompson and Bell prediction model for *Oreochromis niloticus* stock from Lake Chamo

Length group (cm) L_1, L_2	Numbers caught $C(L_1, L_2)$	Population number $N(L_1)$	Fishing mortality (year^{-1}) $F(L_1, L_2)$	Mean weight $W(L_1, L_2)$	Yield (tons) $Y(L_1, L_2)$	Mean biomass (tons) $B(L_1,L_2)$
18–20	19,448	2,100,022	0.09	0.144	2.79	29.79
20–22	59,378	1,941,118	0.27	0.192	11.40	42.57
22–24	86,820	1,747,840	0.41	0.250	21.69	52.99
24–26	124,583	1,535,334	0.64	0.318	39.65	62.28
26–28	170,392	1,296,106	0.99	0.398	67.78	68.15
28–30	173,428	1,025,964	1.23	0.489	84.88	69.13
30–32	202,097	770,352	1.89	0.594	120.01	63.47
32–34	150,589	505,864	2.05	0.712	107.20	52.23
34–36	132,630	312,294	3.00	0.844	111.98	37.31
36–38	81,485	153,290	3.84	0.992	80.83	21.03
38–40	26,363	58,772	2.75	1.156	30.46	11.07
40–42	13,603	26,638	3.03	1.336	18.17	5.99
42–44	3726	10,280	1.70	1.534	5.72	3.36
44–46	1733	5249	1.35	1.750	3.03	2.25
46–48	1097	2751	1.51	1.985	2.18	1.44
48–50	499	1216	1.36	2.240	1.12	0.82
50–52	340	493	2.91	2.516	0.86	0.29
52-∞	324	66	1.884	3.215	1.04	0.62
Total	1,248,535	11,493,649			711	525

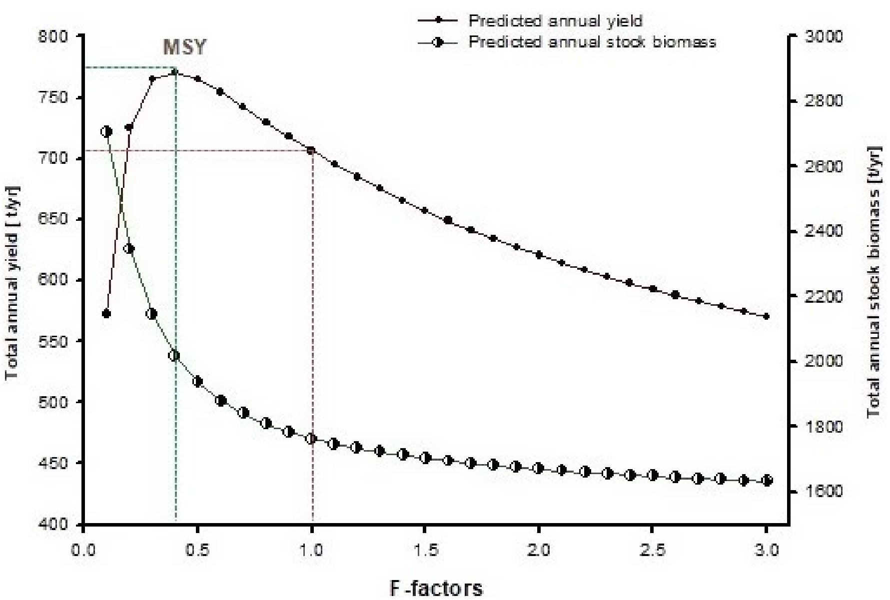


FIGURE 7 Predicted annual yield and stock biomass (tons) at different values of *F*-factors for *Oreochromis niloticus* in Lake Chamo (broken blue and violet lines refer to MSY and current yield, respectively)

beyond the optimum level of effort, thereby suggesting a need to decrease the present *F*-factor by 60% (Figure 7).

4 | DISCUSSION

4.1 | Growth parameters

The estimated growth parameters (L_∞ and K) for *O. niloticus* from Lake Chamo were 59.4 and 0.41/year, respectively. A comparison of these estimated growth parameters with other stocks of the same species from different lakes and reservoirs is provided in Table 4. The L_∞ value attained for Lake Chamo is higher than all the

TABLE 4 Asymptotic length (L_∞), growth coefficient (*K*) and growth performance index (Φ′) of *Oreochromis niloticus* from various regions

Lake/reservoir, country	L_∞	*K* (year^{-1})	Φ′	References
Lake Chamo, Ethiopia	59.4 cm TL	0.41	3.16	Present study
Lake Koka, Ethiopia	44.5 cm TL	0.41	2.90	Tesfaye and Wolff (2015)
Lake Hawassa, Ethiopia	35 cm TL	0.28	2.53	Admassu (1998), Tekle-Giorgis (2002)
Lake Ziway, Ethiopia	28.1 cm TL	0.64	2.76	Tesfaye (2006)
Lake Tana, Ethiopia	35.7 cm TL	0.50	2.80	Wudneh (1998)
Lake Langeno, Ethiopia	32.1 cm TL	0.56	2.71	Tesfaye (2006)
Lake Toho, Benin	42.3 cm TL	0.29	2.70	Montcho et al. (2015)
Lake Kainji, Nigeria	53.2 cm TL	0.29	2.92	Du Feu (2003)
Lake Nasser, Egypt	52.1 cm TL	0.26	2.77	Moreau et al. (1986)
Opa Reservoir, Nigeria	56.7 cm TL	0.26	2.93	King (1997)
Gbedikere Lake, Nigeria	43.8 cm TL	0.32	2.79	Adeyemi et al. (2009)
Nyanza Gulf, Lake Victoria, Kenya	58.8 cm TL	0.59	3.31	Njiru et al. (2006)
Nyanza Gulf, Lake Victoria, Kenya	64.6 cm TL	0.25	3.02	Getabu (1992)
Shallow irrigation reservoir, Sri Lanka	50.7 cm TL	0.64	–	Amarasinghe (2002)
Kaptai Reservoir, Bangladesh	55.6 cm TL	0.39	–	Ahmed et al. (2003)
Victoria Reservoir, Sri Lanka	38.2 cm TL	0.60	–	Moreau et al. (2008)
Minneriya Reservoir, Sri Lanka	43.5 cm TL	0.32	–	Moreau et al. (2008)

