International Journal of Animal Science and Technology
2024, Vol. 8, No. 4, pp. 92-105
https://doi.org/10.11648/j.ijast.20240804.12

Research Article

Aspects of Growth, Diet, and Reproduction of *Oreochromis niloticus* (Linnaeus, 1758) in a Hypertrophic Milieu, the Municipal Lake of Yaoundé, Cameroon

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Abstract

The Nile tilapia, *Oreochromis niloticus*, is a highly valued fish species in Africa for subsistence and commercial purposes. However, overfishing activities in non-supervised lakes or reservoirs threaten its availability. In the view of contributing to the database on the life history traits of this species in Cameroon and supporting its sustainable management, the present study investigated the growth patterns, food preferences, and reproductive aspects of *O. niloticus* in a hypertrophic milieu, the Yaoundé Municipal Lake, from May to October 2018. Fish specimens were sampled, measured, weighed, and sexed. The digestive tract of each specimen and the females' gonads were collected. The intestines were measured, and the stomach contents were identified. The females' reproductive aspects were determined. Overall, 101 specimens were collected and distributed among 48 (47.5%) males and 53 (52.5%) females, with a sex ratio of 1: 1.1. In this hypoxic (1.35 ± 0.4 mg/L) and highly conductive (210.5 ± 56.9 µS/cm) milieu, *O. niloticus* displayed a relatively good condition (*Kn* > 1) throughout the sampling period and negative allometric growth patterns for both sexes ($b < 3$; $p < 0.001$). Materials from plant origin were the preferred prey types, with an index of relative importance (IRI) of 78.20%; meanwhile, mud and materials from animal origin were secondary prey items (IRI: 13 – 17%). The relative gut length (RGL) value above 3.0 and the foraging activity on detritus suggest that *O. niloticus* has an herbivorous or detritivorous dietary habit and is a bottom-feeder. Female length at first maturity (L_{50}) was 17 cm. Their gonado-somatic index (GSI) showed sexual activity throughout the whole sampling period, with the peak spawning phase happening in August. The absolute fecundity of gravid females varied between 316 and 1816 oocytes (942 ± 430 oocytes), and the relative fecundity ranged from 1–5 oocytes/gram of body weight (3 ±1 oocytes/g). The results highlight the performance of the Nile tilapia in this ecosystem and provide information for its sustainable use and improvement of fish culture.

Keywords

Cameroon, Food Preferences, Growth Pattern, Hyperthrophic Milieu, Nile Tilapia, Reproductive Traits

1. Introduction

Knowledge of the life history traits of a fish species in its natural or wild habitat is essential. Such information helps adjust cultural conditions in ponds when the species is reared for economic purposes to enhance rapid growth for successful and profitable production. In 1948, fish farming was introduced to Cameroon and was limited to ponds and freshwater

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Received: 11 September 2024; **Accepted:** 4 October 2024; **Published:** 12 November 2024

areas [1]. This practice aimed to alleviate the protein scarcity exacerbated by the Second World War [2]. Several fish species are reared in Cameroon for domestic consumption, including the native African cichlid teleost species, the Nile tilapia, *Oreochromis niloticus* Linnaeus, 1758 (Perciformes). This species is highly valued in fish farming [3, 4] due to its favourable characteristics that benefit the farmers. In addition to its excellent taste, it is well known for its robustness, ability to adapt to new habitats, and tolerance to stressful environmental conditions such as a wide salinity range, low levels of dissolved oxygen, and extreme temperatures [3, 5, 6]. It also exhibits rapid growth, high fecundity [7], and varied feeding habits that are sometimes described as omnivorous [8, 9], herbivorous, or detritus feeders [10-12]. This physiological plasticity allowed this species to successfully establish itself in various environmental conditions worldwide, whether under culture or in the wild [13].

Oreochromis niloticus was introduced into Cameroon in 1975 from Bangui, Central African Republic. It is self-reproducing and established in the wild, specifically in the Noun Marsh, Djerem River, and Sanaga River, where it has already replaced native species and is now the most important species used in aquaculture throughout the country [14]. In Cameroon ponds, *O. niloticus* thrives under specific conditions. The optimal parameters include a pH range of 6.8 to 7.13, water temperature between 23.2 ℃ and 25.7 ℃, dissolved oxygen levels of 4.43 to 6.2 mg/L, turbidity ranging from 20.6 to 76 NTU, total suspended solids concentration of 8.6 to 43.5 g/L, as well as nitrate and phosphate levels of 0.07 to 0.5 mg/L and 0.3 to 0.4 mg/L, respectively [15].

