Some Aspects of *Oreochromis niloticus baringoensis* (Trewavas, 1983) Fishery Assessment and Influence of Selected Water Quality Parameters in the Hot Springs of Lorwai Swamp, Baringo, Kenya

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Running title: Fishery assessment of Tilapias in hot water springs

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Abstract

Water quality has been documented to affect the biology and well-being of fish. This study therefore investigated some aspects of *Oreochromis niloticus baringoensis* (Trewavas, 1983) fishery assessment and the influence of selected water quality parameters in two hot springs draining into Lorwai Swamp; Lake Bogoria Spa spring and Chelaba spring between the months of July and August 2018. A total of 445 fish were collected; 244 from Lake Bogoria Spa spring and 201 from Chelaba spring using a seine net. Length Weight Relationship (LWR) was determined using Le Cren's equation; $W=aTL^b$ and Fulton's condition factor (k) determined using Ricker's equation; $100W/L^3$. The LWR results indicated an isometric growth for fish from both springs. The mean (± SD) k-values for fish in Lake Bogoria Spa spring were 2.02±0.25 for the males, 2.02±0.27 for the females and 2.00±0.26 for both sexes. In Chelaba spring, the mean k-values were 2.03±0.21 for the males, 1.97±0.25 for the females and 2.00±0.23 for both sexes. These values indicated that the fish in these hot springs are in a very good condition and health status with k-values above 1. Some of the selected water quality parameters indicated a positive correlation with the length, weight and Fulton's condition factor of *O. n. baringoensis* in the two hot springs.

Keywords: Condition factor, hot springs, length-weight relationship, Lorwai Swamp, *Oreochromis niloticus baringoensis*, water quality

Introduction

Oreochromis niloticus baringoensis (Trewavas, 1983), commonly referred to as Baringo tilapia is one of the seven sub-species of *Oreochromis niloticus* and is endemic to Lake Baringo, Kenya (Trewavas, 1983). Although tilapias are native to Africa and the Middle East where the temperatures tend to be warmer, they easily adapt to different environments with different parameters including temperature. This makes them an interesting species of fish to study. Temperature affects the physiology, growth, reproduction and metabolism of tilapia species (El-Sayed and Kawanna, 2008). Tilapia species found in waters outside the required temperature range tend to use a high amount of their dietary energy in maintaining the internal physiology functions rather than for growth (El-Sayed *et al*., 1996). The fish, therefore, experiences stunted growth. Tilapia species tend to grow best and be in good health in waters with a temperature range of 20-30°C, preferably optimal at 28°C (Ngugi *et al*., 2007). However, it should be noted that different strains of Nile tilapia differ with respect to how they cope with an increase or decrease in temperature. For example, a sub-species of Nile tilapia, *O. niloticus filoa* inhabits the hot alkaline springs and pools of the Awash River system in Ethiopia (Trewavas, 1983) and therefore the occurrence of Nile tilapia in hot water springs is not a new phenomenon. A natural population of *O. n. baringoensis* was found in a warm water spring (Lake Bogoria Spa spring) discharging into the Lorwai Swamp system during a genetic survey of the various populations of *O. niloticus* in Kenya (Nyingi *et al*., 2009). The water temperature in the spring was elevated to 36°C (Nyingi *et al*., 2009). Moreover, this population was found to have a slight genetic variation from its counterpart in Lake Baringo and this could indicate that a barrier has prevented gene flow between the two populations at some stage (Nyingi *et al*., 2009). Although not yet explained, the genetic plasticity of this natural population may also be as a result of the high temperatures in the springs.

Apart from temperature, other water quality parameters within these springs which have previously been documented include; pH, dissolved oxygen, electrical conductivity and nitrates concentration (Ashley *et al*., 2004; Owen *et al*., 2004). This, therefore, formed a basis for the study so as to establish the condition and health status of the *O. n. baringoensis* in these hot springs. Results obtained were compared to those in Lake Baringo and this will in turn help in determining whether the habitat is suitable for sustaining the fish population. There are no earlier studies that have been done in a similar environment in Kenya and previous studies documented on the endemic *O. n. baringoensis* are only from Lake Baringo.