TABLE 5 Physical, chemical and chlorophyll-*a* characteristics of Lake Chamo (Utaile & Sulaiman, 2016)

Months	Air temperature (°C)	Dissolved oxygen concentration (mg/L)	Chlorophyll-a concentration (μg/L)	Secchi depth transparency (cm)
March	31.65	5.80	34.00.	23.50
April	28.47	6.56	41.24	17.00
May	27.77	7.00	55.60	13.67
June	31.03	6.03	85.40	18.00
July	28.39	6.63	71.57	20.75
Mean	29.41	6.41	57.57	18.58
SD	±1.67	±0.48	±21.18	±3.74
CV (%)	0.06	0.08	0.37	0.20

Abbreviations: CV, coefficient of variation; SD, standard deviation.

other Ethiopian lakes, indicating *O. niloticus* from Lake Chamo exhibit greater L_∞ values, except for the Nyanza Gulf of Lake Victoria. The rate at which fish size approaches L_∞ is most rapid for *O. niloticus* from Lake Ziway (0.64/year). The estimated growth rate (*K*) for *O. niloticus* from Lake Chamo was similar to that of Lake Koka and Kaptai Reservoir in Bangladesh (0.39/year). However, it was relatively lower than the estimates for Victoria Reservoir in Sri Lanka (0.60/year) and Lake Langeno in Ethiopia (0.56/year). The estimate of *K* in the present study for *O. niloticus* in Lake Chamo was within the range of *K* values for *O. niloticus* investigated by Moreau et al. (1986).

Previous studies indicated growth parameters differ between species and may also vary between stocks within the same species (Sparre & Venema, 1998), with the differences possibly attributable to variation in geographical locations (Amponsah et al., 2016). According to Munro and Pauly (1983), Pauly and Munro (1984) and (Tesfaye & Wolff, 2015), the growth parameters (L_∞ and *K*) were shown to be less meaningful since they can vary even for the same species from different areas, whereas the use of the growth performance index (Φ′) appeared to be better suited for comparing growth intra- and inter-specifically since it integrates over both descriptors of the growth curve.

The estimate of Φ′ for *O. niloticus* in Lake Chamo (3.16) in the present study was higher than all Ethiopian lakes and reservoirs, indicating the *O. niloticus* in Lake Chamo tends to grow better than the population in other lakes and reservoirs. Studies conducted on a screening of *O. niloticus* strains in concrete tanks for their better production from four lakes (Chamo; Koka; Ziway; Hawassa) also confirmed a better growth of *O. niloticus* in Lake Chamo, compared to other investigated populations (Tugie et al., 2017). Moreau et al. (1986) have compared the growth performance of 100 tilapia populations, finding the Φ′ tilapia population is within the range from

2.845 to 3.303, suggesting the growth performance index of the present study is a reliable value.

Apart from the genetic makeup determining the growth potential of a species, the high growth performance index exhibited by *O. niloticus* in Lake Chamo can be attributed to the type and utilization of diet in that the phytoplankton community composition of Lake Chamo differs from that of other lakes (Tadesse, 1998; Teferi et al., 2000). The contribution of feeding to fish growth has been documented by several fishery biologists. Pauly (1982) reported that feeding contributes to growth which, in turn, determines the fish yield. The type of diet and its digestibility has been found to determine the different growth patterns of *O. niloticus* in natural waters (Pullin, 1988). Studies by Moriarty (1973) indicated blue-green algae are the most important food source for *O. niloticus*. Observations on the feeding ecology of *O. niloticus* in Lake Chamo indicated blue-green algae constituted over 60% of their ingested food (Teferi et al., 2000). Thus, it may be one of the factors contributing to the high growth performance in Lake Chamo. Further, the high water temperature of 28°C throughout the year in the lake also promotes the feeding rate and conversion efficiency and, therefore, the high growth performance of the *O. niloticus* stock in the lake.

Another important factor facilitating the excellent growth performance of *O. niloticus* in Lake Chamo is the optimum dissolved oxygen (DO) concentration in the lake (Table 5). There is abundant theoretical and empirical support in the literature for oxygen being both a limiting and controlling factor for the growth of fish and aquatic invertebrates (Amarasinghe & Pauly, 2021; Diaz Pauli et al., 2017; Kolding et al., 2008; Meyer & Schill, 2021; Pauly, 1981, 2019, 2021; Peck & Chapelle, 2003; Pörtner & Peck, 2010; Verberk & Bilton, 2011; Verberk et al., 2011). The gill-oxygen limitation theory (GOLT) proposed by Pauly (1981) provides mechanisms for key biological aspects, including food conversion efficiency, growth and the timing of fish maturation. According to the GOLT principle, the surface area of the gills cannot, as a two-dimensional structure, supply fish with sufficient oxygen to keep up with the growth of their three-dimensional bodies (Pauly, 2021). Thus, a lower relative oxygen supply induces sexual maturation and a subsequent slowing and cessation of growth (Amarasinghe & Pauly, 2021; Meyer & Schill, 2021; Pauly, 2021). Moreover, the desirable DO level for Nile tilapia farming in culture conditions ranges between 3.0 and 8.0 mg/L (Hussain, 2004). DO concentrations higher than 5.0 mg/L are considered optimum for growth (Bhujel, 2013). The recorded minimum and mean DO level (5.8 and 6.41 mg/L, respectively) in Lake Chamo (Table 5) falls within this optimum range, further substantiating the robustness of the estimated growth parameters and computed growth performance index.

