Age and Growth of Nile Tilapia, *Oreochromis niloticus* (Linnaeus, 1758), From Koka Reservoir, Ethiopia

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Abstract

The age and growth rate of the fish species must be known since they are essential input variables that compose stock assessment models to assess the stock status and estimate the exploitable potential of the stock. The age and growth of Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758), in Koka Reservoir, Ethiopia, were studied based on 981 sagittal otoliths collected monthly from December 2017 to November 2018. Otoliths were grounded and examined under a stereoscopic microscope at 10–40× magnification for macrozones analysis using a reflected light source. The age of the fish was determined based on the number of translucent zones counted in the otoliths of *O. niloticus* by considering the time of translucent zone formation and median hatch date. Seasonal records on the macrozones at the edge of otoliths and relative marginal increments suggested that two translucent macrozones associated with biannuli were formed each year, one from January to February, and another one from June to July. The observed ages of *O. niloticus* from Koka Reservoir ranged from 1 to 6.5 years, and the most dominant classes were 2 and 3 years. Growth was determined using the von Bertalanffy growth function. The von Bertalanffy growth parameters (sexes combined) were; asymptotic length (total length), $L\infty = 35.6$ cm, growth rate constant, $K = 0.37$ year^{-1}, theoretical age at zero-length, $t_0 = -0.42$ years and the growth performance length, $\varphi' = 2.67$. It could be concluded that the growth of *O. niloticus* in Koka Reservoir is within the range mentioned in Ethiopian lakes.

Keywords: biannuli, macrozones, otoliths, von Bertalanffy growth parameters

Introduction

Age and growth are closely related terms because determining the fish's age is essential in growth studies. Age determination is an old-age practice and a central part of all work directed to the rational exploitation of fish stock. Knowing the age of fish provides a clue to its longevity, age at first maturity, age at first capture, age of recruitment, and growth (Campana, 2001). Moreover, the established age-length relationship allows the development of catch curves from which the annual mortality rates can be calculated (Stevenson and Campana, 1992). Therefore, accurately determining fish's age is indispensable to understanding the dynamics of their stocks. The age of fish can be estimated indirectly by analysing the length-frequency distribution, which provides the mean length of each age group. Alternatively, it provides the individual age by counting each specimen's annual growth marks in calcified structures, such as scales, otoliths, opercular bones and fin rays. The latter method is more precise and gives more information on the fish population dynamics. In addition, the use of length-frequency data to estimate the age of long-lived fish has limitations (Ferreira and Vooren, 1991). Age determination of fish from scales, otolith, vertebrae, fins, spines, fin rays, and other structures is a matter of routine in most exploited fish stocks. Among these, otoliths have become the most popular and widely used source of age information since resorption is not observed under stress conditions, which is not the

case for other hard parts (Campana, 2001).

Applying the anatomical and length-frequency analysis methods is problematic; hence, the age of tropical fishes was assumed to be almost impossible due to continuous spawning and the absence of growth cycles (Mohr, 1921). Annual growth rings are deposited in the calcified fish tissues partly due to seasonal environmental changes. These periodic changes (temperature cycles, available food) are less regular and less severe in tropical compared to temperate zones. However, investigators indicated the importance of annual growth rings in tropical fish otoliths (Getabu, 1992; Gomez-Marquez, 1998; Bwanika et al., 2007). The reasons for this cyclical annual growth are uncertain. Some authors relate them to spawning periods (Admassu, 1998; Jimenez-Badilo, 2006; Gomez-Marquez et al., 2008; Degsera et al., 2020) and others to water temperature changes (Tekle-Giorgis and Casselman, 1995; Admassu, 1998; Gomez-Marquez, 1998; Degsera et al., 2020).

Fish invest more energy in reproduction in the pre-reproductive period than in growth, and mouth-brooding fish species like *O. niloticus* do not feed during their breeding season. This condition could be responsible for growth zone formation. For example, *O. niloticus* typically reproduces from April to August, with a peak spawning in June/July in Lake Tana, (Ethiopia), which corresponds with the period of translucent zone formation (Degsera et al., 2020). This results in reduced feeding by the female, whereas males are engaged in constricting and safeguarding spawning sites, as well as fertilising numerous females during this period (Jiménez Badillo 2006; Gomez-Marquez, 2008).

It is well known that most fish are poikilotherms; the temperature of their environment influences their metabolic processes. This is reflected in the fast growth during warm periods and slow during colder periods. During the anabolic process, calcareous material is deposited repeatedly in the hard part; this is reflected in the hard parts as wide, shining translucent bands formed during the warmer, fast growth periods and narrower, opaque bands during the colder, slower growth periods. The appearance of translucent and opaque bands depends on whether the light source is reflected from or transmitted through the calcareous material. The translucent band appears dark when viewed with reflected light because it allows a higher proportion of the impacting light to pass through it rather than being reflected to the viewer as compared to the opaque band (Green et al., 2009).

