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# Length-based estimates of growth parameters and mortality rates of Nile Tilapia (*Oreochromis niloticus*, L. 1758) in Lake Abaya, Southern Ethiopia

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Exploitation rate;

Growth parameters;

Lake Abaya;

Length at maturity;

Mortality rates;

Recruitment

## ABSTRACT

The Nile tilapia, *Oreochromis niloticus*, is one of the most commercially important fish species in Ethiopia. Effective management is essential to sustaining their fisheries and providing benefits for the local communities. The study was aimed at determining the basic population characteristics (growth, mortality rates, and recruitment), size at first maturity, length at first capture, and stock status of *O. niloticus* in Lake Abaya. These basic quantitative population characteristics enable a fisheries manager to identify population changes resulting from fishing. The parameters were determined using length frequency data collected from 4089 samples of *O. niloticus* ranging from 23 to 47 cm in total length. The total length (TL) and total weight (TW) of *O. niloticus* samples were gathered between September 2021 and August 2022. The length-weight relationship parameters were ($TW = 0.0157TL^{3.0192}$, $R^2 = 0.9603$) and the condition factor $K$=1.69. The population parameters were determined using the ELEFAN I routine in FiSAT software. Estimated von Bertalanffy growth parameters were ($L\infty$) = 49.35 cm, growth curvature (k) = 0.36 $yr^{-1}$, age at length zero ($t_o$) = -0.40, and growth performance index (Φ') = 3.0.The estimated values of total natural and fishing mortalities were $Z$= 1.34 $yr^{-1}$, $M$ =0.34 $yr^{-1}$,and $F$= 1.0 $yr^{-1}$, respectively. The current exploitation rate ($E$) was0.74, which is higher than the optimal ($E$ = 0.5) and indicates that *O. niloticus* in Lake Abaya was overexploited. In order to maintain the sustainability of the fish population, it is advised that the local authorities establish regulations for the management of *O. noloticus* in Lake Abaya. These regulations should include protecting the use of small fishing gear and safeguarding fish that are caught smaller than their length at first maturity.

## INTRODUCTION

The growth parameters of fish populations can be determined through direct readings of hard structures (otoliths, spines, or vertebrae) and indirect estimates based on length distribution data over time (Gayanilo *et al.*, 2002; Panfili *et al.*, 2002). Length-based stock assessment tools are relatively more useful in tropical and sub-tropical waters since the seasonal differences in the hard structures of these relatively warm waters are subtle and often present unclear band marks (Sparre and Venema, 1992; Panhwar and Liu, 2013).

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The analysis of fish stock population dynamics in tropical environments was made easier by the introduction of relative growth models and length-based stock assessment approaches (Huxley, 1993; Froese and Binohlan, 2000). These techniques were used to evaluate life-history theories and produce empirical estimates of pertinent biological and fisheries parameters, including longevity and length at first maturity (Stergiou, 2000; Froese and Binohlan, 2000). Additionally, it aids in forecasting fish population exploitation, which could be useful in choosing between different management options (da Costa and Araújo, 2003; Froese, 2006; Garcia and Duarte, 2006; da Costa *et al*., 2014; Sá-Oliveira *et al*., 2015).

Fish population biology and ecology are reflected in growth and mortality factors, which are crucial for modeling fish stock population dynamics. These metrics, which offer important information on the fluctuation of fish size over time and the reduction in population biomass owing to fishing and/or natural causes, are essential inputs for stock assessments (Pauly, 1983; Sparre and Venema, 1998).

Lake Abaya is one of the Rift Valley lakes in Ethiopia. Currently, this lake is the 4$^{th}$ most important in the country in terms of fisheries, contributing about 8% of capture fisheries to national and local markets (Gashaw and Wolff, 2014). About four commercially important fish species are in Lake Abaya: Nile tilapia (*Oreochromis niloticus*), Nile perch (*Lates niloticus*), African catfish (*Clarias gariepinus*), and *Bagrus docmac*.

These fish species are used as a source of income and livelihood for fishing communities in Lake Abaya. *Oreochromis niloticus* is the most important fish species and has a great contribution to the annual catch and yield of total landings. Due to high demand for fish food and market prices, the fishing process takes place throughout the year with heavy fishing pressure and a continual trend of yield reduction. The current state of knowledge regarding the life history and population dynamics of *O. niloticus* stock in Lake Abaya is lacking, despite the lake's considerable ecological and socioeconomic significance. A good understanding of fish population dynamic show mortality, growth, and recruitment interact to affect abundance is required for informed fisheries management.

Even though significant stock assessment and population dynamics studies of *O. niloticus* stocks have been carried out in Lakes Tana (Workiye *et al*., 2019), Chamo (Buchale *et al*., 2019; Million Tesfaye *et al*., 2021), Hawassa (Yosef *et al*., 2017), and Langeno (Genanaw *et al*., 2022), there is no comparable data regarding economically significant fish species in Lake Abaya. Therefore, the present study was aimed at determining the basic population parameters (growth, mortality rates, and recruitment), size at first maturity, length at first capture, and stock status of *O. niloticus* in Lake Abaya. The results can provide baseline information for fishery managers and scientists to design fishery exploitation and management strategies for further exploration of *O. niloticus* stock in the lake.

## MATERIALS AND METHODS

### Study area

Lake Abaya is the second-largest lake in Ethiopia after Lake Tana, a highland lake, and one of the two southernmost Rift Valley lakes. It is situated in South Ethiopia Regional State, between 5°55'9'' and6°35'30'' N latitude and 37°36'90'' and 38°03'45'' E longitude (Fig. 1). The lake is 60 km long and 20 km wide, with a surface area of 1160 square kilometers. It has a maximum depth of 13 m and is found at an elevation of 1268 m, which makes it the largest Rift Valley Lake. This lake contains several islands, the greatest of which is Aruro; the others are Gidicho, Welege, Galmaka, and Alkali. Its southwest shore is home to the village of Arba Minch, while the southern banks are part of Nech Sar National Park. The principal perennial rivers that enter Lake Abaya are the Harre, Hamassa, Bilate, Gidabo, and Galana rivers.