4.2 | Mortality and exploitation rates

Growth and mortality rates are very much interrelated. Growth affects the fish's vulnerability to both predation and fishing, and also largely determines the food requirements of each fish (Allen & Hightower, 2010; Tesfaye & Wolff, 2015). The natural fish mortality is attributable to factors not associated with fishing, including predation, competition, cannibalism, diseases, spawning stress, starvation and pollution stress. The higher natural mortality (M = 0.558) observed in the present study could be attributed to a faster growth rate (K). According to Zhang and Megrey (2006), growth and mortality may be correlated in an empirically useful way, with fast-growing fish tending to exhibit higher mortality rates since K is linked to the longevity of the fish which, in turn, is related to its mortality. Zhang and Megrey (2006) further generalized that a long-lived fish approaches its limiting size relatively slowly, whereas short-lived fish grow rapidly. Thus, fish species with high K values usually have high M values and vice-versa. The high natural mortality (M) observed in the present study is comparable with the value of 0.54 reported by Getabu (1992) in his study of *O. niloticus* from the Nyanza Gulf of Lake Victoria. A lower value of natural mortality (M) was observed for Lake Hawassa (0.35; Tekle-Giorgis et al., 2017). The high natural mortality rate observed in the present study could also be attributed to a high number of predatory species in the lake. Ogutu-Ohwayo (1990) confirmed *O. niloticus* was an important prey for *L. niloticus* in Lake Victoria, which might also be true for Lake Chamo. Furher, Dadebo (2009) has reported *O. niloticus* is one of the prey for *C. gariepinus* in the same lake. Thus, since predation is known to be the main cause of natural mortality (M) in wild fish stocks, the high estimate of M for *O. niloticus* is not unexpected.

The Z value was estimated in the present study from length converted catch curves, with the result appearing to be 2.442/year, a value relatively higher than the reported value in the recent study of Tesfaye and Wolff (2015) for Lake Koka, and twice as high as the estimated value of 1.0/year for *O. niloticus* in Lake Hawassa (Tekle-Giorgis et al., 2017). The high total mortality observed in the present study could be linked with intense fishing pressures and a greater value of instantaneous natural mortality (M). Because the highest concentration of fishermen in the lake, which is disproportional to its potential, was observed during the study period, one would expect a higher total mortality rate.

The fishing mortality (F = 1.884/year) in the present study was greater than the natural mortality (M = 0.558/year), contrary to estimates reported by Tesfaye and Wolff (2015), for Lake Koka (F = 0.65/year; M = 0.82), as well as being in agreement with estimates (F = 0.28/year; M = 0.54/year and F = 1.05/year; M = 1.14/year) reported by Getabu (1992) and Yongo and Outa (2016), respectively, for the Nyanza Gulf and Kenyan side of Lake Victoria. The greater value of fishing mortality in Lake Chamo coincides with the fact that *O. niloticus* stock is more susceptible to fishing than natural mortality conditions.

The current exploitation rate was estimated with the Gulland (1971) equation ($E = F/Z$), with the exploitation rate (E = 0.77) indicating the stock of *O. niloticus* of Lake Chamo is under heavy fishing pressures. This assumption is based on the study of Gulland (1971), who stated that sustainable yield is optimized when $F = M$, while the stock is generally considered to be overfished when the value of E

is more than 0.5. Breuil and Damien (2014), also reported overexploitation of the species in Lake Chamo.

4.3 | Length–weight relationship

There was a curvilinear relationship between total weight and total length of *O. niloticus* in Lake Chamo. The total length and total weight for *O. niloticus* in Lake Hawassa and Lake Tana were also related in a curvilinear fashion (Tadesse, 1997; Tekle-Giorgis et al., 2017). The regression coefficient obtained in the present study was close to the cube value ($b = 2.91$). This finding contrasts with that of Njiru et al. (2006) and Costa Novaes and Carvalho (2012), and in line with the reported value by Teferi and Admassu (2002) for the same lake. Thus, the fish may grow isometrically (i.e. an increase in weight at a rate approximately equal to the cube of the increase in length). The regression coefficient values (b) often oscillate between 2.5 and 3.5, depending on the species (Costa Novaes & Carvalho, 2012). Natural intra- and interspecific variation, season, availability of food and reproductive period could have an impact on the regression coefficient (Costa Novaes & Carvalho, 2012).

4.4 | Cohort analysis

The Jones length-based CA (Jones, 1984) is a modification of Pope's age-based CA (Jones, 1984). Based on this analysis, the estimated population abundance of *O. niloticus*, which constitutes the fishery of Lake Chamo in the present study, was 11.5 million fish, which is lower than the estimated population in central Rift Valley Lake Hawassa (14.61 million; Tekle-Giorgis et al., 2017). The estimated annual recruitment rate of *O. niloticus* obtained in the present study was 2.1 million fish of 18–20-cm length, which is closer to the estimates reported by LFDP (1997) for the same lake. Tekle-Giorgis et al. (2017) estimated that an average number of about 3.95 million *O. niloticus* were recruited annually to the fishery, attaining a length of 14–16-cm for Lake Hawassa. Because recruitment is affected by several factors, it varies from year to year. The CA reveals the fishing mortality (F) in the lake is generally high for length groups ranging from 32 to 42-cm and peaks at 36 to 38-cm (Table 2).

4.5 | Predicted yield and stock biomass

Scientific fish stock assessments are a key to fisheries management, providing important information needed for the conservation and management of fish stocks, as well as the elaboration of measures for their sustainable use (Tesfaye & Wolff, 2015). Underexploitation of a fishery may result in reduced socio-economic benefits (Anderson et al., 2012; Hilborn & Walters, 1992), whereas overexploitation can negatively affect the socio-economic benefits and the sustainability of the stock, eventually perhaps leading to the collapse of the stock and possible destabilization of the entire ecosystem (Kuriakose et al., 2017; Tesfaye, 2016).