The importance of determining Length Weight Relationship (LWR) and condition factor of fish in fisheries management has been extensively demonstrated (Allen, 1938; Le Cren, 1951; Barnham and Baxter, 1998; Jones *et al*., 1999; Lizama *et al*., 2002). The occurrence of *O. n. baringoensis* in the hot springs of Lorwai Swamp elicited a lot of interest in this study. There has been a lot of documentation on the biology and behaviour of fish living in an environment with elevated water temperatures including hot springs and geothermal springs. From the temperate regions, a study by Miller (1949) was doneto investigate the survival and tolerance of a *Cyprinodon* sp. in springs of Death Valley in California where temperatures have been recorded to be as high as 43.33°C. The investigations found that the waters in these springs were stratified and that the fish could have been swimming a few inches below the 43.33°C stratum of water where temperatures could have been cooler. Lienau(1991) documented aquaculture operations using geothermal waters across United States of America with water temperatures being as high as 40.56°C. Some of the fish species cultured in these geothermal waters included tilapia, catfish, bass and sturgeons. In the tropical region, Narahara *et al*. (1995) documented the respiratory physiology of *Oreochromis alcalicus grahami* (Lake Magadi tilapia). This fish endures high temperatures of up to 42.50°C in the alkaline and frequently hypoxic hot springs of Lake Magadi, Kenya. However, no study has been carried out to investigate the condition and health status of fish found in these extreme environments. The main focus of this study was to determine the condition factor and health status of *O. niloticus baringoensis* found in the hot springs draining into Lorwai Swamp. This was the first baseline study on the endemic tilapiine species inhabiting hot water springs in East Africa and will provide crucial background information for future studies.

Materials and Methods

Study Area

This study took place at Lorwai Swamp (Figure 1) which is a freshwater wetland located in Baringo County, Kenya. For a long time, it has been documented as Loboi Swamp and has also been well described by various authors including (Ashley *et al*., 2002, 2004; Nyingi *et al*., 2009; Terer *et al*., 2012; Ndiwa *et al*., 2014; Gitau and Verschuren, 2016). The name "Lorwai" according to the local language means a place with water. The swamp has an area of approximately 1.5 km^2 with a length of 3 km and a width of 0.5 km (Ashley *et al*., 2004). It lies just north of the equator at 0º 21′ N and 36º 03′ E at an altitude of 1000 m above sea level within the Eastern Rift Valley. The swamp is shared among three locations; Loboi, Sandai and Kapkuikui on the drainage divide between Lakes Baringo and Bogoria within the extensive Baringo County. Being located in a semi-arid tropical region, the swamp serves as an important reservoir of freshwater during dry seasons (Ashley *et al*., 2004). The Lorwai Swamp ecosystem provides grazing grounds and drinking points for the cattle. The small community living around the swamp use it as a bathing point, laundry area, source of food (fish) and water for domestic use. The papyrus harvested from the swamp is used for making mats, fodder for the cattle, roofing and as fuel (Terer *et al*., 2012). Its source of water is majorly from three main hot water surface springs: Lake Bogoria Spa spring (spring of men), Chelaba spring (spring of women) and a smaller spring called the Turtle spring, as well as a series of artesian blister bogs which discharge water into the swamp (Ashley *et al*., 2002). Lake Bogoria Spa spring is used as a natural spa in the adjacent Lake Bogoria Spa Hotel and also partially diverted to a nearby irrigation scheme known as Loboi-Lorwai Irrigation Scheme for agricultural purposes. The Loboi-Lorwai Irrigation Scheme comprises of many individually owned plots where vegetables are grown. The hot springs harbour two species of fish: *Clarias gariepinus* and a genetically distinct strain of *O. n. baringoensis*.

