



Aspects of the growth and reproductive biology of *Oreochromis niloticus* (Linnaeus, 1758) in a tropical Soda Lake, Lake Shala, Ethiopia

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Abstract

Morphometric relationships, condition factor (CF) and reproductive biology are significant tools in fish stock management, fish biology, physiology, conservation and ecology. Growth and reproductive strategy of *Oreochromis niloticus* were studied from 343 fish specimens collected from Lake Shala between January and December 2018. Fish samples ranged from 7.7 cm to 33.0 cm in total length (TL) and from 7.80 g to 708.21 g in total weight (TW) were collected using gillnets of 4, 6, 8, 10, and 12 mm mesh sizes. The length-weight relationship of *O. niloticus* was $TW = 0.0104TL^{3.19}$, indicating positive allometric growth of the fish. The sex ratio (0.93:1) was insignificant from the ideal fish distribution of 1:1 ($\chi^2 = 0.47, p > 0.05$). Mean CF for males, females and combined sexes was 1.04, 1.06 and 1.05, respectively and statistically insignificant ($p > 0.05$). The spawning peak occurred in July (rainy) and February (dry) periods, as defined by ripe females and the breeding season. Absolute mean fecundity was 806 eggs and correlated positively with TL and TW of the fish ($p < 0.05$) ($F = 0.56TL^{2.29}, R^2 = 0.93, p < 0.05$; $F = 18.83TW^{0.67}, R^2 = 0.90, p < 0.05$). The study provides the first detailed account of the morphometric relationships and reproductive biology of *O. niloticus* in Lake Shala, which can be used as baseline information for successive biological-based studies in Soda Lakes of Ethiopia.

Keywords: Allometric growth, Breeding season, Condition factor, Fecundity, Sex ratio

Introduction

Lake Shala is known for its extreme environmental condition and is characterized by a high surface water temperature (26°C) (Ogato, 2015), pH (9.65), saline-alkaline conditions (18.1 g/L, 224 meq/L) and high phosphate content (2.73 mg/L¹) (Kebede et al., 1994), but with remarkably low nitrogen levels (NH₄⁺, 4.3

µg/L) (Kebede et al., 1994). Despite this extreme nature of the environment, Lake Shala supports *Oreochromis niloticus* and *Aplocheilichthys* sp. (Golubtsov et al., 2002).

Nile tilapia, *O. niloticus*, is a popular fish species in Africa for commercial and subsistence fisheries (Opiyo et al., 2018). In Ethiopia, *O. niloticus* constitute a bulky percentage of the capture fishery and the commercial inland fish catch (Degsera

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et al., 2020; Teame et al., 2018). *O. niloticus* also constitutes an irreplaceable piece of the food chain for local populations residing around lakes (Degsera et al., 2020) and supports substantial populations of fish-eating birds in East African saline-alkaline lakes (Kavembe et al., 2016).

Studies on the length-weight relationships (LWR) and condition factor (CF) of the species are vital in fisheries science (Murua et al., 2017). The LWR can give evidence on the growth patterns and used to forecast weight from length measurements made in the yield assessment (Zuh et al., 2019). It has been widely used to evaluate index of well-being of fish and providing information on growth patterns (Degsera et al., 2020). But the CF indicates the appropriateness of a specific aquatic ecosystem for growth of fish and the physiological state of the fish (Mondal & Chakravartty, 2016). Information on the LWR and CF of *O. niloticus* has been reported by Hirpo (2012) in Lake Beseka, Ethiopia, Mortuza & Al-Misned (2013) in Wadi Hanifah, Riyadh, Saudi Arabia, and Tessema et al. (2019) in Lake Hayq, Ethiopia. Conferring to these studies, LWR and CF are affected by various factors like stress, age, season, sex, sexual maturity, availability of food sources, and other water physico-chemical parameters. The study of morphometric relationship, growth patterns, CFs, and related environmental issues of fish species are the most significant biological parameter for the management and conservation of fish inhabitants (Mondal & Chakravartty, 2016).