Based on the previously mentioned concerns, fishery management efforts must seek a balance between overexploitation and underexploitation (Restrepo et al., 1992). The risk of overexploitation is that it will allow fishermen to catch too many fish from a lake, thereby negatively impacting the sustainability of the stock and the fishing industry. The risk of underexploitation is that it may place too many obstacles on the fishermen to catch the fish. Thus, the fishery manager must strike a balance by directly controlling the fishing capacity and/or by setting restrictions on the catch. Accordingly, coincident with the growing emphasis on stock assessment in fisheries management (Begg et al., 1999), the present study focused on the tilapia fishery of Lake Chamo, which is vital to support the livelihoods and well-being of the fishing communities and to maintaining the food supply to the local communities and the growing populations. Based on the present study, it is a source of livelihoods for 3855 households on average. Moreover, the crocodile market, the fishery and the lake as a whole, also serve as a tourism attraction and destination for many local and foreign visitors (LFDP, 1997). The number of fishermen observed in the present study is more than double as comapred with the reported number (353 fishermen with 1150 dependents) by LFDP (1997). Surprisingly, the number of nets deployed in the present study was 2564 nets/day, being seven-fold greater than the observed nets reported by LFDP (1997), caused a dramatic decline in the fish catch attributable to the intensive fishing pressure on the stock over the past two decades. The total fish yield estimated in the present study was about 711 *t*/year, which is also two times less than the reported value by LFDP (1997). The estimated annual stock biomass was 525 *t*/year. The current level of fishing pressure is well above the optimum level of fishing effort. The MSY of the tilapia fishery of Lake Chamo was estimated as 778 *t*/year. To attain the MSY of the lake, the results of the present study (Figure 7) suggest the fishing effort should be reduced by 60%, which can be achieved by reducing the number of fishing gears by one-sixth (1538 nets/day) from the present level, noting the optimal level of fishing effort is about 1026 nets/day, a level that will give a MSY (778 ton/year). The estimated MSY value in the present study was lower than values reported in other studies. For example, the estimated optimum level of fishing effort and corresponding MSY by LFDP(1997) was 255 nets/year and 1577 *t*/year, respectively. Eventhough the impacts of environmental factors such as climatic variability, habitat degradation and pollution in the lake is not well understood, the results of the present study suggest the declining MSY trend, and the reduced annual yield of the fisheries of Lake Chamo, is attributable to overfishing, meaning the exploitation rate of the fishery stock is much faster than the replenishment rate. This affects the ability of the fishery to reproduce (recruitment overfishing) and increases the proportion of fish that did not fully realize their growth potential (growth overfishing) (Froese, 2004). Another common symptom for the occurrence of overfishing in Lake Chamo is a reduced mean length of fish in the catch. Before a decades ago, It was not uncommon to observe tilapia that measured 18–28-cm in the catch (ACP Fish II, 2013). However, currently more than 66% of the fish catch is comprised of the length group <32-cm. This might be occurring because gill nets sometimes operated as seine nets and were dragged in the shallow fishing areas, thereby sweeping the ground and indiscriminately collecting juvenile tilapia, as well as the use of monofilament nets (Breuil & Damien, 2014). Thus, the combined effects of the dramatic increment of fishermen, the number of nets used and the use of illegal fishing gears resulted in overfishing of the Lake Chamo tilapia stock. The part of the lake included in the Nechsar National Park was considered to be a closed area, being patrolled by park personnel every day. In fact, several illegal fishermen were observed in this area during the study period. At least during the study period, practically every part of the lake was being fished. Nevertheless, this part of the lake is under fencing, under the current GIZ initiative, which is a promising action for sustaining the fish stock in the lake since closed areas are one of the most effective management options (Caddy, 1999). Further, the Ethiopian Orthodox Church followers consume more fish during two short periods of the year (2 months between February and April and 2 weeks in August) in total about 80 days. It was further confirmed that the fishing pressure during this period was twice higher than that during the normal period. This peak fishing period coincides with the tilapia breeding season in Lake Chamo (Teferi & Admassu, 2002; Teferi et al., 2000), further causing a declining fish stock.

There is an immense variation in the potential tilapia yield in different water bodies, which might be attributable to the physical, chemical and biological characteristics of the water bodies. Compared to other Ethiopian lakes, the potential and the actual MSY of *O. niloticus* stock in Lake Chamo is higher. This might be attributable to the fish in the lake having access to good quality food (highly digestible) (Tadesse, 1998). The high water temperature of 28°C throughout the year in the lake is also conducive for the fish to digest and absorb food more efficiently than fish in other lakes (Teferi & Admassu, 2002).

Moreover, the lake is less exposed to point source pollution, unlike to other Rift Valley lakes, which might have a positive impact on fish production. However, compared to previous decades fish production it exhibited a dramatic decline, which might be attributable to the intense fishing pressure exerted over the past 20 years that stimulated the decline in the lake.

5 | CONCLUSIONS AND RECOMMENDATIONS

This study provides vital population growth parameters (L_∞, K, t_o, Φ') and total mortality rate, Z, for *O. niloticus* stock of Lake Chamo, estimated from length-frequency data. This serves as baseline information for additional stock assessment works. The estimated growth performance Index (Φ') showed that *O. niloticus* of Lake Chamo has a good potential for aquaculture and provides a basis to compare the growth performance of the species in the lake with other regions. The present study on the status of the stock clearly showed overfishing in the lake, a drastic decline in catches that was lower than MSY, and by effort level much higher than f_{MSY} observed. Based upon our results, we suggested that there should be a reduction in fishing pressure to obtain the maximum yield as well as to ensure the sustainability of ecological and socio-economic benefits that could be gained from tilapia fishery.