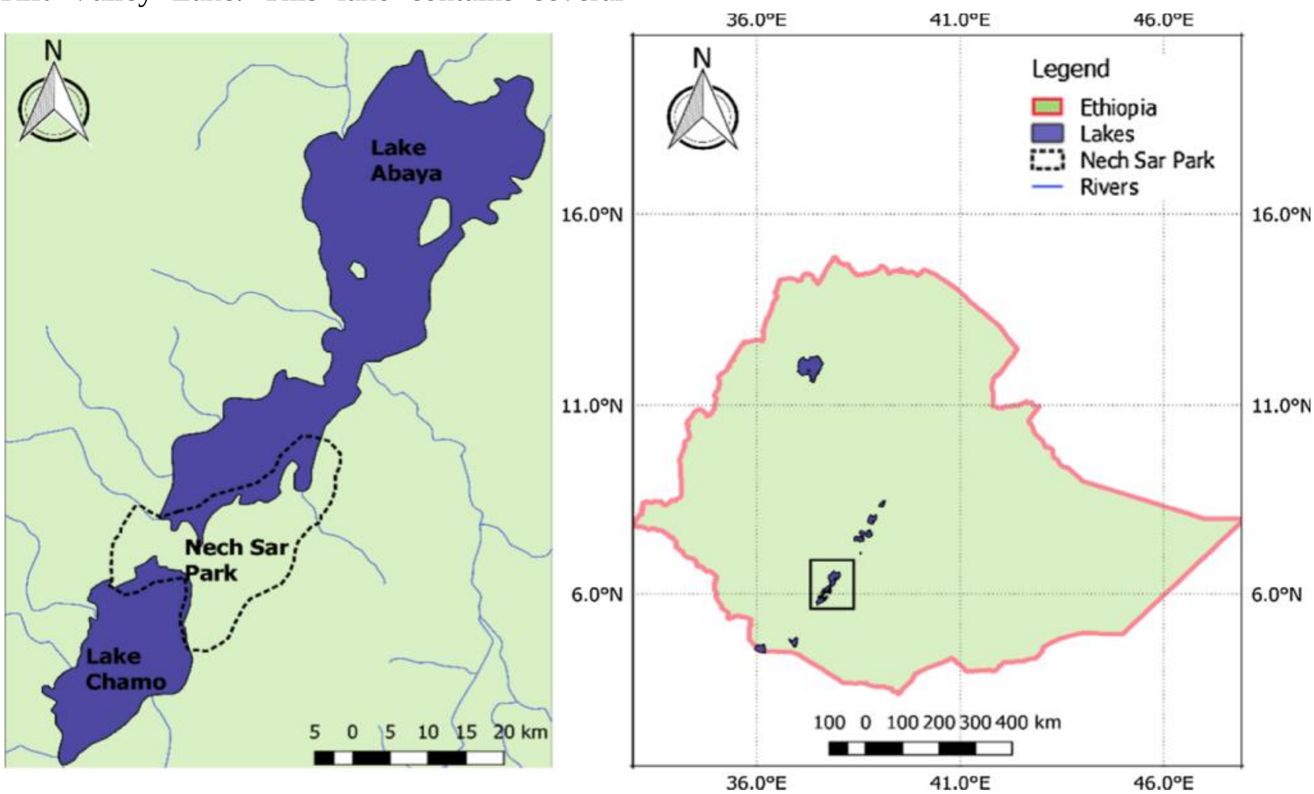


**Figure 1. Outline map of Ethiopia with a detailed view on Lake Abaya and Chamo (Shape file downloaded from [www.maplibrary.org](http://www.maplibrary.org))**

**Methods of sampling and data collection**

Samples of *O. niloticus* were gathered from three cooperatives engaged in commercial fishing in Lake Abaya. From September 2021 to August 2022, samples of *O. niloticus* were randomly collected for 12 days each month at four commercial fishing landing sites (Ella, Hillo, Langama, and Gubena). Employing a measuring board and a sensitive electronic balance, the total length and total weight of fresh fish samples were determined to the nearest 0.1 cm and 0.1 g, respectively. Apart from the visual identification of sex by the examination of the gonads and abdominal dissection, sex was also identified by external features.

**Data analysis**

***Length-weight relationship and condition factor***

The length-weight relationship was calculated using the power function described by Le Cren(1951).

$$TW = a \quad ^{b}\text{--------------------- [1]}$$

Where**,**
*TW* = total weight (g), *a* = the intercept, TL =total length (cm), and *b* = the slope of length-weight regression

The Fulton's condition factor (*K*) is often used to reflect the nutritional status or well-being of an individual fish. It was calculated using the formula described by Fulton (1904), which is indicated below.

$$K = \frac{T}{T^{\ 3}} * 100 \text{ ---------------------- [2]}$$

Where**,**
*K* = Fulton's condition factor
TW = total weight of fish in grams (g)
TL = total length of fish in (cm)

***Estimation of growth parameters***

The FiSAT II, ELEFAN I software's K-scan technique was employed to evaluate the asymptotic length (L∞) and growth rate (K) based on the length frequency data. Using Pauly's empirical formula (Pauly, 1979), the theoretical age at zero ($t_o$) was computed.

$$\text{Log } (-t_0) = -0.3922 - 0.2752 * L \quad (L\infty) - 1.038 * \text{Log}(k)\text{---------------- [3]}$$

Where,

$t_o$= is the theoretical age at which fish would have at zero length.
L∞ = asymptotic length, k= von Bertalanffy growth constant
Growth performance indexes were calculated by Munro and Pauly(1984):

$$\Phi' = L \quad (k) + 2 * L \quad (L\infty)\text{--------- [4]}$$

Where, Φ′ = growth performance index, k and L∞ are defined above

The length at first maturity ($L_{50}$) was computed as Froese and Binohlan's (2000) equation:

$$\text{Log}(L_{50}) = 0.8979 * L \quad (L\infty) - 0.0782\text{---- [5]}$$

The longevity (A0.95)of the cohort was computed as (Spare and Venema, 1997).

$$A0.95 = to + \frac{2.9}{K}\text{------------------------------- [6]}$$

Where,
A0.95 is the age at which 95% of the cohort would be dead as a result of natural means;

$t_o$ = is the theoretical age at which fish would have at zero length;

k = Von Bertalanffy growth constant

***Estimated mortality parameters***

Sparre and Venema (1992) state that the total mortality (*Z*) was estimated using a linearized length-converted catch curve. The natural mortality coefficient (*M*) was computed as follows using Taylor's method:

$$M = \frac{-\ln(1-0.95)}{A0.95}\text{-----------------------------[7]}$$

A0.95 indicates the age at which 95% of the population would die from natural causes. The calculation of the fishing mortality ($F$) was done by Qamar *et al*. (2016).