Morphometrics, length-weight relationships, and the physiological state of a fish species are valuable for fisheries management. These references are used in stock assessment models [16], for estimating the biomass from length measurements [17], and for understanding the well-being of fish in specific environments [18] for comparisons between life histories in different habitats [17]. Better performance of physiological functions such as growth and reproduction for a fish species is reached via a balanced diet [11]. In this respect, studies on the diet composition and feeding habits of fish species help in quality management in different systems (in nature or under culture), the determination of the trophic position in the habitat ecosystem, and the stability of feeding interactions [19, 20]. Good fisheries resource management also involves knowledge of fish reproductive biology [21]. Several studies have assessed the growth, reproduction, or feeding habits of *O. niloticus* in various water reservoirs and lakes in Africa. There is a shortage of such studies in Cameroon, especially in non-monitored artificial lakes presenting characteristics close to the wild, as is the case for the Municipal Lake of Yaoundé. Created in 1951 as a recreational area in the city for leisure and aquatic sports, the Municipal Lake is now part of the Yaoundé town heritage. But since the 1980s, it has been undergoing increasing degradation and eutrophication due to the continuous discharge of wastewater coming from its sloping side that hosts several building estates, hotels, ministerial complexes, and various activities that include car dealerships, garages, waste disposal, agriculture, and effluents [22, 23]. These elements have been threatening the lake's integrity for years, leading to its rapid shift to a hypertrophic status, characterised by low water transparency, high water conductivity, and high dissolved oxygen deficiency, resulting in high levels of ammonium nitrogen, especially in deep water layers. These conditions favoured phytoplankton blooms and the growth of dense floating macrophytes, indicators of poor ecosystem health [22, 24]. Hence, this study aimed to provide insight into the performance of *O. niloticus* in the hypertrophic Municipal Lake of Yaoundé. It focused on its growth patterns, diet composition, feeding type, and female reproductive traits. The goal is to contribute to the database on the life history traits of this species in Cameroon and support its sustainable management.

2. Materials and Methods

2.1. Study Site

The Yaoundé Municipal Lake (3°52'N, 11°31'E, 710.8 m elevation), with a surface area of 7.95 x 104 m^2 and a mean depth of 2.3 m, is located in the heart of the capital city of Yaoundé near the busy administrative centre, in the Central Region of Cameroon. It is the result of the construction of a dam in 1951 on the path of the Mingoa, a tributary of the Mfoundi River, which also acts as a drainage outlet [22, 23]. It falls under the equatorial, hot, and humid Yaoundé special climate regime characterised by four seasons: a long dry season (from mid-November to mid-March), a short rainy season (from mid-March to mid-June), a brief dry season (from mid-June to mid-September), and an extended wet season (from mid-September to mid-November). The climate is attenuated by altitude and characterised by moderate rainfall (1576 mm/year) and an almost constant temperature [25].

2.2. Sampling and Laboratory Procedures

Due to the timeframe allocated for this research and in order to cover at least dry and wet seasons, the field samplings took place from May to October 2018. Freshly collected *O. niloticus* specimens were bought, monthly whenever available, from fishermen from the municipal lake of Yaoundé and immediately transported on ice to the laboratory for data collection and analysis. At each sampling period, the lake water parameters such as temperature (℃), electrical conductivity (μS/cm), and dissolved oxygen (mg/l) were measured *in situ* with the aid of a portable multimeter. In the laboratory, for each specimen, the total weight (TW) and total length (TL) (from the tip of the mouth to the tail fin's tip end) were determined using appropriate devices to the nearest 0.1 gram and 0.1 centimetres, respectively. The sex of each individual was determined *ex situ* following visual examination and gonad examination after fish dissection using fine scissors. The sex ratio was computed as the ratio between the total number of males and the total number of females [26] and expressed as males: females.

2.3. Growth Parameters and Condition Factor

The fish length and weight relationships were determined as follows: $TW = aTL^b$, whereby TW is the total body weight of the fish (g), TL is its total length (cm), *a* is the intercept, and *b* is the slope of the regression (the allometric coefficient), obtained from the examination of the scatter plot diagram [27, 28]. The logarithmic transformation of this formula ($\log \mathrm{TW} = \log a + b \log \mathrm{TL}$) [27] made it possible to estimate the *a* and *b* coefficients. A *b* value statistically different from the isometric value 3 is an indication of an allometric growth that could be negative ($b < 3$) or positive ($b > 3$) [29].

The relative fish condition (*Kn*), indicating the degree of fish well-being according to its weight at a given length [30], was computed according to [27] as follows: $Kn = TW/aTL^b$, with TW as the total body weight of the individual fish (g), TL its total length (cm), and *a* and *b* are the length-weight relationship parameters.

2.4. Gut Morphometrics and Food Content Analysis

Under dissection, each fish intestine was extracted and measured to the nearest 0.1 cm. The stomach of each specimen was isolated. Because the gut length of an organism informs on its dietary habits [31], the relative gut length (RGL) was determined as the ratio between the gut length and the total length of individual fish and expressed as mean ± SD. For a given body length in fish species, the more they feed on algae and detritus containing hundreds of non-digestible materials such as sand and vegetal fibre, the higher the RGL ratio [31, 32]. A value of RGL < 1 indicates a strict carnivorous diet; when the RGL value is between 1.0 and 3.0, the fish has an omnivorous diet; if RGL > 3.0, the fish is herbivorous or feeds on detritus [33].