The conditions on the edges of otoliths are carefully examined to investigate if the translucent zone formation occurred at a particular time or season of the year. The conditions on the edges of otoliths could be classified into four conditions: "o" Condition – translucent zones associated with an annulus on the edge of otoliths. "*" Condition – it is a translucent zone

formation is completed; there is a narrow opaque zone on the edge of translucent zones. "+" Condition – opaque zones at the edges, 50 % or less than the width of the preceding opaque zones. "++" Condition – opaque zones at the edges are larger than 50 % of the width of the preceding opaque zones (Tekle-Giorgis and Casselman, 1995).

Tilapias are important fish species in several parts of the world. They represent a significant component of commercial inland fish landings in Africa, and they contribute 32 to 100 % of the catch in many countries of Africa (World Bank, 2012). They are generally grouped into four genera, *Tilapia, Sarotherodon, Danakilia*, and *Oreochromis* (Trewavas, 1983). *Oreochromis niloticus* (Linnaeus, 1758), is one of the species which is a widely distributed cichlid of commercial importance in the Eastern Africa Rift Valley (Hyuha et al., 2017). It is one of the most important commercial freshwater fish species found in almost all Ethiopian lakes and rivers (Tewabe, 2013; Dejen et al., 2017). According to Tesfaye (2016), it accounts for about 50 % of the annual commercial fishery of Ethiopia. Therefore, knowledge of this important specie's age and growth is necessary to understand its stock status better and to plan optimal management strategies.

The temperature of Koka Reservoir showed seasonal variations. According to Wondimu's (2014) report, during the dry season, the water temperature was high compared to the wet season. This was also corroborated by the data collected during the current investigation.

There is limited information on the age and growth of *O. niloticus* in Ethiopia (Admassu and Casselman, 2004; Degsera et al., 2020). This is also true for the age and growth of *O. niloticus* in Koka Reservoir. Tesfaye and Wolff (2015) studied the growth of *O. niloticus* and other commercially targeted fish stocks in Koka Reservoir using mainly length-frequency analysis. However, no studies have yet evaluated the age and growth of this species in Koka Reservoir using age determination based on hard bony structures alone. The present study focused on the actual age and growth determination of *O. niloticus* in Koka Reservoir based on the interpretation of annual rings on the otoliths of the specimen collected throughout the year.

Materials and Methods

Ethical approval

The school of Fisheries and Wildlife Ethical Committee, Bahir Dar University, Ethiopia gave ethical clearance prior to the starting of the investigation on 11-11-2017, Reference No. FASc.160/17/17.

Description of the study area

Koka Reservoir, also known as Lake Gelila, (8°19'–

8°28'N and 39°01'–39°09'E), is a manmade lake constructed in the 1960s for hydroelectric power production. It is located in the Awash Basin, at an elevation of 1,590 masl in South-central Ethiopia, approximately 90 km southeast of Addis Ababa in the Ethiopian Rift Valley (Fig. 1). The inflow to the lake comes from the Awash and Modjo rivers, whereas the outflow is Awash River itself. The lake has a surface area of 225 km^2 with a maximum and average depth of 14 m and 9 m, respectively (LFDP, 1997; Dadebo et al., 2014; Tessema et al., 2020). The main rainy season of the area starts in June and extends to the end of August/September, while the short rainy season of the area also occurs from March to May. The maximum and minimum temperature of the reservoir area is 30.4 °C and 14 °C, respectively (Mengesha, 2009).

The surface water temperature of Koka Reservoir, recorded at sampling time, ranged from 17.5 °C to 24.5 °C. The minimum surface water temperatures were recorded during July (17.5 °C), and higher water temperatures ranged from 22.6 °C to 24.5 °C between March and May, and September and October. The area is characterised by a wide and open plain, suitable for the cultivation of crops. Koka Reservoir is among the most important lakes for Ethiopian small-scale fisheries in general and riparian societies in particular; it supports a fishing industry of about 625 tons of fish each year (LFDP, 1997). The lake contributes an average of 7 % of the total annual catch in the country and is the most important for the Ethiopian fishery (Tesfaye and Wolff, 2014). Four species dominate the commercial fish landings at Koka Reservoir: the common carp, *Cyprinus carpio* Linnaeus, 1758, *O. niloticus*, the North African catfish, *Clarias gariepinus (*Burchell, 1822), and the Ethiopian barb, *Labeobarbus intermedius* (Rüppell, 1835), (Mengesha, 2009). *Oreochromis niloticus* and *C. gariepinus* are the most dominant species constituting based on biomass about 40 % and 42 %, respectively, of the total landings in the lake, followed by Common carp 6 % and the least is *L. intermedius* with 2 % (Tesfaye and Wolff, 2014; 2015; Tesfaye, 2016).

