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LENGTH-BASED GROWTH AND STOCK CHARACTERISTICS OF THE NILE TILAPIA *OREOCHROMIS NILOTICUS* (LINNAEUS, 1758) IN LAKE TANA, ETHIOPIA

Belay Abdissa[1]

ABSTRACT: Age, growth and stock characteristics of the Lake Tana Nile tilapia (*Oreochromis niloticus*) were studied from 2000 to 2006. Fishery independent data from the Bahir Dar Fisheries and Other Aquatic Life Research Centre (BFALRC) and 12 months commercial data of the motorized boat from Fish Production and Marketing Enterprise (FPME), Bahir Dar branch, were analysed. Commercial length frequency and catch data were recorded and more than 5000 samples were taken from experimental fishery. Individual fish in the experimental fishery were caught monthly during February 2000 to December 2004 and bimonthly during January 2005 to December 2006. The size of *O. niloticus* in the commercial landings ranged from 13 to 41 cm total length (TL). The length at first capture (LC) was 26.95 cm and about 53% of the fish in the commercial catches measured were <27 cm. Length-based stock assessment using the FISAT software package showed an asymptotic length ($L\infty$) of 44.2 cm TL, growth coefficient of 0.43 yr^{-1} and t_0 = -0.33296 yrs. The estimated maximum age (longevity) was 6.64 years. These results gave a growth performance index (ø) of 2.92. The total mortality coefficient was estimated to 1.53 yr^{-1}, a natural mortality of 0.63 yr^{-1} and fishing mortality of 0.9 yr^{-1}. The estimated total mortality which is in relative terms, was considered average (1.53 yr^{-1}), coupled with the currently observed exploitation rate of 0.59 for *O. niloticus*, estimated from the mortality rates, suggested that the species was maximally exploited. The estimates of MSY stood at 155.11 MT by Cadima's formula.

Key words/phrases: Growth, Lake Tana, *Oreochromis niloticus*, Stock assessment.

INTRODUCTION

Nile tilapia (*Oreochromis niloticus*) is a commercially important fish species of Lake Tana (Ethiopia) and forms an important constituent of motorized and reed boat fisheries. In the northern part of Lake Tana and southern Gulf of Bahir Dar, the Nile tilapia is commercially harvested by the artisanal fishermen. They use reed boats with monofilament gillnets through overnight deploy and chase and trap, whereas in the eastern part motorized boat fishery are engaged with a combination of monofilament and multifilament gillnets.

[1] Bahir Dar Fisheries and Other Aquatic Life Research Centre, Bahir Dar, Ethiopia. E-mail: epheson2002@yahoo.com

Catch of *O. niloticus* in Lake Tana fishery is variable and highly correlated with seasonal changes in water levels (de Graaf *et al*., 2006). Catch per unit effort (CPUE) decreased significantly in the rainy season from July to December when water levels are high. When water levels are high, *O. niloticus* migrates towards the inundated floodplains where the commercial gill net fishery has no access. Regular seasonal dispersion of *O. niloticus* associated with inundation of floodplains has been reported for several African lakes (Kolding, 1993; de Graff *et al*., 2006).

Length-based cohort analysis was developed for species that cannot be aged. The principle is the same for age-based cohort analysis, but fishes are separated into length classes (Jones, 1981). Growth, recruitment and mortality estimates are the basic parameters needed to quantify the stock dynamics for a particular fish population. When these parameters are used as input parameters in fishery yield models, management alternatives and their consequences for the fish population or community can be quantified in relation to yield (King, 1995).

Various methods have been employed to study fish growth in tropical African lakes. Of these, analysis of population size structure or length frequency used Peterson method (Peterson, 1896) in Lake Tana (Tesfaye Wudneh (1998) and Lake Koka (Gashaw Tesfaye and Wolff, 2015). The study of growth marks on calcified hard structures such as scales, otoliths, vertebrae and opercular bones were used in Lake Awassa (Yosef Teklegiorgis, 1990); Lakes Zwai, Langeno and Chamo (Demeke Admassu, 1998); Lake Tana (Tesfaye Wudneh, 1998); Lake Awassa (Yosef Teklegiorgis and Casselman, 1995), and mark-recapture method were used for growth studies of captive fish in enclosures in Lake Awassa (Yosef Teklegiorgis, 1990) and Lake Victory (Rinne, 1975). In Lake Tana, the first attempt to estimate the growth of fish stocks was done by Tesfaye Wudneh (1998) using hard structure and length frequency analysis. This paper has attempted to examine the situation after 20 years and tried to update the growth and stock characteristics of Nile tilapia *O. niloticus* in Lake Tana under current fishing practices (monofilament gillnet) and water hyacinth infestation conditions.