O. niloticus can reproduce incessantly throughout the year, but in some, breeding more exhaustive during periods of strong sunshine and rainfall (Tessema et al., 2019). However, all fish species have different passions of breeding time in the year, which governed by the accessibility and quality of food, water level fluctuation, and seasonal differences in water temperature (Teame et al., 2018). Therefore, information on the influence of season on the reproductive biology of *O. niloticus* can provide basic knowledge for the appropriate management and conservation of the fish populations.

In Ethiopia, the morphometric relationship, growth patterns, reproduction strategies and breeding seasons of *O. niloticus* in lakes, including the Rift Valley Lakes, are well documented (Admassu, 1990; Kebede et al., 2018; Teferi & Admassu, 2002; Tesfaye & Tadesse, 2008). Almost no such data is available for the same species in Soda Lakes (Kavembe et al., 2016). *O. niloticus* of Lake Shala have been reported by Golubtsov et al. (2002) and Klemperer & Cash (2007); the latter reported *Aplocheilichthys* species retrieved after seismic explosions in the lake. Therefore, our objectives were to study the LWR, growth

performance, sex proportion, CF, fecundity rate and breeding seasons of *O. niloticus* in Lake Shala. By analyzing the aspects of the growth pattern and reproductive biology of *O. niloticus*, we are generating information fundamental for conservation and management of the fish in Soda Lake, Lake Shala, Ethiopia.

Materials and Methods

Description of the study area

Lake Shala is on Ethiopian Central Rift Valley, lie approximately between 7°24' to 7°33'N and 38°23' to 38°39'E at an altitude of 1,558 m above sea level within the Abijata-Shala Lakes National Park (Fig. 1), 207 km South of Addis Ababa. The lake is around maximum 266 m deep and has an area of 329 km², with a massive catchment range (3,920 km²) (Baxter, 2002). The lake region has high evaporation rate (781 million cubic meters) that surpasses the annual mean rainfalls (232 million cubic meters) (Ayenew & Legesse, 2007). The climate is mostly classified by alternating wet and dry seasons following the annual activities of the Intertropical Convergence Zone (Ayenew & Legesse, 2007), with the dry season from October to February and a rainy season from March to September. The rainy season is characterized by a bimodal rainfall pattern, with a minor rainy period ranging from March to May and a heavy rainy period from June to September.

Fish sample collection and length-weight measurements

Specimens of *O. niloticus* were collected using Gillnets (4, 6, 8, 10, and 12 mm stretched mesh size) monthly during the period between January and December 2018 at fixed sampling site of Lake Shala (Fig. 1). Gillnets was used parallel to shallower part of the lake in the evening (about 5:00 PM) and lifted in the next morning (around 7:00 AM). Captured *O. niloticus* were measured the total length (TL, cm) and total weight (TW, g). Each fish specimen was dissected to determine their sexes and gonad maturity stage following Holden & Raitt (1974) procedures. The ovaries were gently detached and the gonad weight (GW, g) were recorded. Ovaries containing eggs were well-preserved in 10% formalin solution and transported to Addis Ababa University for extra laboratory examination.

Length-weight relationship

The relative growth of *O. niloticus* was assessed using LWR following Le Cren (1951):