Fish sampling

Samples of *O. niloticus* were collected every month from December 2017 to November 2018. The fish samples were collected from the main landing site of the commercial fisheries, locally known as Mato-Halaka. The commercial fishers' monofilament gillnets (30 m × 3 m) consist of different stretched mesh sizes (80 mm, 100 mm, 120 mm, 140 mm, and 160 mm). All fish were weighed and measured. The sex and gonad maturity stages of each specimen were visually determined after dissecting the abdomen of the fish (Holden and Raitt, 1974). The length-weight relationship was calculated using the power function for males and females separately, and to confirm the growth characterisation, a student's t-test was performed for each sex to identify whether the slope (b) was significantly different from 3.

$$TW = a \times TL^b \tag{1}$$

where TW is the total weight (g) and TL is the total length (cm).

The largest pair of sagittal otoliths were used for this study. The otoliths *were* removed by making a transverse cut across the dorsal side of the cranium at the bony ridge midway between the eye and the edge of the opercular bone (Admassu, 1989; Tekle-Giorgis, 1990). After removal, otoliths were cleaned and stored in 1.5 mL vials containing 95 % ethanol for three days (Casselman, 1987).

Otolith preparation for macrozone analysis

Of the pair of otoliths, the right one was used for macrozones analysis throughout the study, but when the right otolith was broken or damaged, the left one was used (Lowerre-Barbieri et al., 1994; Dehghani et al., 2016; Tessier et al., 2019). To enhance the appearance of the macrozones, otoliths that were placed in 95 % ethanol for three days were transferred into 40 % of glycerol for 7 days before interpretation (Admassu and Casselman, 2004). This treatment did not usually improve the appearance of macrozones in the otoliths of the larger fish. Therefore, these otoliths were further ground (i.e., thin ground) on the posterior part of the convex side to the level equal to the canal sulcus acusticus using water-wetted carborundum
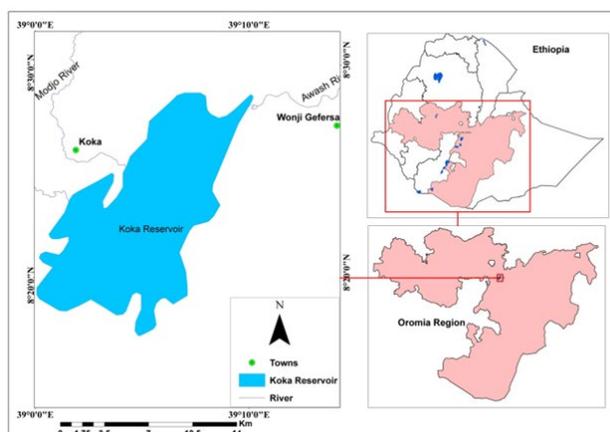

Fig. 1. Map of Ethiopia showing the geographical location of Koka Reservoir.

papers of 400 and 600 grits sizes (Tekle-Giorgis and Casselman, 1995). Subsequently, otoliths were placed in glycerol in a black depression dish and illuminated at an oblique angle from above. The opaque regions appear as white, and the translucent zones appear as dark zones and the wider opaque zone was characterised as the fast growth and the narrower black (translucent) as the slow growth zone (Admassu and Casselman, 2004) (Fig. 2).

Fig. 2. Thin section of an otolith of *Oreochromis niloticus* from Koka Reservoir showing annuli (alternating opaque and translucent zones) counted from nucleus to the posterior end, sampled on 24 December 2017, TL = 21.9 cm, estimated age = 2.89 years (1057 days). The blue dots show the locations of translucent zones associated with annuli.

Time of translucent zone formation and age determination

Otoliths were examined under a binocular stereoscopic microscope (Leica MS5, Germany) for the presence of translucent and opaque zones using a reflected light source. A magnification of 10 to 40× against a black background was used depending on the size of the otoliths. The number of translucent zones found in each otolith was determined and recorded without the knowledge of fish size and date of capture to reduce biases. A confidence ranking system with a value ranging from 1 to 9 was used to quantify the degree of accuracy associated with the counting zones (Casselman, 1986) to maintain an unbiased reading of the translucent zone. Otoliths with less than five confidence rankings were omitted, and otoliths with five and above rankings were used in this investigation.

The frequency of otoliths with the translucent zone at the edge (i.e., "o" condition) was examined throughout the year (Admassu and Casselman, 2004), to determine the period when most of the otoliths have translucent zones at the edge. Chi-square goodness of fit was used to identify months when the percentage of the otoliths with a translucent edge was higher than might be expected by chance.

