Research article

Comparative study on the population dynamics of Nile Tilapia (*Oreochromis niloticus*): insights from Lakes Naivasha and Oloiden while the lakes were merged

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Abstract

The population dynamics of *Oreochromis niloticus* in Lakes Naivasha and Oloiden were assessed for one-year period along the salinity gradient using gill nets of varying mesh sizes. After sorting the fish the length and weight were measured. The condition factor (K) varied significantly across study sites, with Korongo recording the highest (1.98 ± 0.38) and Malewa the lowest (1.81 ± 0.35), indicating differences in habitat quality and food availability. Growth parameters estimated through the Von Bertalanffy Growth Function (VBGF) indicated an asymptotic length (L_∞) of 54.83cm in Lake Naivasha and 56.75cm in Lake Oloiden, suggesting slightly higher growth potential in Oloiden; although; both lakes had a b value of <3. Age at which the fish could be zero (t_0) was estimated to be -0.75year (L. Naivasha) and -0.77year (L. Oloiden). The study revealed a bimodal recruitment pattern, with juvenile influx peaking in April and July in Lake Oloiden, and June and September in Lake Naivasha, aligning with seasonal rainfall cycles. Exploitation rates of 0.49 was recorded in Lake Naivasha (optimum exploitation) and >0.5 in Lake Oloiden (overexploited), highlighting the urgent need for management interventions. The Virtual Population Analysis (VPA) demonstrated that fish below 9.4cm TL have high survivorship but suffer increased natural mortality, while fish at 19.4cm TL experience the highest fishing mortality, indicating size-selective fishing pressure. The findings emphasize the necessity for seasonal fishing regulations, mesh size adjustments, and habitat conservation to ensure long-term sustainability of O. *niloticus* populations in the two lakes. This study provides critical insights into the ecological and fisheries management strategies required to balance conservation efforts with sustainable fishery yields.

Key words: growth patterns, recruitment trends, mortallity rates, exploitation levels, salinity gradient

1.0 Introduction

For the past 8-10 years, the water level in Lake Naivasha has fluctuated, a phenomenon that has been linked to climate change. The water level in Lake Naivasha may be influenced by inflow from the Malewa and Gilgil rivers, precipitation and ground water recharge as well as subsequent outflow via ground water seepage, water abstraction and evapotranspiration (Nyang`au, 2021). On the other hand, Lake Oloiden's water level may be influenced by precipitation, evapotranspiration and underground recharge from the Lake Naivasha. A papyrus reef once separated Lake Oloiden from Lake Naivasha, but they could reconnected during a period of high-water level (Ballot *et al*., 2009; Guto et al., 2024).

An increase in precipitation led to a rise in the water level in Lake Naivasha which consequently merged it with the Lake Oloiden. The merging of these two lakes may have an effect on *Oreochromis niloticus* (Linnaeaus, 1758). The fish can withstand estuarine conditions (Guto *et al*., 2023).

The fish catch composition in Lake Naivasha varies over time (Njiru *et al*., 2019). Five teleosts are commonly found in the catches: *Cyprinus carpio*, *(Linnaeaus, 1758*), *Micropterus salmoides* (*Lacepédé, 1802*), *Coptodon zillii*, (Gervals, 1848), *Enteromius paludinosus*, (Peters, 1852) and *Oreochromis leucostictus*, (Trewavas, 1933) (Aloo *et al*., 2013). *Oreochromis leucostictus* has historically contributed the highest proportion of fin fish in the catch while the catches of M. *salmoides* and C. *zillii* (G) were lower before fish introductions were carried out (Morara *et al*., 2022).

Oreochromis leucostictus, M. *salmoides* and C. zilli were over-exploited, leading to the collapse of their fishery in 2001 (Hickley *et al*., 2004). Various species have been introduced into Lake Naivasha to fill feeding niches of Piscivores, phytoplanktivore, zooplanktivores and benthivores (Morara *et al*., 2022).

Among the introduced fish species is *O. niloticus*. It was introduced in 1960s but failed to establish a population due to predation by young bass (Njiru *et al*., 2017). Later, it was reintroduced by the government under the Economic Stimulus Program (ESP) in 2011 and successfully established a population that now forms a significant part of Lake Naivasha's commercial fishery (Nyang`au, 2021).

Coptodon zillii and *Oreochromis leucostictus* were the fish species that were previously noted in Lake Oloiden (Aloo, 2002). Most fish stocks are dynamic, necessitating periodic assessment for effective management (Nyang`au, 2021). A study on the population biology of O. *niloticus* reported a growth performance (ϕ') of 2.57, an asymptotic length ($L\infty$) of 42cm and growth coefficient (K) of 0.21/year. Its total mortality (Z), natural mortality (M) and fishing mortality (F) coefficients were 0.80year^{-1}, 0.55year^{-1} and 0.26year^{-1} respectively (Waithaka *et al*., 2020).

Oreochromis niloticus has been dominant in the commercial catches from 2011-2019 (Morara *et al*., 2022). The current study was undertaken when Lakes Naivasha (freshwater) and Oloiden (alkaline-saline) were merged, yet no assessment of O. *niloticus* population dynamics has been conducted in Lake Oloiden. Therefore, the objective is to assess the population dynamics of *Oreochromis niloticus* in the Lakes Naivasha-Oloiden along the salinity gradient.

2.0 Materials and methods

2.1 Study site

The sampling was done monthly, for one year (August, 2020 to July, 2021) in the Lake Oloiden (00º50'S, 36º17'E) and Lake Naivasha (00º46'S, 36º22'E) (Ballot *et al*., 2009). Lake Naivasha had 5 sites namely; Oseria, Crescent, Korongo, Middlake and Malewa while Lake Oloiden's sites were Oloiden ST1 and ST2. Sites were chosen based on a salinity gradient; from Oloiden 1 to Malewa and an addition of Crescent and Korongo which were fish breeding sites (Guto *et al*., 2024). The two lakes are close to the equator with a bimodal rainfall pattern (Figure 1). Short rainy season was in the months of November and December while the long rainy season was in April to July. August to October was the long dry season while January to March was the short dry season (Ndungu *et al*., 2013).