Even though there is certain information on the commercial importance of Lake Tana *O. niloticus*, there has been little research carried out to estimate age and growth as well as population characteristics. The present study therefore aims to estimate the age and growth parameters, and evaluate the status of *Oreochromis niloticus* in Lake Tana in order to develop a better management plan for sustainable exploitation of this target species. Length frequency data obtained from fishery independent and commercial catch data were used. We believe that the data gained by these two fishing methods are representative of the Lake Tana *Oreochromis niloticus* population, since the fishing sites touched almost all parts of the lake. Combining length frequency analysis with growth study using hard structure may provide good results, however, we were unable to use hard structures due to lack of logistics. The results of this study might be helpful in developing a management plan for sustainable harvest of lake fisheries.

MATERIALS AND METHODS

Fishery independent catch data from the Bahir Dar Fisheries and Other Aquatic Life Research Centre (BFALRC) and fishery dependent data from Fish Production and Marketing Enterprise (FPME), Bahir Dar branch were used for the analysis. Experimental gillnet fishing was conducted at six sites in the northern and southern parts of Lake Tana. Each of the six sites, whose coordinates are given in Table 1, was further sub-divided into three sub-sites which were identified as “river mouth”, “macrophytes cover” and “open water“. Individual fish in the experimental fishery were caught monthly during February 2000 to December 2004 and bimonthly during January 2005 to December 2006.

Table 1. The coordinates of the six sampling stations of experimental research on Lake Tana.

Station name	**Coordinates**	
	North	**East**
Gerima	11°37′02″	37°23′05″
Zegie	11°42′06″	37°23′09″
Abbay	11°51′05″	37°08′01″
Dirma	12°15′44.8″	37°18′43.4″
Gedamat	12°12′52.2″	37°17′35.3″
Sekela	12°13′20.9″	37°18′47.7″

A one year (July 2010 to June 2011) monthly data of the motorized commercial gillnet fishery from Fishery dependent data from Fish Production and Marketing Enterprise (FPME) Bahir Dar branch were used. The FPME collected the catch from all the fishermen cooperatives and individual fishers around Lake Tana. Fishing sites were grouped before analysis and revised with current situation within fishing areas following Tesfaye Wudneh (1998) and de Graaf *et al*. (2006). NEFP (North-Eastern Flood Plain; includes Nabega, Saben, Rib and Fikr Mecheresha); GRM (Gumara River Mouth; includes Jigrfa, Gumara, Rima and Abuara); BDWC (Bahir Dar Gulf West Coast; includes Lijomie Gebriel, Ambo Bahir, Gerima and Kibran); BDGE (Bahir Dar Gulf East; includes Korata, Gelda and Bet

Menzo) (Fig. 1).

A total of 5,403 fishes from commercial and experimental gillnet fishery were collected. Measurements of total length (TL) and total weight (TW) were taken to the nearest 1 mm and 1 g. The fishing gear used were multi-panel gillnets with stretched mesh sizes 60, 80, 100, 120 and 140 mm in the experimental fishing, and 80 and 100 mm in the commercial fishery.

