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Comparative study of growth rates, condition factors and natural mortality of *Oreochromis niloticus* fish from culture fisheries and capture fisheries at Lake Kariba, Zambia

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Oreochromis niloticus **were sampled from culture fisheries (Yalelo, Fwanyanga and Choombwe) (n = 211) in April and May, 2020. Capture fisheries (Siavonga and Sinazongwe) (n = 198) were sampled between April and November, 2020. The research was aimed to study the population parameters (growth rates, condition factors and natural mortality) of *O. niloticus* at Lake Kariba. The results showed that fish at culture fisheries exhibited positive growth (b > 3; b = 3.093) while fish at capture fisheries exhibited negative growth/negative allometry (b < 3; b = 2.24). The study established that fish at all the aquaculture farms were in good condition (Fulton's condition factors were: Yalelo fishery K_F = 1.95; Fwanyanga fishery K_F = 1.77 and Choombwe fishery K_F = 1.83). Fulton's condition factors at both capture fisheries (K_F = 1.91 at Siavonga and K_F = 1.81 at Sinazongwe) were above the optimal value of 1.0, hence the studied fish were healthy and in good condition. Culture fisheries were in better condition than capture fisheries (K_F for culture fisheries was 2.24 while K_F for capture fisheries was 1.93). Fish from culture fisheries were growing faster than fish from capture fisheries (culture r^2 was 0.960 while capture r^2 was 0.555). It can be further concluded that the habitats at Lake Kariba are favourable for fish production and they are supporting healthy fish stocks. Natural mortality values at capture fisheries and culture fisheries were similar (M_W capture = 0.142, M_W culture = 0.122). The larger condition factors at culture fisheries than capture fisheries and the higher growth rates of fish from culture fisheries than capture fisheries coupled to the lower natural mortality values at culture fisheries than capture fisheries entail that the aquatic habitat at culture fisheries are better than those at capture**

fisheries at Lake Kariba.

Key words: Lake Kariba, *Oreochromis niloticus*, captures fishery, culture fishery, condition factor, natural mortality.

INTRODUCTION

A Length-weight relationship (LWR) provides information on growth patterns, growth and condition of animals. Studies of Length-weight relationships are important in Fisheries biology because they are used for estimating the weight corresponding to a given length which a fish species should attain for it to start reproducing (Osho and Usman, 2019).

Length-weight studies are important in estimating the average weight of a fish species at a given length group and in assessing the wellbeing of a fish population. If the relationship between the length and weight of fish is isometric, it implies that the increase in fish weight is proportional to the cube of its length. Previous studies on fish length-weight relationships showed above-average values of condition factors in Lake Eleyele, Nigeria (Adeosun et al., 2017), in Malilangwe Dam, Zimbabwe (Dalu et al., 2013) and in Lake Kariba, Zambia (Nyirenda, 2017).

Zambia is richly endowed with 145, 194 km^2 of water area that makes it ideally suited to aquaculture. Aquaculture production in Zambia dates back to about four decades ago when there were about 6, 000 small scale farmers mainly found in urban areas, to now over 13, 000 fish ponds throughout the country that are being administered by about 20, 620 fish farmers (ZAEDP, 2019). The Nile Tilapia, *Oreochromis niloticus* is the most preferred fish in aquaculture production. This bream occurs naturally in Africa and the Levant (Marshall, 2010), but it is now an exotic species in almost every country due to aquaculture (Nchimunya et al., 2018). The fisheries sub-sector in Zambia contributes approximately 3.2% to the National Gross Domestic Product (GDP). The sector has seen an appreciable increase in production from 12, 998 metric tonnes in 2012 to 32, 888 metric tonnes in 2017 and fish production is expected to continue increasing due to the disbursement of aquaculture loans by the Government of the Republic of Zambia (ZAEDP, 2019; Mvula and Mwila, 2020). Many private citizens are now venturing into commercial fish farming in the Copperbelt, Lusaka and Southern Provinces, where ideal conditions for aquaculture business exist. Out of the over 10,000 metric tonnes of fish produced from culture fisheries at present, 75% comes from small-scale aquaculture, while commercial fish farmers produce the other 25%. Aquaculture is expanding in all ten provinces of the country, and as a result, Zambia is now one of the largest aquaculture producers in sub-Saharan Africa. Aquaculture systems range from extensive to intensive systems and include both multispecies culture and monoculture. There are three levels of fish farmers: small-scale, emergent (smallholder), and commercial. Small-scale fish farmers rely on family labour and practice extensive culture. Emergent fish farmers purchase some inputs for aquaculture and they practice integration farming, implying that they combine fish farming, crop production and livestock raring, and they may use family or hired labour for various tasks. Commercial fish farming such as Yalelo fisheries Limited is usually very large, intensive and involves large investments (Mudenda et al., 2012).