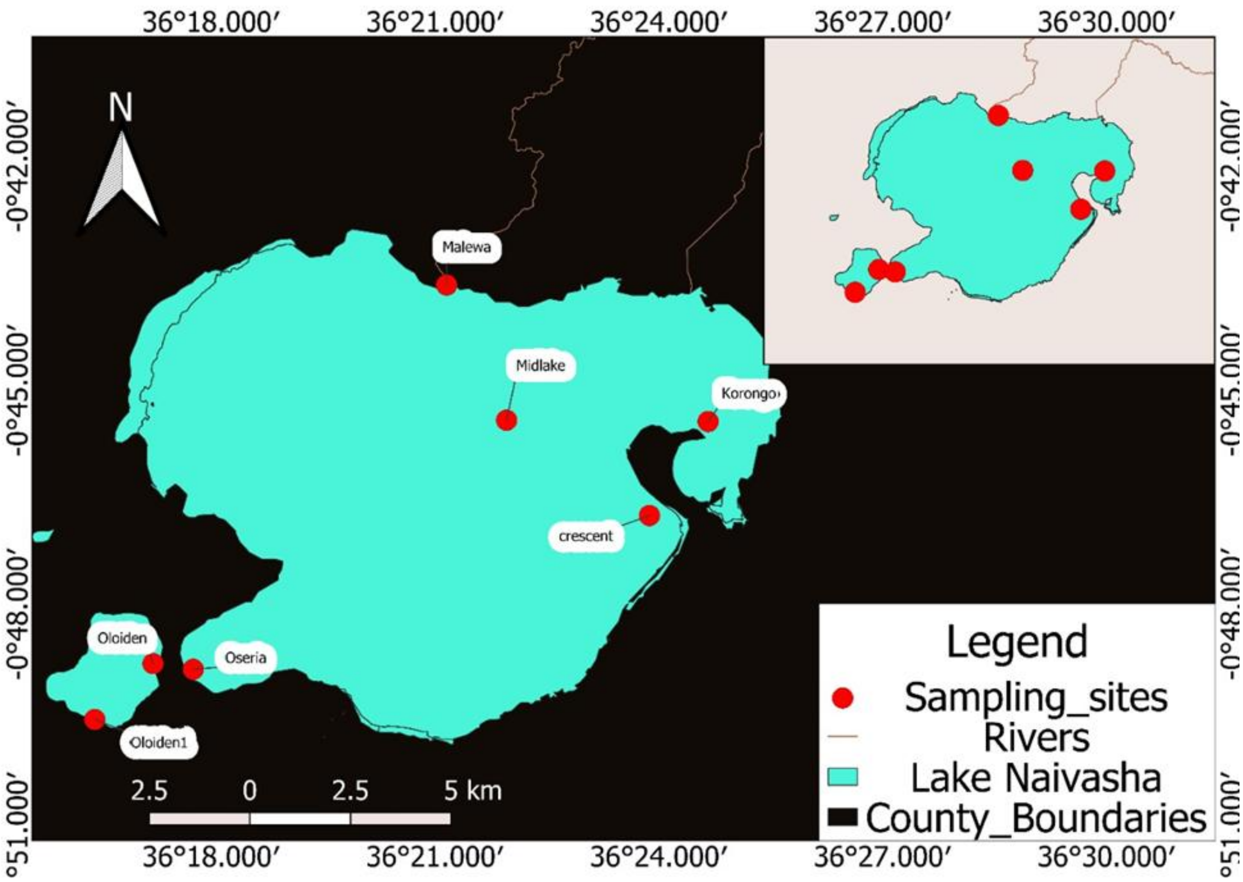


Figure 1. A map of the study sites in the Lakes Naivasha and Oloiden (Openstreetmap.org, 2021)

2.2 Fish sampling

The lakes were accessed using an engine boat. Gill nets (mesh 1,7/8-6 inches) were cast along a Global Positioning System (GPS) determined point for 4-6 hours during the day or overnight (the nets were set in the evening (6.00 pm) and lifted at 6.00 am). In each sampling station a pair of monofilament and a multifilament net were set. Each of the nets consisted of the following mesh sizes: 1.7/8', 2', 2 ½', 3', 3 ½', 4', 4 ½', 5', 5 ½' and 6'. One net was set perpendicular to the other. Once the nets were retrieved from the water, fish were identified and sorted according to the sites, mesh sizes and the species (Keyombe *et al*., 2017a; Nyangau, 2021).

The number of O. *niloticus* that were caught in each mesh were recorded. The length and weight to nearest cm and g respectively in the laboratory at Kenya Marine and Fisheries Research Institute.

2.3 Data analysis

Growth parameters

The total length of O. *niloticus* was grouped into various length classes. Lake Naivasha's (interval of 10cm) smallest was 9.4cm while the largest was 59.4cm while Lake Oloiden's (class interval of 5cm) was 10cm and 49.9cm respectively. Population dynamic parameters were analyzed based on Electronic Length-Frequency Analysis using (ELEFAN in FAO ICLRAM Stock Assessment Tool (FISAT, version 1.2.2)) (Gayanilo, Sparre & Pauly, 1996; Pauly, 1996). The number of fish (n) in the analysis were 955 and 255 for Lake Naivasha and Lake Oloiden respectively.

