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Population dynamics of the Nile tilapia (*Oreochromis niloticus* L. 1758) stock in Lake Langeno, Ethiopia

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ABSTRACT: Nile tilapia, *Oreochromis niloticus*, is a widely distributed and economically most import fish species in Ethiopia. Effective management is essential to sustain their fisheries and the benefits for the local communities. However, little is known about the population dynamics of the Nile tilapia stock in Lake Langeno. Vital parameters of its population were determined using length frequency data collected from 5,949 specimens ranging from 8.5 to 35.7 cm total length (TL). These specimens were collected from August 2017to July 2018. The population parameters were determined using the ELEFAN I routine in FiSAT software. Estimated von Bertalanffy growth parameters were asymptotic length ($L\infty$) = 35.70 cm, growth curvature (K) = 0.32 yr^{-1}, age at length zero (t_o) = -0.49, and growth performance index (Φ') = 2.61. Instantaneous total mortality (Z), natural mortality (M), and fishing mortality (F) rates were determined from length-converted catch curve and empirical models, respectively, and their values obtained were Z = 2.31 yr^{-1}, M = 0.82 and F =1.56 yr-1, respectively. The exploitation rate (E) of Nile tilapia computed from its mortality rates was 0.67 yr^{-1}, suggesting state of overfishing. The size at first capture (Lc) was estimated at 14.0 cm which is much lower than the size at first maturity (L_m=16.62 cm), which further substantiated the state of overfishing. The results of the study are very useful for fishery managers and scientists who wish to manage and further explore the Nile tilapia stock in Lake Langeno.

Keywords/Phrases: Exploitation rate, Growth performance index, Lake Langeno, Length at maturity, Mortality rates, Recruitment, stock assessment

INTRODUCTION

Small-scale fisheries provide food and livelihood benefits for millions of people (Pauly, 2006) especially in low-income families (FAO, 2014). Many of these fisheries are carried out by the rural poor families, mainly for subsistence and small-scale economic security. The sector plays a significant role in addressing nutrient deficiencies like protein, omega-3 fatty acids, and vitamins to those that cannot get other nutritional sources (FAO, 2014). However, inland fish resources were overfished and the stocks have been showing a declining trend (Roberts *et al.*, 2003). This needs proper stock assessment and management to sustain their fisheries and the benefits for society.

Stock assessment includes the study of the population dynamics which is controlled by growth, recruitment, and natural mortality and fishing mortality (King, 2007). Whenever the gains from spawning, recruitment, and individual growth are much less than the losses from natural and fisheries mortalities, fish stocks decrease in size (Gashaw Tesfaye, 2016). In fish stock assessment, the study of life history traits such as growth and mortality rates are helpful for rational fisheries resource utilization and management and predicting the future status of fishing stocks. In stock assessment, length frequency method is preferred to the direct age method to estimate the growth of fish because data on age from hard structures of fish are not easily available due to reasons like budget constraints, lack of trained manpower, and low access to technology (Sparre and Venema, 1998). In Ethiopia, there is a marked reluctance of fishers to allow dissecting their fish

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for hard part extraction as they often sell whole fish (Gashaw Tesfaye *et al*., 2016). Leonce-Valencia and Defeo (1997) stated that the length-based method can provide as accurate growth estimate as to time-consuming direct age-based method, thus the most often used for growth studies especially in tropical fish stock assessment. Once the growth parameters in length are obtained, it is possible to convert length into age using the inverse von Bertalanffy (vBGF) and into weight using the length-weight relationship (Gashaw Tesfaye and Wolff, 2015).

Lake Langeno, was considered in the research and development programs of the Lake Fisheries Development Project (LFDP) in the 1990s. Currently, the lake is the 7th most important in the country in terms of fisheries contributing about 7% of capture fisheries to national and local markets (Gashaw Tesfaye and Wolff, 2014). The Nile tilapia (*Oreochromis niloticus*, Linnaeus, 1758) and the African catfish (*Clarias gariepinus,* Burchell 1882) are commercially important. The Nile tilapia is the most important fish stock contributing more than 90% by weight to the total landings (Mathewos Temesgen, 2018). Due to high demand for the species, its stock is continually exploited (Mathewos Hailu, 2011). This situation could adversely affect the stocks leading to poor fishery conditions. Therefore, it seems imperative to assess of the population dynamics of the species to ensure the management of its fishery in the lake.

There have been limited studies on the population dynamics of the Nile tilapia stocks in Ethiopian water bodies (e.g.,Workiye Worie., *et al*., 2019). Except for the preliminary study by Gashaw Tesfaye (2006), the population dynamics of the Nile tilapia in Lake Langeno have not been studied. This limited information (Gashaw Tesfaye, 2006) is highlighting the importance of the study in the lake. However, the occurrence of any changes (environmental and fisheries) in the past 14 years that could have affected the population might justify the need to conduct similar work in the lake. The present study was thus undertaken to estimate vital population parameters (growth and mortality), size at first maturity, recruitment pattern, length at first capture, and stock status of the Nile tilapia in Lake Langeno. The results can provide baseline information for fishery managers and scientists to design fishery exploitation and management strategies, and further exploration of the Nile tilapia stock in Lake Langeno.

Materials and methods

The study lake

Lake Langeno (Figure 1) has a surface area of 241 km^2, is located about 200 km south of the capital Addis Ababa, and is in the Abijata-Shala Sub-basin of the Ethiopian Rift Valley regions. It lies between 7^{0}36'N and 38^{0}43'E at an altitude of 1585 m above sea level. The lake is fed by six perennial rivers (Huluka, Lepis, Gedemso, Tufa, Metti, and Garabula Rivers) (Genanaw Tesfaye *et al*., 2021), runoffs, and hot springs and is connected to Lake Abijata by Hora Kello River, which is the only outflowing river from the lake. Lake Langeno has a catchment area of 1600 km^2, and a maximum and a mean depth of 48 m and 18 m, respectively (Daniel Gemechu, 1977).

The climate around Lake Langeno is characterized by a semi-arid to sub-humid with monthly rainfall ranging from 2 mm to 171.2 mm (Ethiopian Meteorological Agency, 2017). The rainfall is bi-modal; the main rainy season extends from June to September, while the short rain falls during March and April (Daniel Gemechu, 1977).

The water chemistry of Lake Langeno is characterized by the dominant Na^+ and HCO_3^{-1}+CO_3^{-2} cation and anions, respectively (Kassahun Wodajo and Amha Belay, 1984). The average total phosphorus concentration in the lake is 70.4 µgL^{-1}, the total nitrogen is 30 µgL^{-1}, and the chlorophyll-a concentration is 2 µg-L^{-1} (as revised by Zenebe Tadesse 1999). The color of the water is reddish-brown due to the high colloidal suspension of inorganic silt and has been to contribute 94–98% of light attenuation (Wood *et al.*,1978). The major phytoplankton genera in the lake include, *Microcystis spp*., *Oocystisspp*. and *Cyclotellaspp*., (Kebede, 1996). Zooplankton of the lake is dominated by *Lovenulaspp*., *Mesocyclopsspp*., *Daphniaspp*., *Ceriodaphniaspp*. and *Brachionusspp*. (Kassahun Wodajo and Ameha Belay, 1984). The fish species found in the lake include *O. niloticus* (Linnaeus, 1758), *Coptodon zilli* (Gervais, 1848), *C. gariepinus* (Burchell, 1822), *Cyprinus carpio* (Linnaeus, 1758), *Labeobarbus intermedius* (Rüppell, 1835), *Enteromius paludinosus* (Peters, 1852), and *Microphancha antinori* (Vincigurra, 1883)

(Mathewos Temegen, 2018). Most of the natural vegetation around the lake are composed of *Acacia spp* and scrub grassland (Kassahun Wodajo and Ameha Belay, 1984). The dominant macrophyte vegetation of the lake include *Scirpus sp*. and *Juncellus sp*. (Zenebe Tadesse *et al.*, 1999).