$$TW = aTL^b$$

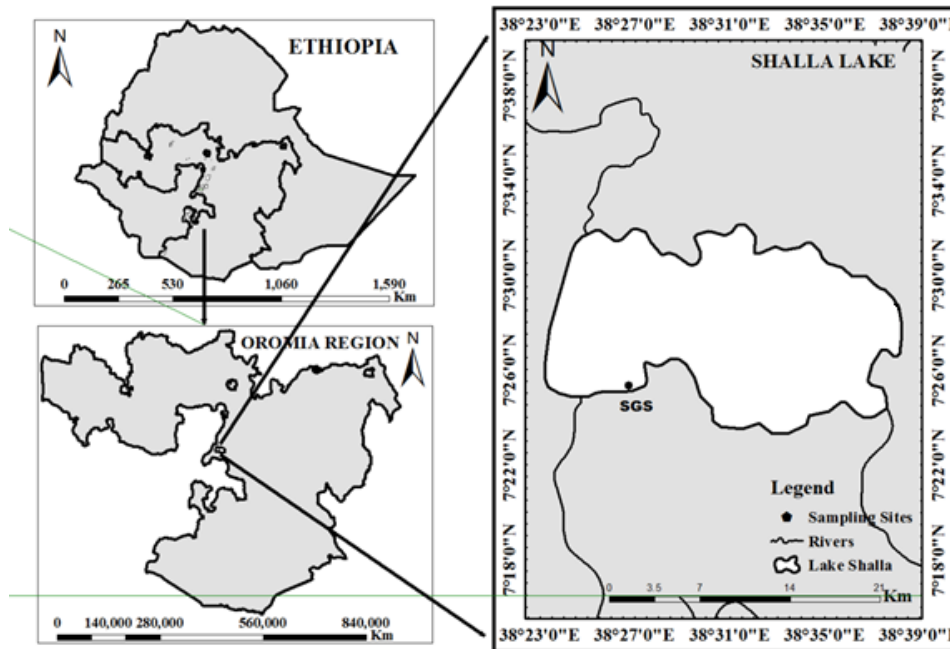


Fig. 1. Map of Lake Shala showing the sampling site in the lake. SGS, Shala Gike Shore.

where, TW = total weight (g), TL = total length (cm), 'a' is the coefficient associated to the fish body shape (intercept), and 'b' is an exponent correlated with changes in body shape (slope) (Le Cren, 1951).

Condition factor (CF) and reproductive biology

Condition factor (CF)

The assessment of 'b' from the length-weight relationship (Murua et al., 2017) was used to compute the relative CF. The CF was calculated conferring to the approaches of Nehemia et al. (2012), following the formula:

$$CF = \frac{TW}{TL^b} \times 100$$

where, CF = condition factor, TW = total weight (g), TL = total length (cm) and 'b' = the value obtained from the length-weight equation.

Fulton condition factor

$$FCF = \frac{TW}{TL^3} \times 100.$$

Where, FCF = fulton condition factor, TW = total weight (g) and TL= total length (cm).

Sex-ratio and gonado-somatic index (GSI)

The sex ratio of individual fish specimen was determined after dissection and gonad maturity rank was assessed by inspection of gonads. The maturity status of individual fish specimen was determined and classified as stages I, II, III, IV, V, and VI following procedures stated by Armstrong et al. (2004). Ovaries of the matured fishes was cross-sectioned and preserved in 10% formalin. The preserved ovaries were transported to Addis Ababa Fishery Laboratory for further analysis.

The gonado-somatic index (GSI) for every fish specimen was calculated for each sex using the equation (Peña-Mendoza et al., 2005):

$$GSI = \frac{GW \times 100}{TW}.$$

Where, GSI = gonado-somatic index, GW = gonad weight (g), TW = total body weight (g), where the weight of the gonad is the weight of the fresh gonad blotted on absorbing paper.

GSI was calculated for monthly sampled fish specimens to govern the breeding season of fishes in the lake (Peña-Mendoza et al., 2005).

Fecundity

Fecundity (F) of mature eggs in the ovaries was assessed by straight counts of the hydrated eggs (Shoko et al., 2015). Fecundity was estimated from total counts of eggs in the ovaries of ripe female fish in IV and V stage development (Shoko et al., 2015). Sub-samples of eggs in the spawning phase were weighed and counted from triplicates of 1-g sub-sample of the eggs. Individual mean fecundity was back-calculated by the gravimetric method:

$$F = GWn (m),$$

where 'n' is the number of eggs in the sub-sample, and 'm' is the weight of the ovarian sub-sample. The association of fecundity with TL (cm) and TW (g) of fish specimens was investigated by regression analysis and expressed by the following formula:

$$F = mTL^n \text{ and} \\ F = aTW^b,$$

where F = fecundity; TL = total length (cm); TW = total weight (g); m, n, a, and b are constants.

Statistical analysis

The LWR data, the relation between absolute fecundity and the TL, fecundity and TW of fishes were subjected to linear regression analysis using SPSS version 20.0 statistical package (IBM, Armonk, NY, USA). To test the 'b' value against the ideal growth value of 3 (isometric), Student's *t*-test was employed to test any significant deviation. Deviations from the hypothetical distribution of sex a 1:1 ratio were statistically tested using the Chi-square goodness (χ^2) with a 5% significance level. One-way analysis of variance, non-parametric Kruskal-Wallis test ($p < 0.05$) was used to compare absolute fecundity, CF and GSI of *O. niloticus*.

