AGE AND GROWTH OF
Oreochromis niloticus (PISCES: CICHLIDAE)
IN LAKE HAYQ,, ETHIOPIA

BY

KEBEDE ALEMU

A THESIS SUBMITTED IN
(PART) FULFILLMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN BIOLOGY

ADDIS ABABA, ETHIOPIA

JUNE, 1995

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ABSTRACT

Otoliths from 447 mature and 308 immature *Oreochromis niloticus* (10 to 304 mm total length) from Lake Hayq were measured and examined for translucent and opaque macrozones. Microzone analysis was also conducted on the 308 immature *O.niloticus* otoliths. Macrozonal daily age estimate was determined by extrapolating the number of days between the date of capture and calender birth dates. Utilization of the number of macrozones, condition on the edge of otoliths and date of capture enabled the separation of fish into recruitment groups. Microzones on the otoliths were enumerated and used as a measure of age in days and to hind cast hatch dates. The relationship between otolith size and fish total length was also examined.

It appears that the breeding of *O.niloticus* in Lake Hayq is continuous with high peaks during March-May and July-October. Two translucent macrozones were formed per year during January-February and June-July. Fish spawned between January and May and July and November of the same year form the first translucent zone associated with biannuli at different times. The close agreement between macrozonal and microzonal daily age estimates (r=0.84) substantiates the usefulness macrozone analysis to assess the age of *O.niloticus*. There was a strong linear relationship between otolith size and fish size and also between microzone count and fish length. However, a linear relationship underestimates fish size at later ages. Values of size-at-age estimates obtained from macrozone and microzone analysis and fish total length-otolith radius relationship were close to each other. This demonstrates the usefulness of results from the latter method in supporting conclusions drawn from macrozone and microzone analysis.

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ACRONYMS

MIZ = Number of microzones

NB = Number of biannuli

OCI = Otolith condition index

OR = Otolith radius

OW = Otolith weight

TL = Total length

TW = Total weight

1. INTRODUCTION

Most of the fishery resources in the inland waters of Ethiopia are either underexploited or virtually virgin. Therefore, the resource can be considered as a potential source of food. In the face of the expanding human populations, comprehensive fish resource management as well as wise and efficient utilization are of utmost importance.

Management of fish resource needs a substantial body of scientific information. One important part of this information base is knowledge of age. The immediate importance of estimating age is that it provides information on growth. As growth or change in size of fish can best be evaluated on a rate basis, a temporal measurement such as age is necessary to calculate growth (Casselman, 1987). Growth studies are essential where fish are exploited as a source of human food, because it is the growth of the fish that provides production estimates and the catch (yield) taken by man (Fryer and Iles, 1972).

Along with growth, information on mortality rates (Houde, 1987; Essig and Coble, 1986) and recruitment, age at maturity (Kilambi, 1986), abundance of different year classes and population structure (Harris and Grossman, 1985) can also be obtained from the age of fish. These pieces of information are relevant to the proper assessment and management of a fishery. Therefore, securing carefully determined age data should be the primary aim of a fishery biologist.

By virtue of their distribution and importance in the development of inland fisheries, the cichlids have received considerable attention from fisheries workers in Africa (Fryer and Iles, 1972). However, it is the Tilapias, a group of species of the family cichlidae, that represent by far the largest component of the commercial inland fish catch. They contribute 32 to 100 % of the catch in these fisheries. They are also important culture fish in several parts of the world. *O.niloticus* (previously *Tilapia nilotica*) is one of the species which is a widely distributed cichlid of commercial value in the Eastern African Rift Valley (Lowe McConnel, 1975; Bishai, 1965). It is one of the most important commercial fresh water fish species in many of the Ethiopian lakes. It is found at about 7400 km^2 of the country's inland waters (Shibru, 1973). Nevertheless, little information exists on the age and growth of this species. Only two studies exist from Ethiopia. These include the age and growth of immature (Yosef, 1990) and adult (Demeke, 1989) *O.niloticus* in Lake Awassa.

Lake Hayq, site of the present study, had no tilapia until *O.niloticus* was introduced by the fisheries department, Ministry of Agriculture, in 1978 (Elizabeth, et al., 1992). Before the introduction, the most abundant fish appeared to be a species of large catfish (Baxter and Golobitsh, 1970). Since the area where Lake Hayq is situated is among those that have been severely affected by drought and famine over the last decades, the introduction of *O.niloticus* was aimed at providing food for people living in this part of the country. As there are now fisheries and *O.niloticus* makes the largest contribution to the commercial catch of Lake Hayq, the introduction appeared to be a success. Despite this, however, the Lake suffered frequent fish kills (Mihret, per. comm) which has resulted in the loss of considerable amount of protein. This calls for management and rational utilization of the fishery of Lake Hayq.

Although age estimation and growth prediction of fishes are important facets of many applied problems of fishery management, there are no studies regarding the age and growth of *O.niloticus* from Lake Hayq. The lack of this important information has prevented further studies on the biology and fishery of this species. Therefore, in the present study age and growth of *O.niloticus* were assessed by the interpretation of biannuli and microzones (daily increments) in the otoliths. In addition the relationship between fish size and otolith size was examined to demonstrate the usefulness of otolith size as a predictor of age and growth. Furthermore, the time of biannuli formation was determined so that their validity to study age and growth and discriminate between cohorts can be tested. The results are based on one year study of fish collected in Lake Hayq.

In the statistical approach, appropriate statistical analysis of length frequency distributions give information about population structure and the growth of age groups. The basis to this method is the assumption that if spawning in a fish population is restricted to a relatively short period of time, there will be regular influx of new recruits. Adequately and randomly sampled fish can then display a length frequency distribution that features a series of modes corresponding to successive age groups (Mac Donald, 1987; Pauly, 1983: Casselman, 1987). Size-at-age can then be obtained from a polymodal length frequency distribution using the Petersen method (Petersen, 1982, in Pauly, 1983) or the modal class progression analysis which was devised by Pauly (1983).

In application, the length frequency analysis is associated with certain practical problems. As fish get older a number of age groups may attain a similar length and appear as a single mode (Bagenal and Tesch, 1978; Pauly, 1983). In addition, most tropical fish have extended spawning periods so there is overlap between sizes of individuals (Mac Donald, 1987). Therefore, length frequency analysis cannot be put to general use for older and tropical fish. However, the method has proved useful in providing growth information for some tropical species of tilapia which have a spawning season that is restricted to a few months (Fryer and Iles, 1972).

The special attention that is given to the anatomical approach (also called osseochronometry) is mainly due to the fact that calcified structures such as scales, otoliths or bones exhibit bipartite formations that can be connected with cyclic events in time (seasons of the year, days). In this method age is assessed by a thorough, systematic interpretation of growth checks or zones in the calcified structures to which a time scale can be assigned. The use of annually occurring marks or annuli on or in calcified structures have been used for a long time in age determination. The zones or checks that are associated with annuli are enumerated to determine age (in years).

Annual or seasonal growth marks have usually been considered to present more difficulties in ageing tropical fish than temperate fish. In temperate regions, the marked difference between seasons, particularly with respect to temperature and photoperiod, leads to a predictable discontinuity in seasonal growth (Casselman, 1987). In the tropics there may be no seasonal variations in growth to induce the formation of checks or zones. Furthermore, larval and young fish less than one year age present more considerable difficulty if annuli are to be used in ageing fish.

The specific mechanisms involved in the formation of annual checks and zones are poorly understood. However, a number of factors resulting in the cessation of somatic growth of fish have been identified. In temperate regions, changes in temperature and associated biotic and abiotic factors are believed to cause check formation in fish calcified tissues (De Bont, 1967). Where regular growth checks have been found on calcified tissues of tropical fish, they are suggested to be associated with annual spawning cycle (Payne, 1976; Nekrasove, 1980), changes in salinity (Fagade, 1974), and seasonal scarcity of food (Lecomte *et al.*, 1989) and low pH (Geen *et al.*, 1984). Furthermore, as fishes could respond to very subtle changes in temperature (Casselman, 1987) , temperature could have additional effects. Although seasonal changes are less drastic under tropical conditions, there is no doubt that seasonal checks or zones are formed on calcified tissues of tropical fish. Since a combination of factors may cause the formation of checks and zones in these structures of tropical fish, more than one time marker (check or zone) per year can be formed. In the calcified tissues of some fish species the occurrence of two annuli each year have been reported (Garrod, 1959; Lecomte *et al.*, 1989; Demeke, 1989; Yosef, 1990). Furthermore, the phenomenon that otoliths grow by daily additions of new tissues (Pannela, 1971, 1974) has opened a new approach to determine the age of tropical fish, primarily young and larval fish.

Otoliths of fish are Calcium Carbonate secretions which are deposited in the membraneous labrynth of the inner ear (Lowenstein, 1971). Historically, they have been utilized to age fish more reliably than other calcified structures. The use of otoliths in the assessment of age proceeds on two levels; macrostructural, involving the enumeration of annual marks; or microstructural, where daily growth increments are usually the counting unit (Brothers, 1987). The assessment involves the interpretation of optically different zones (translucent and opaque zones). If these zones are examined under low power (<40x), the method is referred to as macrozone analysis in contrast to microzone analysis, which involves the examination of otoliths under high power (> 100x) to reveal details of the microstructure of the tissue (Casselman, 1987).

The development of microzone analysis is the most important advancement in age determination studies since Pannella (1971) described microzonations (primary growth increments) in fish otoliths. Since a number of investigations have validated the daily periodicity of these microzonations (Campana and Neilson, 1985; Gjösaeter *et al.*, 1984; Pannella, 1971, 1974; Wild and Forman, 1980), it is assumed that daily incremental growth is a universal phenomenon in fish otoliths. Counting the microzones thus offers a method of assessing the age of fish on a daily basis. Indeed the interpretation of microzones on the otoliths is the most promising method in the tropics. In addition to providing a means for determining ages to the daily level of precision, microzones have been used to corroborate the occurrence of annuli (Pannella, 1971; Taubert and Tranquilli, 1982; Victor and Brothers, 1982).

The other way of obtaining information on growth of fish is by establishing a relationship between otolith size and fish size. Knowing the relationship between otolith size and fish total length is useful to back calculate fish size (Echeverria, 1987). For instance, measuring otolith radius (distance from the core to each translucent zone) helps to calculate the fishe's size at previous age. Then determination of growth rate is much easier. In addition, the investigation that slower somatic growth results in heavier otoliths (Templeman and Squires, 1956; Reznic *et al.*, 1989) demonstrated that otolith size can provide a new information on the relative growth rate of fish.

3. DESCRIPTION OF THE STUDY AREA

Lake Hayq is a highland Lake situated in Wollo province, Ethiopia, at an altitude of 2,030 m, a latitude of 11° 15'N and a longitude of 39° 57'E. It has a surface area of 23 km^2 (Morandini, 1941 in Baxter, 1970) and a maximum depth of 37.7 m (Table 1). The only stream of any size entering the lake is the Anchercah river. The lake lacks surface outlet.

Table 1. Morphometry of lake Hayq in 1938 (from Morandini, 1941; cited in Baxter, 1970).

Max length (north-south)	6.7 km
Max width	6.0 m
Perimeter	21.7k m
Area	23.2 km^2
Max depth	88.2 m
Mean depth	37.37 m
Volume	0.87 km^3
Average slope of basin	3°45'

The land near the west shore, on which a monastry is located and was an island (Fig. 1) as early as the sixteenth century (Pankhrust, 1967) is no more water-locked. From this it is probable that the water level in the Lake has decreased during the past years. During the present study period, annual fluctuations in the water level were noted in relation to the seasonal variation in rainfall and precipitation. The level of

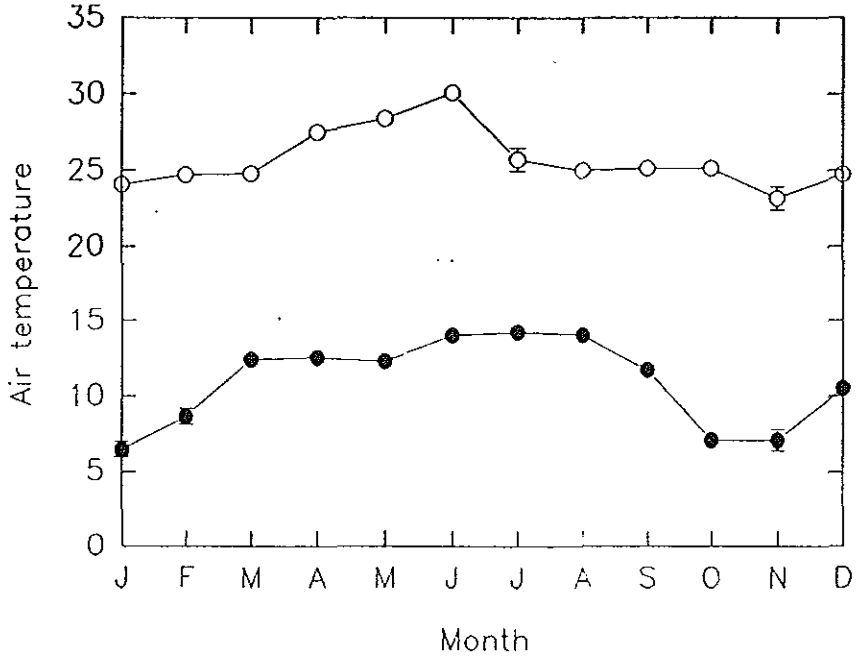


Figure 3. The mean monthly maximum (hollow circles) and minimum (filled circles) air temperatures (°C) from January to December 1994.

the water increases shortly after the rains. July is the wettest month of the year where as February is the driest. Rain fall and temperature data of the lake Hayq region are presented in Fig. 2 and Fig. 3 respectively. Water temperatures for Lake Hayq were taken at the time of sampling where the water depth was about 20 m. The water was cold in January, February, July and November and was warm in March, April, May, August and September (Fig. 4).