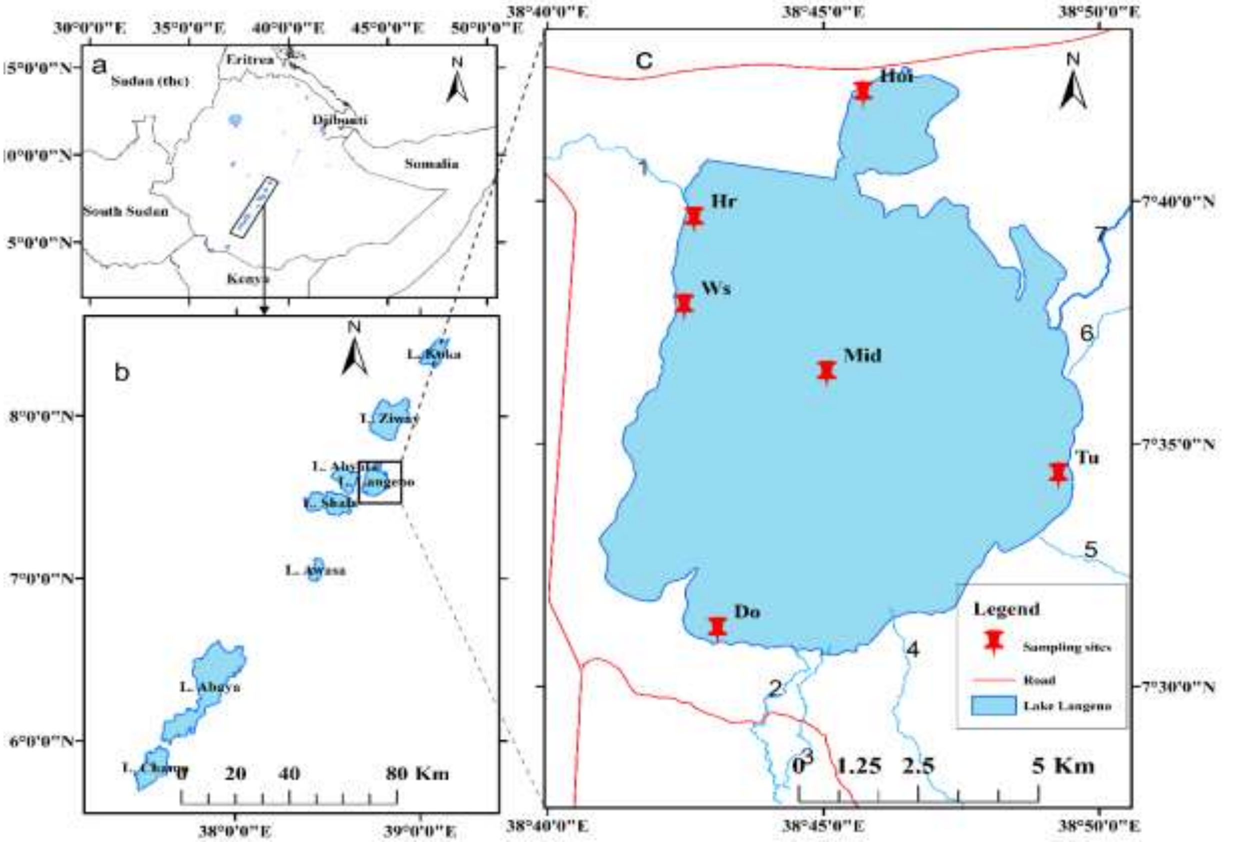


Figure 1. Map showing Eastern African countries (a), Ethiopian Rift Valley lakes, and (b) and Lake Langeno sampling sites (c). (Sampling sites abbreviations: Ho is Hoetu, Hr is Hora Kelo, Ws is Wabi-Shebelle, Do is Dole, Tu is Tuffa and Mid is Middle; Abbrevation of the rivers 1 is Hora Kelo, 2 is Huluka, 3 is Lepsi, 4 is Gedemso, 5 is Garabula, 6 is Meti, and 7 is Tufa).

Data collection:

Fish samples were collected monthly from six sampling sites (Figure 1) for a year (July 2017 to June 2018) using multi-filament gillnets of various mesh sizes (6, 8, 10, and 12 cm). Nets were set late in the afternoon and hauled the following day, soaking for about 12 hr in water. Immediately after the catch, the total length was measured using a measuring board to the nearest 0.1 cm, weight was measured using the electronic weighting scale to the nearest 0.01 g. The sex of each specimen was identified by dissecting the abdomen and maturity levels (I to V) were determined according to Demeke Admassu (1996).

Data analysis

Parameters of the relationship between total length (TL) and total weight (TW) is expressed by the equation: $TW = aTL^b$ (Le Cren, 1951). This is equivalent to the logarithmic form of $\log W = \log a + b \log TL$. Where: TW (gm) is the total weight, TL (cm) is the total length, "*a*" represents y-intercept, "*b*" is the slope of the regression line representing the slope of the transformed line showing the growth pattern of fish in the environment (Karataş, 2007). The coefficient of determination (r^2) was used as an indicator of the quality of the linear regression.

The length at first maturity also called the length at massive maturity (L_m *or* L_{50}) refers to the length at which 50% of the population matures was computed. To estimate the L_m from the maturity stage data, fishes with maturity stages I and II were considered immature and maturity stages III and above were considered as mature fish. The proportion of mature fish per length class was calculated and *Lm* was estimated according to Gunderson et al. (1980). The relationship between the percentage of mature fish per length class and fish length was described with a logistic curve:

$$P = \frac{1}{1+e^{(bL+a)}} \quad \ldots\ldots 1$$

Where P is the proportion of mature fish at length class x, *a* and *b* are model parameters (*a*, intercept and *b*, slope of the logistic regression) estimated by the regression, and L is the length of fish. The L_{m50} was then derived from the relationship of *a* and *b*.

$$L_m = \frac{-a}{b} \quad \ldots\ldots 2$$

Fishes do not reach adult size at a certain age and then do not stop growth like birds and mammals; rather, most fish continue to grow in length and weight until they die. However, the growth rate may be very fast or slow, depending on different factors. The Gomperz, logistic growth, a range of straight lines, and exponential approximations are some of the mathematical functions that have been used to represent growth curves (Beverton and Holt, 1957). However, the von Bertalanffy growth function (vBGF) is the most extensively employed to characterize fish growth (Pauly, 1984; Sparre and Venema, 1998). The growth rate, also known as the curvature parameter (K), asymptotic length ($L\infty$), and theoretical age at length zero (t_0) are the three vBGF parameters. The growth parameters of the Nile tilapia were obtained using the vBGF fitted in FiSAT II, version 1.2.2 software (Gayanilo *et al.*, 2005) as:

$$L_t = L\infty\left[1 - e^{-k(t-to)}\right] \quad \ldots\ldots 3$$

Where L_t(cm)is the length at a given time t, $L\infty$ (cm) is the asymptotic (the mean length of the fish of a given stock that would reach infinity if they grow indefinitely) length in cm, K is the rate at which $L\infty$ approached the asymptote, t_o(yr) the age of the fish at zero-length if they had always grown in the manner described by the equation (note: t_o is generally negative) and t is time (age). The fitting of the best growth curve was based on the ELEFAN I program in FiSAT II software, which allows us to fit the growth curve through the maximum number of peaks of the length-frequency distribution.

