Population biology of Nile tilapia, *Oreochromis niloticus* in Lake Naivasha, Kenya

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Abstract

The Nile tilapia, *Oreochromis niloticus* was introduced in Lake Naivasha to provide exploitable fisheries. It is one of the commercially important fish providing livelihoods to communities around the lake. However, its stocks in the lake have been declining due to intense fishing, ecological changes and effects of other exotic species. This study investigated on its population and biological parameters. Fish samples (1021) were caught monthly from January to December 2017 using gillnets of mesh-sizes 2-5 inches. A total of 1021 *O. niloticus* caught had overall sex ratio of 2.21:1.0 (male: female). Length of fish ranged from 9.0 to 40.0 cm TL and weighed between 20 and 1220 g. Length at first maturity (L_{m50}) was estimated at 28.0 cm TL for all sexes. The mean length and weight for all fish was 22.6 cm and 272.6 g. The slope b of length-weight relationship was 2.86 for all fish. The mean condition factor was 0.99, 1.04 and 1.01 for male, female and all fish, respectively. The asymptotic length (L_{∞}) was 42 cm, growth coefficient (K) 0.21 year^{-1} and growth performance index (Φ) 2.57. The natural (M), fishing (F) and total mortality (Z) coefficients were estimated at 0.55, 0.26 and 0.80 year^{-1} , respectively. Length at first capture (L_{c50}) was calculated at 19.38 cm. The optimum sustainable yield ($E_{0.5}$), maximum sustainable yield (E_{max}) and maximum economic yield ($E_{0.1}$) indices were 0.23, 0.35 and 0.26, respectively. This study has provided some insights into biology of *O. niloticus* and stock assessment relevant information to the fishery management.

Keywords: Nile tilapia, growth, mortality, maturity, condition

Introduction

Lake Naivasha is a freshwater body in Kenya that provides source of livelihood to the neighboring communities. The fishery of Lake Naivasha is based mainly on the introduced species namely Common carp, *Cyprinus carpio*, Nile tilapia, *Oreochromis niloticus*, Blue spotted tilapia, *O. leucostictus*, Red-belly tilapia, *Coptodon zillii*, Largemouth bass, *Micropterus salmoides* and African catfish, *Clarias gariepinus* (Njiru et al. 2017). Before the introductions, Lake Naivasha originally contained only the endemic Black lamprey *Aplocheilichthys antinorii* that was last recorded in 1962 and is believed to have gone extinct through predation pressure

from the introduced *M. salmoides* (Muchiri & Hickley 1991). The *O. niloticus* is one of the most important tilapiine that has been introduced to various countries, primarily for purposes of aquaculture and stock enhancement. In habitats where it has been introduced, *O. niloticus* tend to out-compete native species for food, habitat and spawning sites. This is due to its adaptive characteristics such as tolerance to varying environmental conditions, prolific breeding, short generation time, extended breeding season, territoriality, mouthbrooding behavior and the ability to feed at a range of trophic levels (Russell et al. 2012).

It has been introduced into Lakes Naivasha and Victoria to provide exploitable fisheries (Yongo et al. 2020). The *O. niloticus* was first introduced into Lake Naivasha in 1967 in order to diversify and boost the dwindling fishery of the lake (Kundu et al. 2010). It disappeared from the lake in 1971 (Gozlan et al. 2010), and was later reintroduced during 2011 and 2014. However, its population has continued to decline despite the re-introduction. Accordingly, Lake Naivasha ecosystem has been faced with several challenges that have negatively impacted on the fish stocks. Some of these problems include intense fishing, exotic species introductions, water abstraction, lake level fluctuations, wetland degradation, pollution and eutrophication (Njiru et al. 2017). Records available at Kenya Marine and Fisheries Research Institute show that fish species in the lake are currently being overexploited. Indiscriminate use of illegal fishing gears and poor fishing methods are the main risks to *O. niloticus* population and other species which may adversely affect the overall fishery production in the long run. This study investigated on the population biology of *O. niloticus* in Lake Naivasha including condition, sex ratio, size and first maturity, growth, mortality, recruitment and exploitation.