The pH of the water ranges from 8.8 in February to 9.9 in November, 1994. The pattern of oxygen profiles of Lake Hayk is presented in Table 2. Generally the oxygenated layer was shallow. In January the average oxygen level at five meter depth was 0.49 mg/l, the lowest recorded during the study period. This implies that the oxygen saturated water column didn't extend even to the depth of five meters. As shown by the secci disk reading, transparency had values between 0.85 m in March, 1994 and 2.85 m in December, 1994 (Fig. 5).

The net phytoplankton was dominated by microcystis and diatoms (Cannicci and Almagia 1942, in Baxter, 1970; Elizabeth *et al.*,1989). The zooplankton included copepods, cyclops and cladocerans. The dominant species of rotifers in the lake are *Anuraepsis fissa* (Green and Seyoum, 1991).

The fish fauna of lake Hayq consists of mainly O.niloticus. Observations during the study period confirmed previous reports that claimed the presence of catfish (*Clarias* spp.). Catfish makes up a very small proportion of the commercial catch during the rainy season.

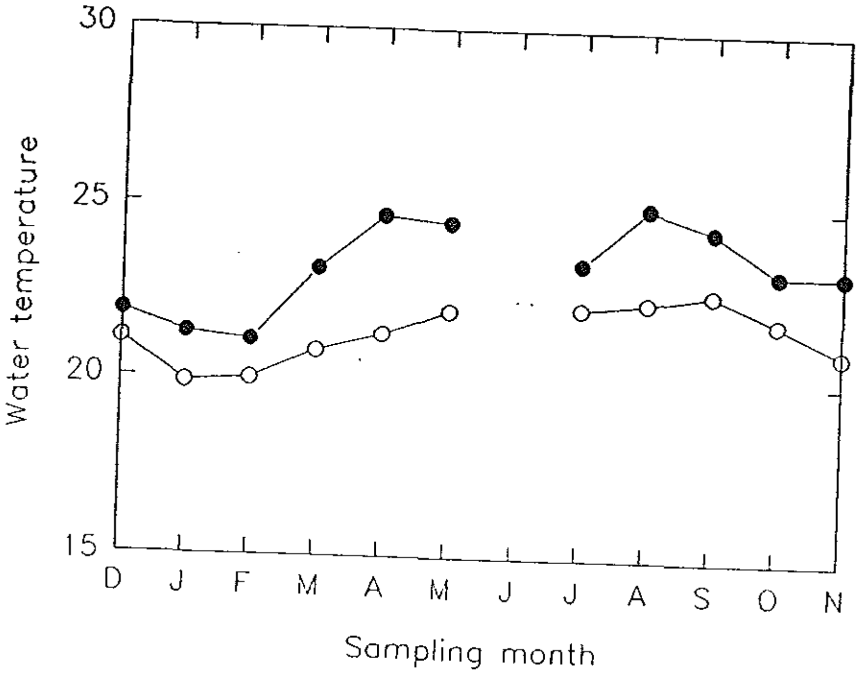


Figure 4. Mean Lake water temperatures (°C) at the surface (filled circles) and at 10m depth (hollow circles) during sampling periods.

Table 2. Oxygen profile in lake Hayq during the periods March 2-6/1989 (Elizabeth, *et al.*, 1989) and December, 1993ot November, 1994. The numbers in the table indicate the amount of oxygen in mg/l.

Sampling date	Depth (m)						
	0	3	5	7	10	15	20
Mar. 2-6/1989	8.30	7.9	2.8	0.4	0.1	0.1	0.00
Dec. 1-2/1993	6.56	6.64	5.40	4.12	3.16	_	_
Jan. 13-17/1994	4.30	2.98	0.49	0.03	0.03	_	_
Feb. 18-20/1994	11.30	8.92	6.58	1.46	0.06	-	-
Mar. 24-26/1994	8.36	7.54	5.96	4.24	1.9	-	-
Apr. 4-5/1994	6.53	6.00	2.98	0.85	0.20	-	-
May 25-27/1994	6.79	6.96	6.19	4.55	0.98	-	-
Jul. 21-22/1994	7.40	7.28	6.93	6.73	5.63	-	-
Aug. 24-26/1994	8.93	8.63	7.95	7.13	3.4	-	-
Sep. 22-24/1994	8.14	7.34	5.65	4.8	1.23	0.23	0.20
Oct. 22-23/1994	7.43	5.58	4.94	4.11	1.03	0.19	0.16
Nov. 27-28/1994	11.56	9.18	4.7	3.66	2.55	2.30	1.18

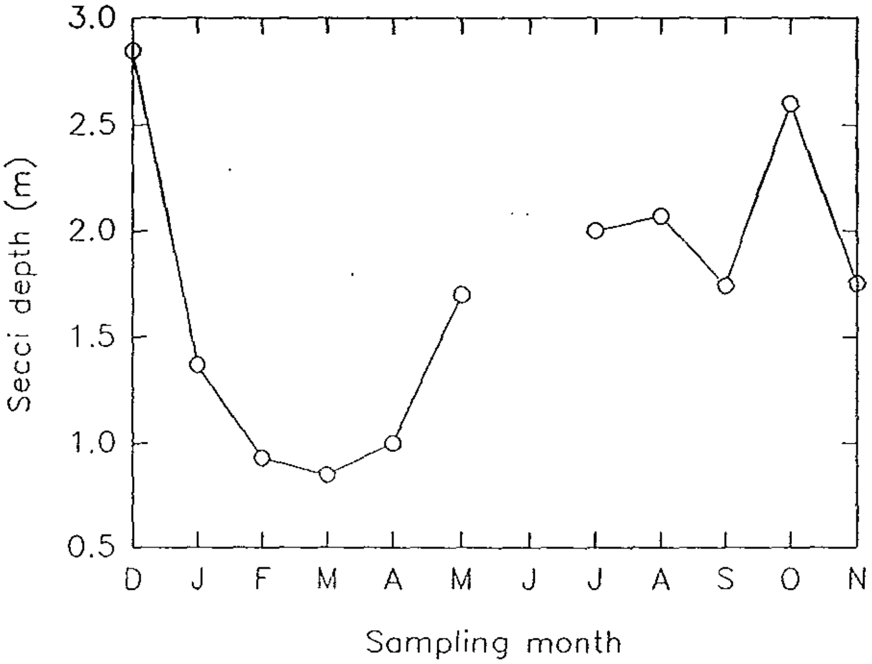


Figure 5. Mean Secci depth (m) during the sampling periods.

4. MATERIALS AND METHODS

4.1. Sampling

Samples of *O.niloticus* ranging in total length (TL) from 10 to 304 mm were collected monthly between December, 1993 and November, 1994. Adult fish were captured by a fleet of floating nylon monofilament gill nets consisting of stretched meshes ranging from 50 to 110 mm (by increments of 10 mm) which are connected end to end. The fleet was 2.1 m deep and 13.2 m long. A fleet of similar mesh size composition was used by Demeke (1989). The sampling gear was set during daytime between 4:00 AM and 11:00 PM at a fixed site of depth about 4 m (3-6 m range). In addition, it was also fished in deeper water occasionally. Immature fish were caught from a fixed site (Fig. 1) using a beach siene which was 18.3 m long and 2.7 m deep and constructed of 0.6 mm mesh.

Immediately after capture, the fish were sorted into length groups of 10 mm intervals and a random subsample of at least five were then taken from each length group. For each fish total length (TL) and total weight (TW) were measured to the nearest 1 mm and 0.1 g, respectively and sex was determined by dissection when possible. The sagittae 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 gill cover. These were kept in scale envelopes. For larger fish the measurements and the removal of otoliths were performed within 3-4 hours of capture. Fish subsampled from beach siene catch (less than 100 mm TL) were preserved in alcohol and transported to Addis Ababa. Later in the laboratory each fish was remeasured to the nearest 1 mm (TL) and reweighed to the nearest 0.1 g. These fish were then dissected to remove the sagittae. Sagittae from both larger and smaller fish were then cleaned with water, air-dried and stored in microcentrifuge vials until examination.

4.2. Otolith radius and weight measurement

The Maximum radius of both sagittae from each fish was measured to the nearest 0.1 mm along the post-rostral growth axis. The average radius of the two otolith was then used in the analysis.

Otolith were weighed on a Sartorius balance with a sensitivity of 0.0001 g. Deformed and broken otoliths were excluded.

Otolith condition index was calculated from otolith radius and otolith weight measurements as in Radtke *et al*. (1985):

$$OCI = OR/OW.\ 100$$

where OCI = otolith condition index, OR = otolith radius, OW = otolith weight.

Fish size-otolith size relationships were determined by least square regression.

4.3. Macrozone analysis and determination of time of translucent zone formation

A total of 755 fish otoliths from 12 sampling occasions were considered for macrozone analysis. The right sagittae were used throughout the study, but if they were broken or missing the left sagittae were used instead. Sagittae were placed (concave side up) in a dark dish containing glycerol. They were then examined under a dissecting microscope (12-40x magnification) using reflected light source for the presence of opaque and translucent macrozones. An opaque zone inhibits whereas translucent zone allows the passage of light rays (Wilson *et al.*, 1987). As a result opaque zones appeared as white and translucent zones appeared as dark bands.

The number of macrozones in each otolith was counted and recorded without knowledge of fish size. A confidence rank system with values ranging from 1 to 9, was used to quantify the degree of accuracy associated with counting the zones (Casselman, 1986). A value of 1 indicates that it is difficult to assess the number of macrozones where as 9 refers to a high degree of confidence placed in the assessment.

The condition at the edge of the otoliths was noted to investigate if translucent zone formation occurs at a particular time or season of the year. A system proposed by Casselman (1987) was used in the present study to describe the conditions on the edge of the otoliths. The categories

Otoliths of fish less than 20 mm TL were mounted on glass slides with the convex surface up. This surface was then ground using 12 and 0.3 μ Aluminium Oxide lapping films. Otoliths of yolk sac larvae required slight polishing only.

Ground and polished otoliths were viewed using Olympus BHB microscope at a magnification of >200x. Increments (microzones) in the otoliths were counted twice and the mean of these was taken when the variation between them was less than 5%. When the variation was greater than 5%, two more countings were done. If these counts disagree the otoliths were discarded. To avoid bias, the two counts of the same otolith were not made consecutively.

In the present study no experiment was conducted to validate the periodicity of microzone deposition. A daily periodicity of microzone formation had to be assumed. This is because daily periodicity of increment formation has now been regarded as a universal phenomenon which has been validated for several temperate and tropical species (Gjösaeter *et al.*, 1984) including *O.niloticus* (Yosef, 1990; Zhang and Runham, 1992). Thus, the number of microzones determined in this study were taken to represent the age of fish in days.

4.5. Estimating hatching (spawning) periods

The approximate individual hatching dates were estimated from the number of microzones in the otoliths of larval and juvenile fish by back calculating from the date of capture(Brothers, *et al*., 1983; Methot, 1983; Yosef, 1990). Then the proportion of fish hatched in each month was calculated. In addition, based on the interpretation of macrozones (biannuli) and the condition on the edge of otoliths fish were discriminated into recruitment cohorts and their age in days was assigned. The proportion of fish belonging to each cohort was then finally determined.

4.6. Growth estimation

4.6.1. Length-weight relationship and Fulton's condition factor

The relationship between total weight (TW,g) and total length (TL,mm) of fish ranging in size from 133 to 304 mm was analyzed by using the equation : $\log TW = a + b (\log TL)$, where a = Y-intercept and b = the slope of the equation.

Seasonal variation in the condition of fish was evaluated by caculating Fulton's condition factor for fish caught in each sampling occasion using:

$$C = 100.TW/TL^3$$

where, C = Fulton's condition factor

4.6.2. Size-at-age estimates

Mean lengths at age were estimated using age information obtained from macrozone analysis. The relationship between total length and microzone count and that between otolith radius and total length were determined using regression analysis. These relationships were used to estimate mean total length at a given mean age to verify the size at age estimates obtained from macrozone analysis.

4.7. Statistical analysis

Least square regression analysis was conducted using Systat software (Systat, inc., 1990).

5. RESULTS

5.1. Time of translucent zone formation

In the present study, two types of translucent zones were identified. The first two translucent zones were formed during the larval stage of life while the formation of the second type of translucent zones followed a seasonal pattern. The translucent zones formed during the larval stage of life will be refered as juvenile marks. Other than the juvenile marks, two translucent zones were formed each year in the otoliths of *O.niloticus* in Lake Hayq. Yosef (1990) used the term biannulus for these translucent zones in otoliths from Lake Awassa *O.niloticus* to refer to a type of annulus formed twice a year. Thus, I have also used the term biannulus (BA) for the fish from Lake Hayq.

5.1.1. Time of formation of juvenile marks

Larval fish sampled from the mouth of brooding females ranged in TL from 7 mm to 12 mm, the majority of being between 7 mm and 10 mm. The yolk-sac was completely consumed in larvae 10 mm or longer. That means, the release of the young does not take place before the larvae were 10 mm long. Otoliths from yolk-sac larvae didn't have translucent macrozones and the whole region of these otoliths was opaque (Fig. 9, Otolith No. 1).

Two narrow translucent zones (i.e. juvenile marks) were observed in the otoliths of fish less than 35mm TL. These juvenile marks were less prominent than the translucent zones considered to be asociated with biannuli. They were also located very close to the nucleus of the otoliths. In addition, the deposition of zones associated with juvenile marks and biannuli doesn't take place at the same time. For instance, in February, when 45.5% of the otoliths from fish greater than 39.0 mm TL had translucent edges, otoliths from smaller fish had wide opaque edge. In contrast, 73.9% of otoliths from fish larger than 37 mm TL sampled in October had opaque zone on their edge, but 90% of otoliths from smaller fish caught at the same time had translucent edges. In some otoliths, the two juvenile marks were not clearly visible because of the overdeposition of calcareous material.