Results

Length-weight relationship

Three hundred forty-three specimens of *O. niloticus* ranged from 7.70 cm to 33 cm in TL and TW between 7.8 g and 708.21 g were used to determine LWR by linear regression analysis and scatter diagrams were plotted (Fig. 2). The LWR of *O. niloticus* representing male, female and the combined sexes (both sexes) are presented in Table 1 and Fig. 2.

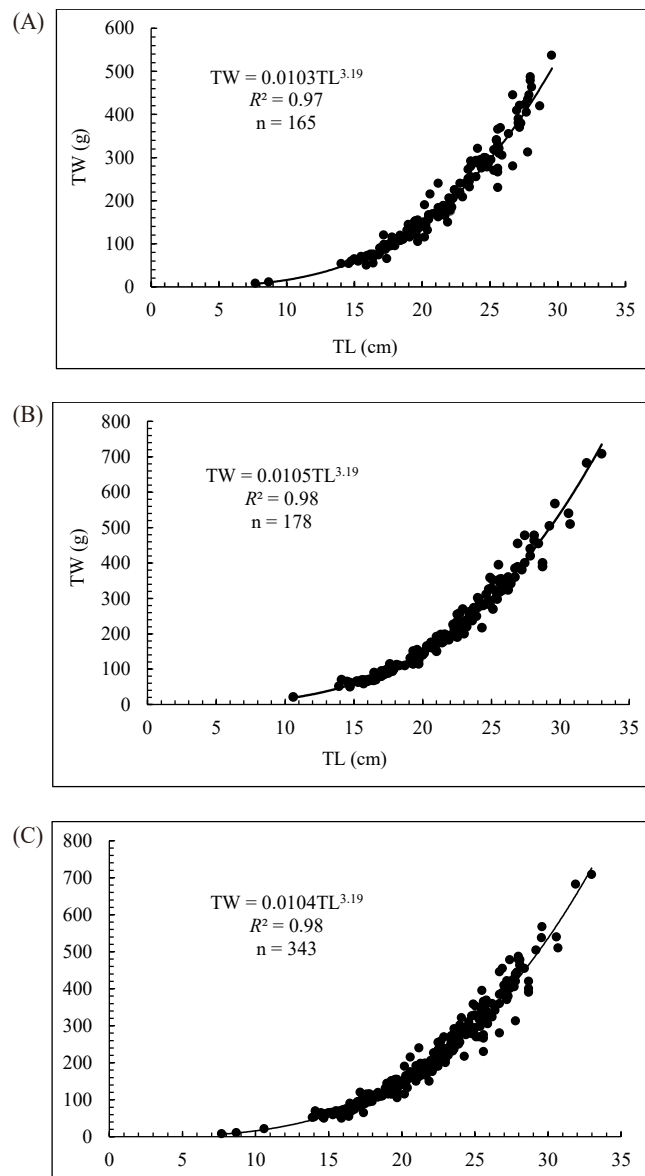


Fig. 2. Length-weight relationship of *Oreochromis niloticus* from Lake Shala. (A) Male, (B) female and (C) combined sexes. TW, total weight; TL, total length.

Condition factor (CF)

Table 2 displays the variation in the mean CF of *O. niloticus* in Lake Shala. The CF of *O. niloticus* varied from 0.72 to 1.51 with a mean of 1.05. The CF for males and females ranged from 0.72 to 1.41 and 0.83 to 1.51, respectively (Table 2). The CF *O. niloticus* exhibited insignificantly variations between males and females ($p > 0.05$), but the value was to some extent higher in females (1.06) as compared to males (1.04).