Based on the findings of this study, the following recommendations are given for the better management of *O. niloticus* stock in Lake Chamo.

- The ban on fishing in the part of the lake under Nechsar National Park (48 km^2) should be urgently and strictly enforced. Our result suggested that fish populations in this area are under heavy fishing pressure and many illegal fishermen were observed. Thus, a complete ban on fishing in this area would be a management measure important for the park as well as for the fishery cooperatives since it is one of the major breeding sites for *O. niloticus* stock of the lake.
- The use of nets with minimum mesh size should be enforced urgently to protect the capture of immature fish thereby minimizing and eventually controlling growth overfishing of *O. niloticus*.
- A reduction of effort level to about 1026 nets/day is recommended for sustainable utilization of Nile tilapia fishery in Lake Chamo. However, since this might cause unemployment to most fishermen, appropriate measures should be put in place to find alternative means of livelihood such as introduction of aquaculture and beekeeping practices along with the natural patterns of local agro-ecological zones.
- Another option is employing catch limit, in the form of Total Allowable Catches by establishing maximum fishing limits annually as recommended in the above without reduction of the number of fishermen in each cooperative.
- Increasing the awareness of different stakeholders for the effective implementation of regulations and enforcement of fisheries law.

ACKNOWLEDGEMENTS

The authors wish to acknowledge the Austrian Development Cooperation (ADC) and Hawassa University for funding this project. Our special thanks also go to the Lake Chamo fishery cooperatives for their immense help and commitment during data collection at the fish landing sites. Addis Ababa University, Department of Zoological Sciences is also well appreciated for providing necessary materials and collaboration for conducting this research work.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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REFERENCES

Abera, L. (2013). Reproductive biology of *Oreochromis niloticus* in Lake Beseka, Ethiopia. *Journal of Cell and Animal Biology*, *7*(9), 116–120. https://doi.org/10.5897/JCAB2013.0388

ACP Fish II (2013). *Final technical report: Provision of Technical Assistance to review and improve the catch and effort data recording system (CEDRS) and deliver basic training in stock assessment in Ethiopia* (p. 159).

Adeyemi, S., Bankole, N., Adikwu, I., & Akombu, P. (2009). Age, growth and mortality of some commercially important fish species in Gbedikere Lake, Kogi State Nigeria. *International Journal of Lakes and Rivers*, *2*(1), 45–51.

Admassu, D. (1996). The breeding season of tilapia, *Oreochromis niloticus* L. in Lake Awassa (Ethiopian rift valley). *Hydrobiologia*, *337*(1–3), 77–83.

Admassu, D. (1998). *Age and growth determination of Nile Tilapia* Oreochromis niloticus *L. (Pisces: Cichlidae) in some lakes in Ethiopia* (p. 180). PhD Thesis, Addis Ababa University, Ethiopia.

Admassu, D., & Ahlgren, I. (2000). Growth of juvenile tilapia, *Oreochromis niloticus* L. from Lakes Zwai, Langeno and Chamo (Ethiopian rift valley) based on otolith microincrement analysis. *Ecology of Freshwater Fish*, *9*(3), 127–137.

Ahmed, K., Amin, S., Haldar, G., & Dewan, S. (2003). Population dynamics and stock assessment of *Oreochromis niloticus* (Linnaeus) in the Kaptai Reservoir, Bangladesh. *Indian Journal of Fisheries*, *50*(1), 47–52.

Allen, M. S., & Hightower, J. E. (2010). Fish population dynamics: Mortality, growth, and recruitment. In *Inland fisheries management in North America* (3rd ed., pp. 43–79). American Fisheries Society.

Amarasinghe, U. (2002). The fishery and population dynamics of *Oreochromis mossambicus* and *Oreochromis niloticus* (Osteichthyes, Cichlidae) in a shallow irrigation reservoir in Sri Lanka. *Asian Fisheries Science*, *15*(1), 7–20.

Amarasinghe, U., & Pauly, D. (2021). The relationship between size at maturity and maximum size in Cichlid populations corroborates the Gill-Oxygen Limitation Theory (GOLT). *Asian Fisheries Science*, *34*, 14–22. https://doi.org/10.33997/j.afs.2021.34.1.002

Amponsah, S. K., Ofori-Danson, P. K., & Nunoo, F. K. (2016). Fishing regime, growth, mortality and exploitation rates of Scomber Japonicus (Houttuyn, 1782) from catches landed along the eastern coastline of Ghana. *International Journal of Fisheries and Aquatic Research*, *1*(1), 05–10.

Anderson, S. C., Branch, T. A., Ricard, D., & Lotze, H. K. (2012). Assessing global marine fishery status with a revised dynamic catch-based method and stock-assessment reference points. *ICES Journal of Marine Science*, *69*(8), 1491–1500. https://doi.org/10.1093/icesjms/fss105

Assefa, W. W., & Getahun, A. (2015). The food and feeding ecology of Nile tilapia, *Oreochromis niloticus*, in Lake Hayq, Ethiopia. *International Journal of Ecology and Environmental Sciences*, *41*(1–2), 55–65.

Beadle, L. C. (1974). *The inland waters of tropical Africa. An introduction to tropical limnology*. Longman Group Ltd.

Begg, G. A., Friedland, K. D., & Pearce, J. B. (1999). Stock identification and its role in stock assessment and fisheries management: An overview. *Fisheries Research*, *43*(1–3), 1–8. https://doi.org/10.1016/S0165-7836(99)00062-4

Béné, C. (2006). *Small-scale fisheries: Assessing their contribution to rural livelihoods in developing countries* (p. 46). Fisheries Circular No. 1008, FAO.

Beverton, R. J., & Holt, S. J. (1957). *On the dynamics of exploited fish populations. Fishery Investigations, Ministry of Agriculture* (Vol. *19*, p. 533). HMSO.