The smallest fish that has a biannulus in its otoliths was 35.0 mm long. 62.3% of the sampled fish ranging in TL from 35.0-54.0 mm had formed the first biannulus. All of the fish greater than 54.0 mm TL had one or more translucent zones associated with biannuli. Thus, the deposition of the first biannulus occured when the fish were between 35 and 54 mm long. Calculation of mean microzone count for otoliths from fish between 22 and 50 mm TL showed that the formation of juvenile marks took place at different times. The mean microzone count up to the first juvenile mark was 14 (SD=0.59, N=40). On the other hand, the number of microzones up to the second was 55 (SD=7.8, N=33). These imply that formation of the first and the second juvenile marks started when the fish were about 14 and 55 days old, respectively.

5.1.2 Time of formation of translucent zones associated with biannuli

Otoliths with translucent zones associated with biannuli at their edge (i.e. "0" condition) were present throughout the year. However, their frequency varied greatly with season of capture. Thus, during the period January - February the frequency of otoliths with "0" condition ranged from 40 to 45%, and that during June - July ranged from 45 to 50% (Fig. 6). In contrast, they occurred at much lower frequencies in samples taken at other periods of the year, during which time otoliths with opaque growth at the edge were more frequent. Data available from gill net sampling fit the same sequence except that the lowest frequency of otoliths with translucent edges (3.8) was obtained in April (Fig. 6). Thus, two translucent zones associated with biannuli form each year in the otoliths of Lake Hayq *O.niloticus*, i.e. one during January - February and another during June-July.

Relative marginal increment also varied with time of the year. For otoliths with one biannulus the relative marginal increment was low during the periods January-February and June-July (Fig. 7). The amount of opaque zone deposited was high between March and May , and August and October with peaks in April and August. Otoliths with two biannuli were not available in December, February and May. However, data available complement results obtained from otoliths with one biannulus (Fig. 7). Otoliths with more than three biannuli were not examined.

5.2. Hatch date estimation and spawning periodicity

Hatch dates hind casted from age estimates obtained from microzone count showed that *O. niloticus* in Lake Hayq spawns over a protracted period. However, there were two distinct peaks suggesting that major spawning occurred during two general periods. Apparently spawning activity was high during the periods, February to May and July to October. For the respective spawning periods, Peak spawning activity was observed in March and September (Fig. 8). In addition, large number of larval fish have been caught between July and November and March and May. These results indicate that *O. nilotocus* in Lake Hayq spawns twice a year and hence there are two recruitment cohorts each year. Fish spawned between January and May were classified as the March cohort while those spawned between July and November were classified as the September cohort.

Based on the spawning pattern presented in Fig. 8, median spawning times (i.e. "calender birth dates") were approximated to be March 14 and September 18.

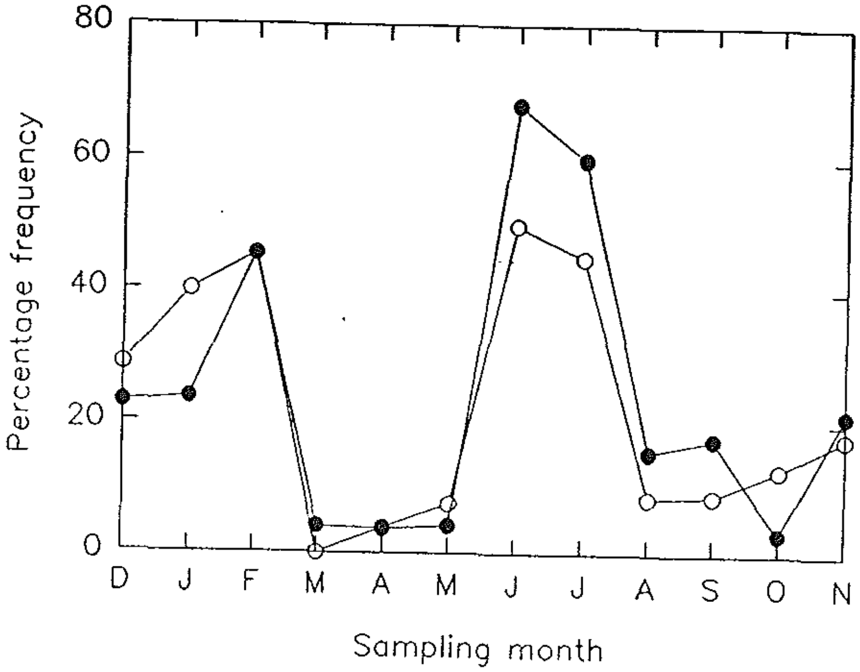


Figure 6. Relative frequency of otoliths with translucent zone at the edge sampled between December 1993 and November 1994. (Hollow circles for beach siene sample and filled circles for gill net sample)

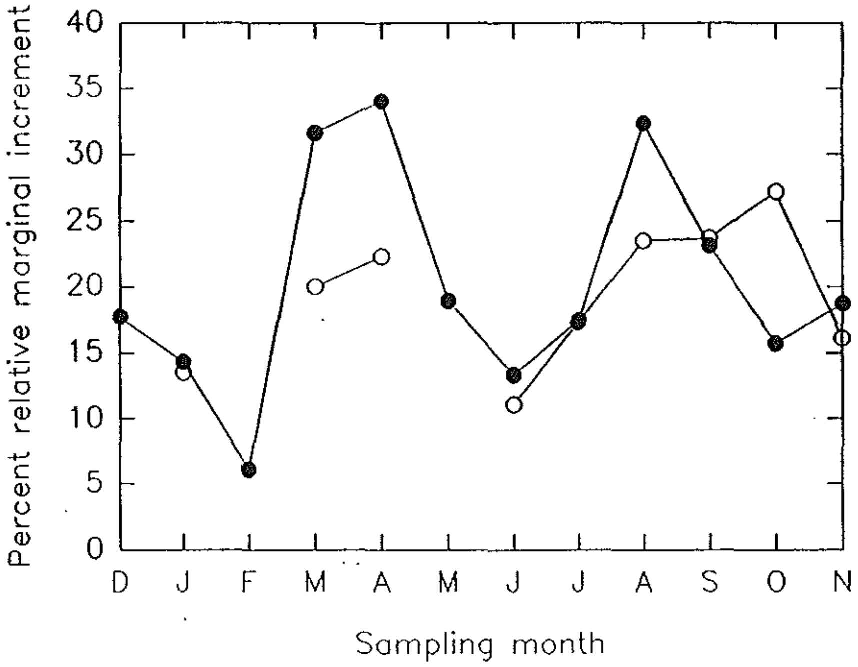


Figure 7. Relative marginal increment (%) for *O.niloticus* with one (filled circles) and two biannuli (hollow circles) from December 1993 to November 1994.

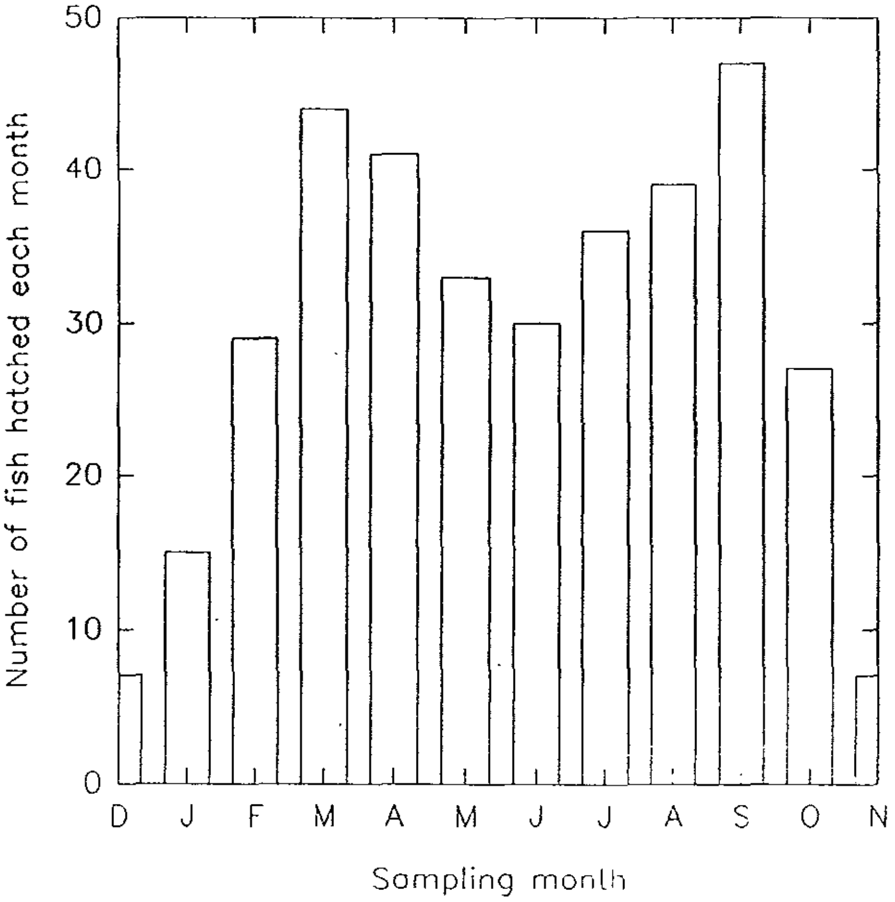


Figure 8. Hatch date distribution by month as determined from microzone count on the otoliths of fish caught between December 1993 and November 1994.

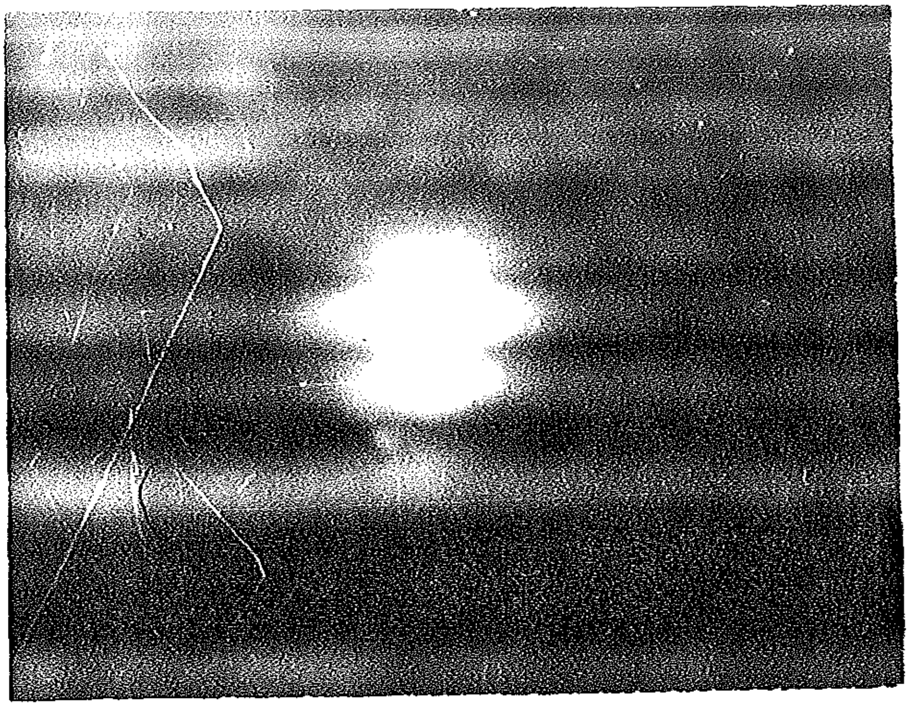
Table 3. Determining the recruitment cohort of fish based on the number of biannuli and condition on the edge of otoliths

No.	Length (mm)	Sampling Date	NB	Edge condition	Cohort	Calender age(days)
1	11	May 25	0	_	March, 1994	_
2	46	July 24	1	"*"	March ,1994	161
3	51	Aug. 25	1	"+"	March, 1994	191
4	81	March 11	1	"++"	September, 1993	171
5	60	March 11	1	"+"	September, 1993	172
6	75	May 25	1	"++"	September, 1993	226
7	134	April 5	2	"++"	March, 1993	322
8	112	Aug. 25	2	"+"	September, 1993	366
9	144	Aug. 25	3	"+"	March, 1993	555
10	150	July 24	3	"0"	March, 1993	492

Fig. 9 were from the same year class, 1993, but from different cohorts (i.e. from September and March cohorts respectively). Otolith No. 4 had one biannulus, where as otolith No. 7 had two biannuli. In otolith No. 4 the first biannulus probably formed in January, 1994, while in the latter the first and second biannuli were deposited in June, 1993 and January, 1994, respectively. In the same manner otolith No. 9 which is from fish of March, 1993 cohort had one more biannulus (i.e. 3 biannuli) than did otolith No. 8 from fish of the September, 1993 cohort (i.e. 2 biannuli).

The mean microzone for fish with one biannulus on March 11 was 229, which gives an estimated hatch time of late July, 1993. Otolith No. 4 and 5 in Fig. 9 belong to this group. By August, 1994 fish of this cohort already completed the deposition of a translucent zone associated with the second biannulus. The mean
total microzone count was 366 which gave a back calculated hatch date of August 21, 1993 (for example, otolith No. 8). Although slightly earlier, the hatch dates hind casted above are close to
the median spawning time determined, i.e. mid-September. This verifies the recruitment cohort of the fish as determined from the number of biannuli. The sample size of the March, 1993 cohort was very small to discern a similar pattern.