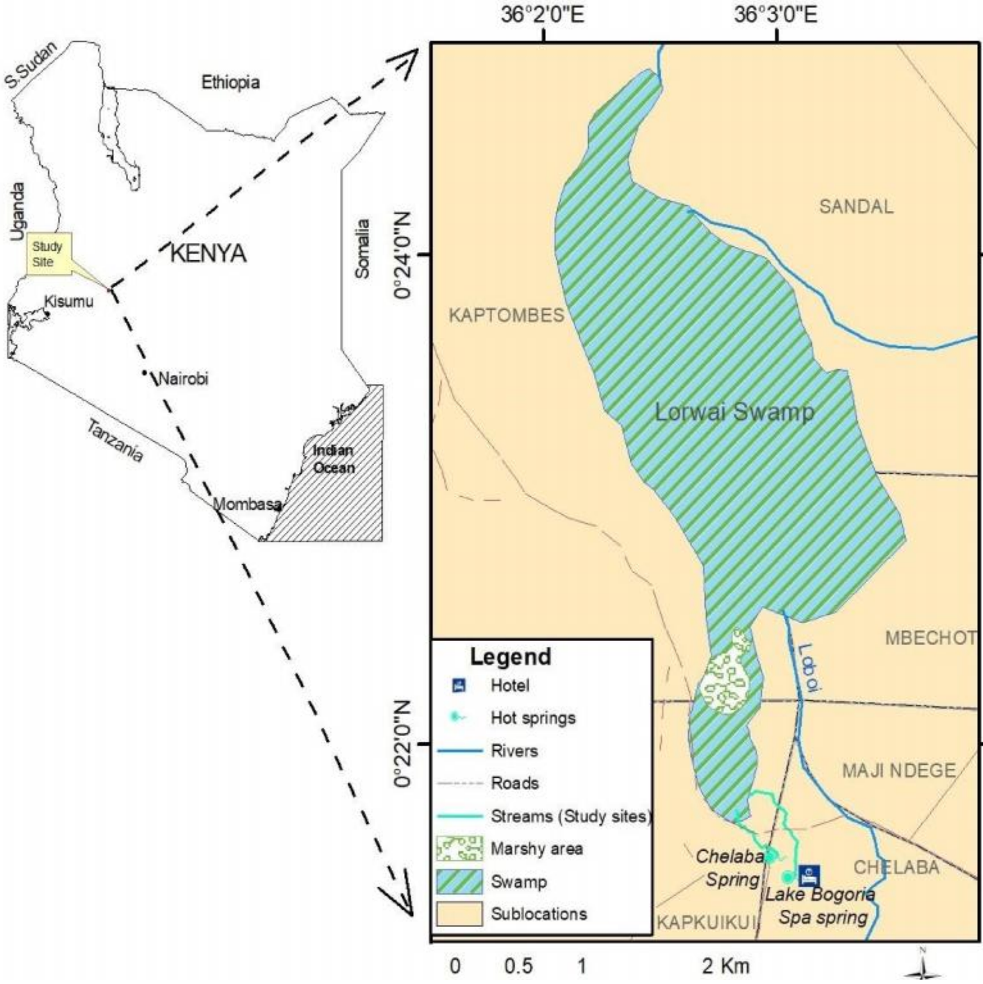

Figure1: Map of Kenya showing the location of Lorwai Swamp. (Source: Redrawn from Survey of Kenya Topographical maps, scale 1:50,000)

Water Quality Parameters

Dissolved Oxygen (DO), Electrical Conductivity (EC), pH, temperature and turbidity were measured *in situ* in the two springs during the study period. These parameters were taken before the fish were collected. The EC, pH and temperature variations were measured using a universal meter (Model: HACH HQ 40d, USA). Turbidity values were measured using a turbidity meter (HACH 2100q, USA) while a DO meter(HACH HQ 30d, USA) was used to measure the DO concentrations in the springs. These measurements were carried out according to APHA (2004) standards. Water samples from the springs were collected in triplicates using 500 ml acid-washed sample bottles during each sampling session. The water samples were stored in a cool box prior to transportation to the water quality laboratory at the Department of Biological Sciences, Egerton University, Njoro and stored in a refrigerator at 4°C before the analyses on Chlorophyll-*a* and Total Suspended Solids (TSS) were carried out. The water samples collected were first filtered using 0.45µm Whatman GF/C filters.The concentration of TSS was determined gravimetrically on Whatman GF/C filters after drying to a constant weight at 95°C. In Chlorophyll-*a* determination, the filter papers together with the seston were folded and then covered by aluminium foil and stored in a freezer overnight so as to aid in the bursting of the cells. The seston and the filters were then homogenised in a tissue grinder at around 5,000-rpm for about 1 minute, covered with 5 ml of 90% aqueous acetone. The samples were then transferred into a centrifuge tube, the grinder rinsed with 90% acetone (volume used was noted) and the rinse added to the extraction slurry. The volume was then adjusted to 10 ml with 90% acetone and the sample left for at least 8 hrs in the dark at 4°C for the Chlorophyll-*a* extraction. After incubation, the sample was centrifuged for 10 min at 3,500 rpm. The clarified extract was then decanted into a clean test tube. Light absorbance of the Chlorophyll-*a* extract was measured with a spectrophotometer at 750 nm and 663 nm. To correct for turbidity and other colours, absorption read at 750 nm was subtracted from the readings made at 663 nm.