$$F = Z - M \quad [8]$$

Where, $F$ = fishing mortality, $Z$ = total mortality, and $M$ = natural mortality.
The exploitation rate ($E$) was calculated as (Georgiev and Kolarov, 1962).

$$E = \frac{F}{Z} \quad [9]$$

The length at first capture (Lc) was estimated from the equation of Beverton and Holt (1957), which applies the growth constants of vBGF, the mean length of the fish catch ( $\bar{L}$), and the total mortality parameter (Z):

$$L_C = \bar{L} - k\left(\frac{L\infty - \bar{L}}{Z}\right) \quad [10]$$

The length at optimum cohort biomass or yield pre-recruitment ($L_{opt}$) was estimated from L∞, K, and M using the Beverton (1992) formula:

$$L_{opt} = L\infty * \left(\frac{3}{3+\frac{M}{K}}\right) \quad [11]$$

Where, L∞, K, and M are as defined above.

## RESULTS AND DISCUSSIONS

### Length-weight relationship and Fulton's condition factor

The present study is conducted on a total sample of 4089 specimens (2344 females and 1745 males) of *O. niloticus*. The monthly pooled length-frequency data of *O. niloticus* specimens were grouped into two-centimeter intervals. The obtained fish samples had lengths ranging 23 to 47 cm (mean = 35 cm) and weights ranging from 190 to 1676 g (mean = 933 g). However, 97.6% of the catches were placed in the 25-41 cm range. The remaining 1% and 1.4% were less than 25cm and greater than 41cm, respectively. The most commonly observed value was the mid-length of 28 cm, which was followed by the length groups of 30 and 32 cm (Fig.2).

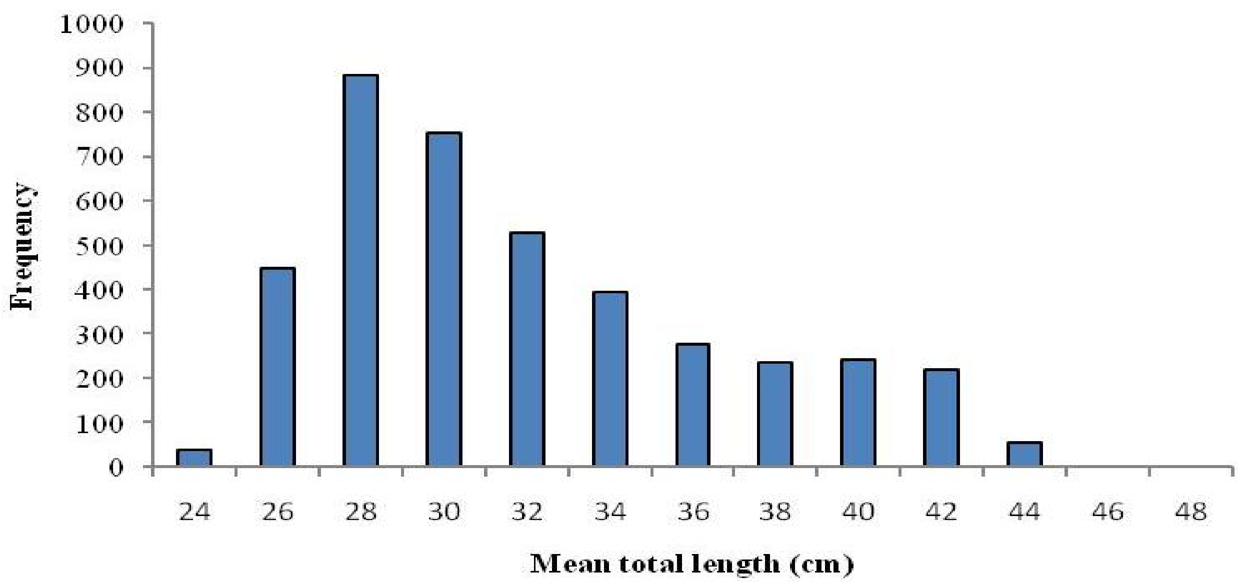


**Figure 2: Size structure of *O. niloticus* in Lake Abaya.**

When comparing, the maximum total length (47cm) observed in the present study is relatively smaller than those reported for the same fish in Lake Chamo: 57 cmTL (Yirgaw *et al.*, 2000) and 53.4 cm TL (Buchale *et al*., 2019), 48.5 cm TL in Gilgel Gibe I Reservoir (Mulugeta, 2013), and 48 cm TL in Alwero Reservoir (Genanaw *et al.*, 2017). However, the observed maximum length for *O. niloticus* in Lake Abaya is larger than those in Lake Langeno, 35.5 cm TL (Genanaw *et al*., 2022), Lake Beseka (25.0 cm TL), and Lake Hawassa (29.0 cm TL) (Yosef *et al*., 2017). Fishing typically reduces fish size structures due to fishing gear selectivity and leads to fisheries-induced evolution toward smaller sizes and earlier maturity (Borrell, 2013). Fish undergo a reduction in size and early maturation to replenish themselves before being eliminated by fishing when fishing pressure increases dramatically.

The relationship between total length and body of *O. niloticus* was established with the use of a scatter plot diagram and power function (Fig. 3). The relationship was described by the equation $TL = 0.0157TL^{3.0192}$($R^2$ = 0.9603, r = 0.9799). A strong positive correlation was found between the length and weight of the *O. niloticus* population in Lake Abaya, as indicated by the correlation coefficient (r = 0.9799). The regression coefficient "b" was found to be 3.0192 when utilizing the best-fit power function regression to analyze the length-weight relationship. The power of the formula did not show a statistically significant deviation from the 3.0 hypothetical value($P > 0.05$).

This study showed an isometric growth of fish and a strong correlation between length and weight, as evidenced by the exponential value (*b* = 3.0192) and correlation coefficient (r = 0.9799), respectively. Fish can grow in three different ways during their lives: isometric (*b* = 3), negative allometric (*b*< 3), or positive allometric (*b*> 3), depending on the deviation of *b* (Nehemia and Maganira, 2012). When “*b*” is greater than 3, the fish increase in weight more than an increase in length, whereas if it is less than 3, the fish becomes lighter for its weight. However, in an isometric growth scenario, the fish maintains its body form as it grows longer (Riedel *et al*., 2007). The growth pattern of *O. niloticus* in Lake Abaya was isometric, based on the "*b*" value found in this investigation.