Table 1. Summary of length-weight relationship parameters of *Oreochromis niloticus* in Lake Shala, Ethiopia

Sex	N	Regression equations	a	b	R ²
Male	165	TW = 0.0103TL ^{3.19}	0.0103	3.19	0.97
Female	178	TW = 0.0105TL ^{3.19}	0.0105	3.19	0.98
Combined	343	TW = 0.0104TL ^{3.19}	0.0104	3.19	0.98

'a' = intercept of the regression line, 'b' = slope, R² = regression coefficient. TW, total weight; TL, total length.

Table 2. The mean CF and FCF of *Oreochromis niloticus* in Lake Shala

	Sex	N	Mean ± SD	Minimum	Maximum
CF	Male	165	1.04 ± 0.11	0.72	1.41
	Female	178	1.06 ± 0.09	0.83	1.51
	Combined	343	1.05 ± 0.10	0.72	1.51
FCF	Male	165	1.85 ± 0.21	1.23	2.52
	Female	178	1.88 ± 0.18	1.50	2.50
	Combined	343	1.87 ± 0.20	1.23	2.52

CF, condition factor; FCF, fulton CF.

Mean fulton CF (FCF) values of *O. niloticus* varied from 1.23 to 2.52 for males with a mean value of 1.85. Whereas female *O. niloticus* the mean FCF values are 1.5 to 2.5 with the mean value of 1.88. For combined sexes of *O. niloticus*, the mean FCF value was 1.87 ± 0.197 (Table 2). There was insignificant variation in mean FCF ($p > 0.05$) between female and male *O. niloticus* in Lake Shala.

Sex ratio

Of 343 collected *O. niloticus* specimens, 165 male (48.1%) and 178 female (51.9%) were obtained from Lake Shala. The sex ratio (male:female) was 0.93:1 which did not deviate significantly from the ideal distribution of 1:1 ($\chi^2 = 0.47, p > 0.05$) (Table 3).

Gonado-somatic indexes (GSI)

Monthly variations in GSI exhibited that both male and female *O. niloticus* followed nearly the same trend (Fig. 3). In females, the mean monthly GSI values ranged from 2.02 to 5.32 and showed a significant temporal variations ($p < 0.05$). Peak points of female GSI values were observed during January, February, June, July and October (Fig. 3). This indicates that female *O. niloticus* may breed more than once in the season. While, GSI value of males *O. niloticus* varied from 0.49 to 1.68 with a mean of 1.0 ± 0.64 (Fig. 3) and did not vary significantly among months ($p > 0.05$).

Table 3. Summary of monthly sex ratio (males:females) of *Oreochromis niloticus* in Lake Shala

Month	Male no.	Female no.	Sex ratio	χ ²
January	13	9	1.45:1	0.89
February	11	14	0.79:1	0.32
March	19	12	1.58:1	2.04
April	12	20	0.60:1	1.6
May	16	13	1.23:1	0.35
June	14	27	0.52:1	3.13
July	14	21	0.67:1	1.17
August	9	21	0.43:1	3.43
September	3	13	0.23:1	3.85*
October	19	10	1.90:1	4.05*
November	16	11	1.45:1	1.14
December	19	7	2.7:1	10.29*
Total	165	178	0.93:1	0.47

* $p < 0.05$.

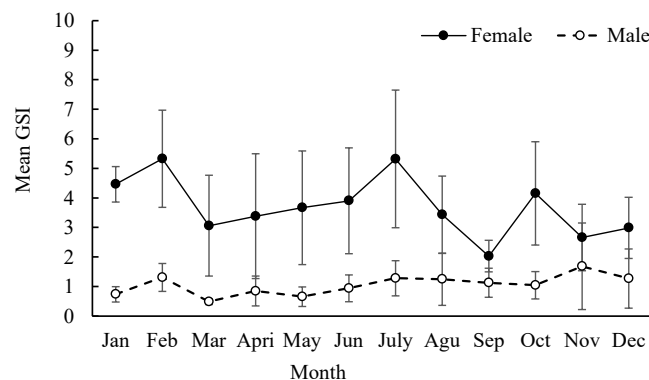


Fig. 3. Overall mean of GSI of female and male *Oreochromis niloticus* from Lake Shala from January to December, 2018. GSI, gonado-somatic index.