Materials & methods

Lake Naivasha is a freshwater body located in the Eastern arm of Great Rift Valley, Kenya at 00°46'S, 36°22'E and lies at an altitude of 1890 m (Fig. 1). It is a small endorheic lake of approximately 145 km² with a catchment area of about 3,200 km² (Hickley et al. 2008). Its mean depth varies between 4 m and 6 m. The lake is fed by the perennial Malewa and Gilgil rivers with the former being the main one (Kitaka et al. 2002). It is characterized by high water levels (Oyugi et al. 2011) due to two wet seasons in the months of March-May (long rains) and October-November (short rains). Lake Naivasha is the major source of fish for the surrounding community and fresh water for the numerous horticultural industries in the area. This study was

carried out at eight sites in Lake Naivasha; Crescent Island (CR), Hippo point (HP), Korongo (KRO), Malewa river mouth (MR), Mid-lake (MDLK), Off Crescent (OCR), Oserian Bay (OS) and Sher (SH) (Fig. 1). Crescent is isolated and characterized with sand-rock substrate; Hippo point is open lake and deep also have sand and rock substrate; Oserian Bay is semi-isolated, shallow and has mud substrate; Korongo is shallow near shore characterized by papyrus; Sher is an extensive shallow bay fringed with papyrus; Malewa river mouth represent a shallow habitat characterized by muddy substrate; Mid-lake represent open deep water with strong wind action. Fish samples (1021) were caught monthly using gillnets of mesh-sizes 3.5-5.0 inches from January to December 2017. Fish caught were sorted and *O. niloticus* were preserved in ice cool box then transported to the laboratory for analysis. In the laboratory, individual fish specimen was measured (cm, TL) and weighed (g). The fish were dissected for determination of sex and maturity stages according to the scheme of Witte and van Densen (1995).

Figure 1: Map of Lake Naivasha, Kenya showing the sampling sites. CR (Crescent Island), HP (Hippo point), KRO (Korongo), MR (Malewa river mouth), MDLK (Mid-lake), OCR (Off Crescent), OS (Oserian Bay) and SH (Sher).

Data analysis

The length-weight relationship was estimated using the formula:

$$W = a \times TL^b$$

The relative condition factor was calculated as follows:

$$Kn = \frac{W}{(a \times TL^b)}$$

Where Kn = condition factor, W = weight of fish (g), TL = total length of fish (cm), a (intercept) and b (slope) are constants of regression equation.

Average size at first maturity (Lm_{50}) referred to as size (total length) at which 50% of individuals in the fish population reach sexual maturity during the reproduction period. It was estimated by modeling the proportion of mature individuals to their respective length classes based on logistic function as follows.

$$P = \frac{1}{1 + e^{-a(L-b)}}$$

Where P = proportion of mature fish by length class, L = total length class, a and b are model parameter estimates of which $b = Lm_{50}$. Chi-square test (χ^2 test) was used to test for the difference in population sex ratio. One-way analysis of variance (ANOVA) was used to test for variation in mean total length between sites. Data analysis for the population parameters was based on length–frequency distribution analysis using the Electronic Length Frequency Analysis (ELEFAN I in FAO ICLRAM Stock Assessment Tool (FiSAT)) (Pauly 1987; Gayanilo *et al.* 1996). Estimates of the growth parameters were based on the von Bertalanffy growth formula (VBGF), expressed as follows:

$$L_t = L_{\infty}(1 - \exp^{-K(t-t_0)})$$

where L_t = predicted length at age t ; L_{∞} = asymptotic length; K = growth coefficient; t_0 = age the fish would have been at zero length.

The total mortality (Z) was estimated using a length-converted catch curve. The coefficient of natural mortality (M) was estimated with K (year^{-1}), L_{∞} (cm) and T (mean annual water temperature of 24°C), following Pauly's empirical formula (Pauly, 1980) as follows:

$$\ln(M) = -0.0152 - 0.279 \ln(L_{\infty}) + 0.6543 \ln(K) + 0.463 \ln(T)$$

The fishing mortality (F) was computed from the relationship

$$F = Z - M$$

The exploitation rate (E) was calculated from the relationship

$$E = \frac{F}{Z} = \frac{F}{F + M}$$

The growth performance index (Φ) was computed according to Pauly and Munro (1984)

$$\Phi = \ln(K) + 2(\ln(L_{\infty}))$$

The probability of capture was obtained from the backward extrapolation of the length-converted catch curve, according to Pauly *et al.* (1984). Growth parameters L_{∞} and K were used as inputs. The relative yield-per-recruit model was based on Beverton and Holt (1966) model. The options assuming knife-edge selection was utilized using probabilities of capture.