The fish stomach contents were then collected and put in a 5% formalin solution for preservation until identification. The prey items were examined under a dissecting scope, identified to the lowest taxonomic level possible using different keys and literature [34, 35], and grouped based on their taxonomic category (order or family level). Individuals of each prey type were numbered and recorded. Following the examination of stomach contents, the prey preferences of this fish species were determined based on the evaluation of the following elements [36]:

1. the vacuity index: percentage of the number of empty stomachs on the total number of stomachs examined;
2. the stomach fullness: percentage of the number of full stomachs on the total number of stomachs examined;
3. the frequency of occurrence *(%O)*: the ratio between the number of digestive tracts containing a prey type and the total number of non-empty tracts examined;
4. the percent abundance (*%N*): the ratio between the number of each prey type encountered and the total number of prey pooled together for all tracts;
5. the contribution percentage (*%V*) of all prey categories found in the gut to the entire gut content was visually estimated to improve the numerical methods and assess the relative importance of each food item [37, 38].

The index of relative importance (IRI) of each prey type was calculated as: $\%\mathrm{IRI} = \%O \times (\%N + \%V)$ [39], where *%O* denotes the frequency of occurrence and *%V* and *%N* are the numerical and volumetric percentage values of the prey item, respectively.

2.5. Female Reproductive Parameters

The ovaries were extracted and weighed to the nearest 0.1 gram; their maturity stages were assessed by observation of their appearance, texture, and size, following the scale of [40]. The maturity coefficient, known as the gonado-somatic index (GSI), of each adult female was computed as: $\mathrm{GSI}\,(\%) = 100 \times (\text{ovary weight}/\text{total body weight})$ [41]. A GSI plot based on sampling periods helped detect the breeding period. Upon determination of the female gonad maturity stages, stages I and II were considered immature, and stages III to V were considered mature. The size at which 50% of females reach sexual maturity (L_{50}) was calculated using logistic regression [42]. This calculation takes into account the mature stages. It uses the equation: $P = 1/(1 + e^{-a\,(\mathrm{TL}-b)})$, where *P* represents the proportion of mature females at a specific length, *a* and *b* are the model parameters to be determined, and TL is the total length of the fish. The L_{50} was further calculated after the logarithmic transformation of the equation as follows [43]: $L_{50} = -a/b$.

To assess fecundity, 1 g of the mature ovaries was collected and placed in Gilson fluid to dissociate the oocytes. About 40 of the biggest oocytes were selected to measure their diameter using a microscope with a micrometric ocular at 40x magnification. The absolute fecundity (Fa) was determined as the total number of oocytes in an individual gonad before the next spawning period, as follows: $\mathrm{F}a = NoT \times GW$, where NoT is the total number of oocytes in a gram of ovary and GW is the gonad weight [44, 45]. The relative fecundity (Fr) was estimated as the total number of oocytes per gram of individual body weight [30].

2.6. Ethical Approval

The handling of fish was in respect with the Cameroon National Ethical Committee (Reg. Num. FWAIRD 0001954) in conformity with the international guidelines of the European Union on Animal Care (CEE council 86/609).

2.7. Statistical Analyses

The data were analysed using Microsoft Office Excel and Statistica 6 software. They were statistically described as mean ± standard deviation or percentage and presented as graphs or tables. The data were tested for homogeneity using Levene's test [47]. All statistical tests were checked for significance at $p < 0.05$. The sex ratio was determined using the Chi-square goodness of fit test. The evaluation of the fitting model and measure of the quality of regression predictions were given by the determination coefficient (R^2), which, when close to 1, indicates a better model. The Student's *t*-test helped compare the slope of the length-weight relationships (LWR) to the isometric value 3 [48] and between sexes. The non-parametric Kruskal-Wallis test helped compare the *Kn* values between sexes and sampling periods. A one-way analysis of variance was employed to compare the periodic variation of GSI. The Pearson correlation coefficient helped check for any association between growth, reproduction, and environmental parameters.

3. Results

3.1. Length-Weight Relationships and Condition Factor

During the sampling period, 101 specimens of *O. niloticus* were collected and distributed among 48 (47.5%) males and 53 (52.5%) females. The fish's total length ranged from 14.4 to 32.4 cm (24.86 ± 5.34 cm) with a total weight range of 95.7–650 g (356.04 ± 165.36 g). During the study, the length and weight parameters did not differ between sexes (24.33 ± 5.12 cm and 341.08 ± 165.36 g for males; 25.33 ± 5.56 cm and 75.56 ± 27.20 g for females) ($p > 0.05$). The no statistical difference between male and female body weight may be due to the larger variability in male body weight, suggesting a greater individual variation in growth rates among males. The LWR of *O. niloticus* in the study site were of the power type, positive, and highly significant, with the species experiencing negative allometric growth for male, female, and combined sexes ($b < 3$; $p < 0.001$) (Figure 1). The length increase here is more significant than the weight input.