Figure 9. Photographs of otoliths from some of the sampling occasions to show condition on the edge of otoliths. The translucent zones associated with biannuli are indicated by arrows. For detailed information on each otolith see Table 3.



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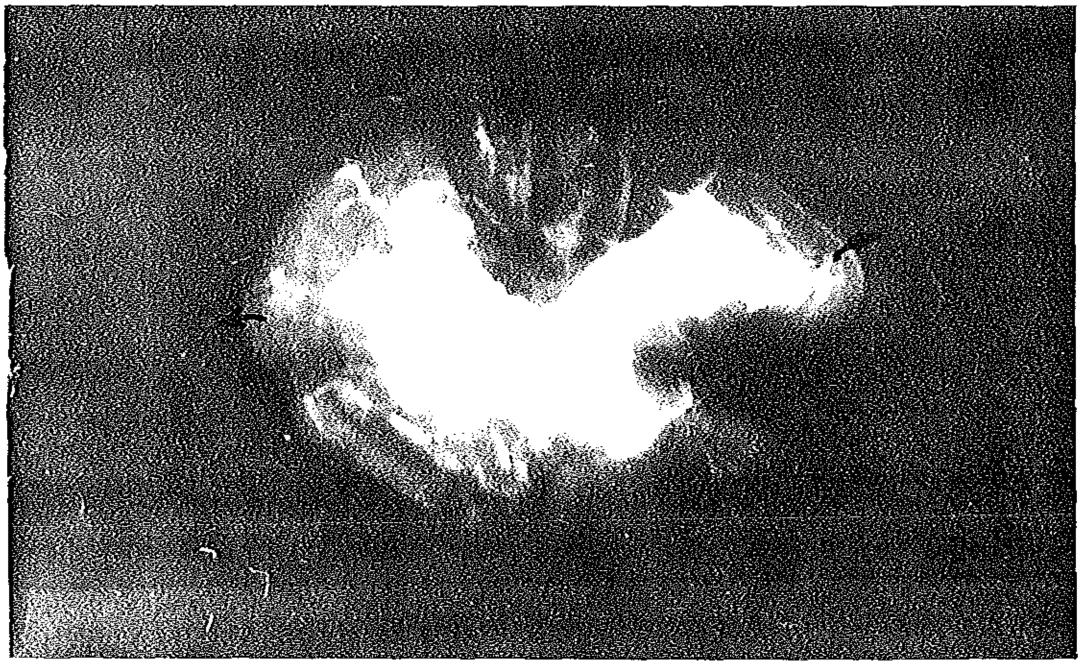

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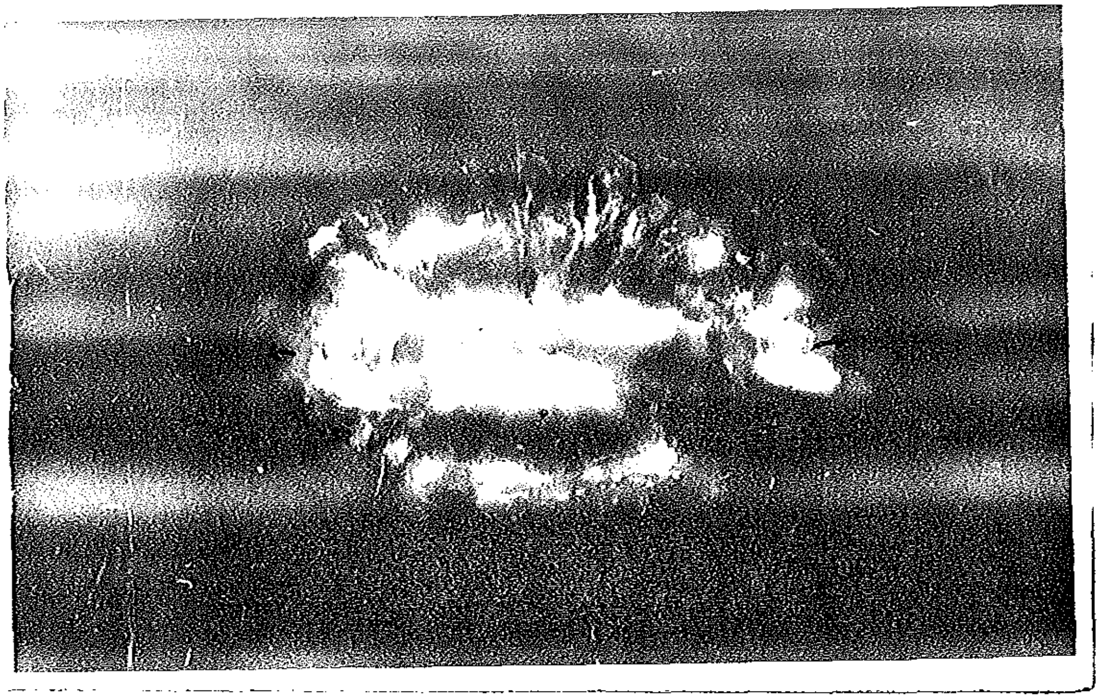

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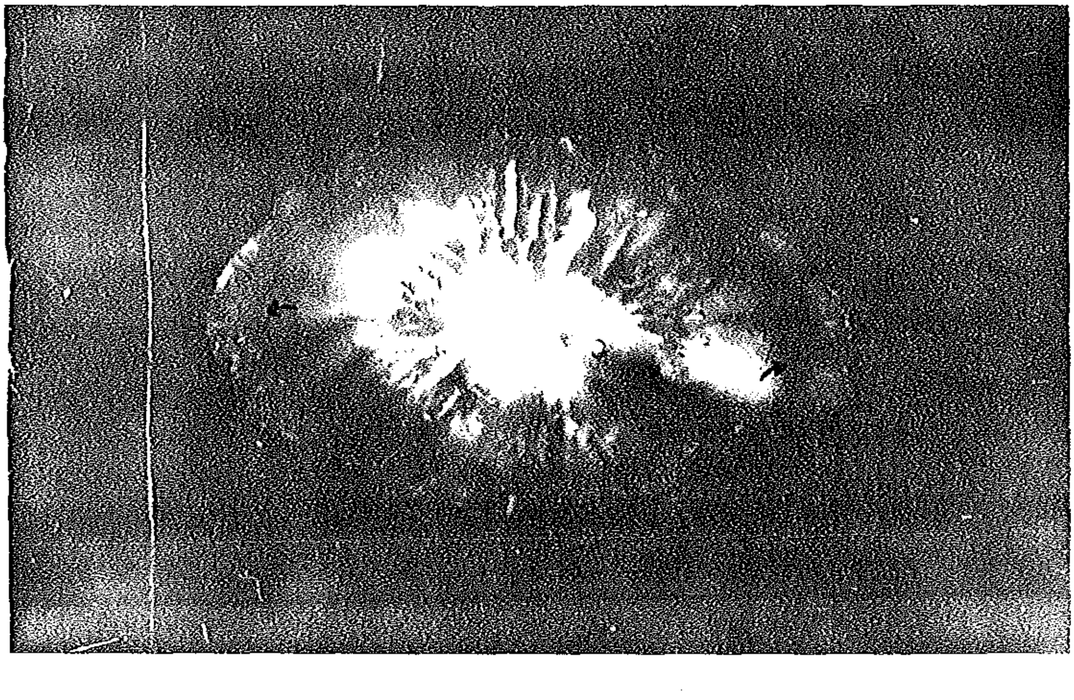

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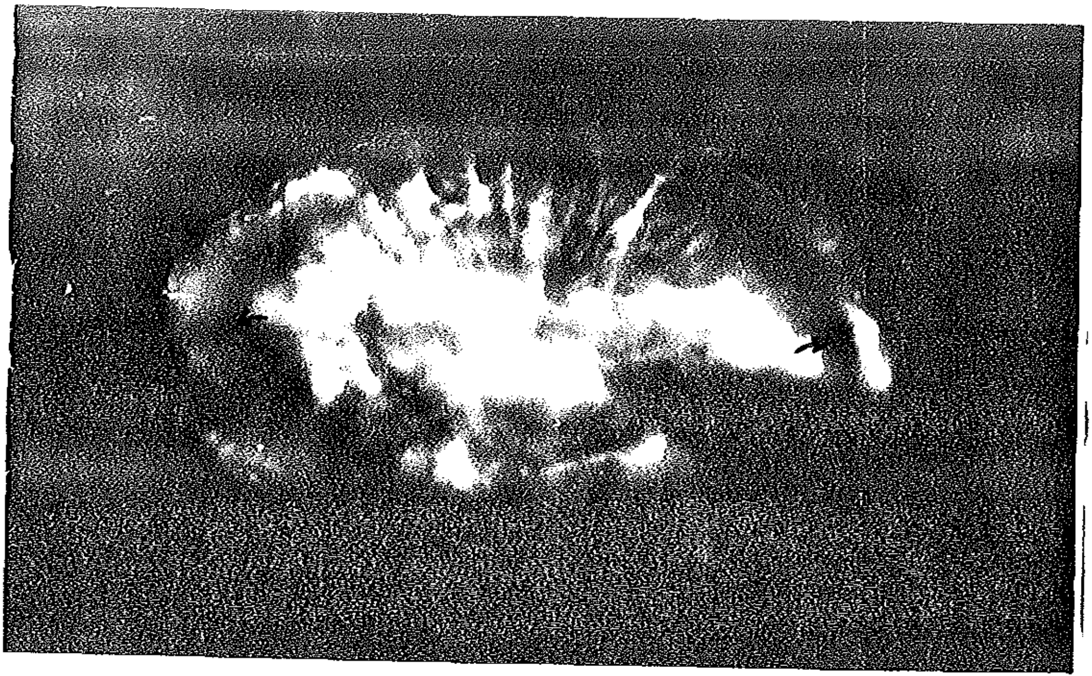

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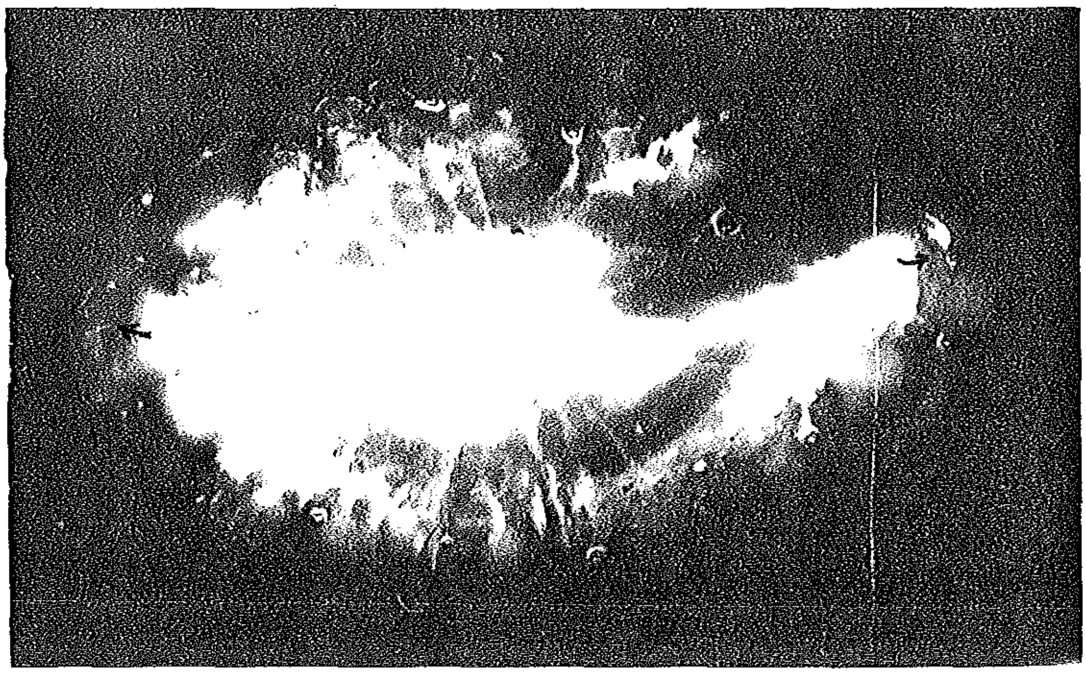

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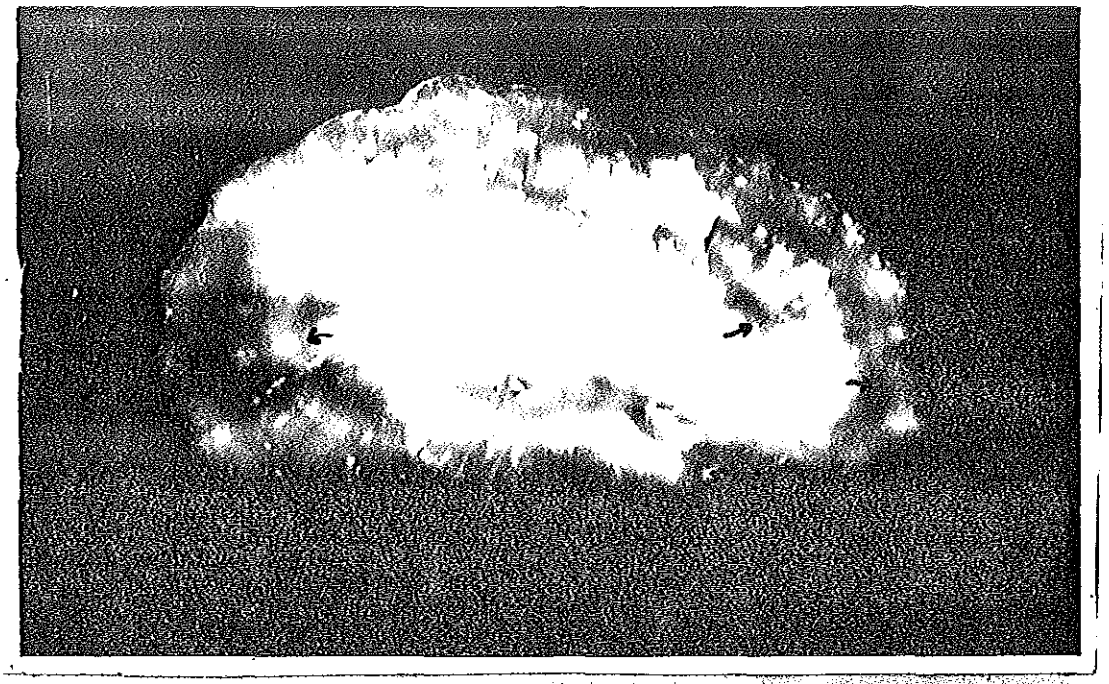