Bhujel, R. C. (2013). On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Thailand. In M. R. Hasan, & M. B. New (Eds.), *On-farm feeding and feed management in aquaculture* (Vol. *583*, pp. 159–189). FAO.

Breuil, C., & Damien, G. (2014). Baseline report Ethiopia. Smart Fish Programme of the Indian Ocean Commission. In *Fisheries management, FAO component, Ebene, Mauritius* (Vol. *24*). FAO.

Caddy, J. (1999). Deciding on precautionary management measures for a stock based on a suite of limit reference points(LRPs) as a basis for a multi-LRP Harvest Law. *Scientific Council Studies, Northwest Atlantic Fisheries Organization, Dartmouth NS*, *32*, 55–68.

Costa Novaes, J. L., & Carvalho, E. D. (2012). Reproduction, food dynamics and exploitation level of *Oreochromis niloticus* (Perciformes: Cichlidae) from artisanal fisheries in Barra Bonita Reservoir. *Brazil. Revista de Biologia Tropical*, *60*(2), 721–734.

Dadebo, E. (2009). Filter feeding habit of the African catfish *Clarias gariepinus* Burchell, 1822 (Pisces: Clariidae) in Lake Chamo. *Ethiopia. Ethiopian Journal of Biological Sciences*, *8*(1), 15–30.

Dadebo, E., Mengistou, S., & Gebre-Mariam, Z. (2005). Feeding habits of the Nile perch, *Lates niloticus* (L.)(Pisces: Centropomidae) in Lake Chamo, Ethiopia . *SINET: Ethiopian Journal of Science*, *28*(1), 61–68.

Degefu, F., Gashaw, T., & Fikadu, T. (2012). Study on the adaptability status and reproductive success of *Oreochromis niloticus* L. (Pisces: Cichlidae) and carp (*Cyprinus carpio* L., 1758) in a tropic reservoir (Fincha, Ethiopia). *International Journal of Aquaculture* (Vol. *2*, 1st ed., pp. 65–71).

Diaz Pauli, B., Kolding, J., Jeyakanth, G., & Heino, M. (2017). Effects of ambient oxygen and size-selective mortality on growth and maturation in guppies. *Conservation Physiology*, *5*(1), 1–13.

Du Feu, T. (2003). Population parameters for six commercial species in Lake Kainji, Nigeria, using lenght frequency data sampled from artisanal fish catches. In M. L. D. Palomares, B. Samb, T. Diouf, J. M. Vakily, & D. Pauly (Eds.), *Fish biodiversity: Local studies as basis for global interferences* (pp. 31–45). ACP-EU.

Engdaw, F., Dadebo, E., & Raja, N. (2013). Morphometric relationships and feeding habits of Nile tilapia *Oreochromis niloticus* (L.)(Pisces: Cichlidae) from Lake Koka, Ethiopia. *International Journal of Fish and Aquatic Science*, *2*(4), 65–71.

Froese, R. (2004). Keep it simple: Three indicators to deal with overfishing. *Fish and Fisheries*, *5*(1), 86–91.

Gayanilo, F. C., Sparre, P., & Pauly, D. (2005). *FAO-ICLARM stock assessment tools II: User's guide*. FAO.

Gerenfes, D. (2017). *Levels of selected heavy metals in water and fish samples from Abaya and Chamo Rift valley lakes*. MSc Thesis, Haramaya University, Haramaya, Ethiopia.

Getabu, A. (1992). Growth parameters and total mortality in *Oreochromis niloticus* (Linnaeus) from Nyanza Gulf. *Lake Victoria. Hydrobiologia*, *232*(1), 91–97. https://doi.org/10.1007/BF00014617

Gulland, J. (1971). *The Fish Resources of the ocean*: JA Gulland (Compiler & Editor) (pp. 9–52). Fishing News.

Hicks, C. C., & McClanahan, T. R. (2012). Assessing gear modifications needed to optimize yields in a heavily exploited, multi-species, seagrass and coral reef fishery. *PLoS One*, *7*(5), e36022. https://doi.org/10.1371/journal.pone.0036022

Hilborn, R., & Walters, C. J. (1992). Quantitative fisheries stock assessment: Choice, dynamics and uncertainty. *Reviews in Fish Biology and Fisheries*, *2*(2), 177–178.

Hussain, M. (2004). Farming of tilapia: Breeding plans, mass seed production and aquaculture techniques. *Habiba Akter Hussain*, *55*, 1–149.

Jones, R. (1984). *Assessing the effects of changes in exploitation pattern using length composition data (with notes on VPA and cohort analysis)*. FAO.

King, R. (1997). Growth performance of Nigerian fish stocks. *Naga, the ICLARM Quarterly*, *20*(2), 31–35.

Kolding, J., Haug, L., & Stefansson, S. (2008). Effect of ambient oxygen on growth and reproduction in Nile tilapia (*Oreochromis niloticus*). *Canadian Journal of Fisheries and Aquatic Sciences*, *65*(7), 1413–1424. https://doi.org/10.1139/F08-059

Kuriakose, S., Mini, K., & Sathianandan, T. (2017). *Course manual, ICAR-funded summer school on advanced methods for fish stock assessment and fisheries management*. CMFRI.

Le Cren, E. (1951). The length-weight relationship and seasonal cycle in gonad weight and condition in the perch (Perca fluviatilis). *The Journal of Animal Ecology*, *20*(2), 201–219. https://doi.org/10.2307/1540

LFDP (1997). *Lake fisheries development project phase II. Lake management plans. WP23* (2nd ed.). Commission of European Communities(EDF VI) and Fisheries Resources Development Division (MoA), GOPA - Consultants.