Results

A total of 1021 *O. niloticus* caught from Lake Naivasha comprised of 703 males and 318 females. The overall sex ratio was 2.21:1.0 (male: female) that significantly deviated from the 1:1 ratio (Chi-square $\chi^2 = 145.18$, $p < 0.05$). Length of fish ranged from 9.0 to 40.0 cm TL and weighed between 20 and 1220 g. The fish showed a unimodal size frequency distribution pattern with the modal class between 20-25 cm (Fig. 2). Length at first maturity (L_{m50}) was estimated at 28.0 cm TL for all sexes (Fig. 2). The mean ($\pm$ SE) length and weight for all fish was 22.6 ± 0.2 cm and 272.6 ± 7.4 g (Table 1). The length varied significantly between sites ($F=18.55$, $p < 0.05$), with the highest (26.0 ± 1.3 cm) and lowest (18.8 ± 1.0 cm) values recorded at Off crescent and Malewa, respectively. The slope b of length-weight relationship was 2.86 for all fish (Table 1). The mean condition factor was 0.99, 1.04 and 1.01 for male, female and all fish, respectively. The *O. niloticus* had highest condition values during September (female=1.71, male=1.52) and

October (female=1.69, male=1.60) (Fig. 3). The asymptotic length (L_{∞}) was 42 cm, growth coefficient (K) 0.21 year⁻¹ and growth performance index (Φ) 2.57. The natural (M), fishing (F) and total mortality (Z) coefficients were estimated at 0.55, 0.26 and 0.80 year⁻¹, respectively (Fig. 4a). Length at first capture (L_{C50}) was calculated at 19.38 cm (Fig. 4b). The fish showed a peak recruitment in June accounting for 17.74% (Fig. 5a). The optimum sustainable yield ($E_{0.5}$), maximum sustainable yield (E_{max}) and maximum economic yield ($E_{0.1}$) indices were 0.23, 0.35 and 0.26, respectively (Fig. 5b).

Figure 2: Length frequency of *O. niloticus* from Lake Naivasha, Kenya 2017.

Table 1: Descriptive statistics for *O. niloticus* from Lake Naivasha, Kenya 2017.

Stations	n	Length (cm TL)	Weight (g)	Kn	a	b	R^2
Crescent	224	24.1±0.3	302.4±12.5	0.98±0.02	0.020	2.98	0.93
Hippo Point	66	19.2±0.7	153.0±14.5	0.87±0.02	0.024	2.90	0.96
Korongo	128	24.8±0.6	349.1±38.4	1.02±0.02	0.024	2.94	0.96
Malewa	20	18.8±1.0	175.9±24.5	1.11±0.09	0.007	3.39	0.87
Mid-lake	33	22.2±0.7	209.5±17.0	0.86±0.03	0.011	3.13	0.96
Off Crescent	30	26.0±1.3	421.1±48.9	0.98±0.03	0.012	3.14	0.99
Oserian	498	21.5±0.2	236.6±7.4	1.08±0.01	0.053	2.67	0.88
Sher	22	21.3±1.4	214.0±32.5	0.88±0.04	0.015	3.07	0.98
Whole lake	1021	22.6±0.2	272.6±7.4	1.01±0.01	0.031	2.86	0.92

n=samples, Kn = condition factor, a =intercept, b = slope, R^2 = coefficient of determination

Figure 3: Monthly changes in relative condition factor of male and female *O. niloticus* in Lake Naivasha, Kenya 2017. Vertical bars are standard deviations.

Figure 4 (a) Values of total mortality (Z), natural mortality (M), fishing mortality (F) coefficients and exploitation rates (E) from length-converted catch curve. (b) Logistic curve showing 25%, 50% and 75% capture length (cm TL) of *O. niloticus* (broken lines) Lake Naivasha, Kenya 2017

Figure 5 (a). Estimated percentage recruitment. (b) Beverton & Holt's relative yield per recruit and average biomass per recruit models, showing levels of yield indices: $E_{0.5}$ -optimum sustainable yield, $E_{0.1}$ -maximum economic yield and E_{max} -maximum sustainable yield.

