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RESEARCH NOTE

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Population Biology of Nile tilapia (*Oreochromis niloticus*) in Lake Naivasha, Kenya

Edna Waithaka[1] | **Edwine Yongo**[2] | **Nicholas Outa**[3] | **Eunice Mutethya**[4]

[1]Kenya Marine and Fisheries Research Institute (KMFRI), Naivasha Station, Kenya
[2]Faculty of Life and Pharmaceutical Sciences, Hainan University, China
[3]Department of Fisheries and Natural Resources, Maseno University, Kenya
[4]Department of Fisheries and Aquatic Sciences, University of Eldoret, Kenya

Correspondence
Edna Waithaka, Kenya Marine and Fisheries Research Institute (KMFRI), Naivasha Station, Kenya.
Email: ewaithaka@yahoo.com

Abstract

The Nile tilapia (*Oreochromis niloticus*) was introduced into Lake Naivasha to provide exploitable fisheries, being one of the commercially important fish providing livelihoods to communities around the lake. Its stocks in the lake have been declining, however, because of intense fishing, ecological changes and effects of other exotic species. The present study was undertaken to investigate the population and biological parameters of *Oreochromis niloticus*. Fish samples (1,021) were caught monthly from January to December 2017, collecting a total of 1,021 *O. niloticus*, with an overall sex ratio of 2.21:1.0 (male: female). The length of the fish ranged from 9.0 to 40.0 cmTL and weighed between 20 and 1,220 g. 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, indicating negative allometry. The mean condition factors were 0.99, 1.04 and 1.01 for male, female and all fish, respectively. The length at first maturity (Lm_{50}) was estimated to be 28.0 cmTL for all sexes, indicating the fish matures at smaller sizes. The length at first capture (Lc_{50}) was calculated to be 19.38 cm, a value much lower than its Lm_{50}, reflecting the capture of juvenile fish. The asymptotic length ($L\infty$) was 42 cm, the growth coefficient (K) was 0.21/year, and the growth performance index (Φ) was 2.57. The natural (M), fishing (F) and total mortality (Z) coefficients were estimated to be 0.55, 0.26 and 0.80/year, respectively. The optimum sustainable yield ($E_{0.5}$), maximum sustainable yield (E_{max}) and maximum economic yield ($E_{0.1}$) indices of 0.23, 0.35 and 0.26, respectively, imply an optimal exploitation of *O. niloticus*. The results of the present study provided some important insights into the biology and management needs of the *O. niloticus* fishery in Lake Naivasha, as well as revealing a gap for further research on its reproductive biology.

KEYWORDS
condition, growth, maturity, mortality, Nile tilapia

1 | INTRODUCTION

Lake Naivasha is a freshwater body in Kenya that provides a source of livelihood to the neighbouring communities. The fishery of Lake Naivasha is based mainly on the introduced species of 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, Waithaka, & Aloo, 2017). Before the introduction of these fish species, Lake Naivasha originally contained only the endemic Black lamprey (*Aplocheilichthys antinorii*), which was last recorded in 1962 and is believed to have gone extinct because of predation pressure from the introduced *M. salmoides* since that time (Muchiri & Hickley, 1991). *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 situation is attributed to such adaptive characteristics as tolerance to varying environmental conditions, prolific breeding, short generation time, extended breeding season, territoriality, mouthbrooding behaviour and its ability to feed at a range of trophic levels (Russell, Thuesen, & Thomson, 2012).

O. niloticus was introduced into Lakes Naivasha and Victoria to provide exploitable fisheries (Yongo, Laurent, & Mutethya, 2020). It was first introduced into Lake Naivasha in 1967 to diversify and boost the dwindling fishery of the lake (Kundu, Aura, Muchiri, Njiru, & Ojuok, 2010). It disappeared from the lake in 1971 (Gozlan, Britton, Cowx, & Copp, 2010), being later reintroduced during 2011 and 2014. Its population has continued to decline, however, despite the reintroductions. Accordingly, the Lake Naivasha ecosystem has experienced several challenges that negatively impacted its 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). Data from the Kenya Marine and Fisheries Research Institute indicate 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 that may adversely affect the overall fishery production of the lake over the long term. Accordingly, the present study investigated the population biology of *O. niloticus* in Lake Naivasha, including aspects such as condition factor, sex ratio, size at first maturity, growth, mortality, recruitment and exploitation.