Water samples for nutrient analysis, which included ammonium nitrogen (NH_4-N), nitrite-nitrogen (NO_2-N), nitrate nitrogen (NO_3-N) and Total Nitrogen (TN), Soluble Reactive Phosphorus (SRP), and Total Phosphorus (TP) were also collected in triplicates using 500-ml acid-washed plastic bottles. The samples were transported in a cool box to Egerton University, Department of Biological Sciences for analysis immediately on arrival. Nutrient (nitrogen and phosphorus) concentrations were determined calorimetrically following conversion of the concentrations from sample absorbance values in relation to the known standards. NH_4-N was determined by phenol-hypochlorite method, NO_2-N using the sulphanilamide method, NO_3-N using sodium-salicylate method (APHA, 2004), and TN using persulphate method (Koroleff, 1999). On the other hand, phosphorus components such as SRP and TP were analyzed using the ascorbic acid method. However, TP had to be first subjected to digestion of unfiltered water using persulphate to reduce phosphorus present into SRP before the use of ascorbic method (APHA, 2004).

Field Sampling and Measurements for Fish

Samples of *O. n. baringoensis* were collected from two of the hot springs; Lake Bogoria Spa spring and Chelaba spring. Sampling took place between

July 2018 and August 2018. Samples were collected every fortnight using a seine net. The fish were then placed into buckets with the springs' water and transported live to the laboratory at the Department of Biological Sciences at Egerton University, Njoro, Kenya. In the laboratory, the fish were killed by cervical dislocation (Schäperclaus, 1990). The total lengths (TL, cm) and the Weights (W, g) of the fish were measured using a fish measuring board (Lagler, 1970) and a digital weighing balance (Sartorius ED4202S, Germany) respectively and then dissected so as to determine the sex. A total of 244 fish were collected from Lake Bogoria Spa spring and 201 fish from Chelaba spring.

Determination of Length – Weight Relationship

Using the observed and recorded lengths and weights, the length-weight relationship was calculated according to Le Cren(1951) as $W=aTL^b$, Where: W= the weight of the fish in grams (g), TL= the total length of the fish in centimeters (cm), a= the intercept of the regression line, b= the slope of the regression line (Allometric coefficient).

Determination of Fulton's Condition Factor

The value of the "b" exponent from the LWR provides important information on fish growth and whether Fulton's condition factor "k" can be used or not. Once the LWR had been determined and b proven to be equal to 3, the condition factor of each fish was calculated using the formula $k = \frac{100W}{L^3}$(Ricker, 1975), where: k=Fulton's condition factor, W= the weight of the fish in grams and L= the total length of the fish in centimeters. The "k" values were then sorted according to sex and the mean "k" value for the male and female fish calculated separately.

Influence of the Selected Water Quality Parameters on the Length, Weight and "k" Values of *O. n. baringoensis* from Lake Bogoria Spa and Chelaba Springs

The correlation between the selected water quality parameters and the length, weight and Fulton's Condition Factor values was determined by running a Principal Component Analysis test using IBM-SPSS Version 20 (Tharwat, 2016).

All statistical analyses and tests were carried out at a significance level of p=0.05.

Results

Water Quality Parameters

The mean ± standard deviation (SD) values of the selected water quality parameters in the two hot springs flowing into Lorwai Swamp are presented in Table 1. In Lake Bogoria Spa spring, the temperature ranged between 35.60 – 36.90°C. Electrical Conductivity ranged between 354.00 – 442.00 µScm^{-1} and dissolved oxygen mean was 4.10 mgL^{-1}. On the other hand, Chelaba spring on the other hand had a temperature range of between 33.50 – 36.80°C. The EC range was between 340.00 – 427.00 µScm^{-1} with a DO mean of 4.33 mgL^{-1}. Most of the physico-chemical variables measured did not differ significantly between the two hot springs ($p > 0.05$) except turbidity (Student's *t*-test, t = -3.81, df = 22, p=0.01). Turbidity was significantly higher in Chelaba spring than in Lake Bogoria Spa spring. For the nutrient concentrations, Lake Bogoria Spa spring had higher concentrations of NH_4-N and NO_2-N while Chelaba spring had higher concentrations of NO_3-N, SRP and TP. The concentration of TN was the same in the two springs. There was a significant difference in the NO_3-N (Student's *t*-test, t = 0.70, df = 22, p=0.001) and TP (Student's *t*-test, t = -1.09, df = 22, p=0.03) concentrations.