Because the theoretical age at birth (t_o) is not a direct output of FISAT from length -frequency data, an estimate was made independently using Pauly's (1979) empirical formula:

$$\mathrm{Log}(-to) = -0.3922 - 0.275 * \log L\infty - 1.038 * \log K \ldots\ldots 4$$

Terms are defined above (equation 3)

The longevity (also called maximum age) (t_{max}) was obtained from Pauly (1983) equation: -

$$t_{max} = \frac{3}{K} + t_o \quad \ldots\ldots 5$$

Terms are defined above (equation 3).

The growth performance index (Φ') was generated using the formula proposed by Munro et al. (1986):

$$\Phi' = 2\log L\infty + \log K \quad \ldots\ldots 6$$

where K and $L\infty$ are growth parameters of the von Bertalanffy growth equation.

This is an important parameter used to compare the growth of the Nile tilapia from Lake Langeno with those from other studied stocks.

The instantaneous total mortality rate (Z) was calculated using the length converted catch curves (linearized catch curve) method described by Pauly (1983) as follows:

$$Z = \ln\left(\frac{dNi}{dti}\right) = a + bti \quad \ldots\ldots 7$$

Where Z is the total mortality, *Ni* is the number of fish in length class *i*, dt is the time needed for the fish to grow through length class *i*, t_i is the age (or the relative age, computed with $t_o = 0$) corresponding to the mid-length of class *i*, and *b* is the slope of the regression, and with the sign changed, is an estimate of Z.

This method assumes that *Z is* constant beyond some reference age (often the age at first capture, t_c), thus, only individuals that are fully recruited or vulnerable to the fishing gear were considered. The age of individuals fully recruited to the fishery is given by the point when the catch curve begins to decline at a steady rate and the corresponding length refers to the length at first capture Lc (Pauly, 1984). The total mortality was therefore calculated by the regression line on individuals beyond this point (Gashaw Tesfaye and Wolff, 2014).

The natural mortality was calculated using Pauly (1980) empirical formula using vBGF Parameters, $L\infty$ and K as well as the average annual surface water temperature (T) as:

$$\mathrm{Log}M = 0.0066 - 0.27\log L\infty + 0.6543\log K + 0.434\log T \quad \ldots\ldots 8$$

Instantaneous fishing mortality was estimated as F = Z – M (Beverton and Holt, 1957).

Exploitation ratewas calculated from the ratio between fishing mortality and the total mortality (Ricker, 1975; Sparre and Venema, 1998) as:

$$E = \frac{F}{Z} = \frac{F}{M+F} \quad \ldots\ldots 9$$

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):

$$L_c = \bar{L} - K\frac{(L\infty - \bar{L})}{Z} \quad \ldots\ldots 10$$

In addition to the probability of length at first capture (Lc), the lengths at both 25% and 75% captures which corresponds to the probability at 0.25 and 0.75 were estimated using FiSAT II software. These were estimated using logit function of the software.

The recruitment pattern was determined from the estimated growth parameters by the backward projection of length-frequency data, as described in ELEFAN I (Offem *et al*., 2007). This routine allows the identification of the number of seasonal pulses of recruitment that have been generated by the population represented in the length-frequency data (Gayanilo *et al*., 2005). Input parameters were L∞, K and t_o. "Percent of sample total" option in the FiSAT was selected to estimate the recruitment pattern. This is because the samples had dissimilar size.

The estimated length structured virtual population analysis (vPA) was carried out using the FiSAT II routine (Gayanilo *et al*., 2005). The values of the L∞, K, M, F, a (constant), and b (exponent) were used as inputs. The constants a and b were estimated from the length-weight relationship ($W= aL^b$) as expressed above. Biological reference points were estimated using Beverton and Holt's model relative yield per recruit (Y'/R) and relative biomass per recruit (B'/R), using the knife-edge selection procedure as functions of E incorporated into FiSAT II software (Gayanilo *et al*., 2005).

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

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

where, L∞, K and M are as defined above. The length at first maturity (L_m) estimates described above was used and the numerical percentage of specimens in the catches larger than L_m was computed. The percentage of fish between L_m and L_{opt} + 10% larger sizes referred as the L_{opt} range was then calculated as well as the percentage of fish beyond this L_{opt} range, referred to as mega-spawners (Froese, 2004). These values were used as size indicators to evaluate the status of the stocks.

RESULTS

The monthly pooled length-frequency data of the Nile tilapia specimens were grouped into one-centimeter interval. The fish specimens caught ranged from 8.5 – 35.5 cm (mean =16.0 cm) in length and 10.6 – 561 g (mean = 68.1 g) in weight. However, about 96% of the catch were less than or equal to 20.0 cm. The mid-length 15 cm was the highest frequently observed value (mode), followed by length group16 cm and 17 cm (Figure 2).

The relationship between body weight and total length of the Nile tilapia in Lake Langeno was established with the use of a scatter plot diagram. The length-weight relationship of the Nile tilapia sex combined was described by the equation Tw = $0.021TL^{2.8897}$ (r^2 =0.9031) (Figure 3a). The power of the equation (b=2.8897) was not different from the hypothetical value (3.0). The regression coefficient of the equation (r^2=0.9031) indicated that there was a strong positive correlation between the weight and length of the Nile tilapia population in the lake.