2 | MATERIAL AND METHODS

2.1 | Study site and sample collection

Lake Naivasha is a freshwater body located in the eastern arm of Great Rift Valley, Kenya, at 00°46′S, 36°22′E, lying at an altitude of 1,890 m (Figure 1). It is a small endorheic lake covering ~145 km^2, with a catchment area of about 3,200 km^2 (Hickley, Muchiri, Britton, & Boar, 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, Harper, & Mavuti, 2002). It is characterized by high water levels (Oyugi, Harper, Ntiba, Kisia, & Britton, 2011) attributable to two wet seasons during 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 freshwater for the numerous horticultural industries in the area. The present study was carried out at eight sites in Lake Naivasha, including Crescent Island (CR), Hippo Point (HP), Korongo (KRO), Malewa River mouth (MR), Mid-lake (MDLK), Off crescent (OCR), Oserian Bay (OS) and Sher (SH) (Figure 1). Sampling sites were selected on the basis of their habitat characteristics. For instance, Crescent is isolated and characterized with sand-rock substrate. Hippo Point is an open lake and deep site with sand and rock substrate. Oserian Bay is semi-isolated, shallow and has mud substrate. Korongo is a shallow nearshore site characterized by papyrus, while Sher is an extensive shallow bay fringed with papyrus. The Malewa River mouth site is a shallow habitat characterized by muddy substrate, while the mid-lake is an open lake deep water site that experiences strong wind action. Fish samples (1,021) were collected monthly from January to December 2017, using gillnets of 3.5 to 5.0-inch mesh size. The collected fish were sorted, with *O. niloticus* being preserved in ice-cooled box until transported to the laboratory for analysis. Individual fish specimens was measured (TL in cm and weighed (g) in the laboratory. The fish were dissected for determination of sex and maturity stages according to the scheme of Witte and van Densen (1995).

2.2 | Data analysis

The length–weight relationship was estimated using the formula:

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

And the relative condition factor was calculated as follows:

$$Kn = \frac{W}{\left(a \times TL^b\right)} \tag{2}$$

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

Average fish size at first maturity (Lm_{50}) refers to the size (total length) at which 50% of individuals in the fish population reach sexual maturity during the reproduction period. It was estimated by

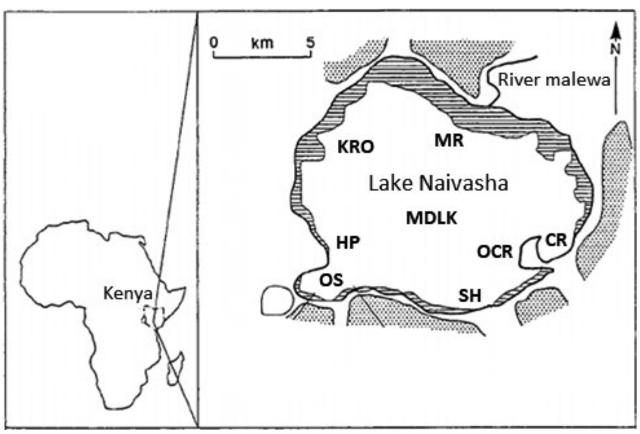

FIGURE 1 Map of Lake Naivasha, Kenya showing the sampling sites. CR (Crescent Island), HP (Hippo point), KRO (Korongo), MR (Malewa river mouth), MDLK (Mid-lake), OCR (Off Crescent), OS (Oserian Bay) and SH (Sher)

modelling the proportion of mature individuals to their respective length classes based on a logistic function, as follows:

$$P = \frac{1}{1 + e^{-a(L-b)}} \quad (3)$$

where P = proportion of mature fish by length class; L = total length class; and a and b = model parameter estimates of which $b = Lm_{50}$. A 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 variations 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]) (Gayanilo, Sparre, & Pauly, 1996; Pauly, 1987). Estimates of the growth parameters were based on the von Bertalanffy growth formula (VBGF), expressed as follows:

$$L_t = L_\infty \left(1 - \exp^{-K(t-t_0)}\right) \quad (4)$$

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

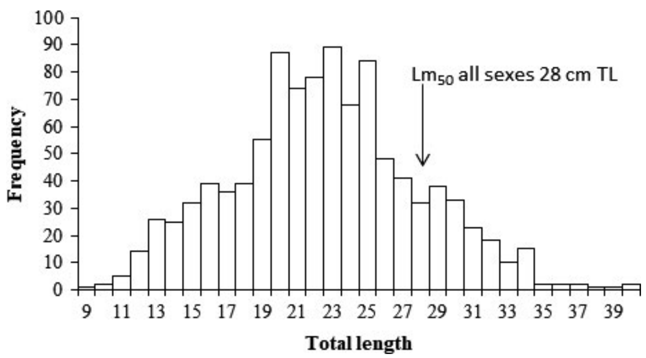

FIGURE 2 Length frequency of *O. niloticus* from Lake Naivasha, Kenya 2017

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:

$$\text{Ln}(M) = -0.0152 - 0.279\text{Ln}(L_\infty) + 0.6543\text{Ln}(K) + 0.463\text{Ln}(T) \quad (5)$$

The fishing mortality (F) was computed from the relationship:

$$F = Z - M \quad (6)$$

The exploitation rate (E) was calculated from the relationship:

$$E = \frac{F}{Z} = \frac{F}{F+M} \quad (7)$$

The growth performance index (Φ) was computed according to Pauly and Munro (1984), as follows:

$$\Phi = \text{Ln}(K) + 2(L_\infty) \quad (8)$$

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

3 | RESULTS AND DISCUSSION

A total of 1,021 *O. niloticus*, comprising 703 males and 318 females, were caught in Lake Naivasha. The overall sex ratio of 2.21:1.0 (male: female) significantly deviated from a 1:1 ratio (chi-square χ^2 = 145.18; df = 1; $p < .05$). The fish length ranged from 9.0 to 40.0 cm TL and weighed between 20 and 1,220 g. The fish exhibited a unimodal size–frequency distribution pattern with the modal class between 20 and 25 cm (Figure 2). Length

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	1,021	22.6 ± 0.2	272.6 ± 7.4	1.01 ± 0.01	0.031	2.86	0.92

Note: n = samples, Kn = condition factor, a = intercept, b = slope, R^2 = coefficient of determination at first maturity (Lm_{50}) was estimated to be 28.0 cm TL for all sexes (Figure 2). The mean (±*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 ($F = 18.55$; $df = 1{,}013$; $p < .05$), with the highest (26.0 ± 1.3 cm) and lowest (18.8 ± 1.0 cm) values recorded at the Off crescent and Malewa sites, 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* exhibited highest condition values during September (female = 1.71; male = 1.52) and October (female = 1.69; male = 1.60) (Figure 3). The asymptotic length ($L\infty$) was 42 cm, growth coefficient (*K*) 0.21/year and growth performance index (Φ) 2.57. The natural (*M*), fishing (*F*) and total mortality (*Z*) coefficients were estimated to be 0.55, 0.26 and 0.80/year, respectively (Figure 4a). The length at first capture (Lc_{50}) was calculated to be 19.38 cm (Figure 4b). The fish exhibited a peak recruitment in June, accounting for 17.74% (Figure 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 (Figure 5b).