The length-weight relationship of *O. niloticus* was found to be similar in some of the earlier studies: 3.03 in Lake Ziway (Zenebe, 1988); 3.04 in Lake Langeno (Gashaw and Zenebe, 2008); 3.017 in the River Nile (Shalloof and El-Far, 2017); 3.034 in the Aulia Dam (Ahmed and Abdel, 2016); and 3.09 in the Lake Victoria cage system (Ngodhe and Owuor, 2019).

On the other hand, some of the previously reported studies showed positive allometric length-weight relationships of *O. niloticus* were 3.18 in Lake Chamo (Buchale, 2020), 3.16 Lake Victoria (Ngodhe and Owuor, 2019), 3.19 in Lake Ziway (Gashaw and Zenebe, 2008), and 3.366 in Lake Naivasha (Keyombe *et al*., 2017) while, 2.33 in Lake Naivasha (Cishahayo *et al*., 2022), 2.89 in Lake Langeno (Genanaw *et al*., 2022), 2.76 in Alwero Reservoir (Genanaw *et al.*, 2017), and 2.934 in Lake Ardibo (Endalk *et al*., 2018) were some of the negative allometric length-weight relationships of *O. niloticus*.

The value of *b* can vary annually due to a variety of factors, such as season, habitat, gonad maturity, sex, nutrition, stomach fullness, health, preservation techniques, and environmental circumstances (Bagenal and Tesch, 1978; Arslan *et al*., 2004; Froese, 2006; Yilmaz *et al*., 2012; Ali *et al*., 2016). Furthermore, variations in fish growth patterns could also be related to the species' condition, phenotype, environment, and specific geographic region (Tsoumani *et al*., 2006).

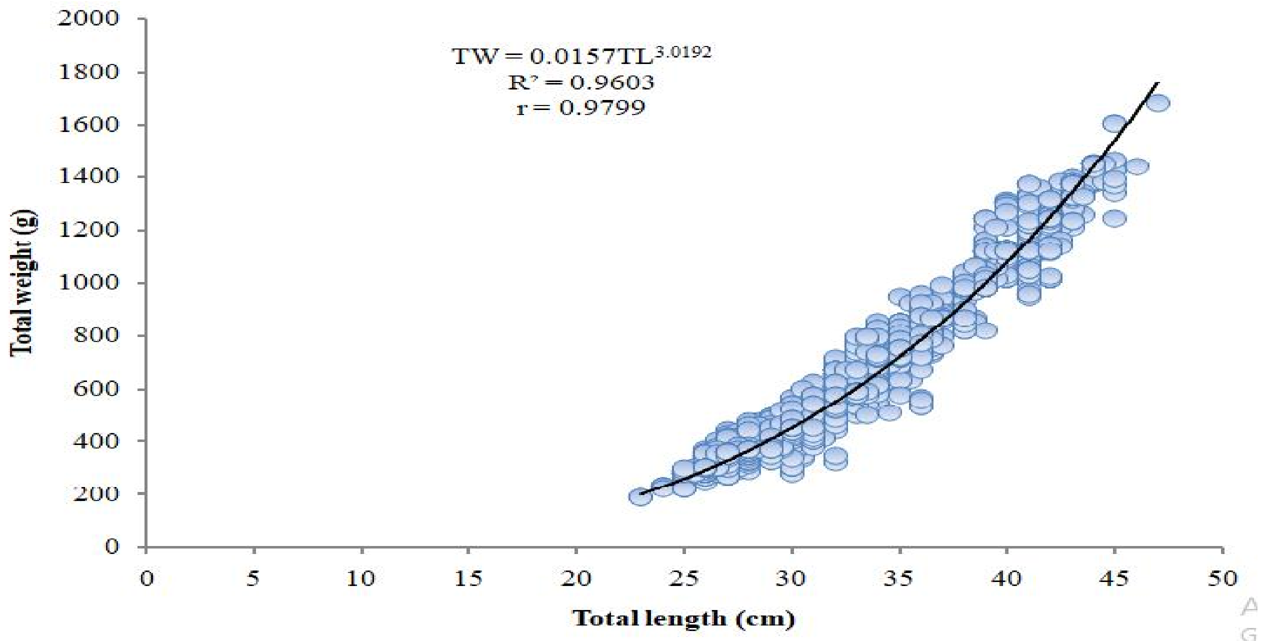


**Figure 3: Length-weight relationship of pooled *O. niloticus* in Lake Abaya.**

**Fulton's condition factor**

As shown in Table 1, the monthly mean values of Fulton's condition factor (K) for females, males, and combined sexes ranged from 1.58 to 1.77. For females, males, and combined sexes, the average K value was 1.70, 1.68, and 1.69, respectively. In *O. niloticus* of Lake Abaya, there was statistically no significant variation in K between the sexes or with the month's interaction (P > 0.05).

The condition factor is a metric that represents the fish's physiological state with respect to feeding, spawning, and other elements of their overall health. According to Blackwell *et al.* (2000), high condition factor values imply advantageous environmental conditions (such as habitat and prey availability), while low values suggest less favorable environmental conditions. The ecological habitat of fish species can be evaluated using the condition factor, which is also highly influenced by biotic and abiotic environmental factors (Ayoade, 2011; Onimisi and Ogbe, 2015; Abu and Agarin, 2016).Five categories were created by Morton and Routledge (2006) based on the K values: very bad (0.8–1.0), bad (1.0–1.2), balance (1.2–1.4), good (1.4–1.6), and very good (> 1.6). However, according to Ayoade (2011), a fish in good health has a condition factor greater than one.

In the present study, the average value of the condition factor was 1.70, 1.68, and 1.69 for females, males, and combined sexes, respectively. As previously mentioned, the condition factor in this study was more than 1.6, indicating that *O. niloticus*in Lake Abaya is doing quite well.