Zambia's aquaculture systems range from small-scale extensive to intensive polyculture of Nile Tilapia (*O. niloticus*) and the Kafue Bream (*Oreochromis andersonii*) in earthen ponds, tanks, raceways and cages. Fish farming is practiced in all Zambian provinces most especially in urban areas and neighboring towns such as Chisamba, Kafue, Serenje and Mkushi (Nchimunya et al., 2018).

Lake Kariba ranks third in terms of fish output in Zambia after Lake Tanyanyika and Lake Bangweulu (Lake Kariba Fisheries Research Unit, 2015). Besides fish production, the major socio-economic benefit of aquaculture conducted on Lake Kariba is creation of employment. Lake Kariba is one of the main fishery areas that are being targeted for large-scale aquaculture fish production in Zambia. The other areas being targeted include Bangweulu, Kasempa, Mungwi and Rufunsa. These areas are ideal for aquaculture production because of their proximity to urban areas and they have abundant aquatic habitats (ZAEDP, 2019).

Fish growth is usually studied by analysing length-weight growth exponents and condition factors (Dalu et al., 2013; Ndiaye et al., 2015; Amponsah et al., 2020). Determination of growth parameters such as growth exponents are important in studying the wellbeing of fish, fish maturity, the ideal harvesting size and adaptability (Mahomoud et al., 2011; Saha et al., 2021). Condition factors are generally above average (greater than 1) among fish that have access to abundant food, and also among fish that live in good environmental conditions

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such as optimal temperature (about 25℃) and unpolluted water which has abundant oxygen and has good turbidity. Condition factors of fish are affected by fish health, sex and the genetic make-up of fish (Adeosun et al., 2017). *O. niloticus* of Lake Kariba were chosen for this study because they are the most preferred fish on the market; notwithstanding their common prevalence in most Zambian fisheries. Fish species with condition factor values greater than or equal to one (≥ 1) were considered to be in good condition and healthy while fish species with condition factors less than one (< 1) were considered to be in a bad condition and unhealthy (Adeosun et al., 2017; Saha et al., 2021).

Both condition factor and form factor are fundamental tools that can be used to differentiate organisms that belong to the same species (Rypel and Richter, 2008; Chaklader et al., 2016; Hasan et al., 2020).

A condition factor can be used as an indicator of the health and sustainability of a fish stock. Condition factor variables decrease with increase in length (Osho and Usman, 2019). In aquaculture farming, the condition factor can be used to provide information on the variation requirements of major dietary components such as protein and energy requirements of farmed fish (Keri et al., 2011). Condition factors of fish are affected by such factors as sex, seasons, environmental conditions, stress and availability of food. Ngodhe and Owuor (2019) observed stress as a result of the reduction in the breeding and nursery grounds of *O. niloticus* in Lake Victoria, Kenya.