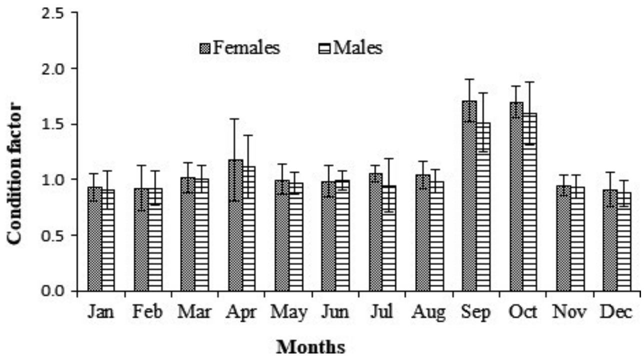

FIGURE 3 Monthly changes in relative condition factor of male and female *O. niloticus* in Lake Naivasha, Kenya 2017. Vertical bars are standard deviations

Table 2 compares the sex ratio, slope (*b*) of the 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. The data on sex ratios suggest more bias towards males in Lake Naivasha (2.00:1 in 2013/2014; 2.23:1 in 2017; Table 2) than in Lake Victoria (1.20 in 2014/2015; 1.42:1 in 1998/2000). Laurent, Yongo, Waithaka, & Mutethya, 2020 reported a predominance of male *O. leucosticus* over females (2.19:1.0), indicating male Tilapiines are more dominant than females in Lake Naivasha. The slope (*b*) of length–weight relationship of *O. niloticus* in Lake Victoria exhibited least variation over time (Table 2). For Lake Naivasha, however, Outa, Kitaka, & Njiru, 2014 (Table 2) found lower *b* value (2.30) during 2013/2014 compared with this study (2.87). The condition value of 1.02 determined in the present study is much lower compared with those reported during 2013/2014 and 2015 from the same lake by Outa et al., 2014 and Keyombe, Malala, Waithaka, Lewo, & Obwanga, 2017 (Table 2). The condition of the fish is affected by changes in food availability, environmental quality, seasonality and reproductive status (Yongo, Olukoye,

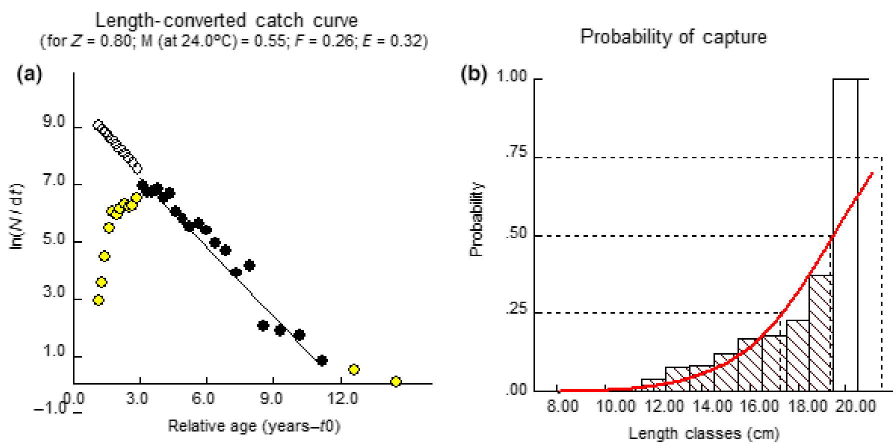

FIGURE 4 (a) Values of total mortality (*Z*), natural mortality (*M*), fishing mortality (*F*) coefficients and exploitation rates (*E*) from length-converted catch curve. (b) Logistic curve showing 25%, 50% and 75% capture length (cm TL) of *O. niloticus* (broken lines) Lake Naivasha, Kenya 2017

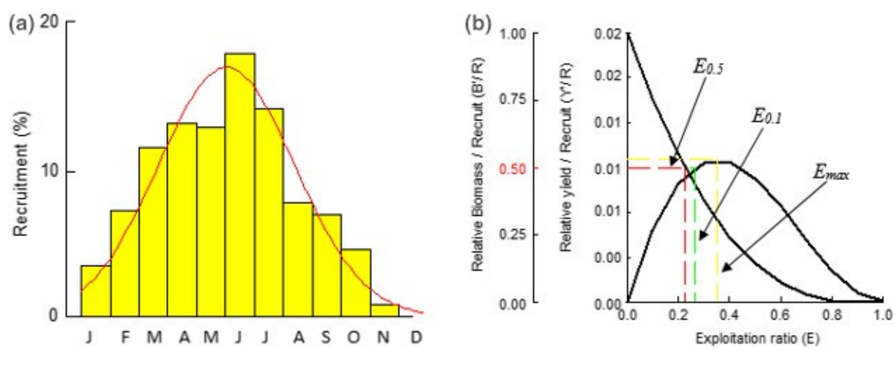

FIGURE 5 (a). Estimated percentage recruitment. (b) Beverton & Holt's relative yield per recruit and average biomass per recruit models, showing levels of yield indices: $E_{0.5}$-optimum sustainable yield, $E_{0.1}$-maximum economic yield and E_{max}-maximum sustainable yield