**Table 1. Mean monthly condition factor of females, males and combined *O. niloticus***

| Months | Females | Males | Combined sexes |
|---|---|---|---|
| Sep-21 | 1.58 | 1.60 | 1.58 |
| Oct-21 | 1.68 | 1.66 | 1.67 |
| Nov-21 | 1.63 | 1.63 | 1.63 |
| Dec-21 | 1.61 | 1.59 | 1.60 |
| Jan-22 | 1.67 | 1.62 | 1.65 |
| Feb-22 | 1.71 | 1.69 | 1.70 |
| Mar-22 | 1.73 | 1.67 | 1.70 |
| Apr-22 | 1.71 | 1.71 | 1.71 |
| May-22 | 1.77 | 1.75 | 1.76 |
| Jun-22 | 1.76 | 1.72 | 1.74 |
| Jul-22 | 1.77 | 1.77 | 1.77 |
| Aug-22 | 1.75 | 1.75 | 1.75 |
| Average | 1.70 | 1.68 | 1.69 |

**Estimated growth parameters**

The *O. niloticus* in Lake Abaya was predicted to have von Bertalanffy growth parameters of asymptotic length (L∞) and annual growth constant (k) of 49.35 cm and 0.36 $yr^{-1}$, respectively. The estimated theoretical age at birth ($t_o$) was -0.40. The longevity (A0.95), the age at which 95% of the population would be dead as a result of natural means, was 8.72 years. The growth performance index Phi (*Φ*') was estimated at 3.0 (Fig. 4).

The estimated value of L∞ in this study was lower than the estimates from the studies in Lakes Chamo, 55.0 cm (Buchale *et al*., 2019), and Victoria, 58.8 cm (Njiru *et al*., 2004). However, compared to Lakes Langeno (35.7 cm; Genanaw *et al*., 2022), Tana (44.1 cm; Workiye *et al*., 2019), Victoria (46.24 cm; Yongo *et al*., 2018), Koka (44.5 cm; Gashaw, 2016), and Naivasha (42.0 cm; Waithaka *et al*., 2020), the L∞ in this study was higher.

It is possible that the various water bodies' varying environmental conditions account for the differences in estimations of the von Bertalanffy growth parameters (L∞ and k) when compared to similar research. The size of the population and the ways in which fish adjust throughout their lives are other elements that influence growth. As noted by Sparre and Venema (1998), this could potentially vary throughout stocks and species and be impacted by various methods of analysis. Similar species can have different growth rates in different habitats (Lowe-McConnell, 1982). The length characteristics ($TL_{max}$ and L∞) may be influenced by genetics, resource availability, and population density. The fishing pressure is also a factor for change in the asymptote length (L∞) of fish in a given water body. If fishing gear is selective and oriented toward harvesting larger individuals, large individuals may become rare in overexploited fisheries, and the scarcity of these individuals in a given sample will certainly underestimate growth parameters.

In comparison to Lakes Langeno, 2.61 (Genanaw *et al*., 2022), Ziway, 2.76 (Gashaw, 2006), and Naivasha, 2.57 (Waithaka *et al*., 2020), the estimated growth performance index (*Φ'* = 3.0) in the current study was greater. On the other hand, the index in the present study was lower than in Lakes Chamo, 3.16 (Million *et al*., 2021), and Victoria, 3.14 (Yongo *et al*., 2018). The most effective method for determining the average growth parameters of a particular species is to use the growth performance index, which should show comparable values when comparing several groups within the same species (Gulland, 1983; Sparre and Venema, 1998). The availability of food, environmental factors, and fishing pressures can all have an impact on a fish species' growth performance index, in addition to the genetic composition that dictates the species' potential for growth (Getabu, 1992).

*O. niloticus* in Lake Abaya had an approximate lifespan of 8.72 years, which is comparable to the lifespan of *O. niliticus* in Lake Langeno, 8.9 years, as indicated in Genanaw *et al*. (2022). Both biological elements and environmental factors can have an impact on lifespan. Fish life spans are significantly influenced by a variety of biological criteria, including sex, genetic makeup, diet, reproduction, age, and maturation, in addition to environmental influences including salinity, temperature, and predation (Das, 1994).