The time of translucent zone formations and breeding season were determined to assign the age of the fish. The breeding season of the species was determined by the proportion of matured gonads collected during the sampling period. The proportion of mature fish based on the gonad maturity stage of the fish collected during the study period was considered the indicator of the breeding season (Admassu and Casselman, 2004). The proportion of fish with matured gonads was calculated each month and the peak points were considered median hatching dates. The age of the fish was then determined depending on the total number of translucent zones counted in the otoliths; the fish was then categorised into different spawning periods and year classes. Finally, after categorising the fish into their specific year classes (cohorts), the age of individuals was determined by calculating the time gap between the median hatch date of each fish and the date of capture (Tekle-Giorgis, 1990; Admassu and Casselman, 2004). The age-at-length data calculated in this manner was constructed by rounding the age decimals to the nearest age year and a frequency table was constructed, where the age of fish could be reliably estimated from its length (Bwanika et al., 2007).

Validation

The period of biannuli formation was validated by marginal increment analysis (MIA). The width of the opaque macrozone at the edge of the otoliths was measured along the maximum posterior radius using an ocular micrometre. The marginal increment is the width of the opaque macrozone on the edge divided by the mean width of that particular opaque zone in *O. niloticus* that were caught later having a similar number of growth zones and had completed their seasonal growth (Tekle-Giorgis and Casselman, 1995; Casselman, 1987). The values of the relative marginal increment were plotted against the sampling date. The period when minimum relative marginal increments were measured was considered the time of translucent macrozone formation. In addition, the time when the relative marginal increment began to increase was considered to be when translucent macrozone formation was completed. (Tekle-Giorgis and Casselman, 1995). The mean MIA widths per month for fish with four and five biannuli were compared using single factor ANOVA and post hoc Tukey test ($P = 0.05$).

Back calculations

The maximum otolith's posterior radius at the time of capture (RC) and the radius of each translucent associated with the biannuli (RA) were measured using an ocular micrometre. RA was measured from the nucleus to the outer boundary between the translucent and the opaque zone. The relationship between the fish's total length and the total otolith radius was then established using least square

regression and fitted into a logarithmic equation, which has the following form:

$$\log TL = \log a + (b \times \log OR) \qquad (2)$$

where TL = total length in centimetres and OR = otolith radius in micrometres. The back-calculated total lengths at each age were determined from the body proportional equation (Francis, 1990):

$$LA = \left[\left(\frac{a+bRA}{a+bRC}\right)\right] \times LC \qquad (3)$$

where LA = back-calculated total length to annulus A, RA = otolith radius to annulus A, RC = total otolith radius at the time of capture, LC = total length of fish at the time of capture.

Growth parameters and fitting of the von Bertalanffy growth curve

The von Bertalanffy growth function parameters (VBGFP) (von Bertalanffy, 1938); asymptotic length in cm (L_∞ in cm) and growth rate constant (K, per year) were determined using the FiSAT II software (FAO-ICLARM Stock Assessment Tool II), a computer program package developed mainly for the analysis of length-frequency data. The software also enables related size-at-age and catch-at-age analysis, as well as gear selection and other analyses (Gayanilo and Pauly, 1997). An estimate of t_o (arbitrary origin of the growth curve or theoretical age, in years, when the fish length is 0 cm) was calculated using the Pauly (1979) empirical equation:

$$\log(-t_o) - 0.3922 - 0.275 \times \log L_\infty - 1.038 \times \log K \qquad (4)$$

The theoretical growth parameters for both sexes were estimated by fitting the length-at-age to the VBGF.

$$L_t = L_\infty \times [1 - \exp^{-K(t-t_o)}] \qquad (5)$$

where Lt = Length at age t, t = age of the fish. The growth performance length (φ' or $phi - prime$) value was calculated according to Munro and Pauly (1983):

$$\varphi' = \log K + 2 \times \log L_\infty \qquad (6)$$

Results

Fish population characteristics

From the total of 981 fish samples collected, about 507 were females and 474 were males. Fish ranged in size from 15.6 to 35.3 cm TL (73.5 to 762.5 g body weight), with the majority between 19.5 to 25 cm (Fig. 3).

The relationship between total length (cm) and total weight (g) was curvilinear. This was done for both sexes separately. The one-sample t-test showed that the slope value of males was slightly greater than 3 with 95 % CL (3.02, 3.13); whereas the females were equal to 3 with 95 % c CL (2.97, 3.07). So, data for males and females were separately fitted in two regression equations (Fig. 4).
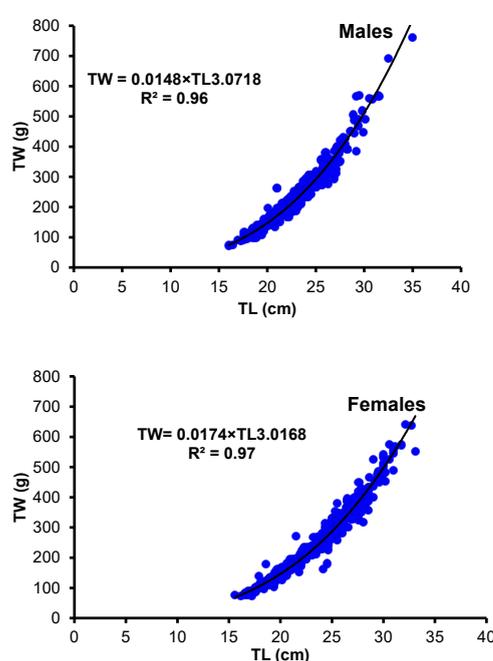