Fecundity estimation

The fecundity of *O. niloticus* was estimated from 79 ripe females ranging in TL from 15.3 cm to 31.9 cm and TW from 63.7 g to 682.1 g (Fig. 4). The estimated mean fecundity was found to vary from 240 and 1,642 eggs with the corresponding fish size and weight. The mean fecundity of *O. niloticus* in Lake Shala was 806 eggs per fish. The fecundity of *O. niloticus* in Lake Shala was strongly correlated with TL ($F = 0.56TL^{2.29}, R^2 = 0.93, p < 0.05$) (Fig. 4A) and TW ($F = 18.83TW^{0.67}, R^2 = 0.90, p < 0.05$) (Fig. 4B).

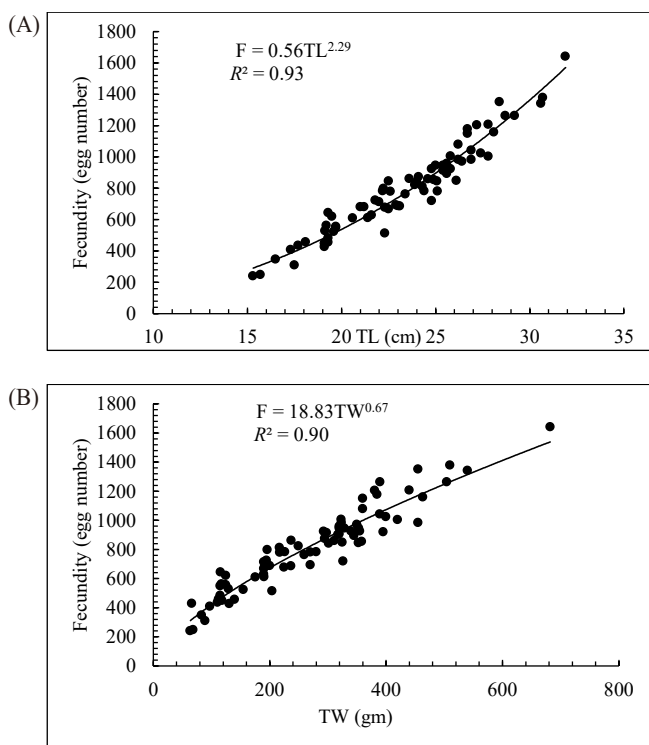


Fig. 4. Fecundity. Relationship between fecundity and TL (A), fecundity and TW (B) of *Oreochromis niloticus* in Lake Shala. TL, total length; TW, total weight; F, fecundity.

DISCUSSION

Length-weight relationship (LWR)

In the present study, *O. niloticus* in Lake Shala exhibited positive allometric growth pattern with regression analyses exponent 'b' (3.19) values (Table 1 and Fig. 2). For an ideal isometric growth pattern, the 'b' value is 3.0, and populations in which the exponent varies from 3.0 show allometric growths (Allen, 1966). The correlation coefficients (r) of *O. niloticus* which ranged between 0.97 and 0.98 showed positive correlation between their TL and TW of the fish. The implication is that the weight of the fishes increased with increasing in TL (Allen, 1966; Njiru et al., 2006). Our results follow to the result reported by Stewart (1988) and Njiru et al. (2006) in their study conducted in the Lake Turkana and Lake Victoria, respectively. These researchers reported the 'b' value for *O. niloticus* as 3.17 and 3.20, respectively. Conversely, this 'b' value is higher than for the same species reported by Hirpo (2013) in Lake Beseka ($b = 2.69$), Lake Hayq ($b = 2.95$) (Assefa & Getahun, 2014) and Lake Langeno ($b = 2.88$) (Kebede et al., 2018). These variations possibly because of variance in fat-

ness and gonad development stage, sex, health, amount of feed and feeding habits, habitat type, different stages in the ontogenetic development, spawning season, water temperature, preservation techniques and differences in a geographical location with the related ecological factors (Alhassan et al., 2015; Froese, 2006).