Mortality parameters are essential to the execution of sustainable management practices for improved conservation (Hossain et al., 2016, 2019; Ahmed et al., 2020; Saha et al., 2021). Natural mortality is an important component which is used to estimate exploitation ratios of a fish stock in an aquatic habitat. An exploitation ratio which is less than 0.5 denotes under-exploitation while an exploitation ratio value above 0.5 depicts over-exploitation. A natural aquatic habitat is optimally exploited if its exploitation ratio is 0.5. In a natural water body, if the natural mortality is higher than the fishing mortality, this may denote that the fishery is dominated by small sized-individuals (juveniles). Juvenile fishes are most prone to natural mortality induced conditions such as high temperature, predators and fluctuations in climate. A higher precautionary limit than the fishing mortality suggests a lower exploitation among fish species in a natural water body (Makeche, 2017; Amponsah et al., 2020).

The majority of studies in Zambia on length-weight relationships of *O. niloticus* have focussed on capture fisheries. Information about growth parameters and natural mortality among *O. niloticus* from culture fisheries is very limited. This study was initiated to fill this gap in information and also provide useful information for fish management and conservation at Lake Kariba. It will also allow for future comparisons between wild *O. niloticus* and reared *O. niloticus* in other aquatic habitats in Zambia.

The study had four main objectives: 1. to compare the growth rates of *O. niloticus* from capture and culture fisheries using growth exponent coefficients, 2. to determine growth forms of *O. niloticus* at Lake Kariba, 3. To determine condition factors of *O. niloticus* at Lake Kariba and hence deduce the wellbeing of fish at Lake and, 4. To determine the natural mortality of *O. niloticus* at Lake Kariba.

MATERIALS AND METHODS

Study area

The research was conducted from Lake Kariba because it houses Zambia's largest commercial fishery called Yalelo fishery Limited, and it is the largest man-made Lake in Zambia that has diverse ecological habitats that are rich in fish biodiversity (Mudenda et al., 2012; Lake Kariba Research Unit, 2015). *Oreochromis niloticus* fish samples were collected from capture fisheries of Siavonga and Sinazongwe while samples from culture fisheries were collected from Yalelo fishery, Choombwe fishery and Fwanyanga fishery (Figure 1).

Capture fisheries research design

The selection of sampling sites for wild *O. niloticus* fish species took into consideration wetland classification criteria for lacustrine systems (Cowardin et al., 1979). Four days were dedicated at each sampling station during each sampling month; one day was reserved for travel and setting up camp. Actual sampling was conducted in three consecutive nights at each site, from April to November, 2020. Sampling during this period coincided with previously observed periods of heightened breeding activity (Offem et al., 2007). Sampling for *O. niloticus* fish species from the wild was confined to estuaries and lagoons of Lake Kariba because these areas are rich in fish biodiversity. The sampled littoral subsystems at Siavonga and Sinazongwe belonged to either one of the following classes: rocky shore or rocky bottom, unconsolidated shore or unconsolidated bottom and aquatic bed.

The capture fisheries which were sampled in Siavonga were Namachembele and Kanyelele. Namachembele in Siavonga was located along latitude -16.53° S and longitude 28.88° E. Kanyelele was located along latitude -16.61° S and longitude 28.78° E. These study sites had characteristic unconsolidated bottom in the river channel whereas a stretch of sandy shore formed the Lake-front. The estuary was lightly vegetated with emergent macrophytes, whereas patches of grass were present in the sandy shoreline.

Nzenga in Sinazongwe was located along latitude -17.27° S and longitude 27.57° E while Simuzila was located along latitude -17.54° S and longitude 27.56° E. The Nzenga study site was located on the South-Western portion of Lake Kariba and it is drained by the Zongwe River. The sampled areas at Simuzila had a characteristic rocky-bed formation grading into pebbles landwards, and a sandy shoreline on either side of the jetting peninsula that forms the landmass. Figure 1 shows the location of the study sites within Lake Kariba.