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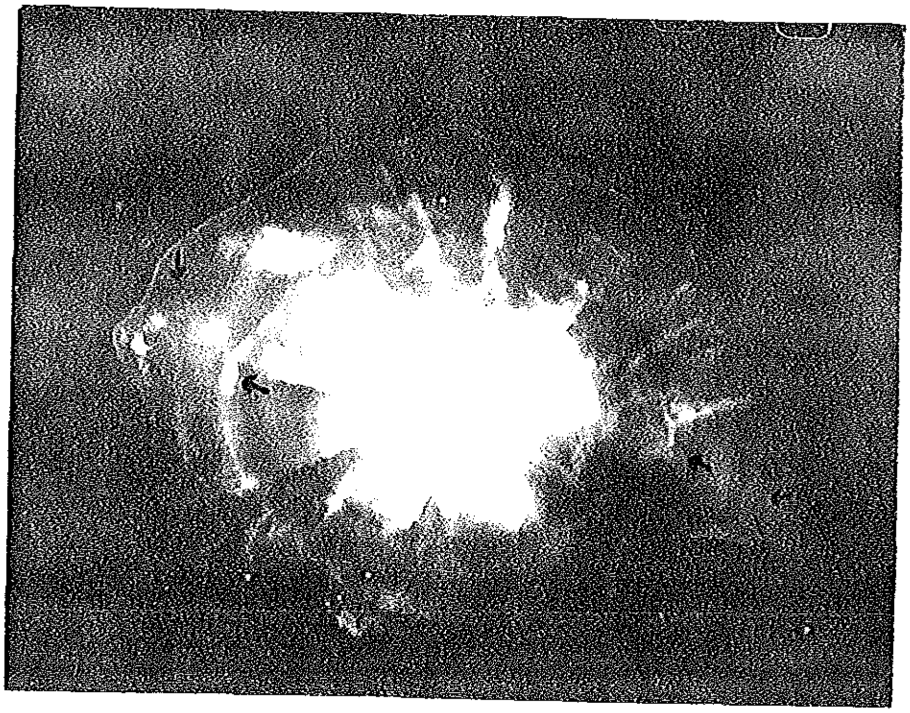

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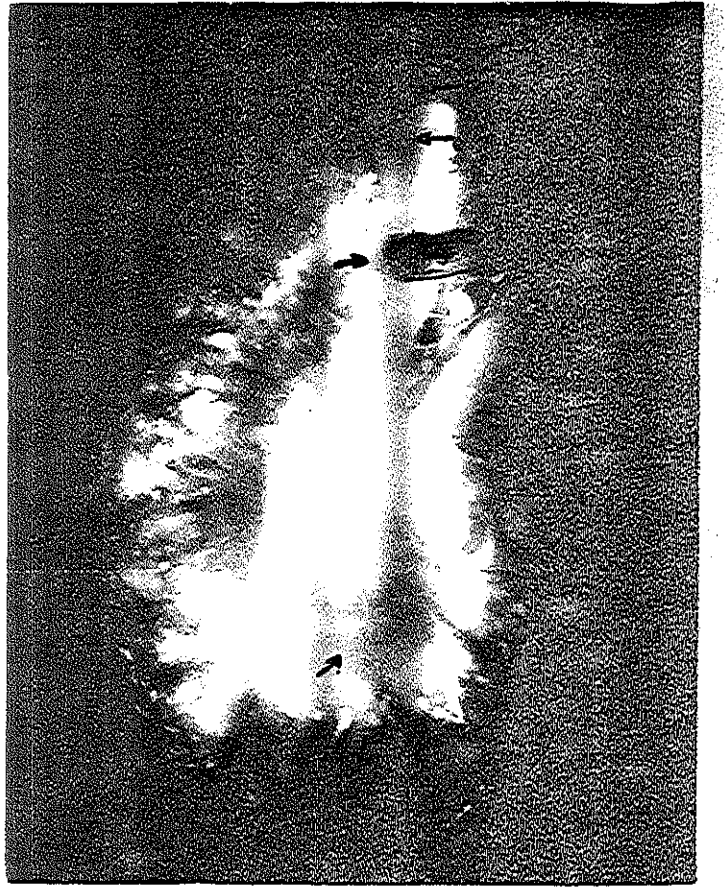

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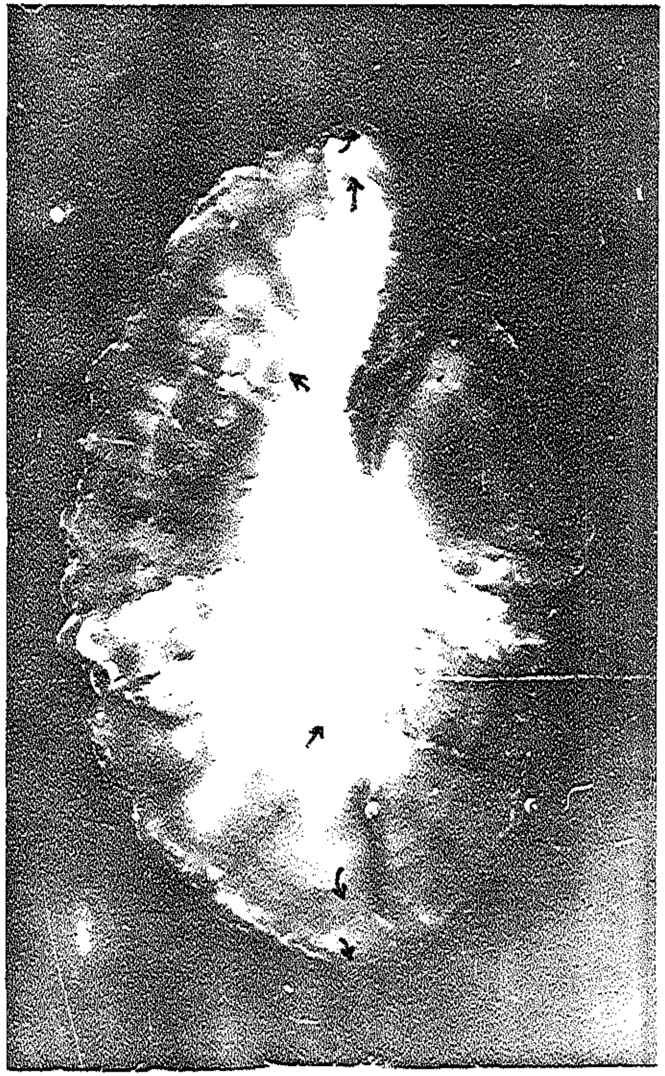

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5.4. Age and Growth assessment

5.4.1. Size at age estimates from macrozone analysis

Samples were taken only up to November, 1994. As a result, the March 1994 cohort had only one biannulus and hence otoliths with two and three biannulus were not available for this cohort. On the other hand, in December, 1993 very few fish with one biannulus were caught. Thus, it was not possible to treat the two cohorts separately. Therefore, data were combined for the two cohorts to calculate mean total length-at-age and to conduct regression analysis.

From the length-at-age estimates given in Table 4 fish that had started forming the first biannulus (i.e. 1"0" condition) had a
mean total length of 49.0 mm. When the fish were approximately one year old (i.e. 2 "0" condition) they had grown to 98.8 mm. By the time of the completion of the third biannulus, they attained a total length of 139.9 mm.

5.4.2. Microzone analysis

There is a strong linear relationship between total length and age in days obtained from microzone count(Fig. 10). The relationship (n=308, r^2=0.91) is given by the equation: Total length = 9.2 + 0.3 microzone count. The slope of the regression line, 0.3 ± 0.005 (SE) corresponds to a growth

Table 4. Mean total length-at-age estimates from macrozone analysis

NB	sample size	edge condition	mean TL (mm)	Standard deviation	mean age (days)	mean OR (mm)
1	27	"0"	49.0	9.2	136	1.1
1	57	"+"	60.8	10.6	176	1.3
1	65	"++"	71.5	10.2	208	1.5
2	21	"0"	98.8	13.6	287	2.1
2	29	"+"	103.6	16.1	309	2.2
2	9	"++"	109.0	21.9	329	2.3
3	9	"0"	139.9	12.6	412	2.8
3	78	"+"	154.1	37.9	-	3.1
3	34	"++"	169.7	16.5	-	3.1
4	26	"0"	193.0	17.1	-	3.7
4	57	"+"	202.4	26.9	-	3.8
4	47	"++"	204.0	36.3	-	3.9

rate of between 8.8 and 9.1 mm per month. A section of an otolith from fish sampled in May showing microzones is presented in Fig. 11.

5.5. Comparison of age estimates from macrozone and microzone analysis

Macrozonal daily age estimates obtained by calculating the number of days between the date of capture and median **spawning times (calender birth dates) closely agreed with those from microzone analysis. Regression analysis conducted using the age in days obtained from microzone count as the (x) variable and calender age as the dependent variable (y) produced the scatter plot shown in Fig.12, (n=308, r^2=0.71).** The slope of the regression line was 0.94 (95% confidence **interval** 0.87-1.009), a value which didn't differ significantly from one. This conforms to what would be expected if the two age estimates were similar.

5.6. Comparison of size at age estimates of O. niloticus from Lake Awassa and Lake Hayq

Comparison of size-at-age estimates from lake Awassa (Demeke, 1989; Yosef, 1990) and lake Hayq show that *O. niloticus* grow at a slightly faster rate in lake Hayq than fish of the same age from lake Awassa (Table 4). For instance , at age one, mean total length for Lake Awassa *O.niloticus* was less than 8.3 mm (Yosef 1990), although a slightly higher value is

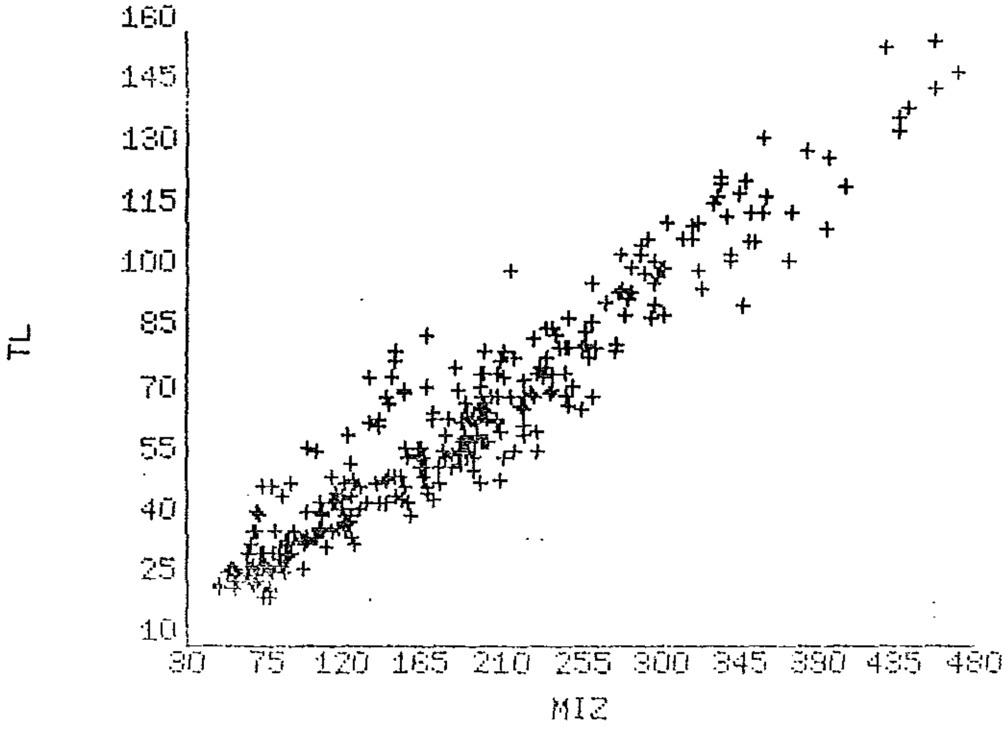

Figure 10. The relationship betweern fish total length and microzone count (N=308, r^2=0.92).