An estimate of growth parameters was based on Von Bertalanffy Growth Function (VBGF) that was entered in FISAT. Its formular is as stated below;

$Lt = L\infty(1 - \exp ^ - K(t - to))$------ (i)

Where Lt= length that was predicted at an age t; L∞= asymptotic length; K= growth efficiency and t_0= the age the fish could have been at zero length. The length frequency data (monthly) was entered in FISAT (Gayanilo &Pauly, 1997). Asymptotic length was estimated using Powell-Wetherall plot function of FISAT. It relied on the mean length and some length at which all fish equal to that length/ longer were prone to full exploitation (Powell, 1979; Wetherall *et al*., 1987; Spare & Venama, 1998). Thus, the output was L∞, Z (total mortality) and K. The K-scan function of FISAT was used in estimating the growth function (K); where L∞ was the input parameter. Expected initial age to was estimated using the formular in Njiru *et al*., 2008a. The scan starting length was from 27.50cm and 34.40cm with the maximum length set at 35cm and 39.4cm for Lake Oloiden and Lake Naivasha respectively.

$t0 = -0..3922 - 0.27553LogL\infty - 1.038LogK$ ---- (ii)

Von Bertalanffy growth curves were fitted (using ELEFAN 1) using L∞ and K estimates. These same parameters were substituted for calculating growth performance index/ Munro's phi prime (ɸ’) in Pauly and Munro's formula as stated below (Pauly & Munro, 1984).

$\Phi' = Log\ K + 2LogL\infty$ ----- (iii)

The Pauly's empirical formular equation was used in calculating the Natural mortality (M) (Pauly, 1980). Total mortality (Z), an index of instantaneous rate of death in fish was estimated using linearized length converted catch curve (Spare & Venama, 1998). It required input of K, L∞ and mean temperature of the habitat which was 21.1 ^{o}C and 23.73 ^{o}C for Lake Naivasha and Lake Oloiden respectively.

$Log\ (M) = -0.0066 - 0.279Log(L\infty) + 0.6543LogK + 0.463Llog(T)$ --- (iv)

The fishing mortality (F) was calculated by getting the difference between Z and M.

$F = Z - M$ ---- (v)

While the exploitation rate (E) was a fraction of F in Z

$E = \frac{F}{Z}$ -----(vi)

Analysis of the recruitment pattern of O. *niloticus* followed method in FISAT software (Moreau and Cuende, 1991). The technique used restructured length-frequency analysis to identify possible recruitment peaks in the population. As input data, predetermined growth parameters derivatives (L∞ and K values) were fixed in NORMSEP routine to decompose length-frequency distribution data into two Gaussian distributions, each group given a starting period of 6 months. The procedure computed the relative strength of the observed recruitment pulses of O. *niloticus* during the study period.

The Virtual population analysis (VPA) was determine using a length structured VPA function in FISAT. The following were the input parameters: growth parameters (L∞ and K), numbers in each length class and length-weight relationship parameters (a and b). The length structured method reconstructed the population structure based on time series data of length sizes and numbers in each of the respective sizes classes, from which it was possible to estimate the virtual total population size, survivors, loss to natural and fishing mortalities and the total annual catches in each length class.

The condition factor of O. *niloticus* was calculated using Fulton’s cube law equation:

$K = \frac{W}{L^3}$ ----- (vii)

Where: K was the condition factor, W was the fish weight (g) and L was total body length (cm) (Fulton, 1911).

The Length and the weight relationship (LWR) :for O. *niloticus* was estimated using the equation below. The power function determines the parameters a (y - intercept) and b (allometry coefficient). Its equation was as stated below:

$W=aL^b$ -----(viii)

where: a was intercept, b was the slope, W was the fish weight (g) and L was the total body length (cm) (Wooton, 1990; Otieno et al., 2014).

Analysis of Variance for the total length, weight and the condition factor for O. *niloticus* were done in the Statistical Package for Social Scientists (SPSS, version 25). Further, a post-hoc test (Tukey pairwise) was done for those with significant differences.

3.0 Results

Oreochromis niloticus' condition factor was significantly different with respect to study site ($p<0.05$). Malewa's fish had the lowest while Korongo's had the highest condition factor (Table 1).

Table 1. The condition factor (K) of *Oreochromis niloticus* in the various study sites and Lakes Naivasha and Oloiden for one year

Study site	Condition factor K±SD
Oseria	1.86±0.17 (250)
Crescent	1.92±0.54 (245)
Korongo	1.98±0.38 (244)
Midlake	1.93±0.42 (86)
Malewa	1.81±0.35 (122)
Oloiden ST1	1.89±0.39 (162)
Oloiden ST2	1.84±0.48 (89)
Lake Oloiden	1.87±0.42 (255)
Lake Naivasha	1.90±0.403 (956)
Overall	1.89±0.41 (1212)

Note* = In brackets are the number of fish analyzed

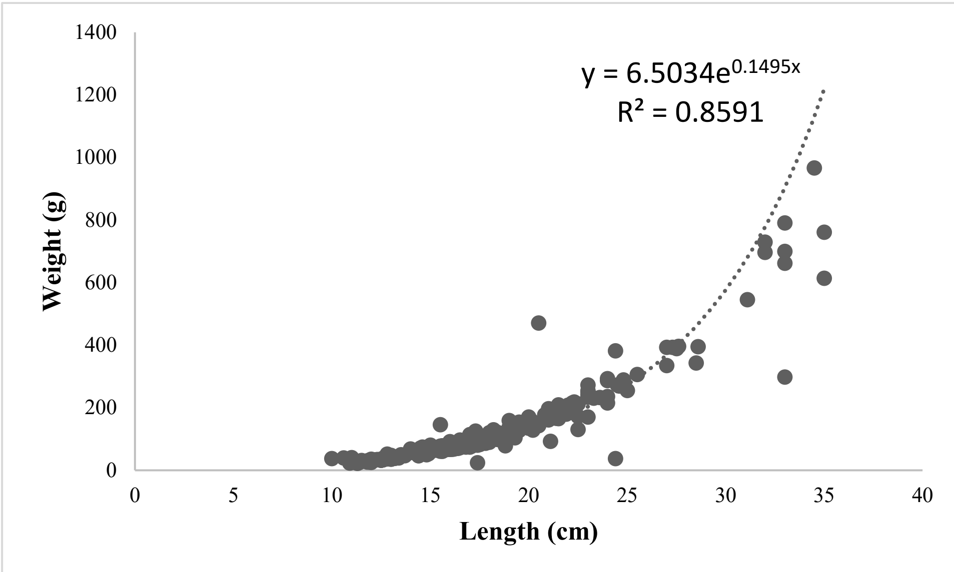
There was no significant variation in length and weight of O. *niloticus* in all the sites ($p<0.05$). Female's fish length did not vary from male ($p<0.05$); although, they were weightier than the male ($p<0.05$) (Table 2).