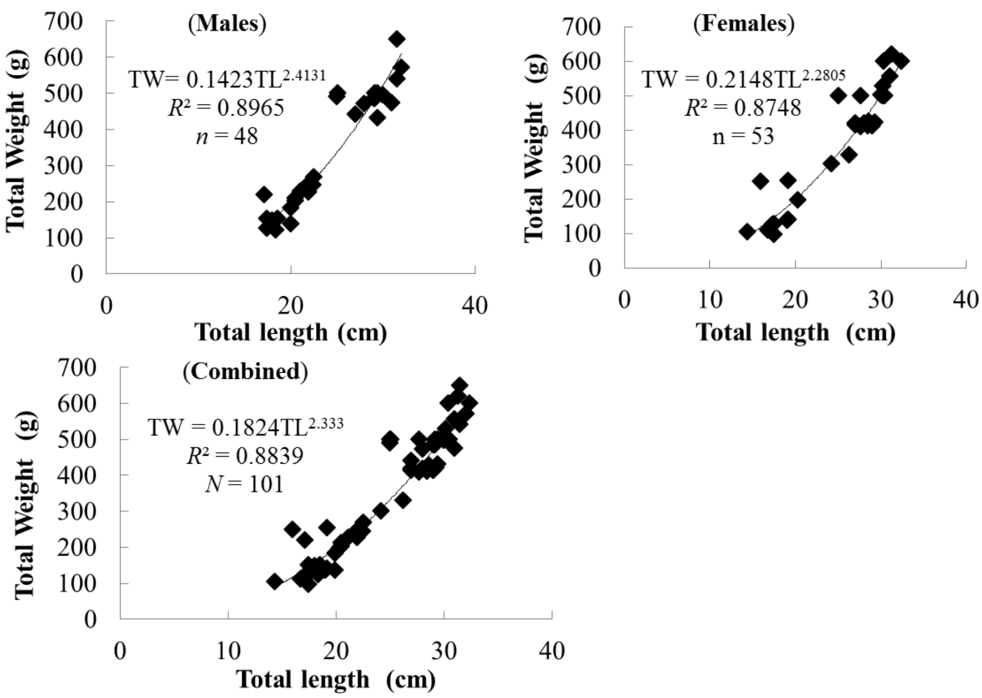

Figure 1. *Length-weight relationships of O. niloticus from the Yaoundé Municipal Lake.*

The mean relative condition factor *Kn* value for combined specimens varied from 0.68 to 2.17 (1.04 ± 0.24) and did not differ between sexes. This parameter was greater than 1 throughout the sampling period (Table 1), showing that *O. niloticus* displayed a good condition in the sampling environment. There was no correlation between the *Kn* value and the fish size and weight ($p > 0.05$), and this parameter did not differ between the sampling periods (Kruskal-Wallis test: $H = 7.09$, $p = 0.06$).

Table 1. *Mean relative condition factor (Kn) of O. niloticus from the Yaoundé Municipal Lake.*

Sex	***Number of individuals***	***Kn* (Mean ± SD)**	**Minimum**	**Maximum**
Male	48	1.04 ± 0.20	0.72	1.66
Female	53	1.04 ± 0.27	0.68	2.17
Combined sexes	101	1.04 ± 0.24	0.68	2.17

3.2. Relative Gut Length (RGL), Diet Composition, and Relative Importance of Food Items

Overall, the RGL values of the combined sexes recorded during the study period varied between 2.24 and 0.86, with a mean value of 6.38 ± 1.79. This parameter did not differ between males (6.31 ± 1.63) and females (6.44 ± 1.94). The vacuity index in *O. niloticus* was low (22.95%), while the stomach fullness was high (77.05%). The analysis of the intestinal contents of 101 individuals of *O. niloticus* made it possible to identify the seven food items grouped into three categories: mud, plant organic matter (phytoplankton/algae, plant debris), and animal organic matter [fish detritus, mosquito larvae, insects (Ephemeroptera), and crustaceans (Cladocera)]. Table 2 summarises the frequencies of occurrence, relative abundance, and percent volume of each item and food category, as well as their relative importance in the diet of *O. niloticus*.

Table 2. *Relative importance of prey items in the diet of O. niloticus in the Yaoundé Municipal Lake.*

Food item	***%O***	***%N***	***%V***	**IRI (%)**	**Prey importance**	**Rank**
Mud	38.30	2.20	24.32	16.54	Secondary	2
Plant organic matter	*78.72*	*78.73*	*50.00*	*78.20*	*Preferred*	*1*
Phytoplankton (Algae)	61.70	3.55	39.19	42.94	Secondary	2
Plant detritus	17.02	75.18	10.81	23.84	Secondary	2
Animal organic matter	*40.43*	*19.07*	*25.68*	*13.96*	*Secondary*	*2*
Fish remains	4.26	0.24	2.70	0.20	Accidental	3
Crustaceans (Cladocera)	2.13	0.12	1.35	0.05	Accidental	3
Mosquito larvae	27.66	17.73	17.57	15.90	Secondary	2
Insects (Ephemeroptera)	6.38	0.98	4.05	0.52	Accidental	3

Percent occurrence (*%O*); percent in number (*%N*); percent volume (*%V*); index of relative importance (%IRI). (Broken lines separate ecologically different food categories).