Lorenzen, K., Cowx, I. G., Entsua-Mensah, R., Lester, N. P., Koehn, J., Randall, R., So, N., Bonar, S. A., Bunnell, D. B., & Venturelli, P. (2016). Stock assessment in inland fisheries: A foundation for sustainable use and conservation. *Reviews in Fish Biology and Fisheries*, *26*(3), 405–440. https://doi.org/10.1007/s11160-016-9435-0

Mereke, K., & Mulugeta, B. (2016). Prediction of yield and optimum fishing effort for the Nile perch (*Lates niloticus*) stock of Lake Chamo, Ethiopia. *International Journal of Fisheries and Aquatic Studies*, *4*(2), 433–436.

Meyer, K. A., & Schill, D. J. (2021). The Gill-Oxygen Limitation Theory and size at maturity/maximum size relationships for salmonid populations occupying flowing waters. *Journal of Fish Biology*, *98*(1), 44–49.

Mildenberger, T. K., Taylor, M. H., & Wolff, M. (2017). TropFishR: An R package for fisheries analysis with length-frequency data. *Methods in Ecology and Evolution*, *8*(11), 1520–1527.

Montcho, S. A., Agadjihouèdé, H., Montchowui, E., Lalèyè, P. A., & Moreau, J. (2015). Population parameters of *Oreochromis niloticus* (Cichlidae) recently introduced in Lake Toho (Benin, West Africa). *International Journal of Fisheries and Aquatic Studies*, *2*(3), 141–145.

Moreau, J., Amarasinghe, U. S., & Ajith Kumara, P. (2008). Population dynamics of non-exploited and under-exploited fish species in three Sri Lankan reservoirs. In F. Schiemer, D. Simon, U. S. Amarasinghe, & J. Moreau (Eds.), *Aquatic ecosystem and development: Comparative Asian perspectives* (pp. 285–294).

Moreau, J., Bambino, C., & Pauly, D. (1986). Indices of overall growth performance of 100 tilapia (Cichlidae) populations [Africa; Asia]. In J. L. Maclean, L. B. Dizon & L. V. hosillo (Eds.), *The first Asian Fisheries Forum*. Asian Fisheries Society, 201–206.

Moriarty, D. (1973). The assimilation of carbon from phytoplankton by two herbivorous fishes: *Tilapia nilotica* and *Haplochromis nigripinnis*. *Journal of Zoology of London*, *171*, 41–55.

Munro, J., & Pauly, D. (1983). A simple method for comparing the growth of fishes and invertebrates. *Fishbyte*, *1*(1), 5–6.

Njiru, M., Ojuok, J., Okeyo-Owuor, J., Muchiri, M., Ntiba, M., & Cowx, I. (2006). Some biological aspects and life history strategies of Nile tilapia *Oreochromis niloticus* (L.) in Lake Victoria, Kenya. *African Journal of Ecology*, *44*(1), 30–37.

Ogutu-Ohwayo, R. (1990). The decline of the native fishes of lakes Victoria and Kyoga (East Africa) and the impact of introduced species, especially the Nile perch, *Lates niloticus*, and the Nile tilapia, *Oreochromis niloticus*. *Environmental Biology of Fishes*, *27*(2), 81–96.

Pauly, D. (1979). *Gill size and temperature as governing factors in fish growth: A generalization of von Bertalanffy's growth formula*. Christian Albrechts University.

Pauly, D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. *ICES Journal of Marine Science*, *39*(2), 175–192.

Pauly, D. (1981). The relationships between gill surface area and growth performance in fish: A generalization of von Bertalanffy's theory of growth. *Berichte der Deutschen Wissenchaftlichen Kommission für Meeresforschung*, *28*(4), 251–282.

Pauly, D. (1982). Studying single-species dynamics in a tropical multispecies context. In D. Pauly & G.I. Murphy (Eds.), *Theory and management of tropical fisheries*. Proceedings, ICLARM Conference, International Centre for Living Aquatic Resources Manila, Philippines (Vol. *9*, pp. 33–70).

Pauly, D. (1984). Fish population dynamics in tropical waters: A manual for use with programmable calculators. *ICLARM Studies and Reviews*, *8*, 325.

Pauly, D. (2019). *Gasping fish and panting squids: Oxygen, temperature and the growth of water-breathing animals* (Vol. *22*, p. 279). International Ecology Institute.

Pauly, D. (2021). The gill-oxygen limitation theory (GOLT) and its critics. *Science Advances*, *7*(2), eabc6050.

Pauly, D., Christensen, V., Dalsgaard, J., Froese, R., & Torres, F. (1998). Fishing down marine food webs. *Science*, *279*(5352), 860–863.

Pauly, D., & Munro, J. (1984). *Once more on the comparison of growth in fish and invertebrates*. Fishbyte.

Peck, L., & Chapelle, G. (2003). Reduced oxygen at high altitude limits maximum size. *Proceedings, Royal Society of London, Series B: Biological Sciences*, *270*(suppl. 2), S166–S167.

Pörtner, H. O., & Peck, M. (2010). Climate change effects on fishes and fisheries: Toward a cause-and-effect understanding. *Journal of Fish Biology*, *77*(8), 1745–1779.

Pullin, R. S. (1988). *Tilapia genetic resources for aquaculture. Workshop on Tilapia Genetic Resources for Aquaculture, 23-24 March 1987, Bangkok, Thailand, Proceedings, ICLARM Conference* (Vol. *16*, p. 108).

Restrepo, V. R., Hoenig, J., Powers, J. E., Baird, J. W., & Turner, S. C. (1992). A simple simulation approach to risk and cost analysis, with applications to swordfish and cod fisheries. *Fishery Bulletin*, *90*(4), 736–748.

Sparre, P., & Venema, S. C. (1998). *Introduction to tropical fish stock assessment-Part 1: Manual*. FAO.

Tadesse, Z. (1997). Breeding season, fecundity, length-weight relationship and condition factor of *Oreochromis niloticus* L. (Pisces: Cichlidae) in Lake Tana, Ethiopia. *SINET: Ethiopian Journal of Science*, *20*(1), 31–47.