Table 2. *Oreochromis niloticus'* average total length (cm) and weight (g) in the respective sites, sexes and overall, in the study sites of Lakes Naivasha and Oloiden for one year

Site/ Category	N	TL (cm)±SE	W (g)±SE
Oseria	252	20.76 ± 0.37	210 ± 14.26
Crescent	247	22.08 ± 0.35	244 ± 13.01
Korongo	246	19.58 ± 0.31	175.79 ± 9.8
Midlake	88	18.25 ± 0.40	120.55 ± 8.4
Malewa	124	23.25 ± 2.3	186 ± 12.79
Oloiden ST1	164	18.96 ± 0.4	156 ± 12.32
Oloiden ST2	91	16.55 ± 0.47	102.68 ± 10
Female*	411	21.20 ± 0.27	217.90 ± 9.67
Male*	726	20.46 ± 0.43	182.07 ± 6.4
Overall	1212	20.30 ± 0.28	185.99 ± 5.15

Note: * immature were excluded (N=fish counts, TL=total length, W=weight and SE=standard error).

There was a curvilinear relationship between the length and weight and the fish had an allometric growth (b<3) while correlation was strong (0.86) (Figure 2).



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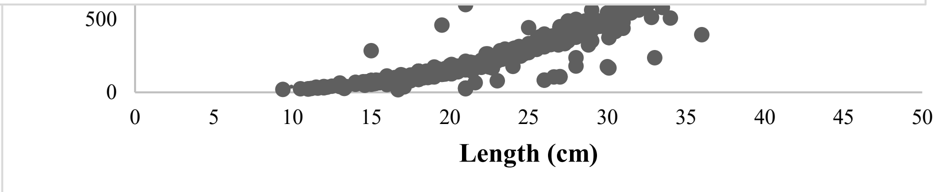

Figure 3. Length and weight relationship of *Oreochromis niloticus* in the Lake Oloiden (pooled data for both sexes) for one year

Powell-Wetheall estimate for the assymptotic length (L∞) was 54.83cm while mortality ratio (Z/K) estimate was 4.89 (Figure 4).

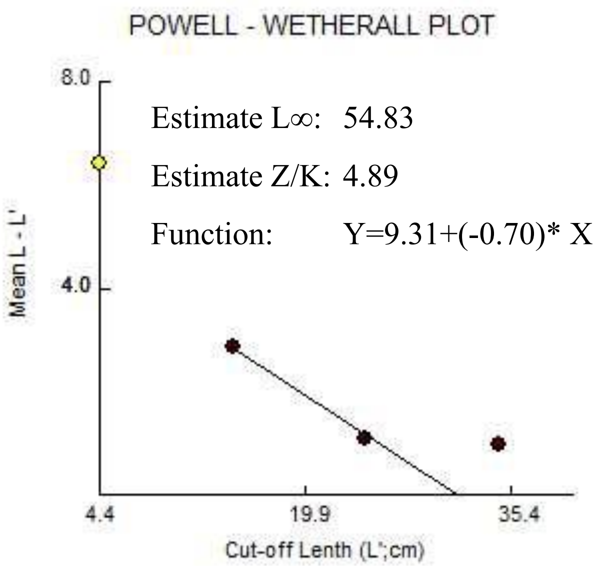

Figure 4. Powell-Wetherall plot for asymptotic length estimate of *Oreochromis niloticus* in Lake Naivasha for one year

Powell-Wetheall estimate for the assymptotic length L∞ was 56.75cm while the mortality ratio (Z/K) estimate was 7.24 (Figure 5).

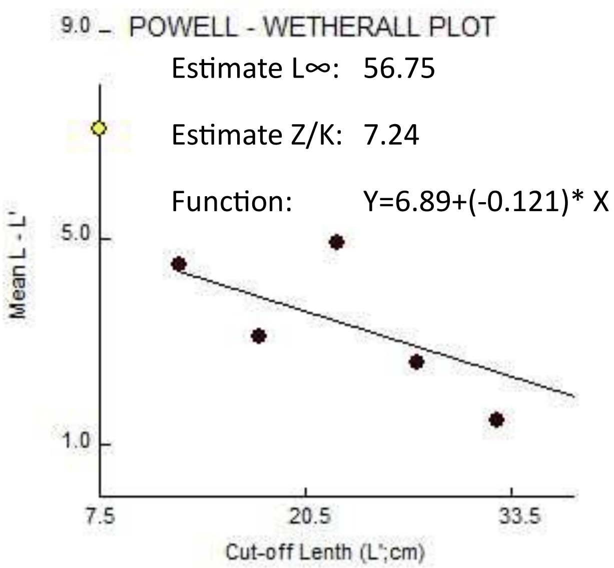

Figure 5. Powell-Wetherall plot for asymptotic length estimate of *Oreochromis niloticus* in Lake Oloiden for one year

The asymptotic length (L∞) was 41.37cm and the growth constant was $0.83yr^{-1}$. Estimated asymptotic length and growth constant yielded the growth curves superimposed on the structured length frequency of O. *niloticus* samples with an estimated growth performance (Munro phi prime, ϕ') of 3.15. In June, the highest frequency was 9.4cm while the lowest was 39.4cm (Figure 6). The age at which the fish could be zero (t_0) was estimated to be -0.75 year.