In terms of occurrence and importance, phytoplankton (algae) was the most ingested prey item (*%O* > 50%), and together with plant detritus, mud, and mosquito larvae, they constituted the major food items rated as secondary prey type (10 < IRI < 50%). Insects (Ephemeroptera), fish remains, and crustaceans (Cladocera) were accidental prey (IRI < 1%). When pooling prey items into food categories, plant organic matter was the preferred prey type of this fish species (IRI > 50%), animal prey and mud being secondary. The frequency of occurrence and relative abundance of plant organic matter were significantly higher than the animal organic matter and mud ($p < 0.05$). The RGL value greater than 3.0 suggests that *O. niloticus* has an herbivorous or detritivorous dietary habit. Also, the foraging activity on detritus indicates the bottom-feeder characteristic of this species.

3.3. Reproductive Parameters

3.3.1. Sex Ratio

The sex ratio was 1: 1.10 (males: females) but the proportions of males and females did not differ ($\chi^2 = 0.12$, $p > 0.05$), even between the sampling periods (Table 3).

Table 3. Periodic sex-ratio of O. niloticus in the Yaoundé Municipal Lake from May to October 2018.

Sampling period	Combined	Male	Female	Sex-ratio	χ^2	*p*
May	29	12	17	1: 1.42	0.43	
July	26	12	14	1: 1.16	0.15	
August	24	16	8	1: 0.50	2.67	> 0.05
October	22	8	14	1: 1.75	1.63	
Total	101	48	53	1: 1.11	0.12	

3.3.2. Female Size at First Maturity (L_{50}) and Gonado-Somatic Index (GSI)

The frequency distribution of mature females (stage IV) based on TL showed that the smallest individuals with mature gonads had a TL of 16.8 cm. Female L_{50} was 17 cm. The relationship between the gonad weight and total length in mature females was poorly correlated, with a regression equation of GW = 0.2564 TL + 0.4254 (R^2 = 0.3554, p = 0.003). Among the various ovary development stages encountered during the study, the most common stages were the immature (43.75%), followed by ready-to-spawn stage IV (28.1%) and maturing stage III (21.90%) ovaries. Stage V represented 6.25%.

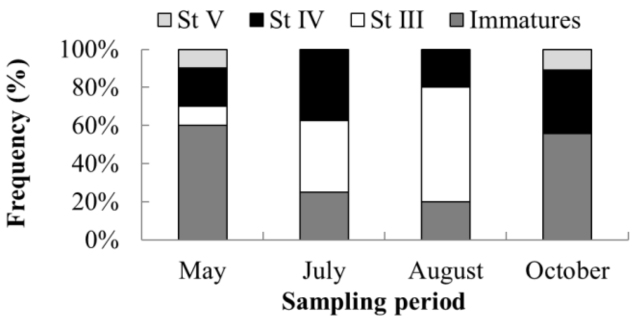

Figure 2. Periodic frequency of female O. niloticus maturity stages from May to October 2018. (St III, IV and V: sexual maturity stages).

Figure 2 shows the monthly frequency of the gonad maturity stages in females. During the sampling period, immature stages were present at all times, but they were comparatively more common in May and October (60% and 55.6%, respectively); maturing stages (stage III) were more present in August (60%); and ripe ovaries (stage IV) predominated in July and October (37.5% and 33.3%, respectively). However, these values did not differ (p > 0.05). Ripe females were present throughout the sampling period, with high frequencies in July, suggesting that the female breeding period occurred throughout the study period.

Table 4 summarises the mean values of the gonado-somatic index (GSI) and water parameters recorded during the sampling period. The species evolved in a poorly oxygenated (mean dissolved oxygen: 1.35 ± 0.4 mg/L) and highly conductive (salinity) (210.5 ± 56.9 µS/cm) water environment. The mean GSI of mature females of *O. niloticus* ranged from 1 to 5.4% (2.26 ± 1.18), with their condition factor varying from 1.69 to 3.58 (2.1 ± 0.44). A peak in the periodic evolution of mean GSI during the sampling period occurred in August (3.9 ± 1.3%) (Figure 3). Moreover, the GSI values differed significantly between the sampling periods due to the mean GSI of August (F (3, 14) = 8.62, p = 0.001) ($p < 0.05$). These findings might suggest that, even though sexual activity occurred throughout the whole sampling period, the peak spawning phase happened around August. There was no linear relationship between the GSI and the fish condition evolution curves (Figure 4), despite the similarity of their evolution curves (R^2= 0.0604, p = 0.32); in contrast, there were significant negative correlations between the GSI and the fish total length (r = -0.7712) and total weight (r = -0.7915) (p < 0.0001).

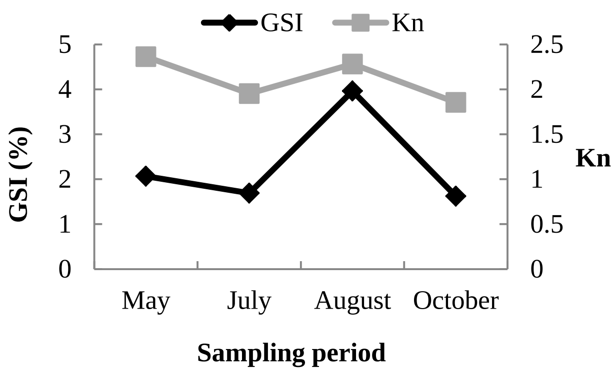

Figure 3. Periodic evolution of female O. niloticus gonado-somatic index (GSI) and condition factor (Kn) in the Yaoundé Municipal Lake.