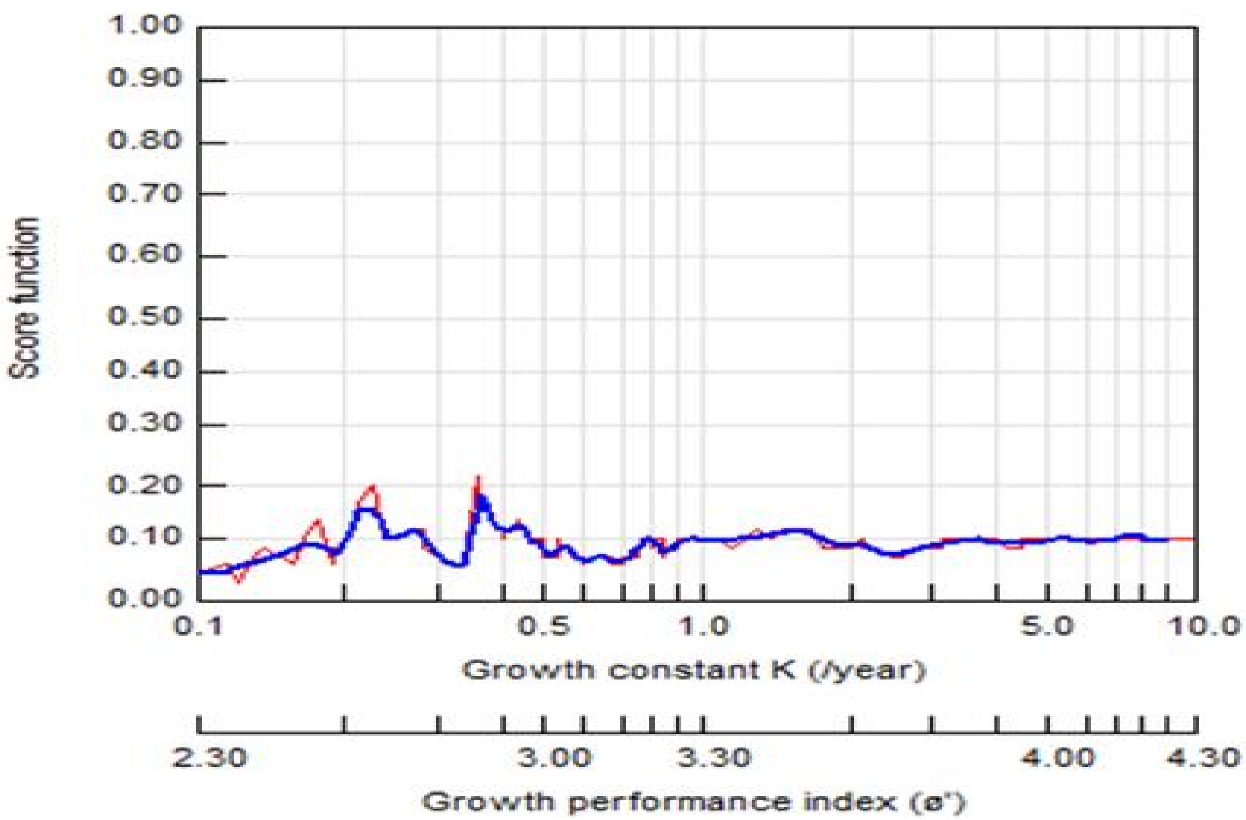


**Figure 4: ELEFAN I K-Scan routine FiSAT II output for *O. niloticus* in Lake Abaya.**

**Estimated mortality parameters**

In order to estimate total mortality, a length composition data set was created and prepared for a linear regression analysis between the X and Y variables (Table 2). The mortality parameters were determined using a linearized length-based catch curve analysis. As indicated in figure 5, the slope of the regression line (b) is -1.34, and hence, the estimated total mortality rate (*Z*) was 1.34 $yr^{-1}$. The natural mortality rate (*M*) and fishing mortality rate (*F*) were 0.34 $yr^{-1}$and 1.0 $yr^{-1}$,respectively. Using these mortality estimates, the exploitation rate (*E*) was computed as 0.74, which indicates that *O. niloticus* in Lake Abaya is overexploited.

**Table 2: Parameters for length-based catch curve analysis**

| Length group (cm) | | | | | | x | y |
|---|---|---|---|---|---|---|---|
| | Catch | k | L∞ (cm) | Δt (L1,L2) | (L1+L2)/2 | t(L1+L2)/2 | Ln(C(L1,L2)/Δt) |
| 23-25 | 40 | 0.36 | 49.35 | 0.22 | 24 | 1.85 | 5.21 |
| 25-27 | 450 | 0.36 | 49.35 | 0.24 | 26 | 2.08 | 7.54 |
| 27-29 | 884 | 0.36 | 49.35 | 0.26 | 28 | 2.33 | 8.13 |
| 29-31 | 752 | 0.36 | 49.35 | 0.29 | 30 | 2.60 | 7.87 |
| 31-33 | 529 | 0.36 | 49.35 | 0.32 | 32 | 2.90 | 7.41 |
| 33-35 | 394 | 0.36 | 49.35 | 0.36 | 34 | 3.24 | 6.99 |
| 35-37 | 279 | 0.36 | 49.35 | 0.42 | 36 | 3.63 | 6.51 |
| 37-39 | 237 | 0.36 | 49.35 | 0.49 | 38 | 4.08 | 6.18 |
| 39-41 | 243 | 0.36 | 49.35 | 0.60 | 40 | 4.62 | 6.01 |
| 41-43 | 222 | 0.36 | 49.35 | 0.76 | 42 | 5.29 | 5.68 |
| 43-45 | 57 | 0.36 | 49.35 | 1.05 | 44 | 6.17 | 3.99 |
| 45-47 | 2 | 0.36 | 49.35 | 1.71 | 46 | 7.47 | 0.16 |
| Total | 4089 | | | | | | |

Fish mortality can be attributed to both natural and anthropogenic factors. Most of the natural mortality could be attributed to old age, diseases, and predation factors in the aquatic ecosystem. The natural mortality (*M*) in the present study is lower than the fishing mortality (*F*), and indicating that the primary cause of mortality for *O. niloticus* in Lake Abaya is attributed by fishing factors. When comparing the estimated values for mortality (*F* >*M*), it is possible to conclude that fishing mortality was a more important source of mortality for *O. niloticus* in Lake Abaya.

A population dominated by mortality was also indicated by the Z/K ratio of 3.72 estimated in this study. The population is growth-dominated if the ratio Z/K is less than 1, mortality-dominated if it is greater than 1, and in equilibrium when growth and mortality are equal if it is equal to 1. If Z/K = 2 in a mortality-dominated population, the population is considered lightly exploited (Beverton and Holt, 1957). According to Beverton and Holt's (1957) general criteria, the Z/K value in the current study indicated that the *O. niloticus* population in Lake Abaya was highly exploited. This is also revealed by the estimated high exploitation rate ($E$= 0.74), which indicates a state of overexploitation. As per Gulland's (1971) assumptions, a sustainable yield is considered optimal if $F$ is equal to $M$ or if the rate of exploitation ($E$) is 0.5. If $E$>0.5, it is typically assumed that the stock has been overexploited.