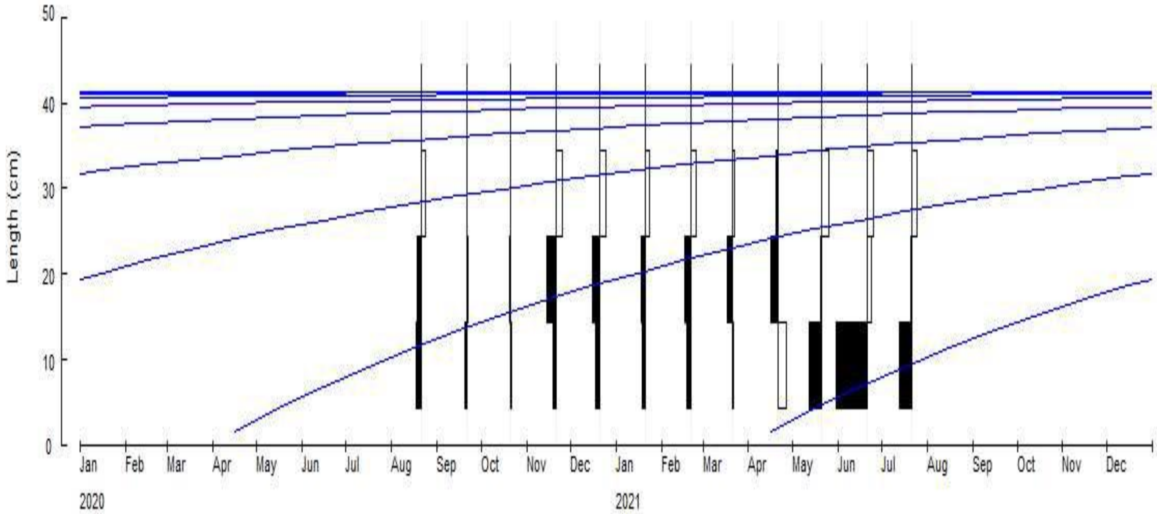

Figure 6. Von Bertallanfy Growth Function for *Oreochromis niloticus* in Lake Naivasha that was fitted by ELEFAN on restructured length frequency distribution for one year (L∞ = 41.37cm)

The asymptotic length (L∞) Was 36.75cm and the growth constant was 0.89yr^{-1}. Estimated asymptotic length and constant yielded the growth curves on structured length frequency of O. *niloticus* sample with an estimated growth performance (ϕ') of 3.08. February had the highest frequency for 19.4cm while its lowest was 39.4cm (Figure 7). The age at which the fish could be zero (t_0) was determined to be -0.77year.

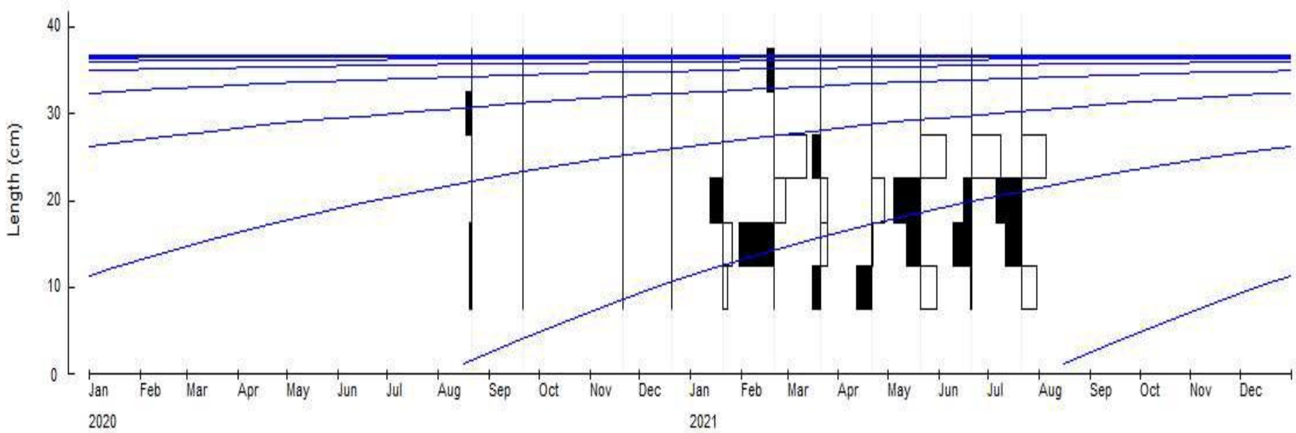

Figure 7. Von Bertallanfy Growth Function for *Oreochromis niloticus* in Lake Oloiden that was fitted by ELEFAN on restructured length frequency distribution for one year (L∞ = 36.75cm)

The graph illustrates two recruitment peaks (bimodal) with two pulses in a year. It had a weak recruitment pulse in June and a stronger in September. The lowest recruitment was observed in November (Figure 8).

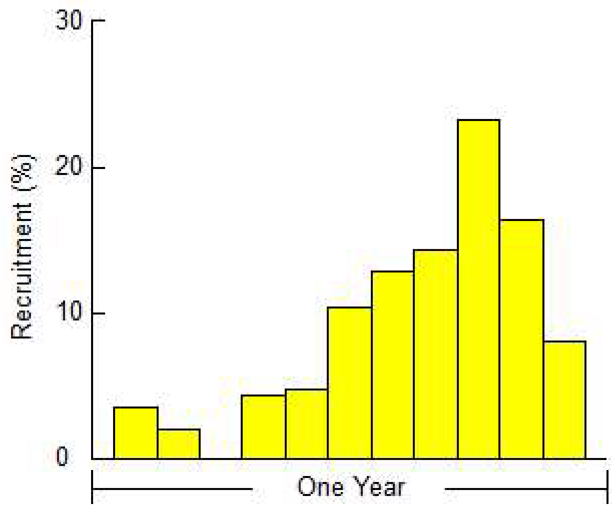

Figure 8. Recruitment pattern for *Oreochromis niloticus* in Lake Naivasha for one year

There was a bimodal recruitment peak with two pulses in a year. The first peak was highest in April and lowest was in January. The second peak was strongest in July while November had the weakest pulse (Figure 9).