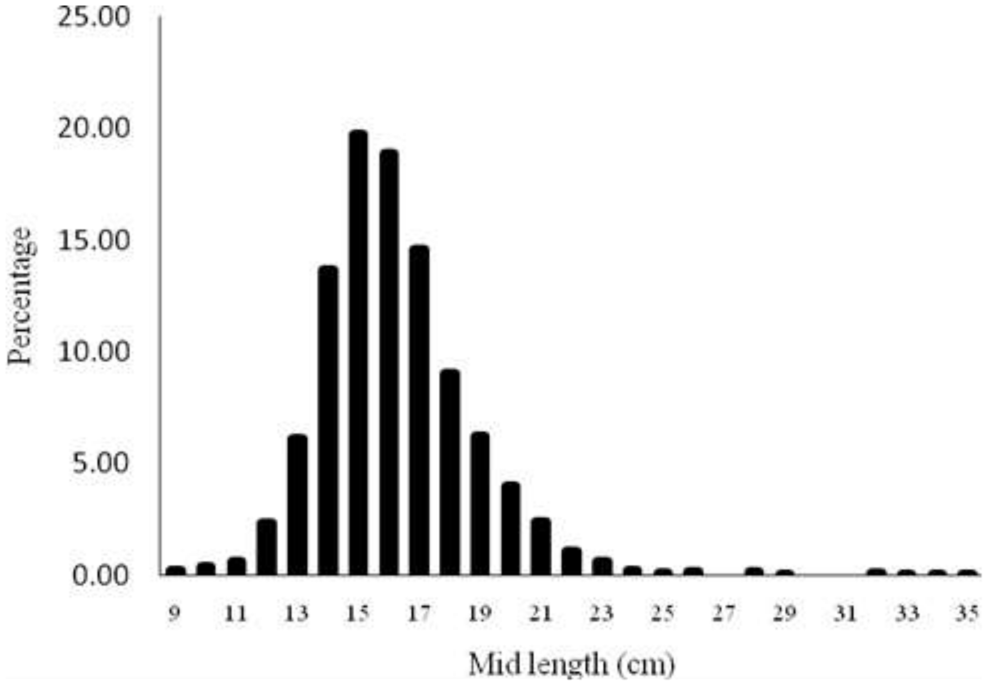
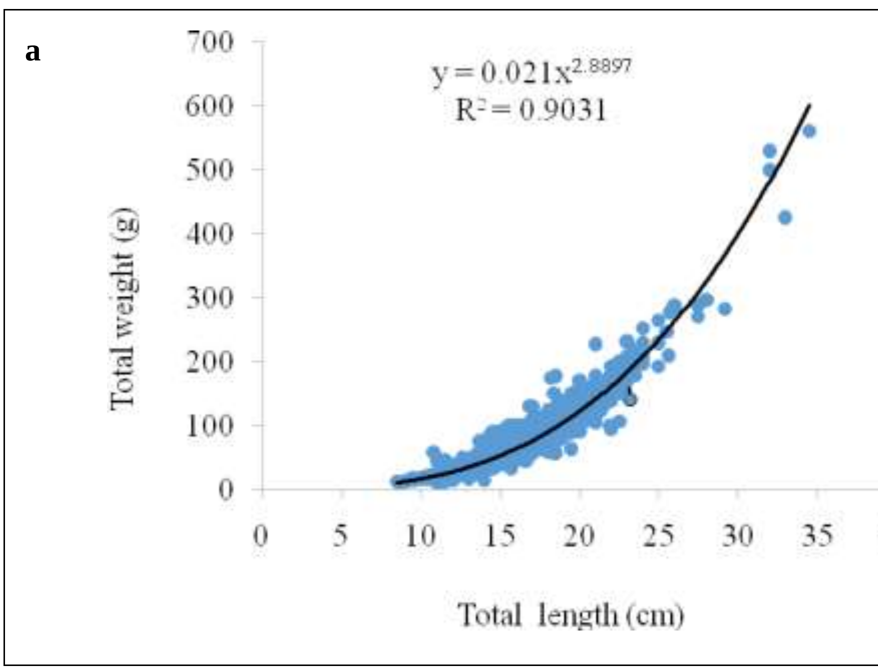


Figure 2. Size spectrum of the Nile tilapia in Lake Langeno (n=5,949). Sizes are represented by the total length (cm).



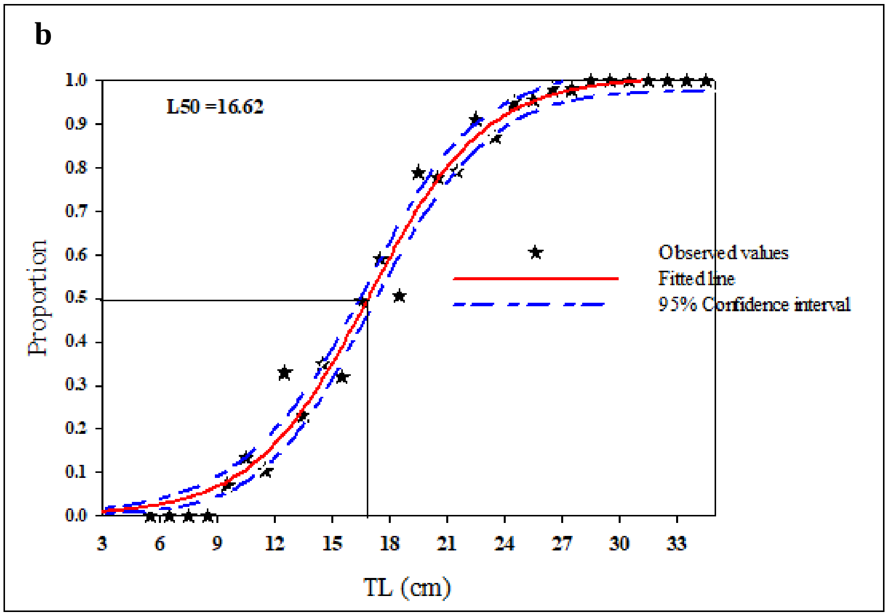


Figure 3. Length-weight relationship (a) and length at first sexual maturity (L_m) (b) of the Nile tilapia in Lake Langeno, Ethiopia.

The smallest sexually mature fish specimen caught in the current study was 9.5 cm TL; its respective total weight was 18.66 gm. The length at 50% sexual maturity (L_m) obtained was 16.62 cm TL (Figure 3b).

The von Bertalanffy growth parameters estimated using automatic routine within ELEFAN1 of FiSAT II software were 35.7 cm and 0.32 yr^{-1} for asymptotic length (L_∞) and growth rate or curvature parameter (K), respectively. The estimated theoretical age at birth (t_o) was 0.49. Thus, based on the estimated growth parameters of the Nile tilapia population in Lake Langeno, its vBGF for length at time (t) was expressed as: $L_t = 35.7 * \left(1 - exp^{-0.32(t+0.49)}\right)$ cm and the fitted growth curves are given in Figure 4a. The maximum age (t_{max}) was estimated at 8.90 years, while the growth performance index (Φ') was estimated at 2.61.

The instantaneous total mortality rate (Z) estimated from the linearized length-converted catch cure for the Nile tilapia in Lake Langeno was 2.31 yr^{-1} (Figure 4b). The darker circles represent the points used in calculating Z through least-square linear regression. The blank (yellow) circles represent points either not fully recruited (left side) or nearing to L∞ (right side), hence discarded from the calculation. A good fit to the descending right-hand limb of the catch curve was considered. The regression parameters were *a* = 13. 84 and *b* = -2.31 and the coefficient of determination for the regression (r^2) was 0.96.

The natural mortality coefficient (M) at 24.1^{o}C was estimated at 0.75 yr^{-1}, while the fishing mortality (F) was 1.56 yr^{-1}. The current exploitation rate E was estimated at 0.67, which indicated a state of overfishing.

The selection curve generated by the ascending part of the length-converted catch curve for the tilapia in Lake Langeno is shown in Figure 5a. The broken lines denote that the length groupings that correlate to 25%, 50% and 75% probability of capture, respectively.