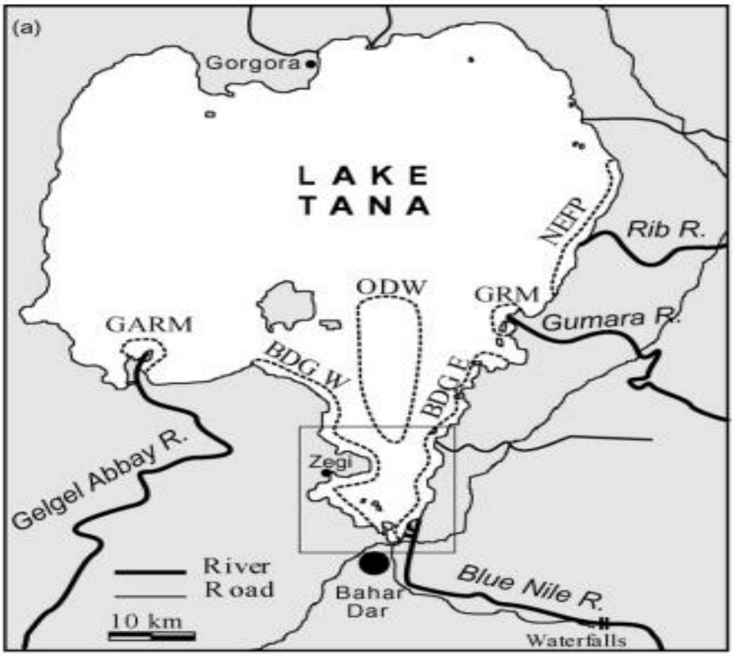

Fig. 1. Location of the fishing grounds in Lake Tana. GARM: Gelgel Abbay River Mouth, 5 km^2; BDG W: Bahir Dar Gulf West coast, 50 km^2; BDG E: Bahir Dar Gulf East coast, 50 km^2; GRM: Gumara River Mouth, 5 km^2; NEFP: North-Eastern Flood Plains, 35 km^2; ODW: Offshore Deep Water area, 80 km^2 (after de Graaf *et al*., 2006).

To estimate the von Bertalanffy growth (VBGF) parameters ($L\infty$, K and t_0) of *O. niloticus*, 1,828 sexed TL frequency data from research catch were grouped into 1 cm class interval to fit the equation, $L_t = L\infty*[1 - e^{-K*(t-t0)}]$. The ELEFAN II (version 1.2.0) with non-seasonal version of VBGF curve were fitted to the TL data to calculate VBGF parameters.

Where, $L_{(t)}$ = length at age t (years); $L\infty$ = asymptotic length that the fish attains at an older age (cm); K = growth rate constant (yr^{-1}) the rate at which $L_{(t)}$ approaches $L\infty$; t = age of fish (years) and is the theoretical age of fish at zero length. Length frequency data of 874 female and 987 male fish from the experimental fishing gears were grouped into 1 cm class interval to estimate growth. Length at first capture (Lc) was estimated by plotting cumulative percentage of fish against length classes, and following Beverton and Holt (1957) equation:

$$Lc = \frac{L - K(L\infty - Lmean)}{z}$$

Where, Lc is the length at first capture, Lmean is the mean length of fish in the catch sample, K and L∞ are parameters of the von Bertalanffy growth equation and Z is the instantaneous mortality rate.

The study of length-weight (LWR) and length-length (LLR) relationships is considered to be important to obtain different kinds of information of fish in fish biology such as growth rate, age structure, age at first maturity, discrimination of stocks and population dynamic studies (Kohler *et al*., 1995; Borah *et al*., 2017; da Silva *et al*., 2017; Ergüden *et al*., 2017). The length-weight relationship was used to convert the asymptotic length (L∞) to the corresponding asymptotic weight (W∞). To calculate length-weight relationship, a one-year monthly collected commercial data from 1829 male and female fish were used for the analysis. The general equation is:

$W = aL^b$

Where, W is the total weight in g, L is the total length in cm and ‘*a*’ and ‘*b*’ are constants to be determined.

The value of phi-prime (*Ø*) was used to compare growth parameters obtained in the present work with those reported by others. The overall growth performance index (Phi prime (Ø′) for the fish were calculated empirically using the equation proposed by Pauly and Munro (1984):

$Ø' = \log_{10} K + 2 \log_{10} L\infty$

Where, K is expressed on annual basis and L∞ in cm.

The instantaneous total mortality rate (Z) of fish was estimated by the length converted catch curve method (Pauly, 1983) from the commercial catches using the routines provided in the FISAT II software and Beverton-Holt method (Beverton and Holt, 1956) using the formula:

$$Z = k\left[\frac{L\infty - L_{avg}}{L_{avg} - L'}\right]$$

Where, K and L∞ are parameters of the von Bertalanffy growth equation, L_{avg} is mean length of fish in the catch sample, L′ is the length at and above which all fish are fully vulnerable to the fishery, and Z is the instantaneous mortality rate.

Natural mortality coefficient (M) of fish was predicted by empirical method of updated Pauly$_{nls-T}$ estimator since t_{max} was not available (Then *et al*., 2015).

$M_{est} = 4.118K^{0.73} L\infty^{-0.333}$

Where, M_{est} denotes a new prediction of M.

The fishing mortality (F) was computed by subtracting natural mortality from total mortality as:

F = Z – M

The exploitation rate (E) was then estimated from Z and F values as defined by the equation (Gulland (1971) as, E = F/Z. It tells us ratio between the number of individuals caught and the total number of individuals dead, over a certain period of time.