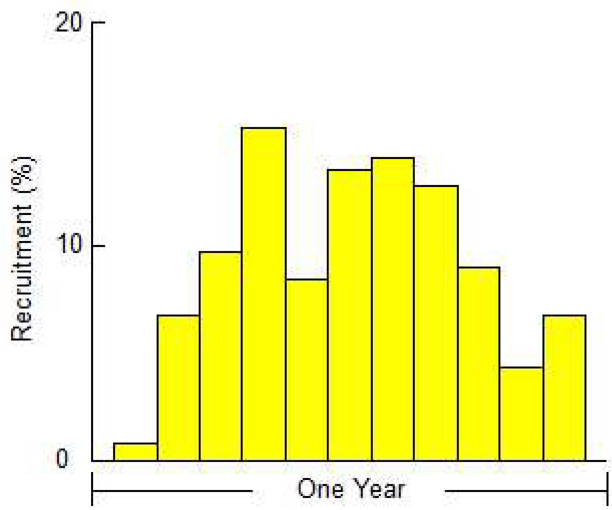

Figure 9. Recruitment pattern for *Oreochromis niloticus* in Lake Oloiden for one year

The total mortality was estimated from the linearized catch curve (dark points were estmate of the catch curve). The total mortality (Z) in Lake Naivasha was 2.51year^{-1}. The natural mortality (M) by Pauly's empirical formular was 1.27year^{-1} while the natural mortality was 1.24year^{-1}. Exploitation rate was 0.49 and the catch curve illustrated mortality of less than one year old fish (Figure 10).

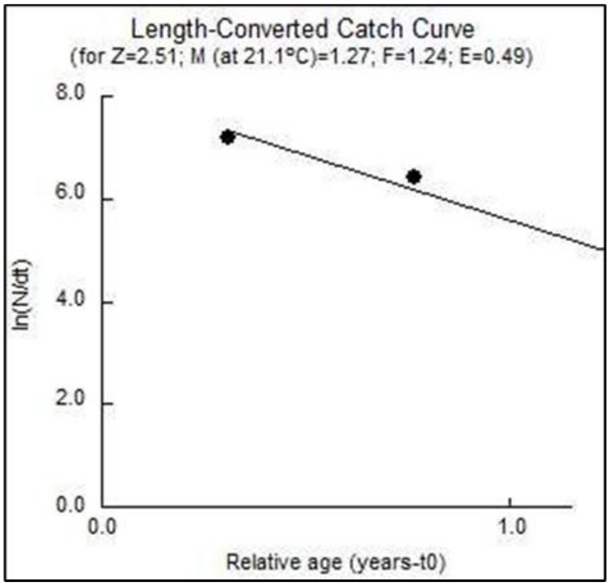

Figure 10. Length-Converted Catch Curve for *Oreochromis niloticus* in Lake Naivasha for one year

The total mortality (Z) in Lake Oloiden was 3.53year^{-1}, fishing mortality (F) was 2.08year^{-1} while the natural mortality was 1.45year^{-1}. Exploitation rate was 0.59 and the dark shaded points were selected for estimated from the catch curve. Unshaded points were extrapolated with the natural mortality (M) estimate. Catch curve illustrated mortality of less than two years old fish (Figure 11).

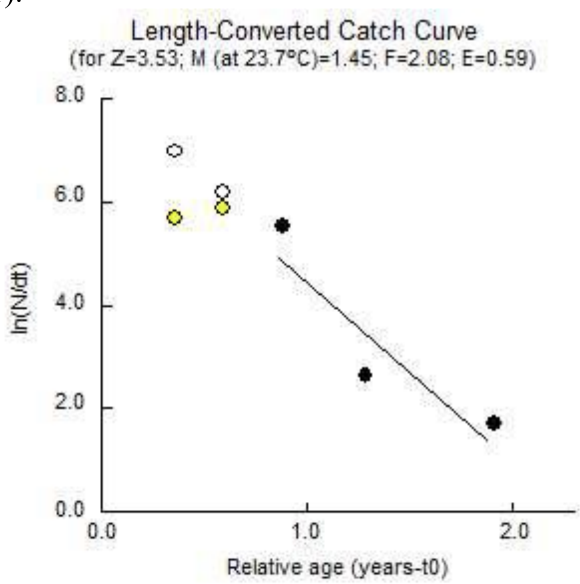

Figure 11. Length-Converted Catch Curve in FISAT for *Oreochromis niloticus* in Lake Oloiden's estimation of the total mortality from length frequency distribution.

Fish of 19.40cm TL had the highest fishing mortality. Fish of 9.4cm TL have the highest number of survivors and natural mortality. The sizes from 19.4cm TL were fully exposed to fishing mortality and they contributed to the annual catch (Figure 12).

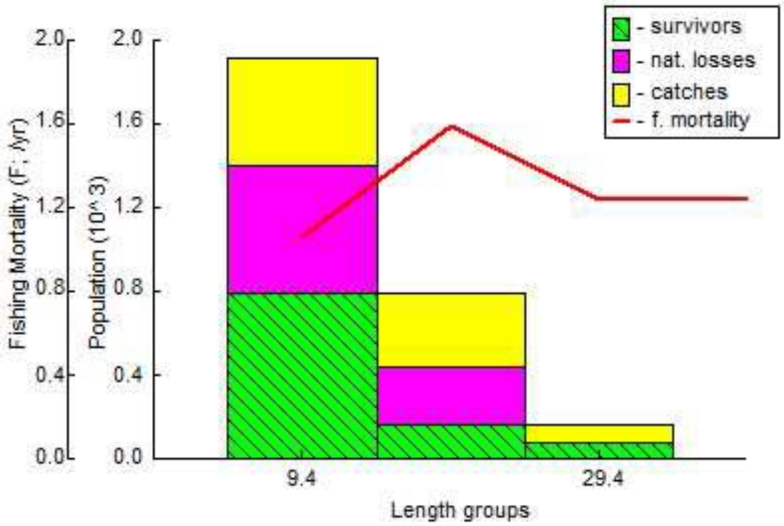

Figure 12. FISAT output of virtual population analysis (VPA) for *Oreochromis niloticus* in Lake Naivasha showing the population structure by length groups; survivors=estimate number of surviving individuals per length class; nat. losses=estimated number lost to natural mortality; catches=estimated number of total catches; f.mortality=estimated fishing mortality per year

Fish of 20cm TL had the highest fishing mortality. Fish of 10cm TL have the highest number of survivors and natural mortality. Figure 13 shows that there were seldom survivors above 30cm TL.