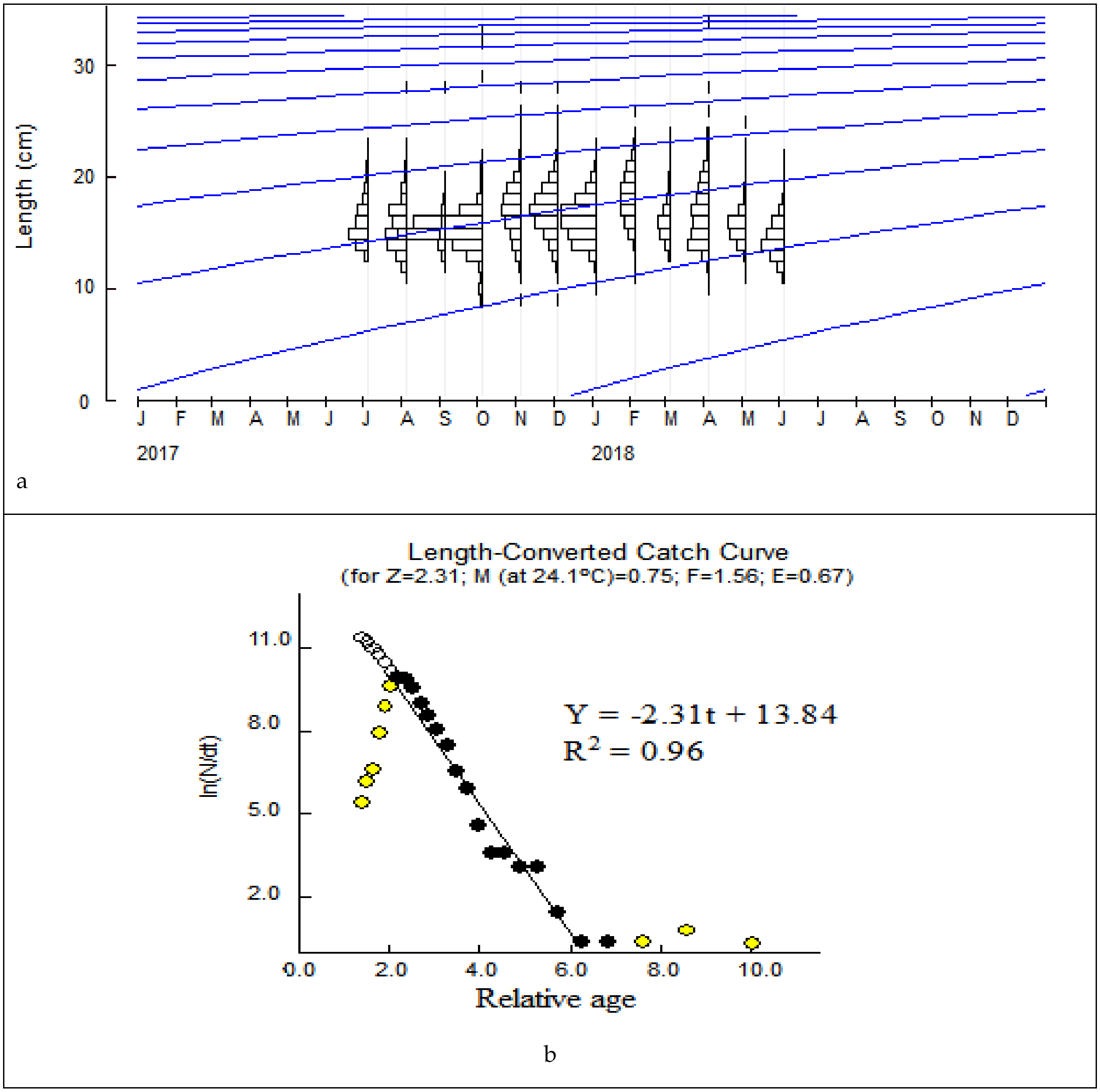


Figure 4. Von Bertalanffy growth curve (a) (L∞=35.7cm; K = 0.32 yr⁻¹; Rn = 0.242) superimposed on length-frequency distribution and linearized length-converted catch curve (b) of the Nile tilapia in Lake Langeno.

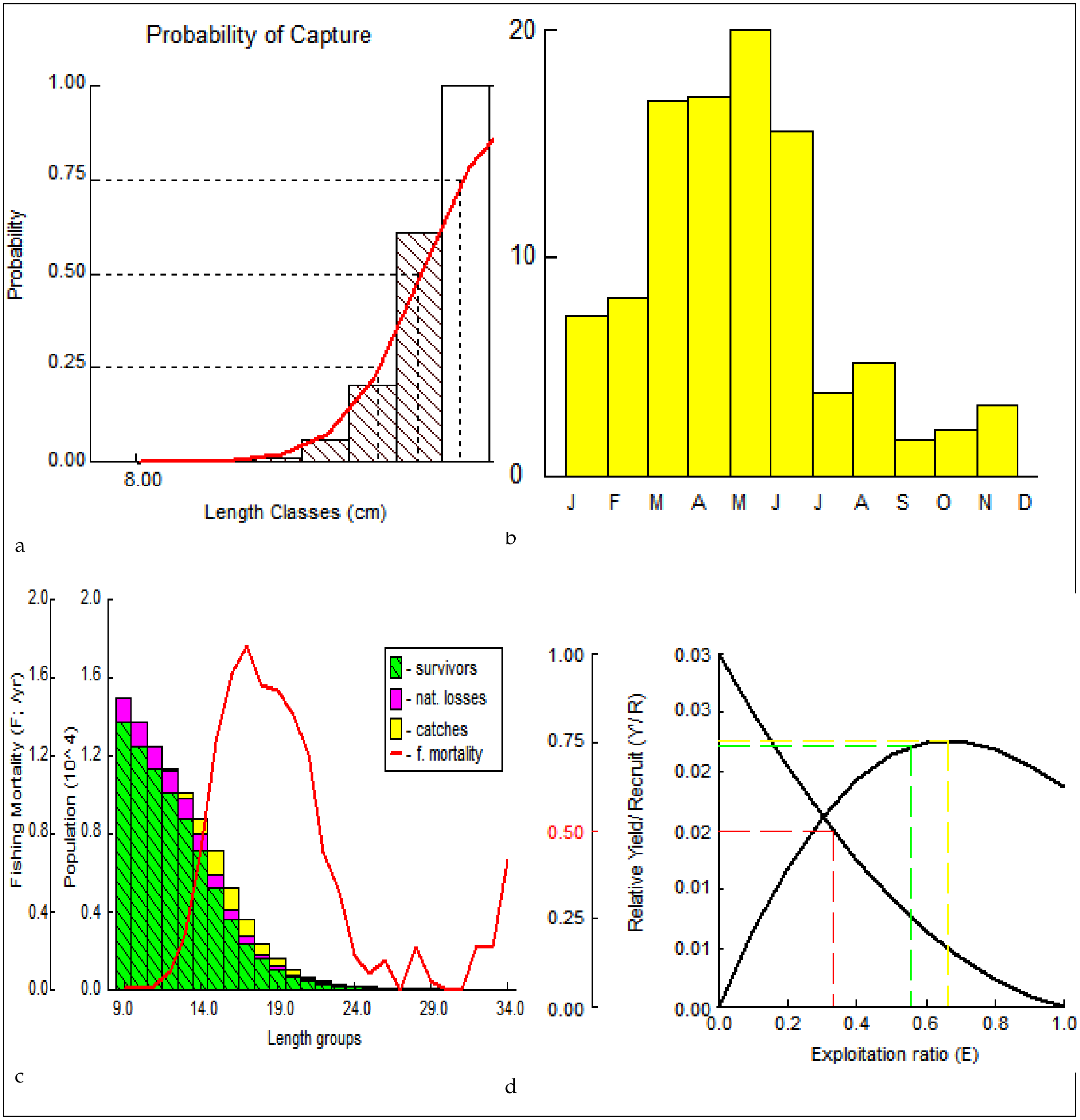


Figure 5. The selective curve showing probability of capture (a) the seasonal recruitment pattern (b) population estimation using VPA from FiSAT output (c), and Beverton and Holt relative yield per recruitment (Y/R) and biomass per recruit (B/R) (d) of the Nile tilapia in Lake Langeno.

From the curve, the mean length at Lc, also commonly abbreviated as Lc_{50} was calculated as 14.00 cm TL. Similarly, the probability of capture at 25% and 75% were estimated at 13.13 cm and 14.87 cm, respectively, which gave a selection range of almost 1.74 cm. The probability of capture at 25%, 50%, and 75% provides information on the size structure of the fish in the fishing area that is caught by a specific gear or gillnet mesh size.