The exploitation ratio (U) was estimated by the equation (Beverton and Holt, 1957; Ricker, 1975) as:

$$U = F / Z (1-e^{-z})$$

Relative yield-per-recruit (Y'/R) is computed from:

$$Y'/R = EU^{M/K} = \{1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m}\}$$

The data from Fish Production and Marketing Enterprise (FPME) Bahir Dar branch record annual average catch of *O. niloticus* during 2011 was considered as yield (Y).

The standing stock of fish was estimated using the formula:

Standing stock = Y/F

Where, Y is the fish yield and F is the fishing mortality.

The total stock was calculated by the relation between yield and exploitation ratio as:

Total stock = Y/U

Where, Y is the fish yield and U is the exploitation ratio. The maximum sustainable yield (MSY) of *O. niloticus* was estimated using Cadima's formula as:

MSY = 0.5* (Y+M*B)

Where, Y is the total catch in a year and B is the current average (annual) biomass calculated from cohort analysis in the same year and M is the natural mortality.

RESULTS AND DISCUSSION

The length frequency distribution of *O. niloticus* in the commercial catches ranged from 13 cm to 41 cm of TL and that of experimental fishing net ranged from 11 cm to 42 cm. Fish measuring up to 26 cm formed about 53% of the catches. However, fishes in the size range of 27 to 30 cm formed about 36% of the catches and the rest of the higher sized fishes collectively formed about 11% of the catches (Fig. 2).

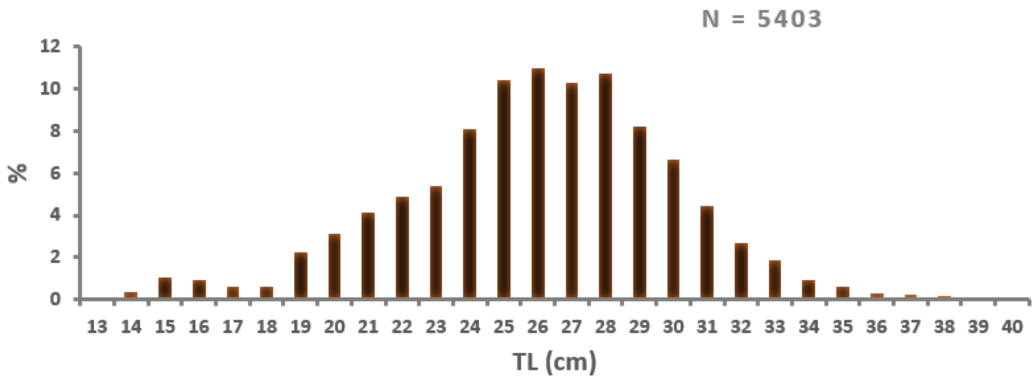

Fig. 2. Length frequency distribution of Lake Tana *O. niloticus* in the commercial and experimental catches.

The length-weight relationships showed that the females were slightly heavier than the males measuring the same length. Analysis of covariance revealed no significant ($p = 0.05$) difference between the sexes. Hence, the length-weight relationship equation for sexes pooled data would provide a good fit for *O. niloticus* data as, $W = 0.0172L^{3.019}$, ($r = 0.976$). Le Cren's concept hypothetically stated that the value of 'b' in ideal fish to be 3, indicating an isometric growth, which is widely used as a scale in length-weight relationship study (Singh and Serajuddin, 2017). The greater value of 'b' mainly depends on shape and fatness of individuals of fish. The b value was not statistically different from 3 which signifies an isometric growth (t-test; $p>0.05$).

Figure 3 shows the VBGF curve of *O. niloticus* estimated using the monthly length frequency data by ELEFAN techniques. The VBGF parameters, L∞ (asymptotic length), K (growth curvature constant) and $-t_0$ (a theoretical age at length zero) of *O. niloticus* in Lake Tana were 44.2 cm, 0.43 yr^{-1}, and -0.33296 year, respectively. The asymptotic weight, W∞ that corresponds to L∞ (calculated using the length-weight relationship; W = q*L∞) was 1.60 kg.