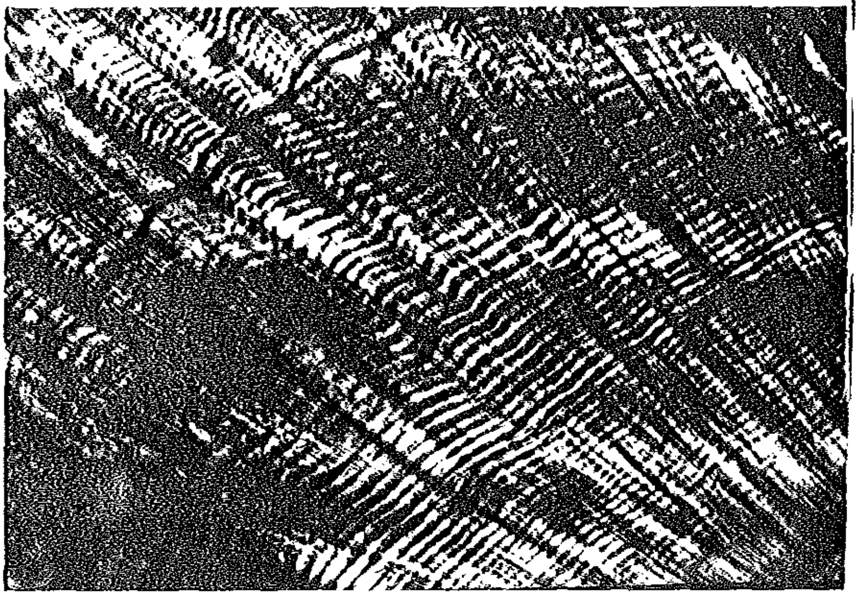

Figure 11. A section of the postrostrum of the sagittae of *O.niloticus* from Lake Hayq showing microzones

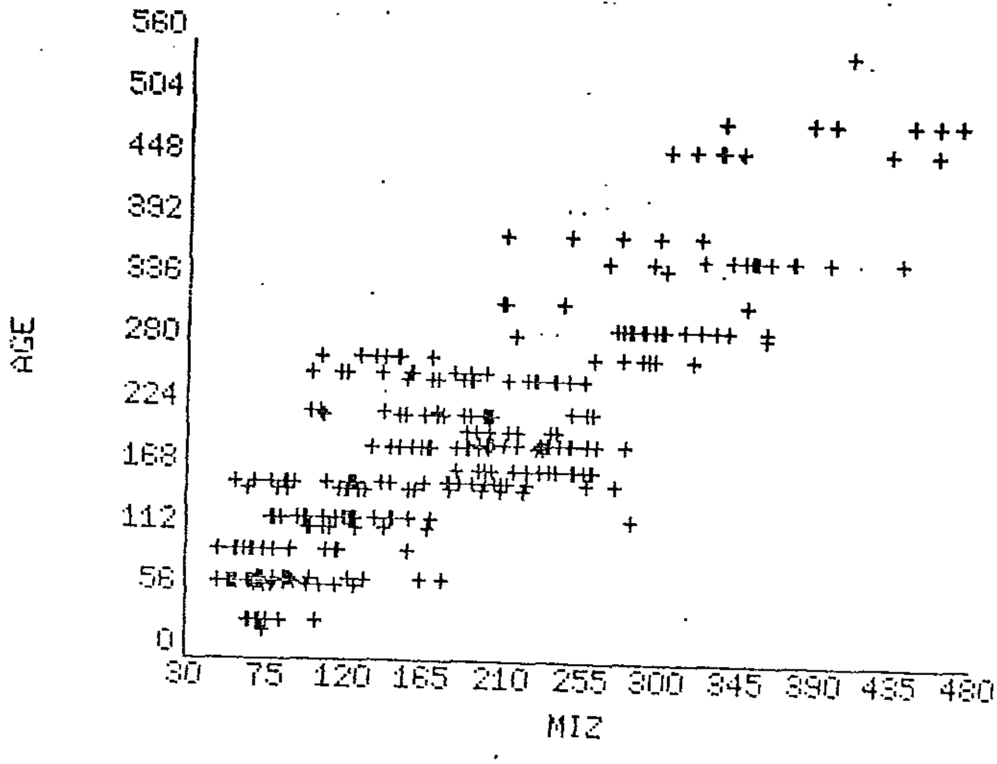

Figure 12. The relationship between age in days dtermined from macrozone analysis (AGE) and microzone count (MIZ). N=308, $r^2=0.71$, .

obtained by Demeke (1989). In contrast, results obtained from all the methods employed in the present study show that *O.niloticus* in Lake Hayq can attain mean length of greater than 95.0 mm in one year.

5.7. The relationship between otolith size and fish size

There was a strong relationship between otolith size and fish size in *O.niloticus* of Lake Hayq. Otolith radius was a linear function of fish total length. Combination of data from young and adult fish improved the total length - otolith radius relationship (N=296, $r^2 = 0.97$). (Fig. 13). From Table 4, a length-age and otolith radius-age relationship can be established to provise a more informative picture (Fig. 14). By measuring the length of fish or otolith radius and then refering to Fig. 14, one can possibly tell the age of a fish.

A scatter plot of otolith weight (x) against total length (y) given in Fig. 15 shows that a linear relationship exists between otolith weight and total length. The predictive regression was: Total length = 140.4+1297.5 otolith weight ($r^2 = 0.85$). Otolith condition index (OCI) data and total fish length (Fig.16) were best assigned to the model:
Total length = 324.9 + (-1.3) OCI ($r^2 = 0.86$) and represent a negative linear relationship. Because of the linearity of the above models and associated high coefficients of

Table 5. Size-at-age estimates of *O. niloticus* from lake Awassa and lake Hayq.

Lake	**Mean TL** at age (years) 1	2	3	**Method of** determination	**Author**
Awassa	92	165	219	macrozone analysis	Demeke (1989)
Awassa	79.3	152.0	-	macrozone anal.	Yosef (1990)
Awassa	82.5	156.0	-	microzone anal.	Yosef (1990)
Awassa	81.7	-	-	length-freq. anal.	Yosef (1990)
Hayq	98.8	193.0	-	macrozone anal.	(present study)
Hayq	95.3	-	-	microzone anal.	(present study)
Hayq	99.4	182.2	-	TL-OR relationship	(present study)

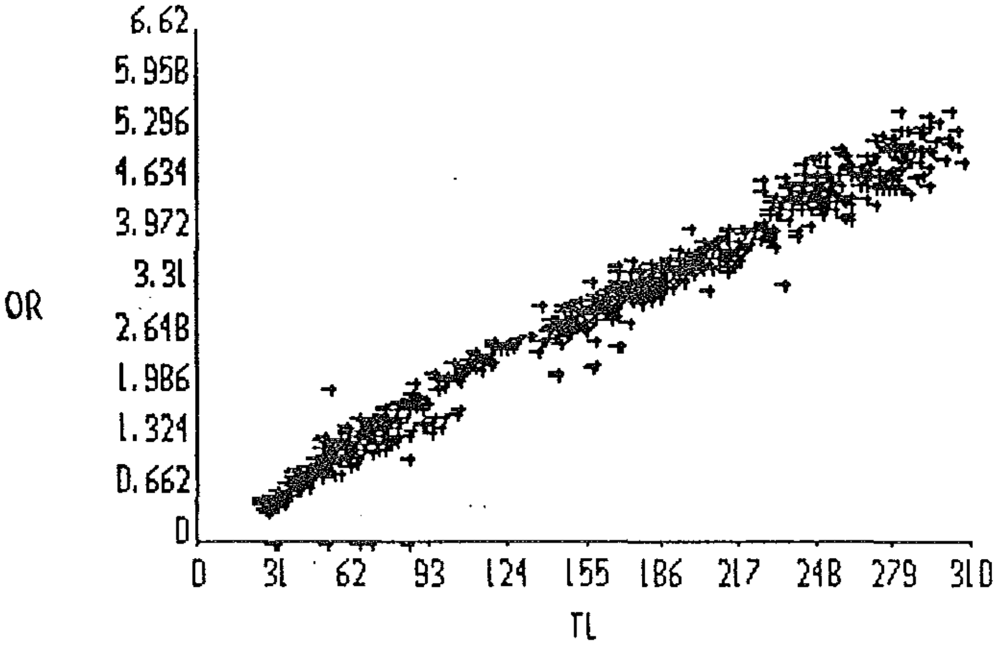

Figure 13. The relationship of saccular otolith radius (OR) to fish total length TL). Data were combined for both young and adult fish. N=754, r^2=0.97.

determination, it would appear that total length can be predicted more reliably from otolith measurements.

To investigate the growth of otolith relative to fish growth, a subsample of 136 fish were examined in this study. One feature of *O.niloticus* otolith from lake Hayq, as indicated in Fig. 17, is its gradual decline in radius relative to the fish total length. Otolith radius is 2.1% of the total length of fish at an average size of 62.8 mm (NB=1) and falls as low as 1.93% at 155.6 mm (NB=3) and 1.83% at an average length of 233.7 mm (NB=5). On the other hand, at increasing ages and lengths, *O.niloticus* were seen to have increasingly greater otolith weight as a percentage of the total length of the fish (Fig. 18).

5.8. Length-weight relationship and condition factor

Total length and total weight of *O.niloticus* in Lake Hayq were curvilinearly related (Fig. 19). There was no sex based significant difference in slopes, data for male and female fish were combined and fitted to a single equation:
$\log10\ TW = -5.05+3.13\ (\log10\ TL)$, $r^2=0.97$. Where TW is given in grams and TL is in millimeters.

Fluctuations in monthly Fulton's condition factor for monthly fish samples are presented in Fig. 20. Mean monthly condition factor ranged from 1.61 to 1.82. Low condition factors were recorded in January (1.66) and July (1.61).

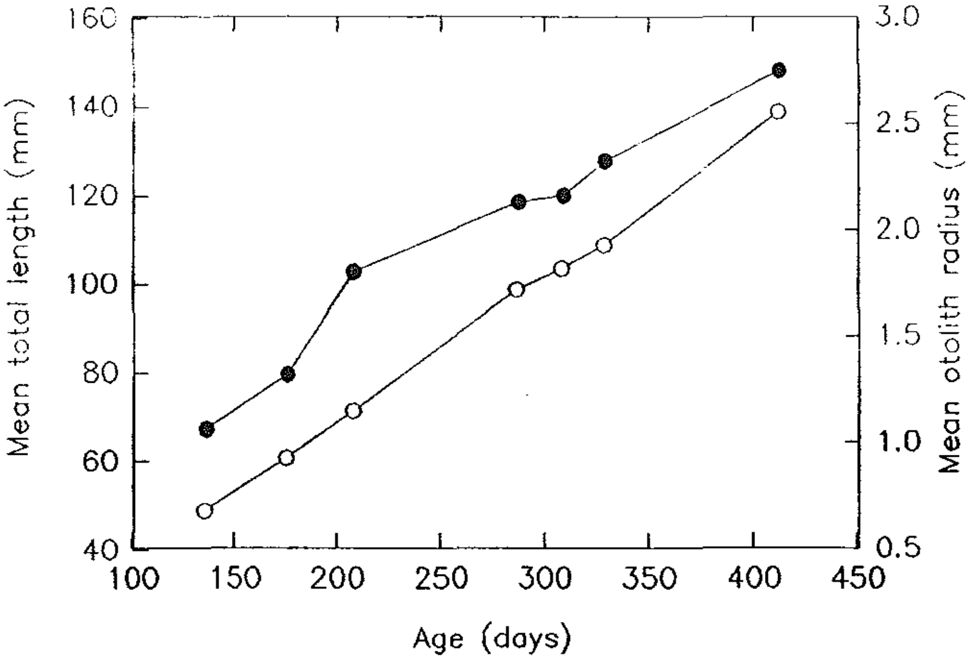

Figure 14. Mean age (days) plotted against mean total length (hollow circles) and mean otolith radius (filled circles).

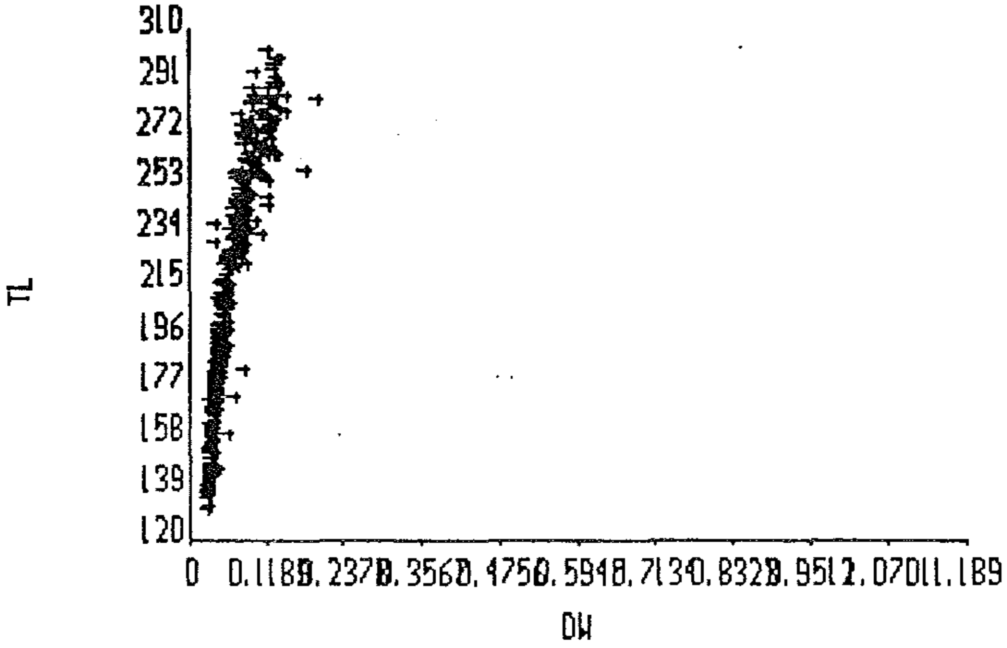

Figure 15. The relationship of saccular otolith weight (OW) to fish total length (TL) for adult fish. N=446, $r^2=0.85$.