The recruitment pattern showed one recruitment pulse with a major peak of recruitment occurred from March to and July and a peak pulse in May. The recruitment was estimated using theoretical age at birth (t_o = -0.49) and other VBG parameters. It appears that about 71.82 % the Nile tilapia population was recruited from March to July (Figure 5b).

The results from virtual population analysis in this study indicated that the maximum number of the Nile tilapia in Lake Langeno was harvested between mid-length of 14 cm and 17 cm TL (Figure 5c). The highest peak of catch (fishing mortality) occurred in the mid-length 16 cm TL. The values of "a" and "b" constants from the length weight relationship were estimated as 0.021 and 2.8897, respectively (Figure 3a).

The relative Y'/R and B'/R analysis of the Nile tilapia were computed using knife-edge technique. The maximum allowable limit of exploitation level (E_{max}), which yields the maximum relative yield-per-recruit was estimated at 0.66 (Figure 5d). $E_{0.1}$, the level of exploitation at which the marginal increase in relative yield per recruit is 10% of the marginal increase computed at a very low value at E, was 0.56. The exploitation level ($E_{0.5}$) which corresponds to 50% of the relative biomass per recruit of the unexploited stock was 0.33.

Figure 6 shows L_m, L_{opt} and L_∞ of the tilapia in Lake Langeno. The results of this study indicated that L_{opt} was 19.8, % > L_{opt} = 8.4, % < L_m = 61.8, % > L_m = 38.2, and % mega spawners = 2.1. The % > L_m and % within the L_{opt} range indicated recruitment overfishing of the Nile tilapia stock in Lake Langeno. Percent mega-spawners also indicated recruitment overfishing as it is only 2.1%.

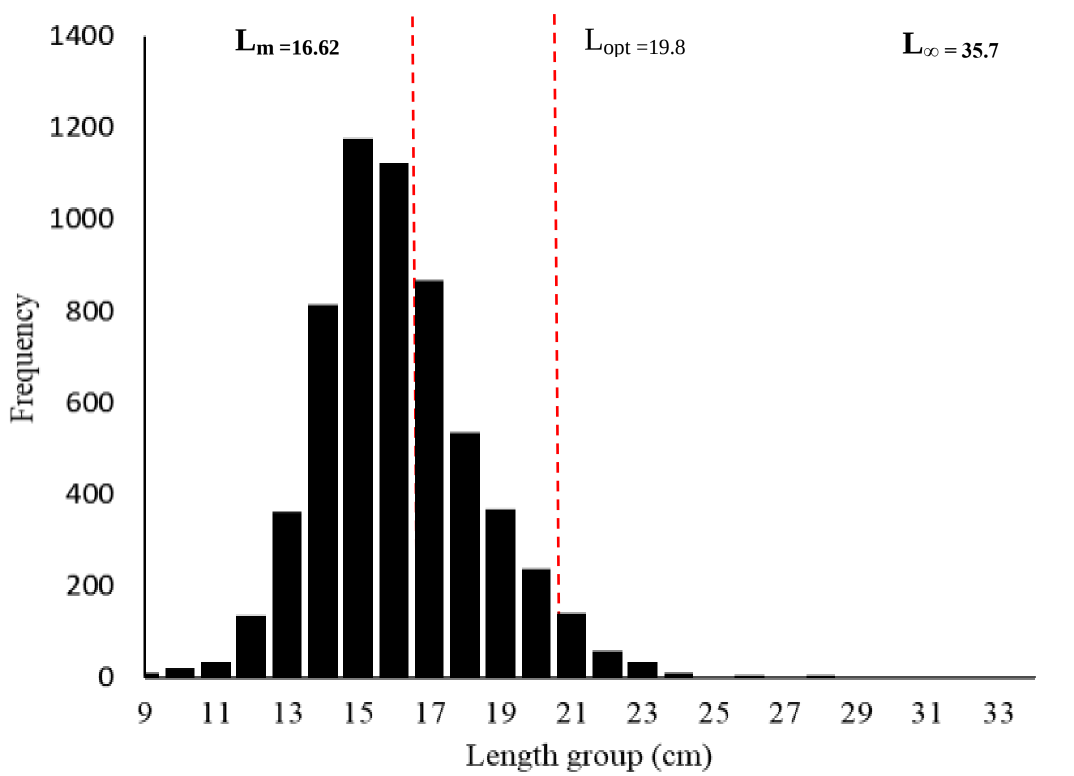


Figure 6. Size spectrum of the Nile tilapia in Lake Langeno.

DISCUSSION

Fishing usually causes truncation of fish size structures due to the selectivity of fishing gears leading to fishery-induced evolution towards smaller size (or stunting) and early maturity (Borrell, 2013). In Lake Langeno, size groups ranging from 14 – 17 cm contributed more than two-third of the total catch (3978 individuals) and the catch size above the size at first maturity was only 38% (Figures 2; and 3b). This showed that small-sized fishes have dominated the catch from the lake. By comparison, the maximum total length of 35.5 cm observed for the Nile tilapia in the present work is relatively smaller than those reported for the same fish in Lake Chamo (TL = 57.0 cm) (Yirgaw Teferi *et al.*, 2000), 48.5 cm TL in Gilgel Gibe I Reservoir (Mulugeta Wakjira, 2013), 48 cm TL in Alwero Reservoir (Genanaw Tesfaye *et al.*, 2017), 43.5 cm TL in Lake Koka (Gashaw Tesfaye *et al.*, 2016), 42.0 cm TL in Fincha Reservoir (Fassil Degefu *et al.*, 2012), and comparable with 35.5 cm TL in Amerti Reservoir (Mathewos Hailu, 2014). However, the observed maximum size for the Nile tilapia in Lake Langeno is larger than those in Lake Beseka (25.0 cm TL) and Lake Hawassa (29.0 cm TL) (Yoseph Tekle-Giorgis *et al.*, 2017). The maximum size recorded in the previous studies for the species in Lake Langeno was 28.5 cm TL (LFDP, 1997) which was lower than the current study (35.5 cm TL). However, the mean size of the catch (16.0 cm TL) recorded in this study is much lower than the mean size of the catch recorded (21.6 cm TL) by LFDP (1997) in the same lake. This variation could be due to the high fishing pressure as shown by the high exploitation rate (E = 0.67) that resulted from increasing fishing effort and the use of smaller mesh-size fishing nets.

The exponent of the equation (b = 2.8897) and the regression coefficient ($r^2 = 0.9031$) (Figure 3a) in this study indicated slightly negative allometry growth of fish and strong correlation between length and weight, respectively. According to Le Cren (1951), the length-weight relationship which is revealed by cube law ($W = aL^b$) where the value of b needs to be 3 in ideal fish. However, based on the deviation of b, fish can achieve isometric (b = 3), negative allometric (b <3), or positive allometric (b>3) growth patterns throughout its life span (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 length. The "b" value is always between 2 and 4 and is mostly close to 3 (Bagenal and Tesch, 1978). The b obtained (b = 2.8897) in this study met this criterion.