Table 1: Water quality parameters in the hot springs flowing into Lorwai Swamp (p=0.05)

Water variable	Lake Bogoria Spa spring	Chelaba Spring	p value	t value	df
Dissolved Oxygen (mgL^{-1})	4.10±0.26	4.33±0.72	0.37	-0.92	19
Electrical Conductivity (µScm^{-1})	397.17±43.92	383.50±42.38	0.45	0.78	22
pH	6.91-7.37	6.77-7.50	0.47	0.74	22
Temperature (°C)	36.42±0.40	36.01±0.97	0.19	1.35	22
Turbidity (NTU)	4.63±0.88	11.00±5.73	0.01	-3.81	22
Chlorophyll *a* (µgL^{-1})	13.79±0.03	13.81±0.02	0.37	0.92	22
TSS (mgL^{-1})	11.67±3.89	15.00±6.74	0.15	-1.48	22
NH_4-N (µgL^{-1})	68.58±43.21	65.58±41.17	0.97	1.74	22
NO_2-N(µgL^{-1})	5.76±4.61	4.43±4.68	0.88	0.70	22
NO_3-N (mgL^{-1})	1.30±0.69	1.81±0.17	0.000	-2.47	22
TN (mgL^{-1})	0.17±0.001	0.17±0.001	0.68	-0.48	22
SRP (µgL^{-1})	53.93±20.80	68.57±25.68	0.08	-1.54	22
TP (µgL^{-1})	73.81±19.81	84.05±25.74	0.03	-1.09	22

Length-Weight Relationship

The total length of fish collected from Lake Bogoria Spa spring ranged between 6.20 and 23.00 cm while the weight ranged between 4.06 and

227.24 g. In Chelaba spring the total length ranged between 6.00 and 23.70 cm while the weight ranged between 8.43 and 299.85 g (Table 2).

Table 2: Total Lengths and weights of *Oreochromis niloticus baringoensis* from the hot springs draining into Lorwai Swamp

Site	Sex	n	TL (cm)		W (g)		a value	b value
			Min	Max	Min	Max		
Lake Bogoria Spa spring	Male	131	6.20	23.00	4.06	227.24	0.21	2.98
	Female	113	6.90	21.60	5.89	155.20	0.02	3.07
	Both sexes	244	6.20	23.00	4.06	227.24	0.02	3.07
Chelaba spring	Male	127	6.00	23.70	8.57	299.85	0.03	3.02
	Female	74	7.70	17.00	8.43	97.70	0.01	3.22
	Both sexes	201	6.00	23.70	8.43	299.85	0.02	3.09

The length-weight relationships for the fish were calculated per spring and further separated according to sexes. Different allometric coefficient (b) values were recorded between the male and female *O. n. baringoensis* collected from Lake Bogoria Spa spring of 2.98 and 3.07 respectively (Figures 2a and 2b). The "b" value for both sexes of *O. n. baringoensis* collected from Lake Bogoria Spa spring was also 3.07 (Figure 2c).