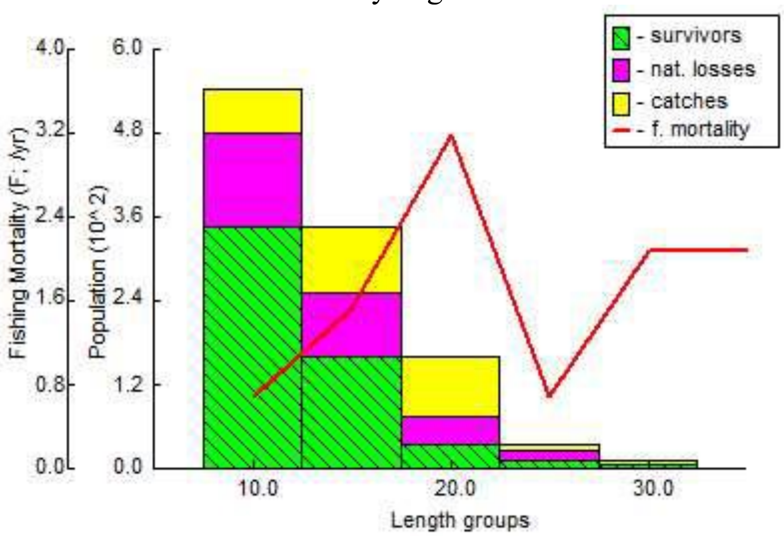

Figure 13. Length-structured Virtual Population Analysis for *Oreochromis niloticus* in Lake Oloiden for one year

4.0 Discussion

A fish stock is a population of a single fish species inhabiting a specific area and sharing common growth and mortality characteristics. Fishery development can influence these stocks, as fish populations respond to changes in exploitation level and species abundance. Studies on the dynamics of a fish populations provide insights into the ecological status of the resource. They also help interprate changes occuring in the fishery that relate to habitat characteristic, exploitation and predation (Nyangau, 2021).

Nile tilapia's condition factor was high and followed cube's law in both Lake Naivasha and Lake Oloiden sites. This findings align with Otieno *et al*., 2014 but contrast with Waithaka *et al*., 2020, which could indicate an improvement in fish health. Malewa's fish had the lowest condition factor while korongo's fish had the highest. This difference could be due to a higher habitat degradation and fishing pressure at Malewa (Njiru *et al*., 2019). The condition factor may be influenced by abiotic factors such as temperature, dissolived oxygen (DO), pH, food availability, seasonal variation and reproductive status (Otieno *et al*., 2014; Nyangau, 2021; Waithaka *et al*., 2020).

There was variation in the mean length and weight of O. *niloticus* across sites and male and female lengths did not vary significantly. Female fish were heavier than male fish, which was consistent with previous findings in Lake Naivasha (Nyangau, 2021). The length and weight relationship (LWR) for O. *niloticus* showed an allometric growth in both lakes' sites, simiar to Waithaika *et al*., 2020 in Lake Naivasha. The current study findings contrasted with the earlier research findings by Otieno *et al*., 2014. Nyang'au, 2021's findings, showed thay some fish in particular sites had allometric growth in the Lake Naivasha. In the present study O. *niloticus* showed a negative allometric growth, indicating that the fish became slender as the length increased. This could be attributed to the variation in physical and chemical parameters post water level rise. The condition factor and LWR gave an insight of the structure of the population and its relation to the habitat (Nyang'au, 2021).

Lake Oloiden had a higher Z/K and which suggested a higher mortality relative to growth. This could be due to environmental factors or a higher fishing pressure, indicated by an exploitation rate greater than 0.5. In contrast Lake Naivasha's Z/K suggested a more balance mortality rate, allowing better population's sustainability. The $L\infty$ for both lakes was lower than that reported by Nyangau, 2021; although, Z/K was similar to Lake Oloiden's. Powell-Wethall estimates of assymptotic length ($L\infty$) and mortality ratio (Z/K) help assess the growth potential and mortality rate respectively.

The growth performance index and asymptotic length ($L\infty$) showed relatively stable growth potential. Although, $L\infty$ was slightly lower in Lake Naivasha compared to Lake Oloiden, this could reflect habitat-related differences. Similar results were reported by waithaka *et al*. (2020) ($L\infty$= 42cm); showing variability in tilapia growth between the sampling periods. The von Bertalanffy Growth Function (VBGF) parameters help interpret and model the length-at-age data and provide insights on growth dynamics of the population.

The estimate for the fish's age at zero (t_0) was - 0.75year and 0.77year for Lake Naivasha and Oloiden respectively). The values were higher than in previous findings; they indicated a slightly onset of measurable growth compared to Nyangau (2021) who reported -0.55year. Lake Oloiden's fish showed a slightly faster early growth rate. The variations could be linked to environmental variation. Abdalla *et al*. (2024) found by values of -0.4year and -0.8year for Sudanese Nile tilapia while Keyombe et al. (2017c) reported -0.53year for Lake Victoria stock. The present study findings aligned with other regional studies on *Oreochromis niloticus*, which suggested favorable conditions that supported early growth. This is key in influencing recruitment strength and population recovery of an exploited fishery.