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 ratio	Slope *b*	Kn	Lm_{50} Female	Lm_{50} Male	Source
Victoria–1998/1999	1.49:1	3.14	0.71	31.0	34.0	Ojuok, Mavuti, and Ntiba (2000)
Victoria-1998/2000	1.42:1	3.07–3.32	0.92–1.07	31.0	35.0	Njiru et al. (2006)
Naivasha-2013/2014	2.00:1	2.30	2.46	18.0	17.7	Outa et al. (2014)
Victoria-2014/2015	1.20:1	3.01	1.02–1.04	26.0	31.0	Yongo et al. (2018)
Naivasha-2017	2.21:1	2.86	1.01	28.0	28.0	This study

TABLE 3 Population parameters of *O. niloticus* from Lakes Victoria & Naivasha 1998–2017

Lake & period	L_∞	*K*	Φ	*Z*	*M*	*F*	*E*	Lc_{50}	Source
Victoria-1985/1986	64.60	0.25	3.03	0.82	0.54	0.28	0.34	–	Getabu (1992)
Victoria-1989/1990	63.10	0.35	3.16	1.71	0.72	0.99	0.58	–	Dache (1994)
Victoria-1998/2000	58.78	0.59	3.36	2.16	1.12	1.04	0.52	28.54	Njiru (2003)
Victoria-2014/2015	46.24	0.69	3.14	2.18	1.14	1.05	0.46	20.31	Yongo and Outa (2016)
Naivasha-2017	42.00	0.21	2.57	0.80	0.55	0.26	0.32	19.38	This study

Makame, & Chebon, 2019). *O. niloticus* exhibited high condition values during the months of September and October (Figure 3), being attributable to more food items and increased productivity after the long rains in May (Mutethya, Yongo, Laurent, Waithaka, & Lomodei, 2020). *O. niloticus* in both Lakes Naivasha and Victoria generally mature at smaller sizes (Table 2), probably being an adaptive strategy to fishing effects and other environmental stresses (Njiru et al., 2006; Yongo, Outa, Kito, & Matsushita, 2018).

Changes in the asymptotic length (L_∞), growth coefficient (*K*), mortality coefficients (*Z*, *M*, *F*), growth performance index (Φ), length at first capture (Lc_{50}) 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 its link with growth rates are described by Yongo and Outa (2016). The Lc_{50} (19.38 cm) was much lower than the reported value of Lm_{50} (28.0 cm; Table 2). When combined with results of the length–frequency distribution (modal class 20–25 cm TL; Figure 2), this information indicates the fishery is landing juvenile fish. Based on the relative yield per recruit and average biomass per recruit (Figure 5b), the exploitation rate of 0.32/year (Figure 5a) was not significantly different from the maximum sustainable yield (0.35), but was higher than the optimum sustainable yield (0.23) and economic yield (0.26) indices, indicating an optimal exploitation of *O. niloticus* in Lake Naivasha.

4 | CONCLUSION

The present study presented data on the population biology of *O. niloticus* introduced into Lake Naivasha. It also provides some insights of relevant stock assessment information regarding the fishery management. The Lake Naivasha fisheries management should focus on controlling the fishing gear and regulating the size of the fish caught, since it is evident that the fish size at first capture is much lower than the size at first maturity. The present study also revealed a gap for further research on the reproductive biology of *O. niloticus* in Lake Naivasha.

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ORCID

Edna Waithaka https://orcid.org/0000-0003-2845-4146

Edwine Yongo https://orcid.org/0000-0001-8843-6113

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