Previously, several studies have described the relationship of TL and TW of the Nile tilapia in different water bodies in Ethiopia (Table 1). Mathewos Temesgen (2018), for example, expressed the relationship between TL and TW of the Nile tilapia population in Lake Langeno by the equation: $Tw = 0.025TL^{2.8724}$ r = 0.933) which is consistent with the current study. The observed result in the current study is also similar to the findings of Gashaw Tesfaye and Zenebe Tadesse (2008) with b value of 2.89 in the Koka Reservoir (Table 1). Beverton and Holt (1957) stated that major deviations from isometric growth are rare. However, in reality, the actual relationship between the variables, length, and weight, may depart from this, either due to environmental conditions or physiological conditions of fish (Le Cren, 1951) such as gonad development and nutritive conditions in the environment of fish (Bagenal, and Tesch, 1978).

From the present study, the size at 50% maturity is 16.62 cm TL for the combined sexes (Figure 3b). This indicates that the fish matures at a smaller size than the sample species found in various bodies in Ethiopia (Table 1). This may have resulted from fishing pressure, because the fishing efforts using smaller mesh-sized net and landings increased since the early 1980s in Lake Langeno (Gashaw Tesfaye, 2006). Size at first maturity of fish is an important trait necessary for the success of fishery management and to the establishment of the means that avoid exploitation of young specimens and consequential reduction of spawning stock (Penha and Mateus, 2007). It depends on demographic conditions and is determined by genes and environment (Gashaw Tesfaye *et al.*, 2016). Generally, fish in poor condition mature at a smaller size than those in good condition. Jonsson et al. (2014) also stated that fish living in stressful environments show an early sexual maturity because it is a strategy to maintain maximum reproduction in response to a high level of stress. The size at first maturity of the Nile tilapia is considerably different in different water bodies of Ethiopia (Table 1). Since the early

1980s, fish landings and fishing efforts using smaller mesh-sized nets have increased in Lake Langeno. Fishing, especially when size-selective, shifts age and size distributions toward a younger age and smaller size through demographic traction effects (Baskett *et al.* 2005). Thus, the observed reduction of L_m of the fish in the lake could be due to of an increase in the fishing pressure and other environmental stresses.

The growth parameter that was determined from length based analysis was different between lakes for the Nile tilapia (Table 2). The estimated values ($L\infty$ = 35.7) for the Nile tilapia in the current study is a little higher than the value ($L\infty$ = 33.3 cm) obtained for the same species in the same lake by LFDP (1997). However, variation was observed for growth rate (K = 0.32) in the current study and (K = 0.55 yr^{-1}) by LFDP (1997). The calculated value of $L\infty$ in this study was lower than the estimates from the studies in Lakes Tana, Koka, Chamo, and Victoria (Table 1). It was slightly higher than the value obtained for the same species in Lake Turkana of Kenya and Lakes Ziway and Hawassa but did not show much difference when compared to the values estimated by other authors. The estimated value of K for the Nile tilapia (0.32 yr^{-1}) in the present study slightly differs from the estimates of the same species in Lake Ziway, Hawassa, Koka, and Turkana but did not show significant variation compared to the values reported by other authors. This indicated that the rate at which fish size approaches $L\infty$ is lower in Lake Langeno as compared to the Nile tilapia populations in Lakes Ziway, Victoria, Koka, and Tana. The probable cause for the variation in estimates for the $L\infty$ and K in comparison with other studies could be due to the variations of environmental conditions among these water bodies. It is also possible that the growth rate varied because of variations in the food conditions of the fish. Other factors affecting growth are population size and life adaptation patterns of fish during their life history. This may also differ among different stocks and species and could also be influenced by different analysis methods (Sparre and Venema, 1998). Lowe-Mc Connell (1982) also pointed out that similar species can have different growth rates in different habitats. Light affects the rate of photosynthesis by aquatic plants, which indirectly influences the fish growth (Bajaj, 2017). In the present study, transparency varied between 10 and 15cm depth. This low light penetration is attributed to high colloidal suspension of inorganic silt in the lake water (Wood *et al.*, 1978). This might have also influenced the growth of Nile tilapia in the lake. Thus, the use of "Φ" is a more accurate estimator in the fish stock assessment which is based on K and $L\infty$ (Munro and Pauly, 1983). Sparre and Venema (1998) indicated that this index is the best way to calculate the average growth parameters of a given species and should present close values in comparing different groups of the same species. The values estimated for the same species in Lake Tana (Workiye Worie *et al.*, 2019) and Lake Koka (Gashaw Tesfaye, 2006) were higher than in present study. The results from Lake Ziway 2.67 (Gashaw Tesfaye, 2006) and in Lake Hawassa 2.66 (LFDP, 1997), were comparable to the present study (Φ' = 2.61). Reliable estimates of Φ' from wild stocks could be used for the selection of species or populations for translocation and introductions (Gashaw Tesfaye and Wolff, 2015).

Fishes have a wide range of life spans. From the present study, the lifespan (t_{max}) of the Nile tilapia in Lake Langeno was estimated as 8.90 years. Workiye Worie et al., (2019) found that the Nile tilapia in Lake Tana had a t_{max} of 6.8 years, which is different from the current finding. The estimated mean t_{max} for 107 Nile tilapia populations reported in FishBase (www.fishBase.org "accessed on 29 May 2021") is 9 years. Thus, the computed t_{max} in this study was comparable to the value reported in FishBase. In addition to environmental factors such as temperature, salinity and predation, biological parameters such as sex, genetic makeup, food, reproduction, age, and maturations are important in influencing the lifespan of fishes (Das, 1994).

The reliability of estimated natural mortality (M) is determined using the M/K ratio which ranges between 1.12 and 2.50 for most fish (Beveryton and Holt, 1957). The ratio (M/K = 2.35) estimated in this study was within this range and suggested that the calculated M for Nile tilapia in Lake Langeno was reliable. Several factors contribute to fish natural mortalities. However, most of the natural mortalities could be attributed to the predation factors in aquatic ecosystems (Laevastu , 1988). For instance, Gashaw Tesfaye and Wolff, (2015) reported the occurrence of the specimens of the Nile tilapia, their eggs, and scales in the gut of *C. gariepinus* in Lake Koka. Similar findings were reported in different water bodies of Ethiopia (e.g.,Flipos Engidaw *et al*., 2013; Elias Dadebo *et al*,

2014) (Table 2). This could be one of the probable reasons for the relatively high M (0.75) of the Nile tilapia in Lake Langeno. It was reported that the population of *C. gariepinus* has increased in Lake Langeno (Mathewos Temesgen, 2018). Natural mortality is also affected by other factors like competition, cannibalism, disease, spawning stress, starvation, senescence, and pollution stress (Beverton and Holt, 1957). In addition, the high value M in the current study probably due to low primary productivity of the lake and habitat destruction caused by the removal of sand in the shallow parts of the lake and this possibly affected the breeding and nursery ground of the fish.

The presence of variations in fish mortality rates among the Nile tilapia populations in different localities in Ethiopia has been reported (Table 1). The estimated value M = 0.75 for the Nile tilapia in the current study is lower than the value estimated (M = 1.076) for the same species by LFDP (1997) in the lake, (M = 1.21) in Lake Ziway (Gashaw Tesfaye, 2006), and (M = 1.00) in Lake Vitoria (Njiru *et al*. 2004) and higher than in Lake Hawassa (M = 0.35). Using M and Z estimates, the current fishing mortality (F) was calculated for the Nile tilapia in Lake Langeno. The total mortality (Z) in this study was 2.31 yr^{-1}, but the estimated Z in other water bodies in Ethiopia were lower (Table 1). Comparing the estimated values for M and F, it can be concluded that the fishing mortality was more important source of mortality (F >M). The computed values of Z, M, and F for the Nile tilapia in Lake Langeno showed high total, natural and fishing mortalities (Figure 4a; Table 2).