Fig. 4. The relationship between total length (cm) and total weight (g) for males and females of *Oreochromis niloticus* in Koka Reservoir.
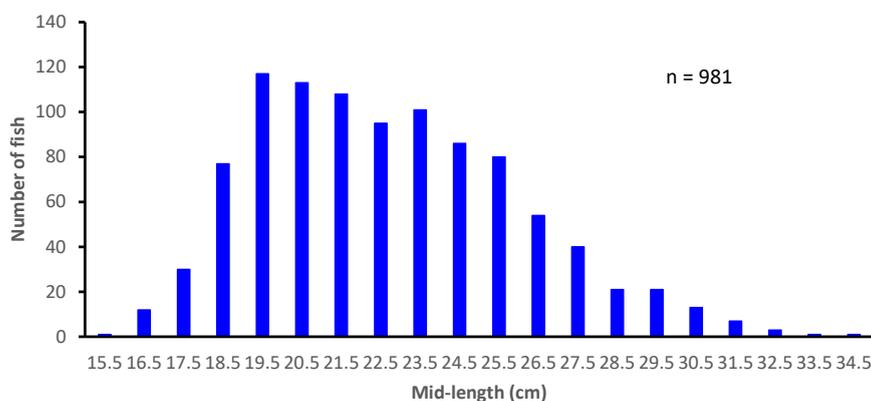

Fig. 3. Length-frequency distribution of *Oreochromis niloticus* in Koka Reservoir sampled from December 2017 to November 2018.

Time of translucent zone formation and age determination

Of the total otolith specimens collected (981), 4.7 % (46) scored below 5 confidence levels and were excluded from further analysis. Otoliths of *O. niloticus* from Koka Reservoir showed alternating opaque and translucent zones (Fig. 2). Otoliths with translucent zones at their edge ("o" condition) were present throughout the year. However, their relative frequency varied greatly with the season of capture. There was a significant difference in the relative frequency of occurrence of translucent zone among months ($P < 0.05$, df = 11, and $\chi^2 = 182.2$). Significantly higher percentages of (monthly χ^2 values >19.67) translucent occurrence were observed in the main dry and wet seasons (January and February, June and July, respectively). From January to February, the frequency of otolith with "o" conditions ranged from 70.8 % to 60.6 % and from June to July ranged from 55.2 % to 71.4 %. In contrast, otoliths with "o" conditions at their edge were relatively much lower in other sampling months ranging from 13.2 % to 26.7 % (Fig. 5), during which otolith with opaque growth at their edge was more frequent. The result suggests that two translucent zones associated with biannuli formed each year in otoliths of *O. niloticus* of Koka Reservoir.
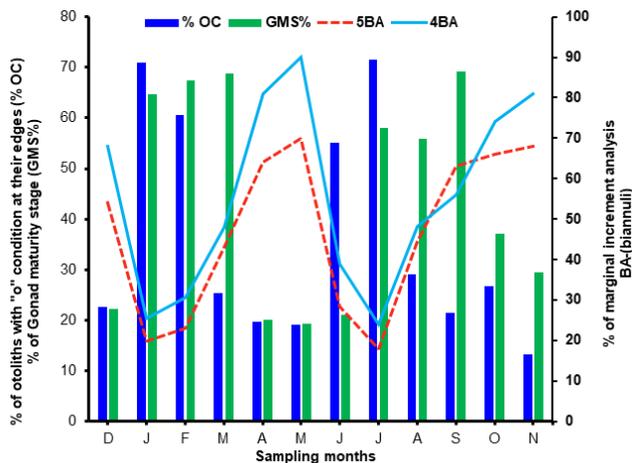

Fig. 5. The relative frequency of otoliths that showed "o" conditions at the edge (% OC), the relative marginal increment with four and five biannuli (5BA and 4BA) and the monthly proportion of *Oreochromis niloticus* with mature gonad stage (GMS%) (stage III to V) sampled from December 2017 to November 2018, 4BA is otoliths that have 4 annuli; 5BA is otoliths that have five biannuli.

Validation

The width of the opaque zone outside the most distal translucent zone varied with the time of the year. Otoliths sampled during mid-March and late August showed a narrow opaque zone at the edge; thus, the condition on the edge of the otoliths was described as an "*" condition. In contrast, a "++" growth was observed at the edge of most otoliths sampled between late April and May and between October and November. During the study, a higher proportion of the sampled fishes for both sexes ranged in size between 20 and 25 cm, and otoliths with four and five biannuli were sufficient in sample size. The comparison of mean relative marginal increment revealed a significant difference between months (one-way ANOVA, $P < 0.05$). It was low in January and February and also in June and July. Prior to March, the relative marginal increment was less than 50 %, whereas, between April and May, it was greater than 50 %. Similarly, prior to August, less than 50 % of the relative marginal increment was deposited and starting early September through November, the fish realised more than 50 % of its total growth (Fig. 5).