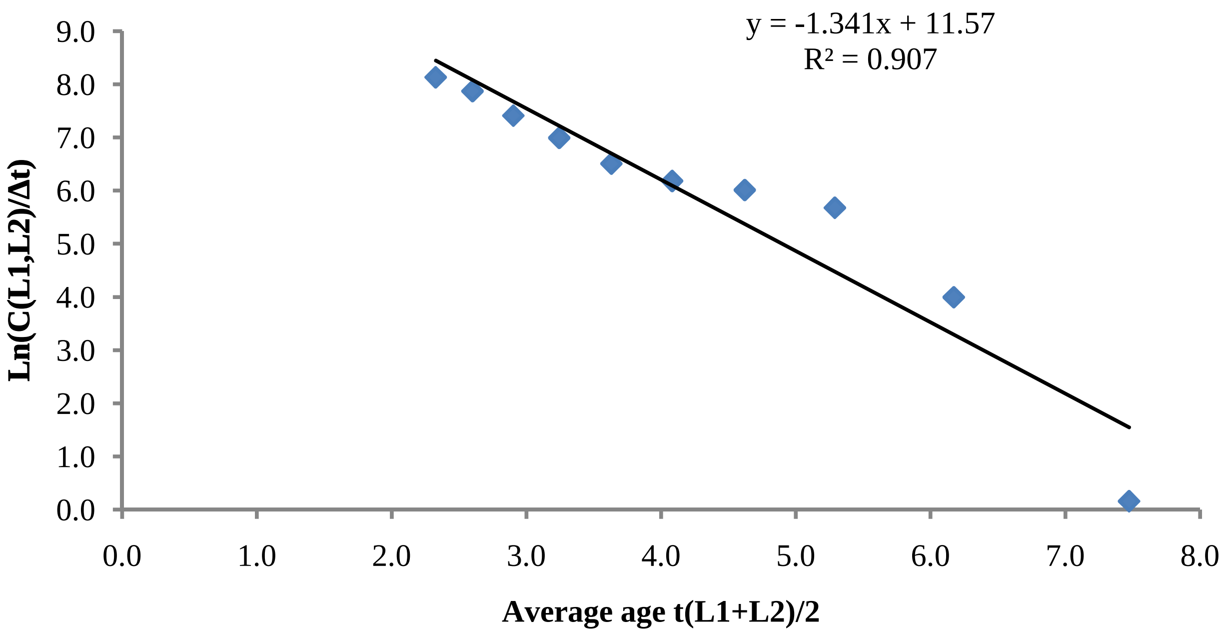


**Figure 5: Linearized length-based catch curve of *O. niloticus* in Lake Abaya.**

Length at first maturity ($L_{50}$) and length at first capture (Lc) were 27.68 cm and 27.97 cm, respectively. The optimum length ($L_{opt}$) of *O. niloticus* in Lake Abaya was also estimated at 37.53 cm. The $L_{50}$ and Lc of *O. niloticus* in Lake Abaya were almost similar and vulnerable for fishing. Based on the evidence shown in this study, *O. niloticus* in Lake Abaya is ready to be removed through fishing at its first spawning stage. Catching fish with total length less than or equal to $L_{50}$ is the main cause of overfishing, and it is recommended that the mesh size of fishing nets used in Lake Abaya should be increased to catch fish above 28 cm for conservation of the stock. When the results of virtual population analysis (VPA) were considered (Fig. 6), fish with total a length of 27-32cm had more exposure to fishing gear, whereas fishing mortality was higher for fish with a total length above 39 cm.

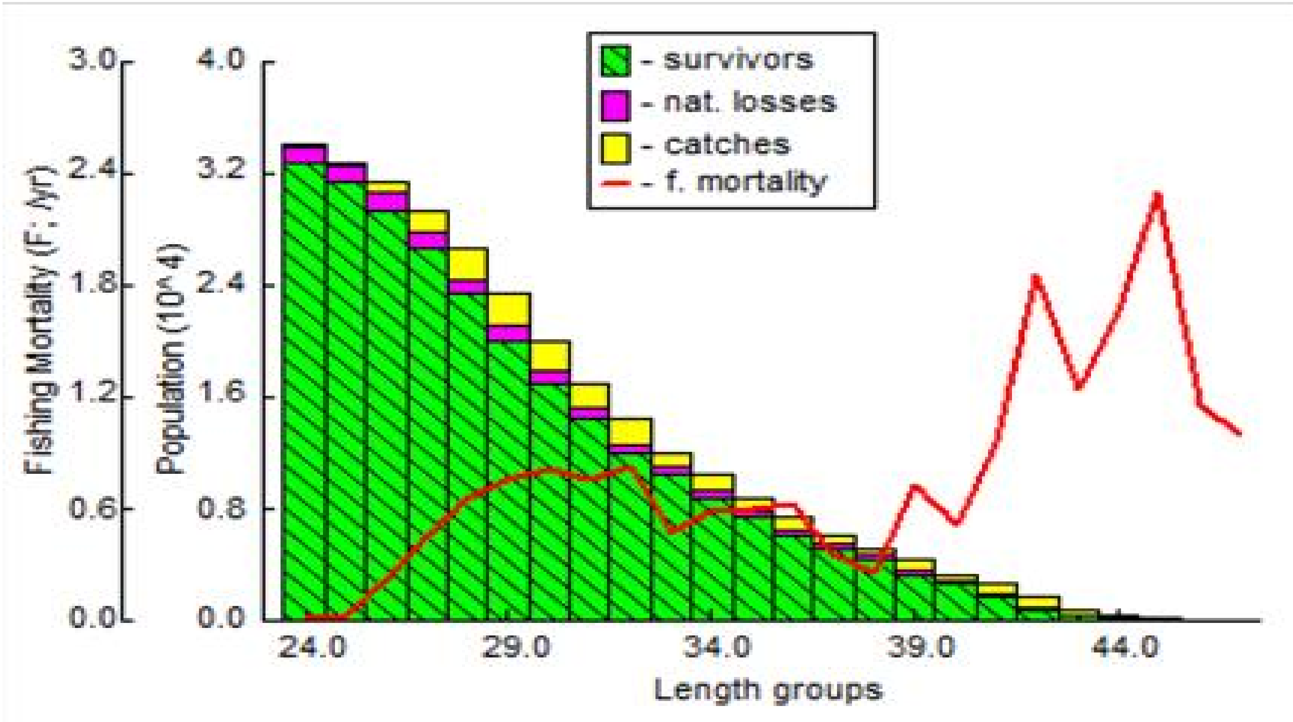


**Figure 6: Estimated virtual population of *O. niloticus* in Lake Abaya.**

The length at first maturity ($L_{50}$) of *O. niloticus* in the present study was higher than that of Lakes Chamo 23.6 cm (Buchale *et al*., 2021), Hayq 12.8 cm for females and 12.9 cm for males (Tessema *et al*., 2019), Langeno 16.62 cm (Genanaw *et al*., 2022), and Hawassa 20.8 cm for females and 20.3 cm for males (Muluye *et al*., 2016). According to Fryer and Iles (1972) and Lowe-McConnell (1987), the size of maturation varies depending on demographic conditions and is influenced by both genes and environment. Depending on the fishery's selectivity, fishing pressure can affect population structure, growth, and early maturation (Jorgensen *et al*., 2007). In water bodies with high fishing pressure, the fish devote more resources to reproduction than to somatic body building (Bandara and Amarasinghe, 2018). According to Jonsson *et al*. (2014), fish that live in harsh situations also exhibit early sexual maturity since this is a coping mechanism for maintaining maximal reproduction under stressful conditions.