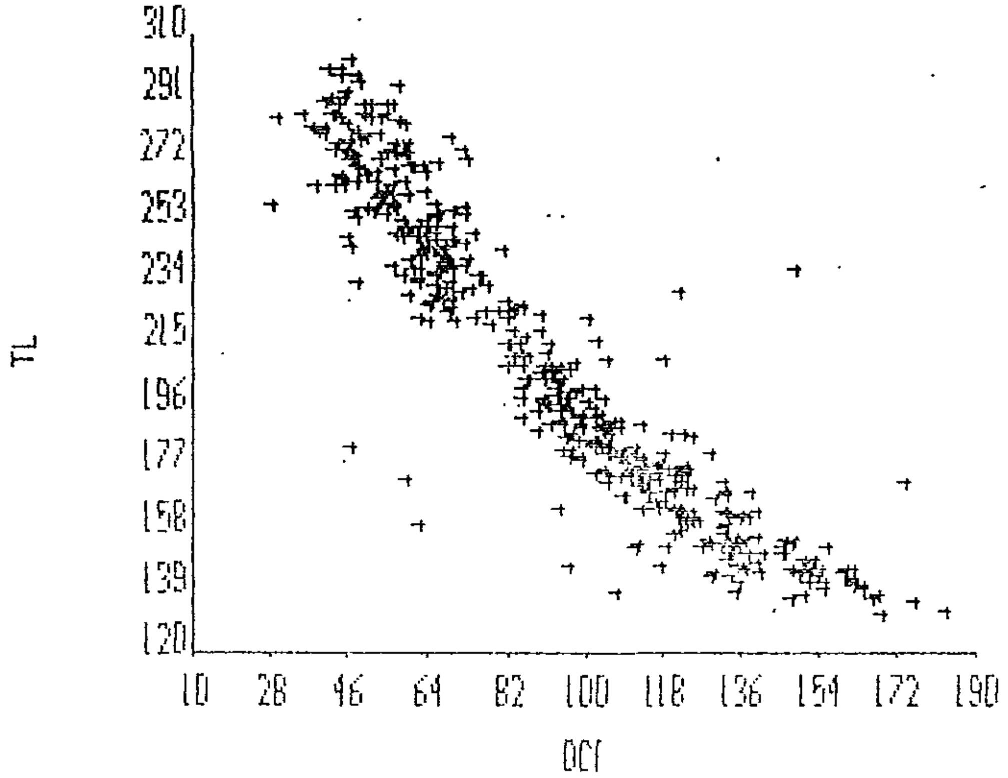

Figure 16. Combination of saccular otolith radius and weight into an otolith condition index (OCI) and its relationship to adult fish total length (TL). N=446, $r^2=0.86$.

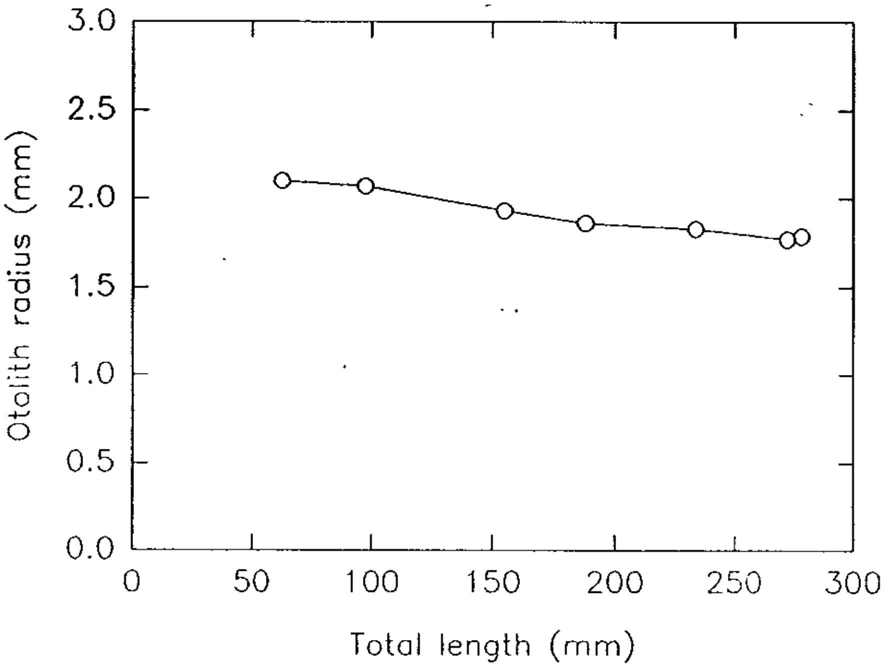

Figure 17. Relative radius of the otolith in Lake Hayq *O.niloticus* at different mean lengths.

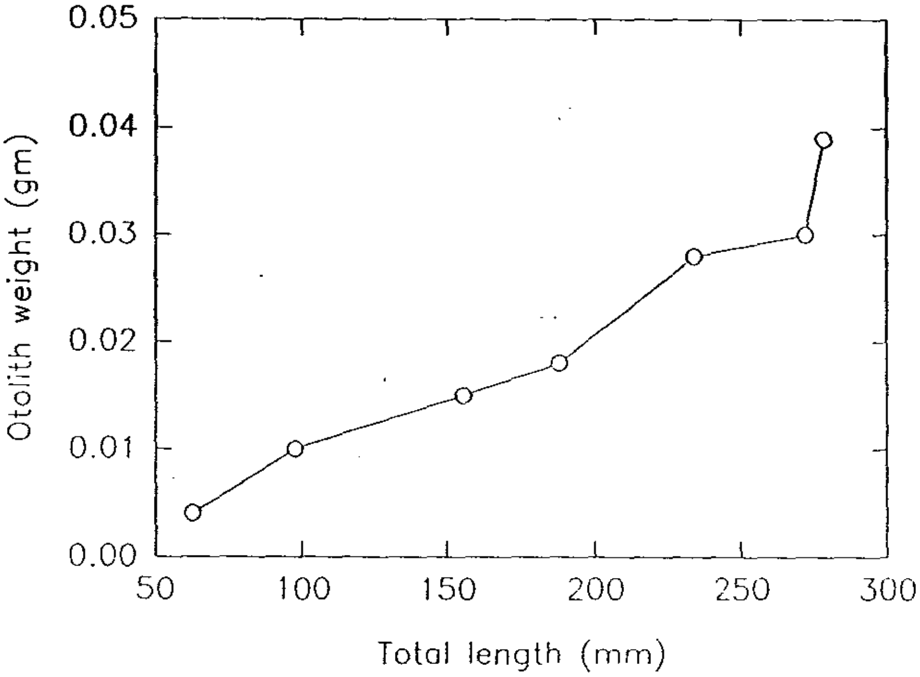

Figure 18. Relative weight of the otolith in Lake Hayq *O.niloticus* at different lengths.

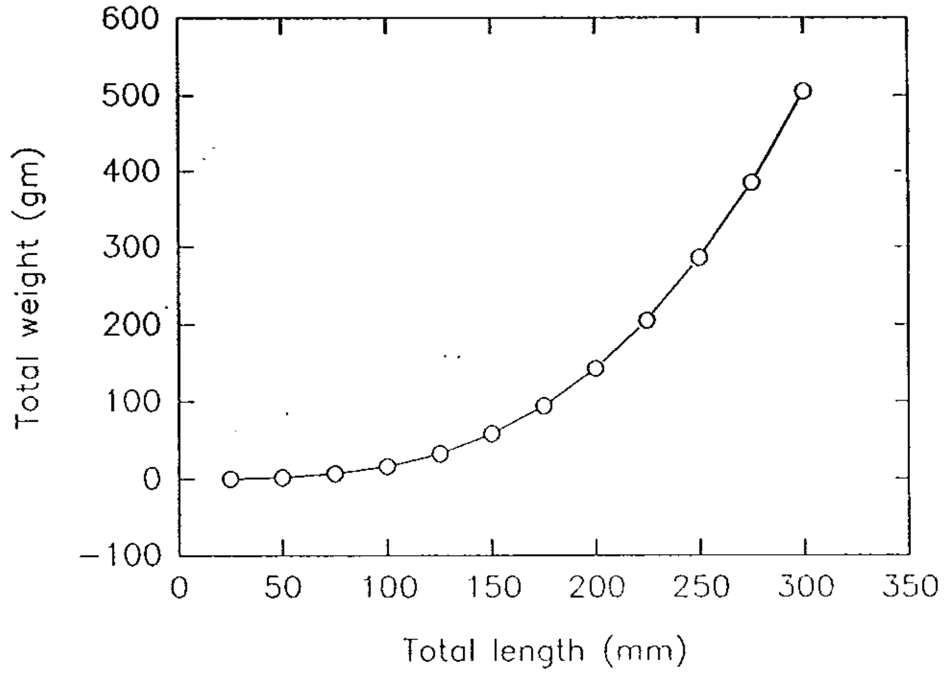

Figure 19. The relationship between total length (TL) in millimeters and total weight (TW) in grams for *O.niloticus* from Lake Hayq sampled between December 1993 and November 1994. N=447, r^2=0.97 .

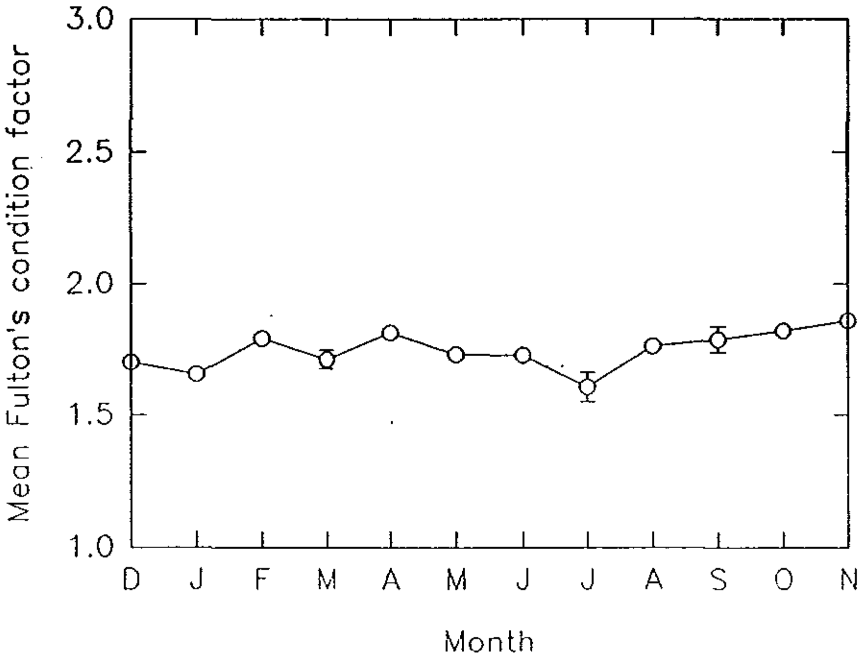

Figure 20. Fluctuation in mean fulton's condition factor of *O.niloticus* in Lake Hayq during December 1993 to November, 1994.

6.DISCUSSION

6.1. Factors associated with translucent zone formation

6.1.1. Juvenile marks

Tilapia like many members of the cichlidae, are maternal mouth brooders (Fryer and Iles, 1972). That is, the eggs are held in the mouth of the female fish and the larvae are subsequently released. The time of release of independent juveniles ready to swim and capable of external feeding varies with the species. The mean number of microzones in the otoliths of *O.niloticus* fry, in Lake Hayq was 10.3 mm. These fry have already consumed their yolk sac when they were taken from the mouth of brooding females. Thus, in lake Hayq the juveniles appear to be released 10 days after hatch and when they are about 10-12 mm long. This result strongly agrees with what has been reported for the same species in lake Awassa (Tudoranceae *et al*, 1988; Yosef, 1990).

Translucent macrozones were not observed in the otoliths of sac fry sampled from the mouth of brooding females (Fig. 9, otolith No.1) and the whole region of the otolith appeared opaque. The first translucent zone (juvenile mark) was formed 2-4 days after the time the larvae were released from their mothers for the first time (mean microzone count=14.2). The length of the fish when this zone appeared on the edge of the otolith was 13.2 mm (as determined from TL-MIZ relationship). According to Yosef (1990), when the fish started to deposit the first translucent zone in Lake Awassa, they were about 14 days old and the mean length was 13.8 mm. The shift to the consumption of natural food could be a stressful process to the larvae and consequently may result in the formation of this zone. Yosef (1990) also concluded the same.

The second juvenile mark appeared in otoliths of fry when they were 55 days old and had attained an average size of 25.7 mm. Yosef (1990) showed that when the fish started to deposit the second juvenile mark, they were about 50 to 60 days old and the mean size was 22.7 mm. It is known that all fishes in both tropical and temperate regions feed on zooplankton in their early stages (Fernando, 1983). According to a study of feeding habits of juvenile tilapia in Lake Awassa (Tudorancea *et al.*, 1988) a marked shift in feeding from a mainly animal food to algae occurred when the fish reached a length of 27.5 mm. Thus the second translucent zone may be formed in *O.niloticus* due to a change in diet and possibly also due to an associated change in habitat.

6.1.2. Biannulus formation

Due to the general belief that the tropical region does not experience climatic fluctuations, seasonally formed macrozones have not been expected in calcified tissues from tropical fish. However, based on the seasonal occurrence of translucent zone at the edge of most otoliths and relative marginal growth of otoliths, translucent zones associated with biannuli formed in the otoliths of Lake Hayq O.niloticus during the periods January to February and June to July. Researchers who believe that two annuli form each year in calcified tissues of fish include Holden (1955), Warburten (1978), Demeke (1989), and Yosef (1990).

Evidence of slow growth in fish populations is often identified by a poorer condition (Lowe-McConnel, 1975). In lake Hayq *O.niloticus* were in poor condition during January and July (Fig. 20). Therefore, it is apparent that biannuli formation coincided with periods of slow growth. The water temperature regime, oxygen profile and food scarcity are the most probable causes for these phenomena.