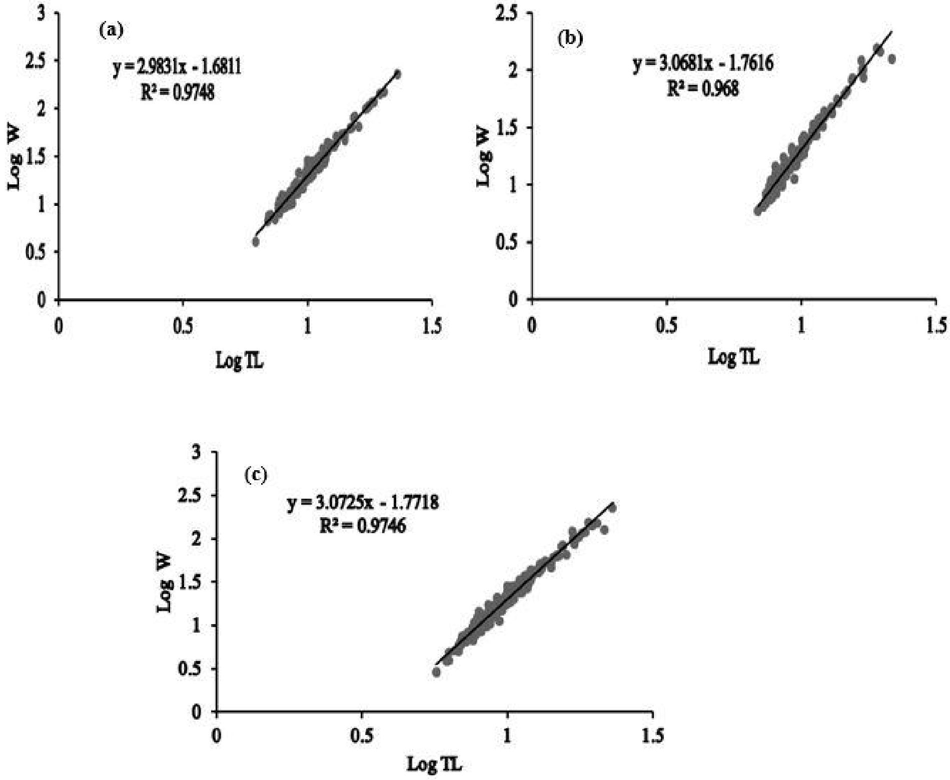

Figure2: Length-weight relationship for the (a) male population, (b) female population and (c) both sexes of Oreochromis niloticus baringoensis in Lake Bogoria Spa spring

From Chelaba spring, the “b” values recorded for the male and female *O. n. baringoensis* were 3.02 and 3.22 (Figures 3a and 3b) while that of both sexes was 3.09 (Figure 3c).

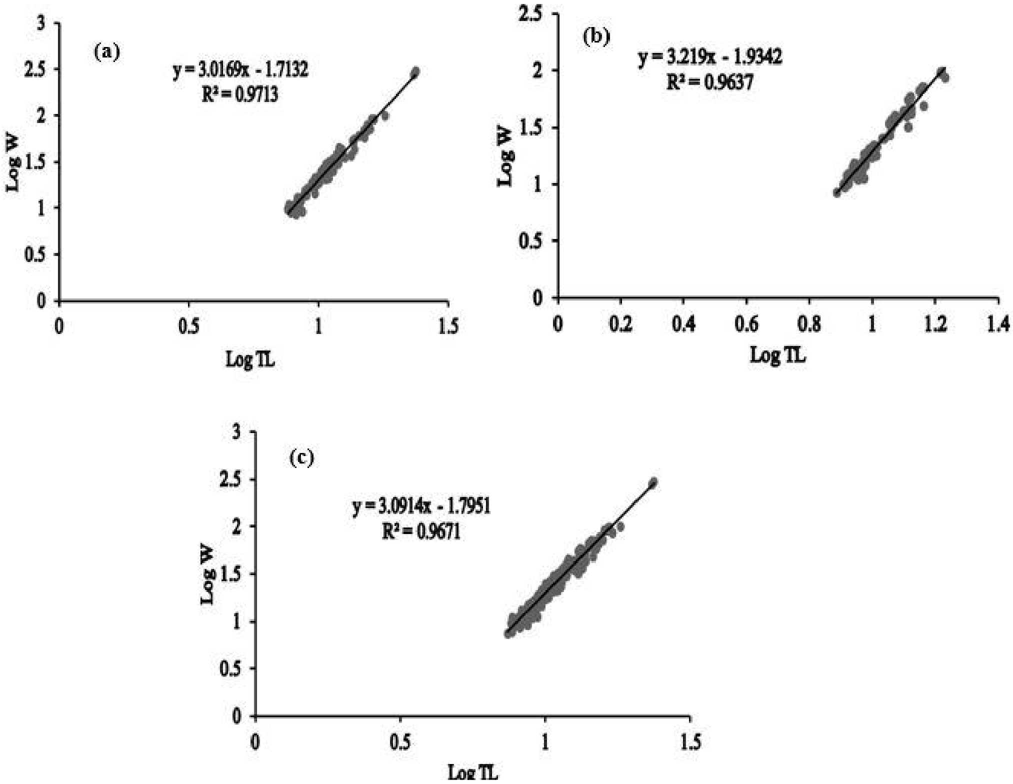

Figure3: Length-weight relationship for the (a) male population, (b) female population and (c) both sexes of Oreochromis niloticus baringoensis in Chelaba spring

Fulton's Condition Factor

The mean Fulton's condition factors (k±SD) of *O. n. baringoensis* collected from the two hot springs draining into Lorwai Swamp are summarized in Table 3. In Lake Bogoria Spa spring, the mean k value of *O. n. baringoensis* sampled was 2.02±0.25 for the males, 2.02±0.27 for the females and 2.01±0.26 for both sexes while in Chelaba spring, the mean k value for the males (2.03 ±0.21) was slightly higher than that of the females (1.97±0.25). The mean k value for both sexes of *O. n. baringoensis* sampled from Chelaba spring was 2.00±0.23.