Tadesse, Z. (1998). *Food and feeding ecology of tilapia*, Oreochromis niloticus *L. and effects of diet on the lipid quality of fish in some lakes in Ethiopia*. PhD Dissertation, School of Graduate Studies (p. 139). Addis Ababa University.

Tadesse, Z. (1999). The nutritional status and digestibility of *Oreochromis niloticus* L. diet in Lake Langeno, Ethiopia. *Hydrobiologia*, *416*, 97–106.

Tefera, G. (1993). The composition and nutritional status of the diet of *Oreochromis niloticus* in Lake Chamo, Ethiopia. *Journal of Fish Biology*, *42*(6), 865–874.

Teferi, Y., & Admassu, D. (2002). Length-weight relationship, body condition and sex ratio of tilapia (*Oreochromis niloticus* L.) in Lake Chamo, Ethiopia. *SINET: Ethiopian Journal of Science*, *25*(1), 19–26.

Teferi, Y., Admassu, D., & Mengistou, S. (2000). The food and feeding habit of *Oreochromis niloticus* L. (Pisces: Cichlidae) in Lake Chamo, Ethiopia. *SINET: Ethiopian Journal of Science*, *23*(1), 1–12.

Tekle-Giorgis, Y. (2002*). Comparative age and growth assessment of the African catfish*, Clarias gariepinus *Burchell (Clariidae) and Nile perch*, Lates niloticus, *Linn (Centropomidae) in the three southern Rift Valley lakes of Ethiopia (Lakes Awassa, Abaya and Chamo)* (p. *160*). Unpublished PhD Thesis, Addis Ababa University, Ethiopia.

Tekle-Giorgis, Y., Berihun, A., & Dadebo, E. (2017). Assessment of sustainable yield and optimum fishing effort for the tilapia (*Oreochromis niloticus* L. 1758) stock of Lake Hawassa, Ethiopia. *Momona Ethiopian Journal of Science*, *9*(1), 1–21.

Temesgen, M. (2017). *Status and trends of fish and fisheries in Lake Langeno, Ethiopia* (p. 231). PhD Dissertation, Department of Zoological Sciences, Addis Ababa University, Ethiopia.

Tesfaye, G. (2006). *Population dynamics and stock assessment of Nile tilapia* (Oreochromis niloticus *L.) in three Rift Valley lakes (Koka, Ziway and Langano), Ethiopia*. Universität Bremen, ZMT.

Tesfaye, G. (2016). *Population and ecosystem-based fisheries assessment of the Rift Valley Lake Koka, Ethiopia* (p. 228).Ph.D Dissertion, Universität Bremen, Germany.

Tesfaye, G., & Tadesse, Z. (2008). Length-weight relationship, Fulton's condition factor and size at first maturity of tilapia, *Oreochromis niloticus* L. in lakes Koka, Ziway and Langano (Ethiopian Rift Valley). *Ethiopian Journal of Biological Sciences*, *7*(2), 139–157.

Tesfaye, G., & Wolff, M. (2014). The state of inland fisheries in Ethiopia: A synopsis with updated estimates of potential yield. *Ecohydrology & Hydrobiology*, *14*(3), 200–219.

Tesfaye, G., & Wolff, M. (2015). Stock assessment of fishery target species in Lake Koka, Ethiopia. *Revista de Biologia Tropical*, *63*(3), 755–770.

Then, A. Y., Hoenig, J. M., Hall, N. G., & Hewitt, D. A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on over 200 fish species. *ICES Journal of Marine Science*, *72*(1), 82–92.

Thompson, W. F., & Bell, F. H. (1934). *Biological statistics of the Pacific halibut fishery 2. Effects of changes in intensity upon total yield and yield per unit of gear. Report of International Fisheries (Pacific halibut). Commission* (Vol. *8*, p. 49).

Tugie, D., Endebu, M., Hailu, D., & Lema, A. (2017). Screening of *Oreochromis niloticus* strains for their important production traits in high stocking density and low CP feed quality without aerating devices in concrete tanks, Batu, Oromia, Ethiopia. *International Journal of Fisheries and Aquatic Research*, *2*(6), 07–10.

Utaile, Y., & Sulaiman, H. (2016). Assessment of water quality parameters of Lake Chamo implications for freshwater fishes, Gamo Gofa Zone, Southern Ethiopia. *Journal of Hill Agriculture*, *7*(2), 237–241.

Verberk, W. C., & Bilton, D. T. (2011). Can oxygen set thermal limits in an insect and drive gigantism? *PLoS One*, *6*(7), e22610.

Verberk, W. C., Bilton, D. T., Calosi, P., & Spicer, J. I. (2011). Oxygen supply in aquatic ectotherms: Partial pressure and solubility together explain biodiversity and size patterns. *Ecology*, *92*(8), 1565–1572.

Wudneh, T. (1998). *Biology and management of fish stocks in Bahir dar Gulf, Lake Tana, Ethiopia* (p. 144). PhD Dissertation, Wageningen University, The Netherlands.

Yongo, E., & Outa, N. (2016). Growth and population parameters of Nile tilapia, *Oreochromis niloticus* (L.) in the open waters of Lake Victoria, Kenya. *Lakes & Reservoirs: Research & Management*, *21*(4), 375–379.

Zhang, C.-I., & Megrey, B. A. (2006). A revised Alverson and Carney model for estimating the instantaneous rate of natural mortality. *Transactions of American Fisheries Society*, *135*(3), 620–633.

How to cite this article: Tesfaye, M., Tesfaye, G., & Getahun, A. (2021). Growth and status of Nile tilapia (*Oreochromis niloticus* L.) stock in Lake Chamo, Ethiopia. *Lakes & Reservoirs: Research & Management*, 26, e12375. https://doi.org/10.1111/lre.12375