Discussion

Table 2 compares the sex ratio, slope (b) of length-weight relationship, condition factor (Kn) and length at first maturity (Lm_{50}) of *O. niloticus* in Lakes Naivasha and Victoria from 1998 to 2017. Data on sex ratios suggests more bias towards males in Lake Naivasha (2013/2014, 2.00:1; 2017, 2.23:1; Table 2) than in Lake Victoria (2014/2015, 1.20: 1; 1998/2000, 1.42:1). In Lake Naivasha, Laurent et al. 2020 reported predominance of male *O. leucosticus* than females (2.19:1.0). These observations are indicative that male Tilapiines are more dominant than females. The slope (b) of length-weight relationship of *O. niloticus* in Lake Victoria has showed least variation over time (Table 2). However, in Lake Naivasha, Outa et al. 2014 (Table 2) found lower b value (2.30) during 2013/2014 compared to this study (2.87). The condition value 1.02 found in this study is much lower compared to those reported during 2013/2014 and 2015 from the same lake by Outa et al. 2014 and Keyombe et al. 2017 (Table 2). Condition of fish is affected by changes in food availability, environmental quality, seasonality and reproductive status (Yongo et al. 2019). The *O. niloticus* had high condition values during the months of September and October (Fig. 3). This observation was attributable to more food items and increased productivity after the long rains in May (Mutethya et al. 2020). Generally, *O. niloticus*

in both Lakes Naivasha and Victoria mature at smaller sizes (Table 2), probably an adaptive strategy to fishing effect and other environmental stress (Njiru et al. 2006; Yongo et al. 2018).

Table 2: Parameters of sex ratio, length-weight relationship, condition factor and length at first maturity of *O. niloticus* from Lakes Victoria and Naivasha 1998-2017.

Lake & period	Sex	Slope	Kn	Lm_{50}	Lm_{50}	Source
	ratio	b		Female	Male	
Victoria-1998/99	1.49:1	3.14	0.71	31.0	34.0	Ojuok <i>et al</i> (2000)
Victoria-1998/00	1.42:1	3.07-3.32	0.92-1.07	31.0	35.0	Njiru <i>et al</i> (2006)
Naivasha-2013/14	2.00:1	2.30	2.46	18.0	17.7	Outa <i>et al</i> (2014)
Victoria-2014/15	1.20:1	3.01	1.02-1.04	26.0	31.0	Yongo <i>et al</i> (2018)
Naivasha-2017	2.21:1	2.86	1.01	28.0	28.0	This study

Changes in asymptotic length (L_{∞}), growth coefficient (K), mortality coefficients (Z , M , F), growth performance index (Φ), length at first capture (L_{C50}) and exploitation rate (E) of *O. niloticus* from Lakes Victoria & Naivasha during 1998-2017 are presented in table 3. The values of L_{∞} , K , Φ , Z , M , F and E of *O. niloticus* in Lake Naivasha are much lower than those in Lake Victoria (Table 3). The causes of natural mortality and link with growth rate are described by Yongo and Outa 2016. The L_{C50} (19.38 cm) was much lower than the reported value of Lm_{50} (28.0 cm, Table 2). This information when combined with results of length frequency distribution (modal class 20-25 cm TL, Fig. 2), indicates that the fishery is landing juvenile fish. From the results of relative yield per recruit and average biomass per recruit (Fig. 5b), the exploitation rate 0.32 yr^{-1} (Fig. 5a) was not different from maximum sustainable yield (0.35), but was higher than the optimum sustainable yield (0.23) and economic yield (0.26) indices. This showed an optimal exploitation of *O. niloticus* in Lake Naivasha.

Table 3: Population parameters of *O. niloticus* from Lakes Victoria & Naivasha 1998-2017.

Lake & period	L_{∞}	K	Φ	Z	M	F	E	L_{C50}	Source
Victoria-1985/86	64.60	0.25	3.03	0.82	0.54	0.28	0.34	-	Getabu (1992)
Victoria-1989/90	63.10	0.35	3.16	1.71	0.72	0.99	0.58	-	Dache (1994)
Victoria-1998/00	58.78	0.59	3.36	2.16	1.12	1.04	0.52	28.54	Njiru (2003)
Victoria-2014/15	46.24	0.69	3.14	2.18	1.14	1.05	0.46	20.31	Yongo & Outa (2016)
Naivasha-2017	42.00	0.21	2.57	0.80	0.55	0.26	0.32	19.38	This study

Conclusion

This study has presented data on the population biology of *O. niloticus* introduced in Lake Naivasha. Also the study provides some insights of the stock assessment relevant information to the fishery management. The fisheries management in Lake Naivasha should focus on controlling the fishing gears and regulating the size of fish caught as it was evident that size at first capture is much lower than size at first maturity. The study has also revealed a gap for further research on the reproductive biology of *O. niloticus* in Lake Naivasha.

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