Otolith's radius was a linear function of the total length of the fish. Combining the data from all-size fish improved the total length to otoliths radius relationship ($n = 125$, $R^2 = 0.89$). The relationship was performed as follows:

$$\log TL = \log 0.19 + 0.018 \times \log OR \qquad (7)$$

Approaches to assign age based on biannuli

The approximate hatching date calculated from the gonad maturation stage (GMS%) showed a bimodal distribution with a maximum from January to March, and a less pronounced peak from July to October (Fig. 5). This result shows that *O. niloticus* in Koka Reservoir has two spawning seasons in a year and hence there are two recruitment cohorts each year.

Fish spawned between January and March were classified as the February cohort, while fish spawned in July and October were classified as the August cohort (Table 1). 1st February and 1st August were assumed to be the calendar hatching dates for January to March and July to October cohorts, respectively. For assigning age for fish based on the number of macrozone analyses, these dates were considered to be the calendar hatching date for the respective recruitments.

After determining the cohort of fish in this way, the age of individuals was assessed by back-calculating the number of days between the calendar hatch date (i.e., 1st February and 1st August) and the date of capture (See Table 1 for the interpretations of the biannuli for determination of cohorts and age assessment). Observed ages of *O. niloticus* from Koka Reservoir ranged from 1 to 6.5 years (Table 2; Fig. 6). Age-length classes showed a range of ages for a given size of *O. niloticus* in Koka Reservoir, the most dominant age classes are 2 and 3 constituting 35 % and 49 %, respectively (Table 2).

Estimation of growth parameters

The growth of Koka Reservoir *O. niloticus* was determined following the VBGF growth equation from

Table 1. Cohort identification based on the spawning seasons and sampling date of *Oreochromis niloticus*.

No.	Mean total length (cm)	Sampling date	NTBA	E.C.	Cohort	Age (Year)
1	21.9	24 Dec. 2017	5	+	Feb. 2015	2.89
2	29.5	24 Feb. 2018	9	o	Aug. 2013	4.57
3	28.0	27 Jan. 2018	8	o	Feb. 2014	3.99
4	17.4	23 Mar. 2018	3	++	Aug. 2016	1.64
5	19.0	23 Mar. 2018	4	+	Feb. 2016	2.13
6	33.1	23 Mar. 2018	12	++	Feb. 2012	6.14
7	21.9	22 Apr. 2018	5	++	Feb. 2015	2.73
8	22.5	19 May 2018	5	++	Aug. 2015	2.8
9	29.2	17 Jun. 2018	9	o	Aug. 2013	4.87
10	27.0	08 Jul. 2018	7	o	Feb. 2015	3.4
11	20.1	14 Aug. 2018	4	o	Aug. 2016	2.03
12	30.0	27 Sep. 2018	10	++	Aug. 2013	5.12
13	21.6	18 Oct. 2018	5	o	Feb. 2016	2.71
14	17.6	18 Nov. 2018	3	++	Feb. 2017	1.79

NTBA: number of translucent zones associated with biannuli.

E.C.: age condition of the otolith.

O: translucent zones associated with an annulus on the edge of otolith.

+: opaque zones at the edges, 50 % or less than the width of the preceding opaque zones.

++: opaque zones at the edges that are larger than 50 % of the width of the preceding opaque zones.

Table 2. Length at age key for combined sexes of *Oreochromis niloticus* in Koka Reservoir sampled from December 2017 to November 2018, giving the number of fish in 1 cm length categories as a function of age.

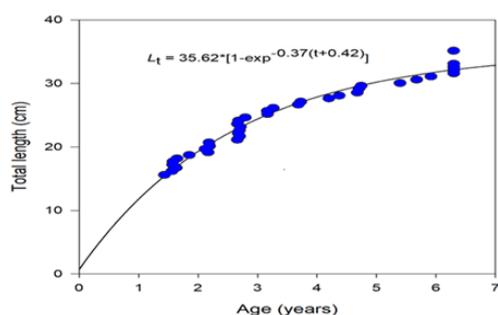| Length class	N	Age in years					
		1	2	3	4	5	6
15–16	1	1					
16–17	12	12					
17–18	30	2	28				
18–19	75		75				
19–20	115		115				
20–21	110		110				
21–22	100			100			
22–23	84			84			
23–24	96			96			
24–25	78			78			
25–26	79			79			
26–27	51			27	24		
27–28	39				39		
28–29	19				7	12	
29–30	20					20	
30–31	13					5	8
≥31	17						17
Total	935	15	328	464	70	37	25
Percentage	100	1.6	34.9	49.4	7.5	3.9	2.7