The study followed the guidelines of the Declaration of Helsinki. Fish samples of wild *O. niloticus* were collected from the selected sampling sites of Lake Kariba using a passive fleet of gillnets of the mesh sizes represented in Table 1 following guidelines stipulated in the Gillnet Survey Manual by the Department of Fisheries of

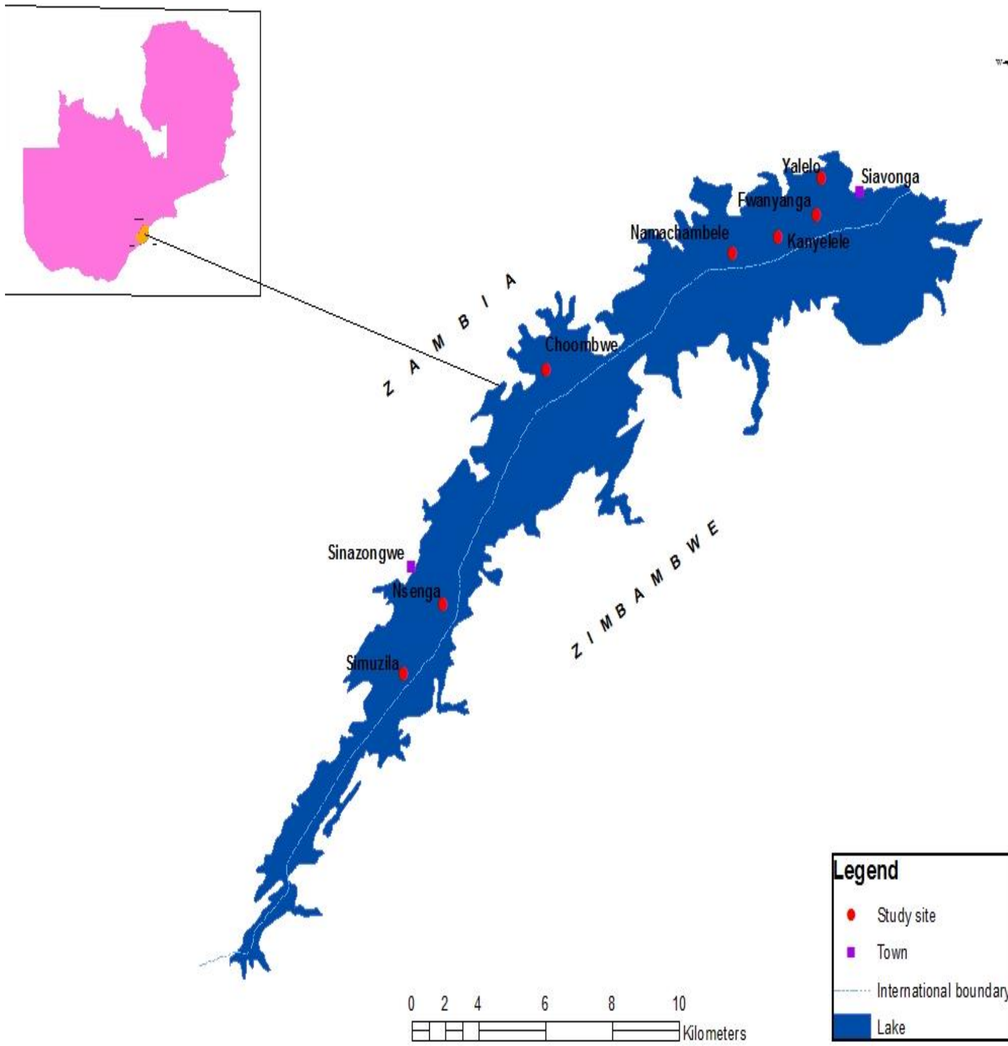


Figure 1. Map of Zambia showing the location of Lake Kariba and the study sites where fish samples were collected from. Capture fisheries include Sinazongwe and Siavonga and culture fisheries include Yalelo, Fwanyanga and Choombwe fisheries.
Source: Quantum Geographic Information System (QGIS Software version 3.22.2).