Table 4. Summary of female O. niloticus gonado-somatic index (GSI) and water physicochemical parameters of the Yaoundé Municipal Lake from May to October 2018.

Parameters	May	July	August	October
Number of fish examined	17	14	8	14
GSI range (%)	1.6–2.33	1.0–2.75	2.27–5.40	1.18–2.41
Mean GSI ± SD (%)	2.06 ± 0.33	1.69 ± 0.65	3.96 ± 1.28	1.62 ± 0.55
Condition factor (*Kn*)	2.36	1.95	2.28	1.85
Temperature (°C)	22.7	26	26.8	28.3
Conductivity (μS/cm)	137	207	223	275
Dissolved oxygen (mg/L)	1.36	1.15	1.87	1.05

Regarding the water physicochemical parameters, the GSI and the dissolved oxygen parameter (Figure 4C) showed a strong and positive correlation (r = 0.996, p = 0.018); in the meantime, the periodic GSI appeared to evolve against the conductivity (Figure 4B) and water temperature (Figure 4A), but it had no relationship with these parameters (r = 0.07 and r = -0.02, respectively, p = 0.9).

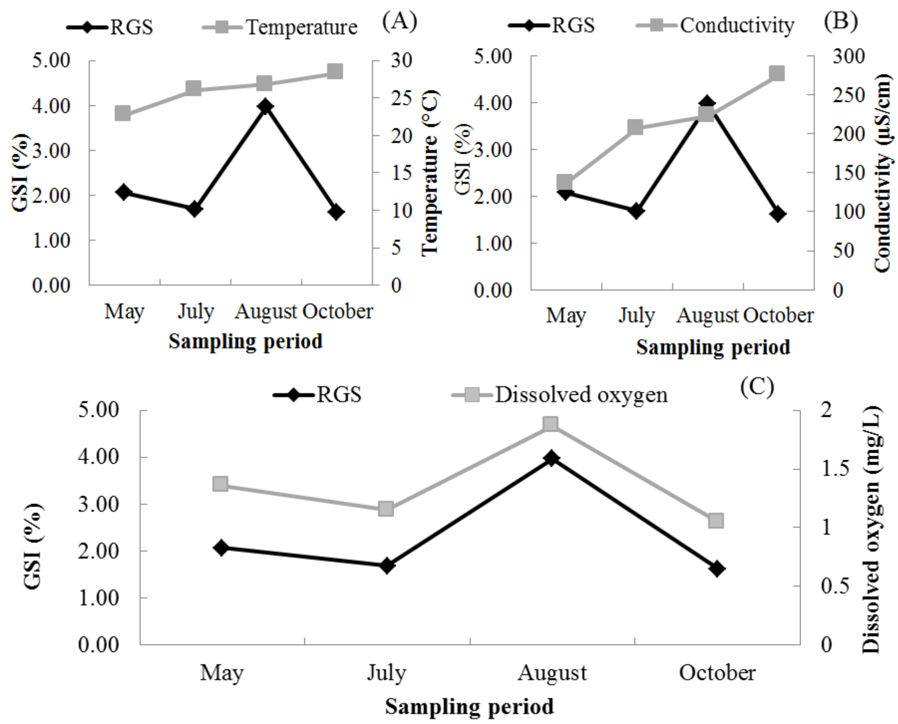

Figure 4. Periodic evolution of female O. niloticus gonado-somatic index (GSI) and water physicochemical parameters in the Yaoundé Municipal Lake. (A) Temperature, (B) conductivity, (C) dissolved oxygen.

3.3.3. Fecundity Estimation

Ripe females had oocyte diameters ranging from 1.27 to 4.28 mm (2.76 ± 0.87 mm). There was no relationship between the oocyte diameter and absolute fecundity, GSI, the gonad weight, the fish length, weight, or condition. Fecundity was estimated from 39 ripe females whose total length ranged between 16.8 and 31 cm (25.73 ± 5.25 cm) with a total body weight between 111.2 and 600 g (373.57 ± 14.35), i.e., a 56.25% rate of gravid females. The female relative fecundity (Fr) was calculated as an index of production capacity based on total fish weight and ranged from 1–5 oocytes/gram of body weight (3±1 oocytes/g). The estimated mean absolute fecundity was 942 ± 430 oocytes, ranging from 316 to 1816 oocytes. The Fa was weakly correlated to the fish length (r = 0.7899, $p < 0.001$) and weight (r = 0.7458, $p < 0.001$), while there was a strong positive linear relationship between the Fa and the ovary weight (r = 0.9298, $p < 0.001$) (Figure 5A–5C).