Fig. 6. The growth of *Oreochromis niloticus* in Koka Reservoir, derived from the von Bertalanffy equation.

the observed age and length:

$$L_t = 35.6[1 - exp^{-0.37(t \mp 0.42)}]$$

Back-calculated growth was also close to the observed one:

$$L_t = 34.8[1 - exp^{-0.33(t \mp 0.39)}]$$

The asymptotic length (L∞ = 35.6 cm) for combined sexes was found near the maximum length caught during the sampling. The largest male caught was 35.3 cm, and the largest female was 35.1 cm. The L∞ calculated is an average theoretical maximum length to which the population grows.

The theoretical length at different ages calculated by the VBGF equation showed a very close agreement with those estimated by back-calculated lengths and the mean observed total length. The back-calculated asymptotic length was 34.8 cm; close to the observed asymptotic length. The value of the growth performance index for the species was 2.67.

Discussion

Biannuli formation

The current study suggested that two translucent zones associated with biannuli formed each year in otoliths of *O. niloticus* of Koka Reservoir: one from January to February and the other between June and July. This was validated with marginal increment analysis and edge conditions. Several studies showed that otoliths of *O. niloticus* in tropical lakes form two translucent zones associated with biannuli formed each year (Blake and Blake 1978; Lecomate et al., 1989; Tekle-Giorgis and Casselman, 1995; Admassu and Casselman, 2004; Bwanika et al., 2007; Gomez-Marquez et al., 2008; Degsera et al., 2020). However, numerous investigations reported the formation of annulus per year in the otoliths of *O. niloticus*. Grammer et al. (2012) investigated *O. niloticus* in temperate Mississippi and found the formation of one annulus per year. Similarly, Chifamba and Videler (2014) from Lake Kariba, Zimbabwe and Tessier et al. (2019) from a subtropical reservoir (Lao PDR) reported a single annulus per year. Tessier et al. (2019) noted that depending on the region considered, there may be one (in the sub-tropical region) or two annual (tropical region) increments deposited. Egger et al. (2004) from Lake Tanganyika reported the formation of a single annulus per year in other cichlid species of *Tropheus moorii* Boulenger, 1898, so there is variation among species. According to Bwanika et al. (2007) in both edge analysis and marginal-increment analysis, unimodality in the 12-month plot indicates that *O. niloticus* deposit only one annulus (one opaque zone and one translucent zone) per year, whereas bimodality suggests that they deposit two complete

annuli each year (i.e., biannuli). Tekle-Giorgis (1990) used the term biannuli to express the translucent zones that are formed twice a year in Lake Awasa *O. niloticus* otoliths. In our case, the 12-month plot of both edge condition and marginal increment analysis showed bimodality (Fig. 5). Thus, we have also used the term biannuli to express the two-time formation of translucent in the otoliths of *O. niloticus* from Koka Reservoir.

The physiological source of annulus formation in calcified structures like otoliths is unclear but both abiotic and biotic factors probably play a role in creating annulus (Ferreira and Russ, 1994; Barrientos et al., 2018). Casselman (1983) also noted that though the physiological foundations for the formation of growth zones in calcified structures have not been directly recognised, their presence has been usually related to varying growth rates, influenced by temperature, photoperiod, feeding rate, or reproductive cycle. Temperature is considered one of the most important factors affecting the physiology, growth, reproduction, and metabolism of tilapia, especially in temperate and subtropical regions, which are characterised by seasonal fluctuations in water temperature. *O. niloticus* are known to tolerate a wide range of water temperatures. The optimum temperature range for the normal development, reproduction, and growth of *O. niloticus* is about 20 °C to 28 °C (Teichert-Coddington et al., 1997). Feeding and other activities of tilapia are reduced at a temperature of below 20 °C and feeding stops completely around 16 °C, and the growth of tilapia significantly decreases at a temperature below 20 °C (Caulton, 1982). Admassu (1998) showed that a temperature change of ~5 °C affected the growth of *O. niloticus* in Lake Awassa. Koka Reservoir has a minimum surface water temperature of 19.5 °C and 17.5 °C in January and July respectively. In addition, Gomez-Marquez (1998) reported the formation of two translucent zones in *O. niloticus*, with one formed when the water temperature was 21 °C. Furthermore, Egger et al. (2004) reported the maximum temperature (27.7 °C) and minimum temperature (24.4 °C) of the year in Lake Tanganyika decelerated the growth rate of *T. moorii* and caused growth zone formation. Therefore, reduced temperature could result in a reduction of somatic growth, which could result in the formation of translucent zones associated with the biannuli of *O. niloticus*. It was found that *O. niloticus* of Koka Reservoir forms translucent zones associated with biannuli January and July coincide with the minimum temperature of the year.