The similar $L\infty$ values were suggested comparable maximum size potential; although there was a difference in the values obtained by Powell-Wetherall and VBGF. This variation indicates that the two methods provide different insights into the potential maximum size the fish can attain under prevailing environmental and ecological conditions. The lower VBGF-derived $L\infty$ values likely reflect more realistic estimates of growth potential based on actual observed growth rates, which are influenced by environmental factors such as food availability, habitat quality, and fishing pressure. Keyombe *et al*., 2017b reported a maximum observed length of 46cm in Lake Naivasha. In the study the condition factor was lower during the dry season compared to the wet season

and the fish showed positive allometry. There was stability in the LWR and K between the seasons which indicates their minimal impact on growth and their condition.
Conversely, the higher Powell-Wetherall estimates are theoretical values derived from length-frequency data, which may overestimate the true asymptotic length, especially if larger individuals are underrepresented due to selective fishing or higher mortality rates. Consequently, Prevailing environmental conditions and activities may prevent the fish population from attaining their maximum length such as environmental stressors and fishing pressure; although, Nyangau, 2021 indicated O. *niloticus* to be more tolerant.
In Lake Naivasha, there was a peak of 9.4cm fish frequency, which suggested high recruitment rate andd dominance of younger fish. Larger fish (>30cm) were significantly much less frequent, which could be due to selective fishing pressure or natural mortality. The presence of varied classes supported the idea of continous recruitment which maintains population sustainability. This aligns with earlier findings by Moreau and Cuende, 1991, who highlighted bimodal recruitment as typical in tilapia fisheries.
Lake Oloiden had a peak fish length at 19.4cm, which indicated a strong presence of juvenile fish, possibly related with mid-year spawning cycle. Small fish were absent in January and November, consistent with low recruitment in those months. Large fish (>50cm) were rare, which could be due to selective fishing pressure or natural mortality. The growth performance index findings in both lakes were similar to previous O. *niloticus* studies in Lake Naivasha (Nyangau, 2021). The growth coefficient was higher in Lake Oloiden than in Lake Naivasha, which suggested faster growth. Its growth performance was moderate in Lake Naivasha while it was higher in Lake Oloiden; a higher $L\infty$ indicated slightly greater growth potential. Nyangau, 2021 showed that the water quality could be favorable or unfavorable to fish growth and productivity. An estuarine environment could support higher productivity, its planktivorous and thus formed a good nursery ground (Guto *et al*., 2023).
The bimodal recruitment peaks of *Oreochromis niloticus* in both lakes meant that the fish population experience two distinct recruitment pulses annually (Nyangau, 2021). In Lake Naivasha, recruitment peaked during the long rainy and long dry season, with the lowest recruitment at the start of long rainy and short rainy season. In Lake Oloiden the recruitment peak coincided with long rainy season while the lowest recruitment was during the short dry season. These patterns aligned with the region's bimodal rainfall pattern and match previous research in Lake Naivasha (Waithaka *et al*., 2020). Seasonal rainfall cycle and habitat condition likely shape recruitment patterns and reproduction. Njiru *et al*., 2008 noted that recruitment success could be influenced by temperature fluctuations, food availability and predation pressure, which explained the low recruitment during the short rainy and short dry seasons.
The catch curve analysis showed that in Lake Naivasha, fish younger than one year faced a high fishing mortality. In Lake Oloiden, fish could live up to two years, but higher mortality rate (Z, F and M) suggested greater fishing pressure and environmental stress. Fish in Lake Naivasha often die before they reach one year while in Lake Oloiden, the entire population could die within two years due to fishing pressure. The exploitation rate was 0.49 in Lake Naivasha, which indicated an optimal exploitation whereas Lake Oloiden's rate was above 0.5, which showed overexploitation; as 0.5 is the maximum sustainable yield threshold. The exploitation rate for Lake Naivasha differed from Nyangau, 2021 findings who found it to be overexploited ($E = 0.69$) (analysis from commercial fishery data). The trend aligned with Njiru *et al*. (2019), who noted that Lake Naivasha faced significant fishing pressure that affected the stock's sustainability.

The length-structured virtual population analysis (VPA) provided insights into the population structure dynamics, survival rates and fishing mortality. In Lake Naivasha, fish smalle than 9.4cm were less vulnerable to fishing but suffered higher natural mortality. Fish around 19.4cm faced the highest fishing mortality which indicated they were the most targeted size In Lake Oloiden fish around 10cm had the highest survival rate while those around 20cm faced the highest fishing mortality. Peak fishing in both lakes was lower than that found by Nyangau, 2021, who reported 21cm TL, in Lake Naivasha. In both lakes, there were almost no survivors among fish larger than 30cm TL, which was consistent with previous finding in Lake Naivasha.

5.0 Conclusion

The assessment of *Oreochromis niloticus* population dynamics in Lake Naivasha and Lake Oloiden provided critical insights into the growth pattern, recruitment trends, mortality rates and exploitation levels. There was a bimodal recruitment pattern in both lakes. Mortality and exploitation rates showed that Lake Naivasha was at optimal exploitation, whereas Lake Oloiden was overexploited. The situation in Lake Naivasha and Lake Oloiden calls for stricter fishing control such as reducing fishing effort, mesh size and enforcing seasonal closures. Additionally, habitat conservation measures could aid to enhance sustainability.

6.0 Acknowledgement

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7.0.Permit and ethical clearance

There was ethical compliance in the sampling according to the guidelines in institution animal care protocol. The study was conducted under Kenya Marine Fisheries Research Institute, Naivasha station (KMFRI). Fish sample of *Oreochromis niloticus* were collected in the routine aquatic research surveys. Thus, the study did not need a permit; since, KMFRI is government agency that's mandated to conduct research in fisheries and ecology in all Kenyan water bodies.

8.0 Conflict of interest

All the authors have no conflict of interest in the research that as undertaken; no financial implications.

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