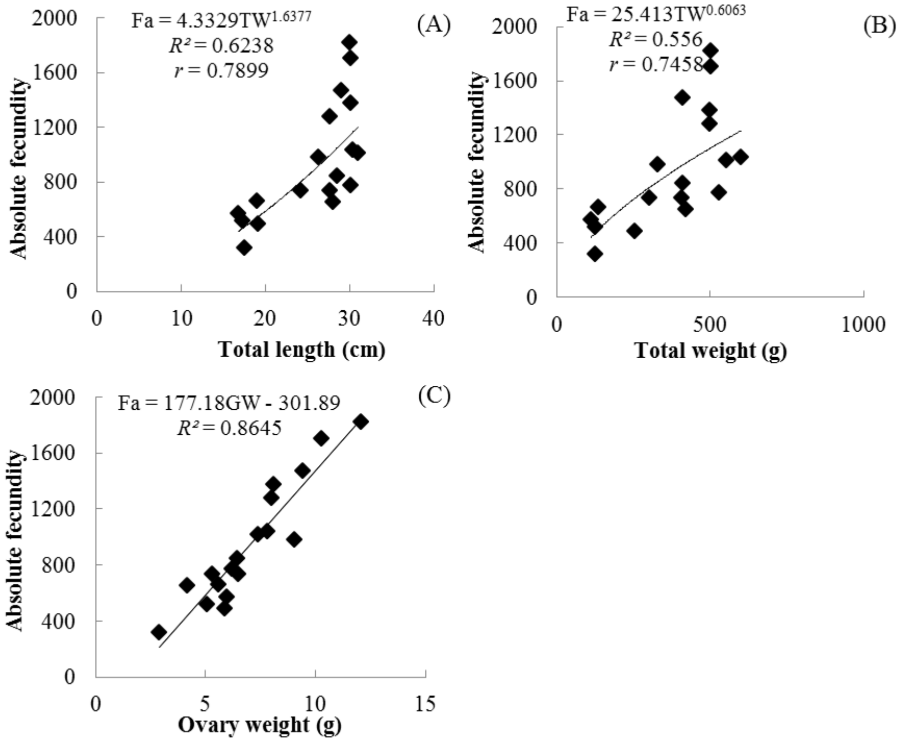

Figure 3. *Relationship between absolute fecundity and the fish length (A), weight (B), and gonad weight (C) in female O. niloticus in the Municipal Lake of Yaoundé.*

4. Discussion

In the municipal lake of Yaoundé, *O. niloticus* displayed a significant negative allometric growth type ($b < 3$), suggesting that it prioritises length growth over an increase in weight. This result is similar to that found in some studies on *O. niloticus* in lacustrine environments [49, 50, 51] but also contrasts with others [12, 52, 53]. Various ecological parameters can influence the slope value and may be responsible for variations in growth patterns throughout study periods. These parameters include different biotic and abiotic interactions inherent to season, habitat, gonad maturity, sex, food, stomach fullness, health, preservation methods, and yearly variations in environmental conditions [46, 54]. Male tilapias are known to grow better than females, and the great individual variability observed in males' growth rates in this study can be attributed to several factors such as the endocrine status of each individual, the increase of their social interactions during sexual maturation, and competition for food resources among congeners which could affect food intake [55].

The fish's relative condition factor indicated good growth in its habitat, as depicted by its somatic overweight. The result corroborates the findings of several authors regarding this fish species [12, 50, 51, 52]. Fish condition is of great importance in fisheries management because it helps monitor the capacity of an environment to favour the growth or well-being of an organism within it. Plump fish with high condition factor values denote favourable environmental conditions (such as the availability of prey and habitat), and thin fish with low condition values denote unfavourable ecological conditions [18]. Fish morphometrics and the gonado-somatic index did not affect the condition of the fish collected for this study; there was no difference in fish condition between sexes or sampling times, unlike found by [56] in the White Nile in Sudan. Certain factors sometimes affect the condition of a fish; they include habitat quality, sex, reproductive status, food availability, seasonality [57-59], or pollution [60].

The food items recovered from the stomach contents in this study corroborate those found in other studies [10-12, 61, 62], with food of plant origin, especially phytoplankton, being the preferred prey type, followed by detritus. Thus, *O. niloticus* exhibits an herbivorous dietary habit and is a bottom-feeder. However, [9] found instead that this species was omnivorous, feeding primarily on mud (sediment), while detritus, phytoplankton, and zooplankton were secondary in its diet. These authors explain this difference in a fish's feeding habits with food sources or habitat characteristics. Indeed, the Municipal Lake of Yaoundé is a hypertrophic milieu resulting from the continuous supply of nutrients in the ongoing discharge of untreated domestic waste waters from the housing and office estates around the lake and drained by the Mingoa Stream into the lake. This condition favours the development of diversified phytoplanktonic populations dominated by Chlorophyta and Euglenophyta that characterise polluted environments rich in putrescible organic substances [24].

Male and female *O. niloticus* proportions were not different in this study, similar to several other studies in some African lakes or reservoirs [12, 63-65]. However, [43, 50, 66] found male individuals to dominate over females of *O. niloticus* in Lake Toho (Benin), Lake Victoria (Kenya), and Naivasha (Kenya), respectively; meanwhile, some other studies instead found females to predominate [67-69]. In a wild population, a fish sex ratio could fluctuate locally or seasonally [70] or due to the sampling method [65] or the formation of monogamous pairs, as is the case of Ciclid species in many cases [71]. The low number of female individuals in the catches in August may indicate the breeding season since reports state that during this period, males of Teleost were more abundant than females in the catches due to their breeding strategy, whereby, as in the case of *O. niloticus*, females are mouth-breeders and probably migrate to the submerged and rocky vegetation to hide from predators and fishermen [63].