Condition factor

In our study, the CF computed for the *O. niloticus* was 1.04 ± 0.11 and 1.06 ± 0.09 for males and females respectively (Table 2). This result is similar to the other study of *O. niloticus* by Ighwela et al. (2011), who reported that CF value which is greater than one signifies that a fish is in good condition. The CF *O. niloticus* in Lake Shala were near to those reported by Olurin & Aderibigbe (2006) in Sanni Luba Fish Farm, Ogun state, where male CF was 1.14 and 1.08 in females *O. niloticus*. In this study, female *O. niloticus* (1.06) was heavier compared to male CF (1.04), but statically insignificant ($p > 0.05$). The higher CF of female *O. niloticus* may be accredited to the better fat accumulation (Mortuza & Al-Misned, 2013), higher state of maturity and GW (Mondal & Chakravarty, 2016).

The mean values of FCF were 1.85 and 1.88 for male and female *O. niloticus*, respectively (Table 2). Findings of this FCF values are in line with those reported for *O. niloticus* by Assefa & Getahun (2014) in Lake Hayq, Kebede et al. (2018) in Lake Langano and Teame et al. (2018) in Tekeze Reservoir. In this study, the FCF of *O. niloticus* was ranged between 1.23 and 2.52 with a total mean of 1.87 (Table 2). These mean FCF values are comparable to those reported by Tesfaye & Tadesse (2008) in Lake Koka (1.87), but the value was higher than the reports made in Lake Ziway (1.81) and Lake Langeno (1.84) (Tefaye & Tadesse, 2008) and Lake Hayq (1.81) (Assefa & Getahun, 2014), which showed that *O. niloticus* in Lake Shala had a good body condition. The current mean FCF value is also very lesser as compared to the same species reported in other Ethiopian water bodies, like Lake Awassa (2.03) (Admassu, 1990), Lake Tana (1.89) (Tadesse, 1997), Lake Chamo (2.35) (Teferi & Admassu, 2002) and Lake Babogaya (2.13) (Hirpo, 2012). Variations in mean FCF obtained in several water bodies could also be credited to the differences in environmental factors, food accessibility and feeding regime, season and water level fluctuation, and water quality. The CF of fishes has also been reported to be influenced by many factors like spawning periods, maturity stage, sex difference (Degsera et al., 2020), and pollution (Alhassan et al., 2015).

Sex ratio

Sex proportion for *O. niloticus* (0.93:1) in Lake Shala shows that males and females are equally distributed in the lake and the variation from the predictable hypothetical distribution of 1:1 (male:female) was insignificant. This is supported by other studies reported on *O. niloticus* in Lake Nyamusingiri and Kyasanduka (Bwanika et al., 2004), and in Itapaji Dam (Omotayo et al., 2019). However, studies on *O. niloticus* have reported the predominance of female *O. niloticus* in other Ethiopian lakes and reservoirs like Lake Beseka (Hirpo, 2013), Lake Hayq (Assefa & Getahun, 2014) and Tekeze Reservoir (Teame et al., 2018). The preponderance of male *O. niloticus* population over females was reported in Lake Tana (Tadesse, 1997), Lake Victoria (Njiru et al., 2006), Lake Babogaya (Hirpo, 2012) and Wadi Hanifah (Mortuza & Al-Misned, 2013). Teame et al. (2018) mentioned that the sex ratio show variation significantly from the same species in different water bodies, but usually it is close to one, and predominance of sex may differ due to sexual segregation during spawning period, difference in habitat preference, behavioral variances between the sexes, vulnerability to fishing gear nature and fishing site.

Gonado-somatic index (GSI) and fecundity

Studies on reproduction period and fecundity potential and their related influences are regularly used to guard the recruits (Nyakuni, 2009) and forecast recruitment variability (Shoko et al., 2015). Fish life history parameters, like spawning period, gonad status and fecundity amount differ among fish species (Peña-Mendoza et al., 2005). During this study, GSI values for female *O. niloticus* exhibited significant temporal variations, with a biannual cycle between January–February and July–September (Fig. 3). Tadesse (1988) in Lake Ziway, Admassu (1996) in Lake Awassa and Teame et al. (2018) in Tekeze Reservoir also reported for *O. niloticus* a bi-modal breeding pattern. However, in the present study, matured ovaries and the breeding period (GSI) of females of *O. niloticus* exhibited several peaks all year round. This extended period showed that female *O. niloticus* breed more than once in the year. Similarly, Njiru et al. (2006) and Teame et al. (2018) pointed out that, there is more than one breeding time per year for the majority *O. niloticus*.