Zambia (Zambia Department of Fisheries, 2008). The different mesh-sized gillnets were intended to capture specimens of different sizes, representing fish at different maturity stages and age-classes. Different mesh sizes were used to ensure that every target fish population was proportionately available in the catch sample. The gillnet panels were set on the Lake at 17:00hours and hauled at 07:00hours the following day. Each of the collected fish specimens was identified to species level, using Skelton (2001) and Marshall (2010). The caught fish specimens were handled ethically by immediately immersing them in 10% formalin. The sampled fish specimen was then weighed, measured and sexed. This sampling procedure was repeated for three nights at each study site.

Culture fisheries research design

The aquaculture fish farms that were sampled in April and May, 2020 were Yalelo fishery Limited, Fwanyanga fishery and Choombwe fishery (Figure 1).

Yalelo fishery Limited is a commercial fishery which is located in Siavonga's Kamimbi bay along longitude 28.63° E and latitude -16.47° S. The average depth of Yalelo fishery Limited is 30.1m. Yalelo fishery Limited sites lie over a 4 km radius in the vicinity of Kamimbi fishing camp in Siavonga. Each cage site consists of eight cages, with each cage covering an area of 314 m^2 to 490m^2 for 20m and 25 m diameter circular cages respectively. Yalelo has 90 cages on Lake Kariba. The cages measure 22m by 8m on average. The total surface area covered by cages is 22,134m^2. Since Lake Kariba has a surface area of 5,580 km^2; the cages cover less than one fifty-thousandth of the Lake surface (Mudenda et al., 2012). 66 fish samples were collected from Yalelo fishery Limited.

Fwanyanga fishery is a subsistence fishery located in Siavonga's Kabyobyo bay of Lake Kariba. Fwanyanga fishery lies along longitude 28.68° E and latitude -16.52° S. Fwanyanga fishery lies at an elevation of 475 m above sea level.

Fwanyanga fishery consists of two cages that measure 6 m by 6 m by 6 m. This fishery has a maximum fish production capacity of about 90 metric tonnes per year (Lake Kariba Fisheries Research Unit, 2015). 81 fish samples were collected from Fwanyanga fishery.

Table 1. Mesh sizes of gill-nets used in sampling wild *O. niloticus* fish samples.

Mesh size (mm)	25	37	50	63	76	89	102	114	127	140	152	165	178	190
Mesh size (inches)	1.0	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7	7.5

Source: Zambia Department of Fisheries (2008).

Choombwe fishery is a subsistence fishery that is located in Gwembe's Chipepo area of Lake Kariba. Choombwe fishery lies along longitude 28.02° E and latitude -16.00° S. Choombwe fishery is situated at an elevation of 488m above sea level. Choombwe fishery consists of one cage that measures 6m by 6m by 6m and it has a fish production capacity of about 90 metric tonnes per year (Lake Kariba Fisheries Research Unit, 2015). 64 fish samples were collected from Choombwe fishery.

The selection of fish samples from culture fisheries at Lake Kariba followed previous recommendations by Rafael et al. (2016). Rafael et al. (2016) suggested that at least 20 individuals from each fish strain should be used to create the baseline dataset, comprising the reference populations.

Statistical analyses

The sampled fish specimens were measured to the nearest 0.1 cm and weighed to the nearest 0.1 g using a fish measuring board and an SF-400 electronic scale. The tilapiine fish specimens were dissected using a scalpel by making a longitudinal slit from the cloaca to the region below the pelvic fins as done in a previous study by Nyirenda (2017) for the purposes of determining whether the sampled fish specimen was male or female. Respective sexes were then determined on the basis of morphological appearance of the gonads.