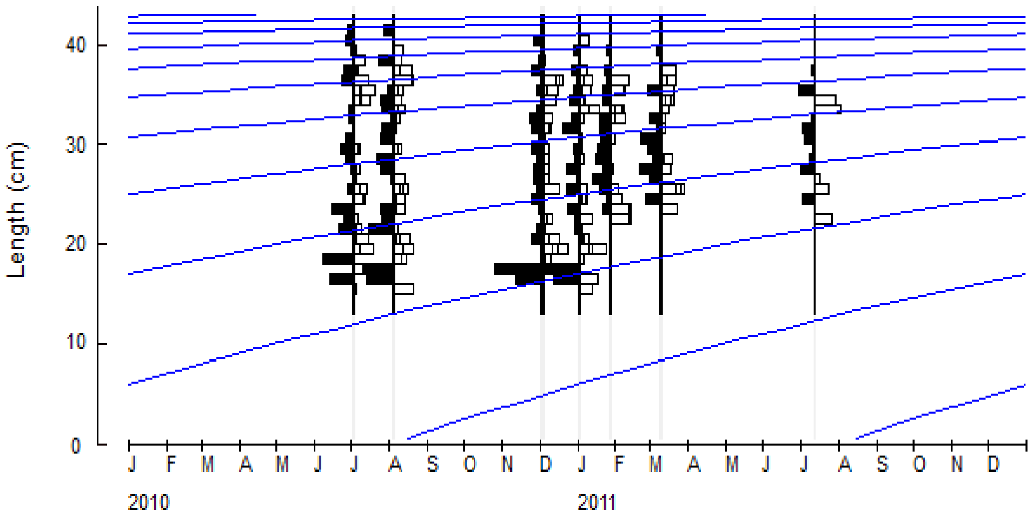

Fig. 3. VBGF curve of *O. niloticus* by ELEFAN 1 technique.

The lengths of *O. niloticus* converted into age ELEFAN 1 techniques showed that the life span would be 6.50 years in Lake Tana (Fig. 4). On the other hand, based on Pauly's equation (1983), it was indicated that the fish might live up to 6.64 years (longevity). The growth performance index (Ø') based on length frequency data was estimated at 2.92 which was higher than that reported by Tesfaye Wudneh (1998) but similar to the one reported by Gashaw Tesfaye and Wolff (2015) and du-Feu and Abiodun (1999) (Table 2). L∞ of *O. niloticus* has increased from 34.0 cm TL in 1998 to 44.2 cm TL in the present study while K decreased from 0.6 yr^{-1} to 0.43 yr^{-1}. Table 2 shows the comparison of the present study of Lake Tana *O. niloticus* growth parameter estimates with other water bodies previously reported. The magnitude of Ø′ is determined by both K and L∞, and as they are inversely related, increase in L∞ and reduction in K results in more or less constant Ø′ for a given stock. The present study of *O. niloticus* population from Lake Tana tends to grow better than the previous study populations (Tesfaye Wudneh, 1998), and in other Ethiopian lakes and Lake Turkana, and resembles that of Lakes Koka and Kainji, Nigeria population, but is smaller than Lake Kaptai, Bangladesh. Fishing activity shifted to the far northern part as compared to the southern gulf of Bahir Dar as reported by Tesfaye Wudneh (1998) which is attributed to index difference. In the current study, the fish belonging to the age groups 1.49 and 2.31 years were dominant. This value was similar with that of Tesfaye Wudneh (1998).

Table 2. Literature information on von Bertalanffy growth parameters and the rate of natural mortality for *O. niloticus*, from different water bodies.

L∞	K	Ø′	M	Location	References
55.6	0.39	3.08	0.80	L.Kaptai, Bangladesh	Ahmed *et al*. (2003)
45.4	0.36	2.87	0.74	L.Koka, Ethiopia	Gashaw Tesfaye (2006)
28.1	0.64	2.76	1.21	L.Ziway, Ethiopia	Gashaw Tesfaye (2006)
44.5	0.41	2.90	0.82	L.Koka, Ethiopia	Gashaw Tesfaye and Wolff (2015)
29.7	0.44	2.59	1.03	L.Turkana, Kenya	Moreau *et al*. (1995)
44.2	0.43	2.92	0.63*	L.Tana, Ethiopia	Present study
35.7	O.50	2.80	0.97	L.Tana, Ethiopia	Tesfaye Wudneh (1998)
33.8	0.40	2.66	0.86	L.Awassa, Ethiopia	LFDP (1997)

M* calculated using Pauly (1980) and Then *et al*. (2015).
L∞ = asymptotic length (cm), K = growth curvature parameter ($year^{-1}$), Ø′ = growth performance index in length (cm $year^{-1}$) and M = natural mortality coefficient ($year^{-1}$).