Water temperature is believed to be one of the most important factors to cause biannulus formation in fish calcified tissues. In lake Hayq, the water temperature recorded in January and February was the lowest during the study period (Fig. 4). This coincided with the time of biannuli formation. Jubb (1966, in Badenhuizen, 1967) found that the natural habitat of *Tilapia mosambica* has a mean temperature of 25°C, with a range of 21°C to 27°C. It has been also found that temperatures below 20°C significantly reduced the growth of tilapias (Caulton, 1982). It is possible, therefore, that lower water temperature resulted in the formation of translucent zones (biannuli) in the otoliths of Lake Hayq *O.niloticus* during the above mentioned months. Water temperature data were not available for June, therefore, it was not possible to determine if translucent zone formation is associated or not with temperature fluctuations. Although the water temperature in July was not as low as that recorded for January and February, it was lower than that measured in the two growing periods, namely March - May and August - October. Neilson and Geen (1982) showed that the transition from the optimal to sub-optimal temperature reduced growth in chinook salmon. It is therefore, likely that a decrease in water temperature from 24.5°C in may to 23.4°C in July and its subsequent increase to 25°C in August caused the slow growth observed in July. Demeke (1989) also suggested that low water temperature resulted in the formation of translucent zones in the otoliths of *O.niloticus* in lake Awassa during June and July.

Pannella (1980) published a photograph of an otolith with a distinct check or translucent zone formed under thermal and anaerobic stress. In addition, a 48 hours stress of oxygen deficiency induced otolith resorption resulting in the formation of a distinct translucent zone in the otoliths of goldfish, *Carassius auratus* (Mugiya and Uchimura, 1989). Elizabeth *et al.*(1989) reported that in lake Hayq the fraction of the column of water that is saturated with oxygen was small at the time of their investigation. This has been also noted in the current study (see Table 2). Shallow oxygen saturated water column was recorded during the period December-February, the shallowest being in January. On the other hand, most of the otoliths from fish sampled during March to May had opaque growth on their margins. In addition fish were in good condition indicating that they were growing better. This period was accompanied by increase in water temperature and increase in the column of water saturated with oxygen. Thus, these observations on lake Hayq appear to explain not only biannulus formation but also the frequent fish kills which occur during January every year.

Among the many factors that cause the formation of translucent zones in fish calcified tissues, availability of food is one (De bont, 1965). Demeke (1989) and Yosef (1990) reported that the formation of checks and translucent zones in scales and otoliths of *O.niloticus* in Lake Awaasa is associated to slow growth due to the reduced quality of food consumed. Although studies regarding the seasonal changes in the diet of *O.niloticus* are lacking, data on biomass indicate that production in Lake Hayq is low during the slow growth periods (Getachew, unpublished data). These periods correspond to the two periods of a year when translucent zones are formed in the majority of the otoliths of *O.niloticus*. Hence, variation in the quantity and quality of available food may also explain the formation of biannuli in the otoliths of *O.niloticus* in Lake Hayq.

The period July to October is generally associated with maximum rainfall for the lake Hayq region and increase in lake water level and water temperature. Better growth was observed during the rainy season for *Tilapia rendali* in a south African water body (Batchelor, 1987). In addition, Elizabeth (1987) noted a greater phytoplankton biomass in lake Awassa after the rainy season because of an increase in nutrients. Therefore, it is possible to regard increase in water temperature and nutrient availability as one of the likely causes of the resumption of better growth during the periods August to November.

From the results of the present study one can conclude that two translucent zones (biannuli) form in the otoliths of *O.niloticus* each year. These can be identified from the first two translucent zones formed during the larval life stage easily.

It is evident that low water temperature, decreased amount of oxygen and food could interact and result in reduced growth with subsequent formation of translucent zones associated with biannuli. The correlation between increased reproductive activity (spawning and brooding) and slow growth, particularly for females, has been documented in the literature for *Oreochromis* (Lowe-McConnel, 1975; Stewart, 1988). According to Demeke (1989) female *O.niloticus* in Lake Awassa reach maturity in the second year of life at about 138 mm TL. He also suggested that spawning could be one of the factors responsible for the decrease in the growth of the mature fish. Spawning and brooding can not be, however, considered as a cause of biannulus deposition in *O.niloticus* in the present study because of the presence of these zones on the otoliths of immature and male fish.

6.2. Comparison of age estimates from macrozone and microzone analysis

The median spawning dates determined in this study (March 14 and September 18) strongly agree with the median hatch dates (mid- March and mid-September) determined by Yosef (1990). Demeke (1989) assumed average calender birth dates for the two cohorts (March and September cohorts) to be February and August and these are slightly earlier. This difference can be attributed to the fact that gonadal development precedes hatch dates. Following the method developed by Yosef and Casselman (unpublished) "calender birth dates" (September 18 and March 14) were used, in the present study, to assign age in days based on the interpretation of macrozone and condition on the edge of otoliths. This made possible to discriminate between fish belonging to the two cohorts (see also Yosef, 1990). The proportional contribution of the March cohort to the total population was 55.2%, whereas that of the September cohort was 44.8%.

The results of the present study showed that there is a close agreement between age estimates obtained on the basis of median spawning times and from microzone analysis (Fig. 12). That the slope of the regression line (0.94) relating the two age estimates was not different from one illustrates the validity of assigning ages (in days) from macrozone analysis. From the relationship of macrozonal and microzonal age estimates the 95% confidence limit is within the range of ±3.7 months. This shows that age estimates obtained by counting and interpreting biannuli is bound to an error of ±3.7 months. If a given fish is spawned mid June and the mean age is calculated from September 18, the true age of the fish is underestimated by three months. On the other hand, the age of fish that spawned in January is underestimated by two months, if the mean age is calculated from March 14. Therefore, an error range of two to three months is expected if median spawning times are to be used in assigning age to fish. The 95% confidence limit determined by Yosef (1990) was ±2.5 months and was in agreement with the expected range. Concidering the difficulties associated with the assessement of the age of tropical fish and the subjectivity of the method, this level of precision is reasonable.

The mean number of microzones in otoliths from fish which have completed the formation of the second biannulus (and hence are approximately one year of age) is 287 (Table 4) and is lower than what is expected, i.e. 365. Fish from the same group had 340 microzones in Yosef's (1990) finding. The different results we obtained may be related to our technique for preparing otolith surfaces and use of the light microscope that has limited resolution power, or it may be the reflection of reader experience. Even with these differences it is apparent that daily age estimates obtained from the counting and interpretation of the biannuli did not seriously misinterpret the true age of fish in the present study. If refined methods and proper equipment are employed, the error gap can be minimized.

It is evident that translucent zone formation and spawning are of biannual periodicity. This knowledge along with date of capture and condition on the edge of otoliths provided a means, not only for assessing age of fish, but also a means of identifying the cohort and year class which individual fish come from.

6.3. Growth estimation

6.3.1. Comparison of size-at-age estimates from microzone and macrozone analysis and fish length-otolith radius relationship

Length calculated from TL-MIZ relationship (Fig.10) for juveniles whose otoliths started depositing the first biannulus was 50 mm. That calculated from TL-OR relationship (Fig. 13) was 50.4 mm. These values are close to 49 mm, length at age estimate obtained from macrozone analysis. The length at age estimate obtained from macrozone analysis for the corresponding group of fish in Lake Awassa was 48.7 mm (Yosef, 1990). Similarly , lengths calculated from TL-MIZ and TL-OR relationships at the time of deposition of the second biannulus were 95.3 and 99.4 mm, respectively. These fairly agree with that calculated from macrozone analysis, i.e., 98.76 mm. At this size, the fish were one year old. The corresponding macrozonal length estimate for fish from Lake Awassa was 79.3 mm (Yosef, 1990). In tropical lakes, under favourable conditions, *O.niloticus* can attain lengths between

140 and 160 mm after one year (Rinne, 1975). Therefore, it appears that *O.niloticus* of Lake Awassa and Lake Hayq are slow growing population, although the latter is slightly better. Computations of length-weight relationships of populations of *O. niloticus* in lake Awassa (Demeke, 1989) and lake Hayq (present study) also showed that lake Hayq population was in a relatively better condition. For instance, fish of 250 mm long weighs 286 and 270 g in Lake Hayq and lake Awassa, respectively. In the same way, the respective weights of 200 mm long fish are 142 and 138g.

By the time of the deposition of the third biannulus length estimates calculated from TL-MIZ; and TL-OR relationships (132.8 and 127.95 mm, respectively), although slightly lower, appeared to agree with that obtained from macrozone analysis (i.e. 139.9 mm). With increasing age underestimation of calculated lengths was obvious for those obtained from microzone analysis and TL-OR relationship (Table. 4). According to Campana and Neilson (1985) growth increments are often compressed during slow growth period so that identification of discrete increments is difficult. As a result, the extent to which microzone count is underestimated becomes more serious with increasing age . This, together with the fact that otolith radius gradually declines relative to fish length (Fig. 17), may explain why a linear model underestimates length at older age.

It was reported that *O.niloticus* can attain sizes of 640 mm in lake Turkana (Lowe Mcconnel, 1958) and 600 mm in lake

Chamo, Ethiopia (Hailu, personal comm.). In the present study, the largest fish caught had a total length of 304 mm. In addition, specimens with more than eight biannuli were not caught in the present study, a result that shows that most fish may not have survived more than four years of age. It is known that a very severe mass fish kill took place in lake Hayq in January, 1989 (Elizabeth *et al.*, 1992). If a fish had been hatched by then, it would have only attained an age of four-five years at the time of the present study. According to Mihret (personal comm.) another major fish kill has taken place in 1992 and few dying fish were observed in January 1994 (period of the present study). Therefore, it is possible that the mass fish kill that took place frequently could be selective of the large/old fish. From the oxygen profile presented in Table. 4, the fish kill which takes place in January every year appeared to be caused by anoxia.

Fish kills caused by anoxia cannot be totaly prevented. Therefore, management activities should be directed towards minimizing their severity. Repeated observation revealed that in Lake Hayq the fish kills take place every year in January. Therefore, intensive fishing on fish sizes that are affected most before January can help to fulfil the objective of reducing the severity of kills. Along with this, installation of cold storage system which insures preservation of fish until they get access to the market should be sought.

6.3.2. Otolith size-fish size relationship

From the results of the present study, it is evident that sagittal otolith dimensions were strongly related to the age and total length of *O.niloticus*. The relative growth relations (Fig. 17) show that with increase in fish length there is a gradual decline in the radius of otoliths relative to the length of the fish. In contrast, Otolith weight increased considerably with increase in fish size. These, together with the fact that OCI is related to fish total length in a negatively linear fashion (Fig. 16) indicate that otoliths increase in weight more rapidly than radius. In addition, larger otoliths are indicative of slower growth, whereas relatively smaller otoliths form during more rapid growth (Templeman and Squires, 1956; Reznic et al., 1989). Such variabilities cannot be explained if any individual variable (either otolith radius or otolith weight) is taken alone. But if otolith radius and otolith weight measurements are combined and included into an otolith condition index, fish length could be predicted more precisely.

Fish otolith dimensions are valuable for the information they contain on a fish's somatic growth pattern. Most studies support the hypothesis of Templeman and Squires (1956) about the patterns in otolith growth related to somatic or body growth; i.e. fish growth rate affects the relative size of otoliths in an inverse fashion. Marshal and Parker (1982) reported that starved, slowly growing fish had larger otoliths than did equally sized, rapidly growing fish. A controlled experimental test with Guppies (*Poecilia reticulata*) demonstrated that slower growth resulted in larger otoliths (Reznick *et al.*, 1989). Also Secor and Dean (1989) found that slower growing groups of young pond-reared stripped bass, *Morone sexatilis*, had larger otoliths relative to their length than did faster growing groups. Furthermore, Radtke *et al.* (1985) claimed that their results agreed with Templeman and Squires' (1956) finding that otolith size - fish size relationship may offer a better separation of fish populations than growth rates. However, the fact that otolith dimensions are strongly related to fish length (as shown in Figs. 13, 15 and, 16) demonstrates the usefulness of otolith size - fish size relationship to support conclusions drawn from other methods regarding fish growth.

The method does not require otolith preparation and also little subjectivity is involved. Therefore, otolith measurements would provide a quick and simple estimate of fish size. The correlation between otolith size-fish size could be used as an additional argument to support conclusions obtained by other means. It also offers a good picture of growth when macrozone or microzone reading is doubtful and it is possible that this method would be successfully applied to other species.

7. CONCLUSION

The otoliths of *O.niloticus* from Lake Hayq depict clearly defined macrozonation from which biannuli could be interpreted to asses the age and growth of the fish. Along with information on the date of capture and condition on the edge of otoliths, the biannuli also provide a possibility to identify recruitment cohorts and year classes.

The concurrence of biannuli formation with low water temperature and decreased amount of oxygen suggest that these factors, among others, interact to result in the formation of translucent zones in the otoliths of *O.niloticus* in Lake Hayq. Data are lacking on the seasonal changes in the nutrition of *O.niloticus*. Therefore, from the results of present study, it is not possible to strongly argue for or against the association of the quality and quantity of available food to the seasonal growth cycle in the otoliths of *O.niloticus* of lake Hayq. This is a problem which awaits further investigation.

There is a close agreement between daily age estimates obtained from macrozone and microzone analysis. This substantiates the usefulness of macrozone analysis to estimate age and growth of *O.niloticus* in Lake Hayq.

The length-at-age estimates from macrozone and microzone analysis and fish length-otolith radius relationship agree fairly closely. But, size estimates obtained from the latter relationships appeared to underestimate the size of *O.niloticus* with increasing age. However, the methods would prove valuable, at least, to study larval and young fish.

In future studies attempts should be made :

1. To obtain data on seasonal changes of the diet of this fish species in the present study site,
2. To find causes for the slow growth rate of *O.niloticus* population in Lake Hayq compared to other water bodies.

The results we obtain from these studies will improve our knowledge and understanding on the growth of *O.niloticus*. They have also significant implications in aquaculture.

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