In Lake Shala, the peak breeding period of *O. niloticus* is not restricted to the rainy period (July to September), but several it also breeds during the dry season (January to February). However, other studies on *O. niloticus* like Hirpo (2012, 2013) found that *O. niloticus* breed intensively during the wet (rainy)

season. Kebede et al. (2018) and Teame et al. (2018) also state the correlation between rainfall and peak breeding periods for *O. niloticus* in Lake Langano and Tekeze Reservoir, respectively. During the rainy season flooding from allochthonous input which could increase nutrient concentration subsequent in increased accessibility and quality of food resources (Tadesse, 1988), so offsprings are produced at times of better growth and survival (Admassu, 1996). Numerous studies also described precipitation (rainfall), subtle variation in water temperature (Assefa & Getahun, 2014) and water level fluctuation (Kebede et al., 2018) as vital environmental factors allied with exhaustive breeding activities of *O. niloticus* in Ethiopian lakes and elsewhere (Nyakuni, 2009; Peña-Mendoza et al., 2005).

In this study, the fecundity *O. niloticus* varied from 240 to 1,642 eggs, with a mean absolute fecundity of 806 eggs. This finding value is lower than that reported by others even among individuals of *O. niloticus* elsewhere. For example, Nyakuni (2009) recorded a fecundity of 412 to 2,380 eggs (mean of 854 eggs) of *O. niloticus* in Albert Nile, Njiru et al. (2006) mean of 2,715 eggs in Lake Victoria and Teame et al. (2018) recorded 399–2,129 eggs per fish of *O. niloticus* in Tekeze Dam, Ethiopia. But, the mean absolute fecundity of *O. niloticus* in Lake Shala was higher than a report in Lake Beseka (261 eggs) by Hirpo (2013), Lake Langano (464 eggs) (Kebede et al., 2018) and Lake Hayq (217 eggs) (Tessema et al., 2019). Cuevas-Rodríguez et al. (2017) detailed that the mean absolute fecundity of *O. niloticus* varies considerably in various factors like abundance and seasonal availability of food and fishing pressure. Body CF and growth of the fish attributed to variation in fecundity of the fish. Fish in poor body condition are reported to possess less fecundity potential than those in better condition (Cuevas-Rodríguez et al., 2017; Peña-Mendoza et al., 2005). Identical fish species also can show variations in mean fecundity from one water body to a different water body because of the TL of the fish examined for analysis. Teame et al. (2018) recorded a maximum fecundity of 2,129 eggs from *O. niloticus* with size of 37 cm TL in Tekeze Reservoir, while Nyakuni (2009) obtained a fecundity of 2,380 eggs at a size of 42 cm TL of *O. niloticus* in Albert Nile. In the present study, the maximum fecundity (1,642 eggs per fish) was recorded at 31.9 cm TL. These findings, therefore, confirm that fecundity potential of *O. niloticus* is variable and correlates with its TL and TW. This finding agrees with other studies within the Ethiopian Rift Valley Lakes (Assefa & Getahun, 2014; Hirpo, 2012; Hirpo, 2013; Kebede et al., 2018; Tessema et al., 2019).

Conclusion

From the findings of this study, it may possibly conclude that the LWR of *O. niloticus* showed a positive allometric growth pattern. The sex ratio of *O. niloticus* in Lake Shala was statistically insignificant from the expected 1:1 hypothetical distribution. In Lake Shala, both males and females *O. niloticus* were in good body condition throughout the study period. The research also revealed that *O. niloticus* breed throughout the year, with several peaks during January, February, June, July and August. Fecundity was significantly correlated with TL and TW of the fish. Therefore, the present study found a very important database for conservation and the management of the species in Lake Shala.

Competing interests

No potential conflict of interest relevant to this article was reported.

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Availability of data and materials

Upon reasonable request, the datasets of this study can be available from the corresponding author.

Ethics approval and consent to participate

This article does not require IRB/IACUC approval because there are no human and animal participants.

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