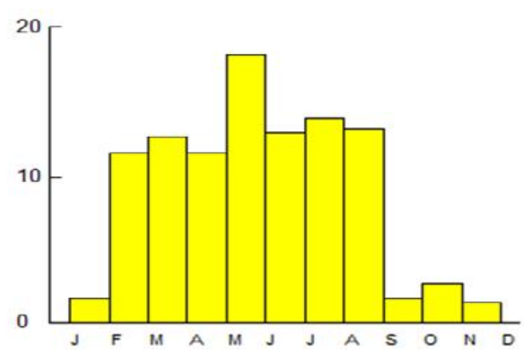


**Figure 7: The seasonal recruitment pattern of *O. niloticus* in Lake Abaya.**

**Estimated seasonal recruitment pattern and relative yield per recruitment**

The estimated recruitment pattern of *O. niloticus* in Lake Abaya was year-round, with one peak period (May)in the year (Fig. 7). Recruitment adds younger fish to the fishery and can vary from year to year by orders of magnitude.

The peak recruitment season of *O. niloticus* in the present study was similar to *O. niloticus* in Lake Langeno, as indicated in Genanaw *et al.* (2022). The biology of tropical freshwater fish reproduction appears to be significantly influenced by patterns of rainfall and variations in water levels (Wootton, 1990). The monthly average rainfall in the study area is higher in April, May, and October, which could be one of the probable reasons for the occurrence of a peak recruitment pattern for *O. niloticus* in May.

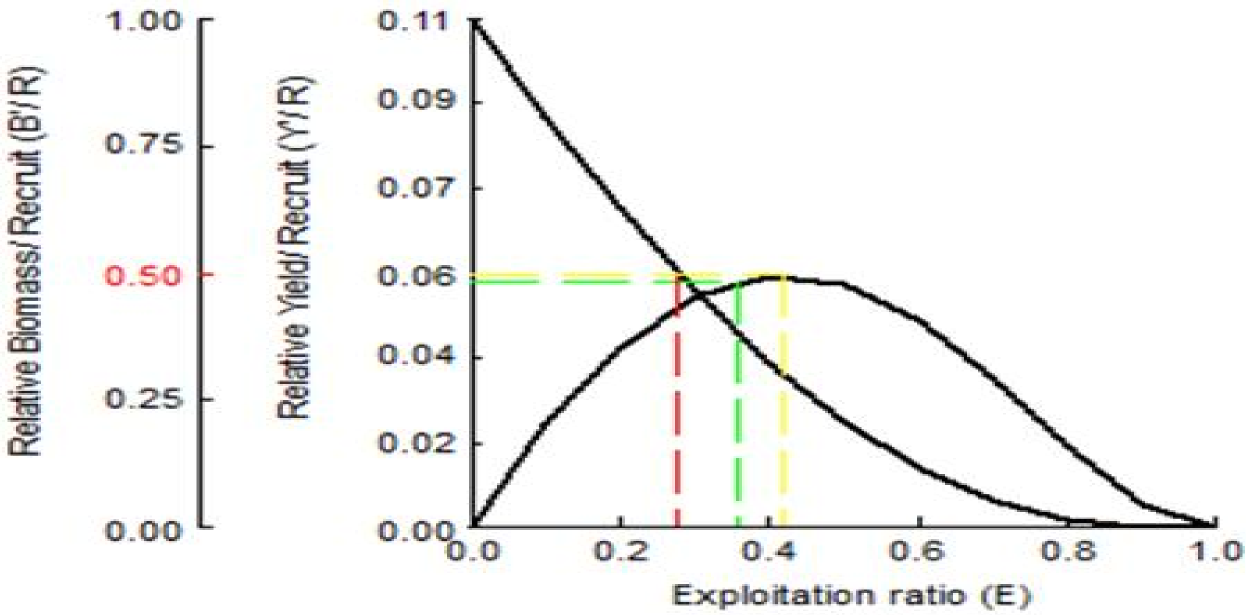


**Figure 8: Beverton and Holt's relative yield per recruitment curve for *O. niloticus* in Lake Abaya.**

The degree to which the current rate of exploitation is optimal, below optimal, or excessive with respect to the population's capacity for self-renewal was ascertained using the correlation curve between the exploitation rate and yield per recruitment. According to the estimated yield per recruitment curve, the current exploitation rate was 0.74 with a yield per recruitment of 0.029, the optimal exploitation rate ($E_{opt}$) was 0.5 with a yield per recruitment of 0.05, and the exploitation rate for maximum yield ($E_{max}$) was 0.421 with a yield per recruitment of 0.053 (Fig. 8). It is evident that the *O. niloticus* population in Lake Abaya was overexploited because the present exploitation rate was higher than the ideal exploitation rate. In order to monitor and set regulations for *O. niloticus* fishing in Lake Abaya, the local authorities need to be aware of this circumstance. The fish that are collected should be the same size at which they have spawned, in order to preserve the sustainability of the fish population.

## CONCLUSIONS & RECOMMENDATIONS

The growth pattern of *O. niloticus* in Lake Abaya was isometric, which implied that an increase in body length is proportional to body weight. The groups with mean lengths ranging from 25 cm to 41 cm accounted for approximately 97.6% of the total capture and significantly influenced the yield of fish. The average value of Fulton's condition factor was 1.70, 1.68, and 1.69 for females, males, and combined sexes, respectively, which implied that the wellbeing of *O. niloticus* in Lake Abaya was in a very good health condition.

This study generated important information on population dynamics parameters (growth, mortality rates, and recruitment) and other crucial life-history characteristics that can serve as basic stock assessment tools for *O. niloticus* management in Lake Abaya. The asymptotic length (L∞) and growth rate (k) were 49.35 cm and 0.36 per year, respectively. The length at first capture (Lc) was estimated at 27.97 cm, while the length at first maturity ($L_{50}$) was estimated at 27.68 cm. Based on the result, harvesting the fish at a length less than or equal to the length at first maturity may alter the recruitment potential of the stock, which in turn may result in thecollapse of the stock. The long lifespan in which 95% of the population would be dead as a result of natural means was 8.72 years.

Moreover, the current exploitation rate (*E*= 0.74) is higher than the optimal (*E* = 0.5) and indicates that *O. niloticus* in Lake Abaya was overexploited. Based on these results, it is recommended that the fisheries management of the lake should include controlling or restricting the usage of small fishing gear in addition to reducing fishing efforts to ensure the sustainability of this commercially important

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