Table 3:Parameters of the Fulton's Condition Factor of *Oreochromis niloticus baringoensis* in the hot springs draining into Lorwai Swamp

Site	Sex	n	k value ±SD	k range
Lake Bogoria Spa spring	Male	131	2.02±0.25	1.56 – 2.85
	Female	113	2.02±0.27	1.25 – 2.84
	Both sexes	244	2.01±0.26	1.25 – 2.85
Chelaba spring	Male	127	2.03±0.21	1.40 – 2.61
	Female	74	1.97±0.25	1.36 – 2.55
	Both sexes	201	2.00±0.23	1.36 - 2.61

Influence of Water Quality Parameters on Length - Weight and Fulton's Condition Factor

There was a marked positive correlation between EC, DO, NO_3, TN and SRP with length, weight and Fulton's condition factor of *O. n. baringoensis* in Lake Bogoria Spa spring. Temperature, however, showed a negative correlation with length and weight in Lake Bogoria Spa spring (Figure 4a). In Chelaba spring, length and weight showed a positive correlation with Chlorophyll-*a*(Figure 4b).

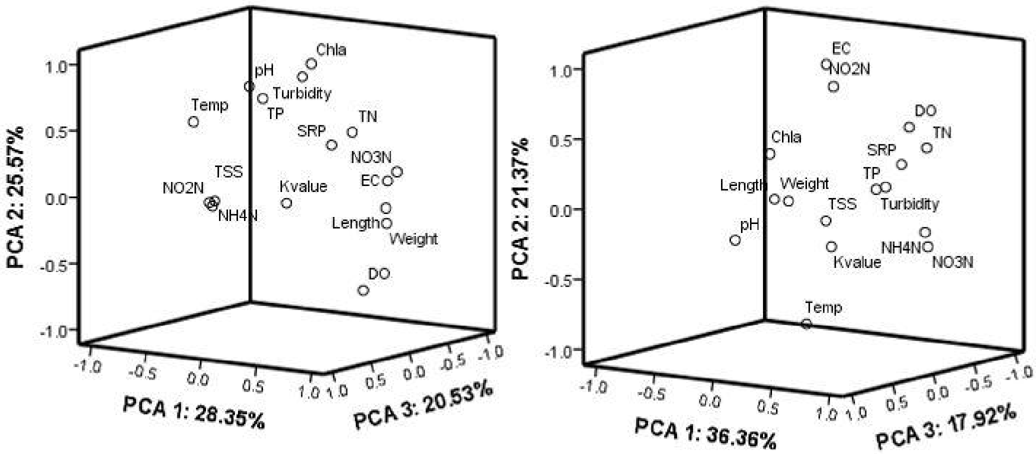

Figure 4: Principal Components Analysis biplots showing influence of the water quality parameters on the length and weight and Fulton's Condition factor of O. n. baringoensis in (a) Lake Bogoria Spa spring and (b) Chelaba spring