The female *O. niloticus* size at first maturity here revealed the precocious breeding nature of this species. This result corroborates those of [72-74], who demonstrated that this early breeding habit was independent of environmental conditions and did not reduce somatic growth. Reports state that under natural conditions, the first maturity of the Nile tilapia occurred when aged between 10 and 12 months and at a length of 8–16 cm [75]. Female early maturation is a strategy to ensure reproductive success [76], possibly in response to overfishing activity in the lake.

Female GSI value compares to that of [12] but is lower than in other reports [67, 73, 77]. These differences could be due to environmental factors such as dissolved oxygen levels. Indeed, as a detritus bottom-feeder, *O. niloticus* dwells mainly in deep water, especially during reproduction. Results showed a strong correlation between the GSI and the dissolved oxygen contents. In the deeper water of this lake, this parameter is below the hypoxic range [78]. Due to the hypertrophic nature of the lake, there is limited light penetration to balance the oxygen consumption in deep water, which impedes ongoing photosynthetic activity [79]. These factors contribute to significant heterotrophic activity because of the accumulation of biodegradable organic materials [22]. It was reported that hypoxia affects fish endocrine systems by retarding gonadal development with lower reproductive success consequences [80, 81]. A periodic variation in the GSI of this fish species was also found in Lake Victoria in Tanzania and Lake Shala in Ethiopia [12, 72]. In Lake Shala, [73] found that female *O. niloticus* breeds more than once a season, following a bi-annual cycle, with the peak spawning times occurring in February (dry season) and July (wet season), which is consistent with other findings [66, 69, 82, 83]. According to various studies, the Nile tilapia spawns from 5 days to 6 weeks [84-86], and females produce multiple batches of synchronous oocytes, allowing them to spawn regularly within a season [77]; this consistent spawning behaviour can result in variations in the fry quality at different times [87]. This study covered the short rainy, short dry, and long rainy seasons encountered in Yaoundé, and females with mature ovaries were present all over the sampling period, a possible indication of more than one breeding time [12, 66, 69], with the peak breeding period around August, the short dry season that immediately follows the small rainy period. A breeding and spawning season during this time frame may be due to nutrient income from rainfall flooding of allochthonous material, which increases the accessibility and quality of food resources into the lake for the growth and survival of juveniles [82, 83]. Continuous breeding throughout the year for *O. niloticus* was reported in equatorial lakes compared to a unique breeding season for its counterpart in lakes away from the equator [88].

The oocyte diameter was not correlated to female length, weight, or reproductive parameters, as found in other studies [73, 89, 90]. In fish species, ripe egg size does not vary much with the fish size or age [73]. The absolute fecundity of *O. niloticus* was strongly related to the ovary weight rather than the fish length or weight, a result that contradicts those of [73], who studied tilapia reared in Lake Victoria in Tanzania and found that the absolute fecundity of this species strongly correlated with the body weight and length rather than the gonad weight. Here, fecundity is generally positively correlated with size and body weight in several fish species [91, 92]. Nonetheless, distinct populations within a species may exhibit notable variations in fecundity, likely associated with accessibility and food quality, particularly proteins, since they are one of the most influential factors regulating fertility [89, 93, 94].

5. Conclusion

The present study assessed some aspects of the biology of the introduced *O. niloticus* in a non-monitored hypertrophic artificial lake in the heart of Yaoundé city in Cameroon. The findings indicate that the Nile tilapia exhibited a relatively good condition in this hypoxic and highly conductive environment, with a negative allometric growth type, length growth preferred over weight input, and rapid maturation, probably because of the likelihood of successful reproduction that may be reduced by fishing activity. As a bottom feeder, the species prefers to eat organic matter from plant origin and detritus. The extended breeding season may be due to the constant inflow of nutrients from nearby waste discharges into the lake, which is the cause of its eutrophication. The species reached maturity at a smaller size and had a low gonado-somatic index, which is valuable information for fishery stock management. Thus, to monitor this species for sustainability, it is necessary to regulate the anthropogenic and fishing activities in this lake by respectively managing the incoming effluents into the lake and adjusting the mesh size for fish capture. When combined with appropriate lake restoration, these measures can help increase tourism and generate revenue for the local community. Further studies are recommended to cover the whole year to involve seasonality and other abiotic and biotic factors on the biology of this species and other native ones in different ecosystems in the country for sustainability.

Abbreviations

GSI	Gonado-Somatic Index
IRI	Index of Relative Importance
LWR	Length-Weight Relationship
NTU	Nephelometric Turbidity Unit
RGL	Relative Gut Length

Author Contributions

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Funding

This work is not supported by any external funding.

Conflicts of Interest

The authors declare no conflicts of interest.

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