In Koka Reservoir, *O. niloticus* was feeding on several different taxa of algal groups, such as the blue-green algae *Microcystis*, *Planktolyngbya*, *Anabaena*, *Chroococcus*, *Lyngbya* and green algae *Spirogyra*, *Botryococcus*, *Scenedesmus*, *Closterium*, and *Pediastrum* (Engdaw et al., 2013). *Botryococcus* species provided poor-quality food for *O. niloticus* in Lake Awassa (Getachew and Fernando, 1989). This

group of phytoplankton species is high in biomass and forms bloom on the water in the dry season (February and January) and is rare in the wet season (Wondimu, 2014). This period of the year corresponded to a period of a year when a majority of the *O. Niloticus* otoliths form translucent zones associated with biannuli, hence the variation in the quantity and quality of available food may be responsible for the formations of biannuli in the otoliths of *O. niloticus* of Koka Reservoir. Gümüs et al. (2002) reported that in two months, September and October, the decrease in food diversity was synchronous with annulus formation on *Chondrostoma regium* (Heckel, 1843) species.

The breeding season of *O. niloticus* in Koka Reservoir is typically from January to March and from July to September (Fig. 5). It was apparent that the peak spawning season coincided with low Fulton's conditions factors (Tesfaye, 2006), and the production of eggs and sperm drain the fish resources. Besides, female *O. niloticus* are mouthbrooders, so they incubate the hatchling of the egg in their mouth; they fast during this time, and males spend energy on nest building. This could result in marking in their calcified tissue (Jiménez Badillo, 2006; Gomez-Marquez et al., 2008). Therefore, spawning-associated activities could reduce the energy invested for growth, which may result in reduced somatic growth. Therefore, reduced somatic could also be considered as one of the major factors in translucent zone formations in otoliths of *O. niloticus* in Koka Reservoir from January to February and June to July. Other investigators reported similar results (Tekle-Giorgis and Casselman, 1995; Degsera et al., 2020) Garrod (1959) reported that the formation of two checks in the scales of *Oreochromis esculentus* (Graham, 1928), resulted from a reduced condition associated with gonad maturation prior to spawning season.

Estimation of growth parameters

The result of this study differs from the preliminary study conducted by Tesfaye (2006) but is similar to the study conducted by LFDP (1997). The highest K value and the lowest L∞ value of *O. niloticus* in the current investigation differed from Tesfaye's (2006) report from Koka Reservoir, which may be due to the difference in fish size used for the analysis. In the present study, 78.28 % of the fish size ranged from 15–35 cm, while the Tesfaye study used 83.5 % of the fish size of 23–33 cm. The exclusion of younger age groups would enhance the underestimation of K, and the overestimation of L∞ (Mulligan and Leaman, 1992). In addition, the calculation method is also another reason for this difference. Tesfaye (2006) did the ELEFAN methods of the length frequencies, while the current study was based on otoliths.

Mosepele and Kolding (2003) stated that the growth of younger fish is fastest, which makes the identification of moving modes over time easier, and the determination of K in relation to L∞ is more robust when the length frequencies containing younger fish made a similar conclusion. Moreover, Lowe-McConnell's (1982) and Admassu's (1989) findings indicate that after the onset of sexual maturity, there is a reduction in the growth of *O. niloticus*. The growth of fish is plastic in nature (Weatherley and Gill, 1987), and especially *O. niloticus* exhibits marked plasticity in growth due to different environmental factors. It could be concluded that the growth of *O. niloticus* in Koka Reservoir is within the range mentioned in Ethiopian lakes (L∞ varies from 28.1– 45.5 cm; K from 0.28–0.43 year⁻¹). Outside of Ethiopian lakes, Bandara et al. (2020) investigated the life history traits of *O. niloticus* in 10 different reservoirs of Sri Lanka. The investigators found great variation in growth parameters across different reservoirs of the same river basin. Their result indicates that the asymptotic length varies from 42.8 cm to 53.4 cm; which is far greater than the current results; whereas the growth rate constant varies from 0.2 year⁻¹ to 0.52 year⁻¹, which are within the range of the present study. The highest value for the asymptotic length could be in part, as summarised by Bandara et al. (2020), due to the productivity of the reservoirs.

Conclusion

When the samples indicate a fish population with a short lifespan (2-4 years), rapid growth, and annual reproduction, the length-frequency analysis methods of estimating fish age and growth are thought to be reliable. Nevertheless, in older fish, there are possibilities of overlapping length frequencies in individuals of different age groups as the growth rates slow down. Therefore, for long-lived species like Nile tilapia, *Oreochromis niloticus*, using otoliths gives more dependable results even if the sample collection and laboratory analysis are labour-intensive. Future studies should consider sampling 2 to 3 years and corroborating the growth zone formation by using growth marking substances like oxytetracycline and the inclusion of immature sample otoliths for microzone analysis to accurately estimate age and growth.

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