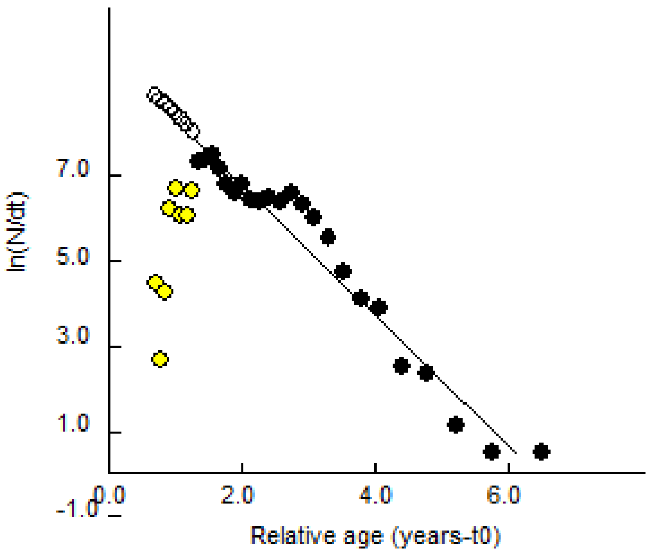

Fig. 4. Length converted catch curve for *O. niloticus* of Lake Tana.
Note: Black dots are number of observations considered for computation of total mortality whereas the yellow dots are observations excluded.

The length at 50% of fish caught (Lc) was calculated to be 27.0 cm. The fishable size in Lake Tana *O. niloticus* appeared to be attained during the second year (Table 3).

Table 3. Length and growth rate of female and male *Oreochromis niloticus* at a given age in Lake Tana.

Age of fish, t(year)	**Body length of fish (cm) Lt =** $L\infty(1-e^{-k(t+t_0)})$	$L(t+\Delta t)$ **(y)**	**Growth rate (cm/yr),** $\frac{\Delta L}{\Delta t}=\frac{L(t+\Delta t)-L(t)}{\Delta t}$	**Mean Length(cm)** $\bar{L}(t)=\frac{L(t+\Delta t)+L(t)}{2}$ **(X)**
1	11.0	22.6	11.6	16.8
2	22.6	30.2	7.5	26.4
3	30.2	35.1	4.9	32.6
4	35.1	38.3	3.2	36.7
5	38.3	40.3	2.1	39.3
6	40.3	41.7	1.4	41.0
7	41.7	42.6	0.9	42.1
8	42.6	43.1	0.6	42.9
9	43.1	43.5	0.4	43.3
10	43.5	43.7	0.2	43.6
11	43.7			

The growth rate of fish decreases through time as mean length increases. As seen in Fig. 5, younger fishes exhibited higher growth rate compared to older and longer fishes. But, the fish continued growing until it reached the asymptotic length (L∞), i.e., the average extreme length of a very old fish.

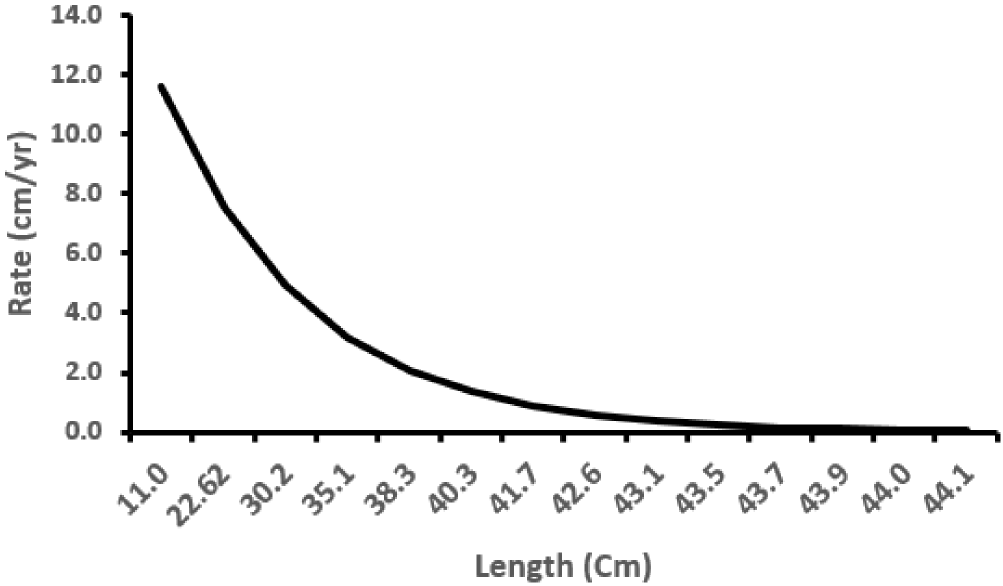

Fig. 5. Growth rate of *Oreochromis niloticus* against mean length.