The Z/K ratio 7.22 estimated in this study also indicated a mortality-dominated population. This is in agreement with the general criteria of Beverton and Holt (1957): if Z/K is <1, the population is growth-dominated; if it is >1, then it is mortality-dominated; if it is equal to 1, then the population is in an equilibrium state where mortality balances growth. In a mortality-dominated population, if Z/K ratio =2, then it is a lightly exploited population (Beverton and Holt, 1957). So, our Z/K value suggested highly exploited stock. This is also substantiated by the estimated high exploitation rate (E=0.67) which suggested a state of overexploitation. So, our Z/K value suggested highly exploited stock.

The exploitation rate value obtained in this study (E=0.67) was higher than the optimum level of E = 0.5 of Gulland (1971). According to the assumptions by Gulland (1971), sustainable yield is optimized when F = M and when E > 0.5 then the stock is generally supposed to be overexploited. Gashaw Tesfaye (2016) reported under exploitation of the population of the Nile tilapia in Lake Koka with an exploitation ratio of 0.45 which was less than the optimal level of Gulland (1971) and the current estimated E = 0.67. However, the E estimated for the Nile tilapia population in Lake Tana (Table 2) showed slight overexploitation with a value of 0.59 (Workiye Worie *et al*., 2019).

The result of this study showed that, Lc at which 50% of the fish become vulnerable to capture was estimated to be 14.00 cm TL (Figure 5c). The current study revealed that the Nile tilapia in Lake Langeno reach first sexual maturity at TL of 16.62 cm (Figure 3a). This means that the fish was caught before being given chance to grow to their first size at maturity. Evidence of overfishing is shown by the fact that L_c is less than the L_{50} for the Nile tilapia in the lake (Beverton, 1992). Therefore, it is recommended that the mesh size of fishing nets used in Lake Langeno for fishing should be increased to catch fish measuring above 14.00 cm TL for conservation of the stock. When the results of VPA were considered (Figure 5c), fish with 9 – 12 cm TL experience low fishing mortality rates, whereas larger fishes ranging 14 – 17 cm TL encounter higher fish mortality rates. Possible reason for such structured fishing rate could be due to the use of small mesh sized fishing nets in Lake Langeno.

Some studies showed that the seasonality of reproduction of fish species is influenced by water temperature, precipitation, and hydrological conditions (e.g. Elias Dadebo *et al*., 2005). According to Christie et al. (2014), reproductive success depends on a favorable period for the production of young individuals who will determine the perpetuation of the species. According to Mathewos Temesgen (2018), a high number of the Nile tilapia fishes with full matured gonads (IV) in Lake Langeno was recorded between April and June which is consistent with the highest recruitment peak in the current study. Similarly, the major recruitment peaking period of the same species in Lake Tana is from May to July. However, two major recruitment peaks yr^{-1} (January to August and March to December) for the Nile tilapia were reported in Lake Tana, Ethiopia, (Workiye Worie *et al*., 2019) compared to one major peak in the current study (Figure 5b).

Wootton (1990) stated that rainfall patterns and water level fluctuations appear to be major influencing factors of the breeding biology of tropical freshwater fish species. This could be one of the probable reasons for the occurrence of peak recruitment pattern for the fish during the rainy season (in July).

Table 1. Length-weight relationship, size at maturity and von Bertalanffy growth parameters for the Nile tilapia from different water bodies.

Lakes and Reservoirs	Length-weight relationship		*L50 (cm)*	Growth parameters				References
	b	R^2		$L\infty$ (cm)	K (yr^{-1})	t_o (yr^{-1})	Φ'	
L. Tana			20.7M 18.1F	35.7	0.50	-	2.80	Tesfaye Wudneh (1998)
L. Tana				44.1	0.44	-0.34	2.93	Workiye Worie et al. (2019)
L. Hayq	2.95	0.95						Workiye Worie and Abebe Getahun (2015)
L. Koka	2.89[a]	0.99[a]	24.6	44.5	0.41	-0.36	2.90	[a]Gashaw Tesfaye and Zenebe Tadesse (2008); Gashaw Tesfaye (2016)
L. Ziway	3.19[a]	0.97[a]	19.4M[y], 14.0	28.1	0.60	-	2.76	Gashaw Tesfaye (2006); [a]Gashaw Tesfaye and Zenebe Tadesse (2008);
L. Langeno	3.04[c]	0.88[c]	19.5c	33.3	0.54	-		LFDP (1997); [c]Gashaw Tesfaye and Zenebe Tadesse (2008)
L. Langeno	2.89	0.90	16.62	35.7	0.32	-0.49	2.61	Present study
L. Hawassa	2.72[e]	-		33.8	0.40	-	2.66	[d]Demeke Admasu (1994); LFDP (1997); [e]Lubaba Mohammed (2017)
L. Chamo			42.2[y]	55.0	0.37	-	-	[y]Yirgaw Teferi et al. (2000); Buchale Shishtu et al. (2019)
L. Chamo	2.91	0.996		59.40	0.41		3.16	Million Tesfaye et al. (2021)
Fincha Reservoir			24.5					Fassil Degefu et al. (2012)
Alwero Reservoir	2.76	0.93	22.5					Genanaw Tesfaye et al. (2017)
Tekeze Reservoir	2.91	0.95						Tsegaye Teame et al. (2018)
L. Victoria				58.8	0.59		3.31	Njiru et al. (2004)
L. Victoria				46.24	0.69		3.14	Yongo et al. (2018)

Table 2. Mortality factors calculated for the Nile tilapia stocks from other water bodies in Ethiopia.

Water body	Z (yr^{-1})	M (yr^{-1})	F (yr^{-1})	E	References
L. Tana, Ethiopia	2.37	0.98	1.39	0.59	Workiye Worie et al. (2019)
L. Koka, Ethiopia	1.47	0.82	0.65	0.45	Gashaw Tesfaye and Wolff (2015)
L. Hawassa, Ethiopia	1.06	0.35	-	-	Yitayal Alemu et al. (2017)
L. Ziway, Ethiopia	-	1.21	-	-	Gashaw Tesfaye (2006)
L. Chamo, Ethiopia	1.509	0.97	0.72	0.48	Buchale Shishitu et al. (2019)
L. Langeno, Ethiopia	2.31	0.75	1.56	0.67	Present study
L. Victoria, Kenya	2.16	1.00	1.12	0.52	Njiru et al. (2004)

In conclusion, this study presented important data on the life history parameters (growth and mortality rates) and some valuable information concerning the fishery management for the Nile tilapia stock in Lake Langeno. The length at first capture (Lc= 14.0 cm) is much less than the size at first maturity (L_m = 16.62 cm) indicating harvesting of small sized/juveniles fish. This estimated lower values may be due to higher fishing pressure using small sized mesh nets on the stocks. The estimated values of % > L_m and % within the L_{opt} also indicated that recruitment overfishing of the stock in Lake Langeno. Moreover, the exploitation rate (E= 0.67) is higher than the optimal (E = 0.5) of Gulland (1971) indicated that the overexploitation of the Nile tilapia stock. Based on these results, we suggest that the fisheries management of the lake should include controlling or restriction of the usage of small sized mesh fishing nets. Additionally, fishing efforts (legal or illegal) need to be reduced to ensure potential of this commercially important species in the lake.

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