Discussion

The results obtained from this particular study indicated that the *O. n. barigoensis* sampled from Lake Bogoria Spa spring showed identical "b" values for the female population and for both sexes combined of 3.07. However, the male population from this spring showed a different value from that of the female and both sexes combined. The males had an equation of W= $0.21TL^{2.98}$, the females' equation was W= $0.02TL^{3.07}$ while that for both sexes from the same spring was W= $0.02TL^{3.07}$ (Table 2). The observation from both sexes combined is similar to a study by Kembenya *et al.* (2014) whereby after carrying out Fulton's Condition factor test (k), *O. n. baringoensis* (both sexes combined) sampled from the nearby Lake Baringo had a "b" value of 3.08. Allometric values obtained from Chelaba spring showed no difference for the males, females and both sexes. The males had an equation of W= $0.03TL^{3.02}$, for the females it was W= $0.01TL^{3.22}$ and for both sexes was W= $0.02TL^{3.09}$ (Table 2). The "b" value for both sexes combined from Chelaba spring was also similar to those recorded by Kembenya *et al*. (2014). A chi-square test was carried out to check for significant deviation (p=0.05) in the "b" values of the fish population from the two hot springs and it was evident that there was no significant deviation from the documented "b" value of 3. In Lake Bogoria Spa spring, ^{2} calculated = 0.00175 was less than chi-square tabulated =3.841 while in Chelaba spring, chi-square calculated = 0.00316 was less than ^{2} tabulated = 3.841. This indicates that there was an isometric growth for the *O. n. baringoensis* populations in both Lake Bogoria Spa spring and Chelaba spring. This means that both the length and weight of the fish population are increasing at a similar rate (Ricker, 1975). The correlation coefficient (r^2) for both sexes of *O. n. baringoensis* sampled from Lake Bogoria Spa spring and Chelaba spring were very high with both having values of 0.97 (Figures 2c and 3c). This showed that there was a very high degree of correlation between length and weight of *O. n. baringoensis* in these hot springs.

The mean k values (±SD) recorded during the study were all greater than 2 except for the female population sampled from Chelaba spring which had a mean k value of 1.97±0.25 (Table 3). The difference in the mean k values of the *O. n. baringoensis* population in Lake Bogoria Spa spring and Chelaba spring was however not significant (Mann-Whitney U test, n=912, p=0.96). The mean k values recorded for both sexes of *O. n. baringoensis* population sampled from Lake Bogoria Spa spring and Chelaba spring were 2.01±0.26 and 2.00±0.23 respectively. These values were higher than those recorded by Kembenya *et al*. (2014) for *O. n. baringoensis* in Lake Baringo where the mean k value was 1.13±0.15. This difference may be attributed to the different water quality parameters between Lake Baringo (Okech *et al*., 2018) and the hot water springs draining into Lorwai Swamp (Table 1).

Water quality parameters play a very important role in the stability of a fish population in any water body. Although there was no significant difference between the DO in both springs, the values recorded were quite low. However, these values were within the acceptable range for the survival of the tilapiine species of 3mgl-^{1} (Ngugi *et al*., 2007). Levels of DO above 3 mgl-^{1} promote the growth of phytoplankton which is food for the fish (Ngugi *et al*., 2007). Water temperature tends to have a strong negative correlation with DO (Wetzel, 2001) and this is evidenced by the high water temperatures recorded in the two springs (Table 1). There is a positive correlation between the levels of DO with length, weight and Fulton's condition factor and this is because the feeding activities tend to increase leading to growth (Allan *et al*., 1995). The metabolic rates in fish also tend to increase with an increase in temperature and in extreme cases may lead to death (Svobodova *et al*., 1993). The EC was also found to have a positive influence on the length, weight and Fulton's condition factor (Figure 4a). The EC values obtained during this study (Table 1) were within the acceptable range for most freshwater bodies (216-526 µs/cm) (Ndungu, 2014). Conductivity levels have a major impact on the productivity of the water. The positive correlation between NO_3, TN, SRP and Chlorophyll-*a* with the length, weight and Fulton's condition factor shows that the *O. n. baringoensis* population is thriving due to the productivity of the springs. This shows that there is ample food leading to the good health of this population in the springs.

Conclusion

We can draw a few conclusions from this study. Firstly, the length-weight relationship of *O. n. baringoensis* indicated that the population in the hot springs had a good growth ratio. The growth of *O. n. baringoensis* in Lake Bogoria Spa and Chelaba springs obeyed the cube law of growth as all fish sampled showed isometric (b=3). Secondly, the mean Fulton's condition factor of *O. n. baringoensis* collected from the two springs indicated that the population was in a very good condition and health despite the high water temperatures of up to 36.42°C, low dissolved oxygen levels of up to 3.25mgL^{-1} and relatively high conductivity values of up to 442.00 µScm^{-1}. The water quality parameters and nutrients concentrations also had positive influence on the health of the *O. n. baringoensis* found in the hot springs draining into Lorwai Swamp. The LWR and condition results will, therefore, serve as an important assessment tool for the management and conservation of the Lorwai Swamp ecosystem. These results will also offer baseline information for other studies dealing with fish in hot springs.

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Conflict of interest

Authors declare that there is no competing interest.

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