The instantaneous total mortality coefficient (Z) of unsexed commercial catches of *O. niloticus* estimated for Lake Tana by the length converted catch curve method was 1.53 yr^{-1}. The Beverton-Holt method also gave similar value (Z = 1.52 yr^{-1}). Hence, the Z calculated by length converted catch curve method (1.53) was taken for further analysis. The results showed that the total instantaneous mortality of Lake Tana *O. niloticus* decreased to 1.53 yr^{-1} from 1.8 yr^{-1} in 1998 (Tesfaye Wudneh, 1998).

The natural mortality coefficient (M) of Lake Tana *O. niloticus* estimated from Lake Tana catches by updated $Pauly_{nls\text{-}T}$ estimator empirical methods gave value of 0.63 yr^{-1}. Hence, the fishing mortality (F) computed for *O. niloticus* in the present study was 0.9 yr^{-1}. Our result showed lower (M) estimated values than previously reported values for Lake Tana and in other Ethiopian lakes (Table 1) but (F) estimated values were higher than 0.84 yr^{-1} (Tesfaye Wudneh, 1998) and Lake Koka (Gashaw Tesfaye and Wolff, 2015). The fishing mortality is more important in the adult size group of the population, whereas the natural mortality affects all size/age classes with the greatest impact on the larval and juvenile groups which are more vulnerable to predation, disease, and environmental changes. Since the fishery on Lake Tana was unregulated, we might assume that fishing mortality, and consequently the total mortality, was high. The estimation of mortality usually done by age or length-based catch curve analysis based on pooled size or age distributions corrected for the fishing effort was applied. The main assumption is a linear relationship between numbers in an age category of the population and numbers of the same age category caught per unit of effort (King, 1995). The current smaller value of natural and bigger fishing mortality might be an indication of Lake Tana’s tilapia stock decline, after which the fishery starts to harvest the parent stocks.

The exploitation rate (E) and exploitation ratio (U) of Lake Tana *O. niloticus* were 0.59 and 0.75, respectively. In the present study, fishing mortality (F) value of the lake was 0.9 yr^{-1} that indicates larger exploitation rate as compared to previous report of 44% (Tesfaye Wudneh, 1998). When we look at the length frequency distribution for the state of the fishery, the catch size distribution showed that three-fourths of the *O. niloticus* catch lies above the size of *Lm* suggesting that stock overfishing is occurring and the very low percentage of mega-spawners (3.6%) would also suggest stock overfishing, which is in agreement with the exploitation rate estimate based on Pauly’s M estimate.

The Beverton and Holt (1957) relative yield per recruit (knife edge selection) model using FISAT II software and the analysis result (Fig. 6) indicates that the indices for sustainable yield were 0.254 for optimum sustainable yield ($E_{0.5}$), 0.389 for the maximum sustainable yield (E_{max}) and 0.317 for economic yield target ($E_{0.1}$). The current estimated exploitation rate was 0.59 obtained from the analysis of mortality rates, which was already above the maximum, optimum and economic yield indices. We, therefore, infer that stock overfishing is occurring in Lake Tana *O. niloticus*.

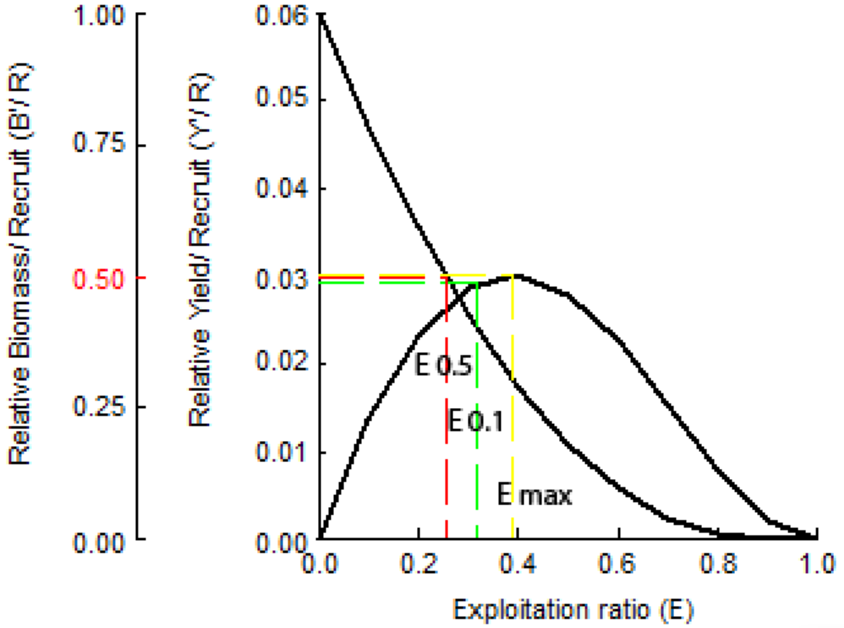

Fig. 6. Beverton and Holt's relative yield per recruit and average biomass per recruit models, showing levels of yield indices: $E_{0.5}$: optimum yield, $E_{0.1}$: maximum economic yield, E_{Max}: maximum sustainable yield for *O. niloticus* in Lake Tana.

Currently in Lake Tana, the fishermen have shifted to monofilament gillnet substituting the multifilament gillnet (80 and 100 mm mesh size). From the evaluation made so far, the highest yield (MSY) of *O. niloticus* was achieved at lower values of F (0.8 yr^{-1}), indicated in a circle (Fig. 7).

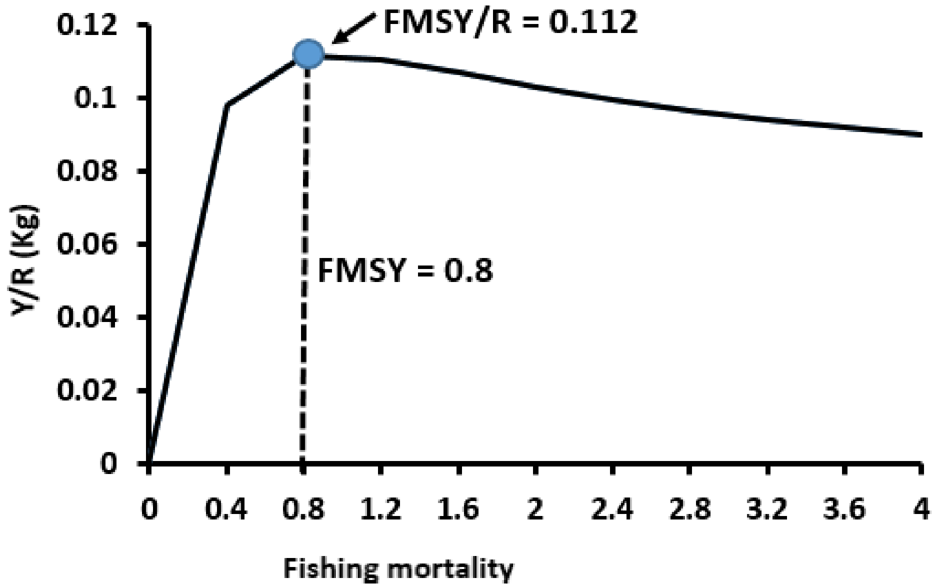

Fig. 7. Yield per recruit curve of *O. niloticus* fishes of Lake Tana as a function of F (parameters taken; K= 0.43 yr^{-1}, Tc =1 year, t_0 = -0.33296 year, M = 0.63 yr^{-1}, Tr = 0.5 year and W∞ = 1.60 kg).

The curves in Fig. 7 allow several generalizations to be made about the fishing mortality of Lake Tana *O. niloticus*, and therefore the fishing effort required to obtain the maximum yield (Y_{max}) from a stock and set management option for sustainable utilization. Fig. 7 indicates that Lake Tana *O. niloticus* stock with a high natural mortality (M = 0.63) required a low fishing effort to maximize yield than the existing estimated F = 0.9 yr^{-1}. According to this result, the optimum fishing rate that gives the maximum sustainable yield is 0.8 yr^{-1}. Hence, the current fishing rate should be decreased to 10% to sustainably exploit the stock.

The annual average catch of Lake Tana *O. niloticus* during 2011 was 168.6 metric tons (MT) (Brehan Mohammed, 2011). This was considered as yield for the year 2011. The average annual yield for both the years worked out to 168.6 metric tons. Based on this yield, the estimated average annual standing stock stood at 187.33 MT with the annual average total stock of 224.8 MT. The MSY calculated by Cadima’s formula stood at 155.11 MT. As the current yield is 168.6 MT, there would be scope of decrease in the catch by 13.49 MT. The calculated E (0.59) also supports this conclusion.

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