The growth exponent coefficient (b) was determined by linear regression from the length-weight relationship (LWR) in Microsoft Excel, 2016 (Microsoft Corporation, 2016) using the equation: $W = aL^b$; where W = weight in grams, L = total length in centimeters, a is a scaling constant and b the growth exponent coefficient. This equation was logarithmically-transformed and expressed as: log Weight = a + b log Total length.

Three different types of condition factors were determined in this study, namely: allometric condition factor, Fulton's condition factor and relative condition factor. The allometric condition factor (K_A) was calculated using following expression proposed by Tesch (1971): W/L^b where W is the body weight (g), L is the Total Length (cm), and b is the length weight relationship parameter. Based on the expression of Fulton (1904): $K_F = 100\times (W/L^3)$, (where W is the body weight in g, and L is the Total Length in cm), Fulton's condition factor (K_F) was estimated. To obtain the K_F close to the unit, a scaling factor of 100 was used (Froese, 2006). Additionally, the relative condition factor (K_R) was evaluated through following the formula of Le Cren (1951): $K_R = W/(a\times L^b)$, where W is the body weight (g), L is the total length (cm), and a and b are the length weight relationship parameters.

The form factor ($a_{3.0}$) of *O. niloticus* was estimated by the formula of Froese (2006) as: $a_{3.0} = {}^{10\ \log a\ -\ s\ (b\text{-}3)}$, where a and b are the regression variables of the length-weight relationship (total length against body weight), and s, is the slope of $\log_a$ against b. A mean slope was used; where S = -1.358 (Froese, 2006) for assessing the form factor.

The natural mortality (M_w) of *O. niloticus* was assessed through the model proposed by Peterson and Wroblewski (1984) and Saha et al. (2021): $Mw = 1.92\ year^{-1} *(W)^{(-0.25)}$; where, Mw = natural mortality at mass W; and $W = a*L^b$, a and b are the regression variables of length weight regression (total length against body weight).

Data analysis

The collected results were analyzed using linear regression and One-way Analysis of Variance (ANOVA) using Microsoft Excel, 2016 (Microsoft Corporation, 2016) and IBM SPSS Statistics Software Version 21.0 (IBM SPSS Statistics, 2012).

Linear regression was conducted using Microsoft Excel, 2016 (Microsoft Corporation, 2016) to determine the growth exponent coefficient 'b' while One-way ANOVA was computed using IBM SPSS Statistics Software version 21.0 (IBM SPSS Statistics, 2012) to determine significant differences (P = 0.05), if any, among the determined variates. Length-weight data was analyzed by constructing growth curves in order to show the growth pattern of sampled fish.

RESULTS

Length-weight relationship and condition factor at Yalelo fishery

Weight measurements ranged from 141.2g to 220.3g with a mean of 221.9 g at Yalelo fishery. Length measurements ranged from a low of 199mm to a high of 226mm with a mean of 225 mm. Fulton's condition factor was 1.95 at Yalelo fishery. There was significant correlation between fish length and fish weight ($r_{65,\ 0.01}$ = 0.812). The adjusted R^2 was 0.765. ANOVA results showed a significant regression of length on weight (P = 0.000). Linear regression equation of fish length and fish weight at Yalelo fishery was described by the mathematical model: log Weight = -1.44 + 2.79 log Total length. The growth exponent coefficient 'b' at Yalelo fishery was 2.79. The graphical representation of the length-weight relation is given in Figure 2.

Length-weight relationship and condition factor at Choombwe fishery

Weight measurements ranged from 80.5 to 809.5 g with a mean of 197.2 g at Choombwe fishery. Length measurements ranged from a low of 170 mm to a high of 360 mm with a mean of 192 mm. Fulton's condition factor was 1.83 at Choombwe fishery. There was significant correlation between fish length and fish weight ($r_{63,\ 0.01}$ = 0.994). The adjusted R^2 was 0.988. ANOVA results showed a significant regression of length on weight (P =

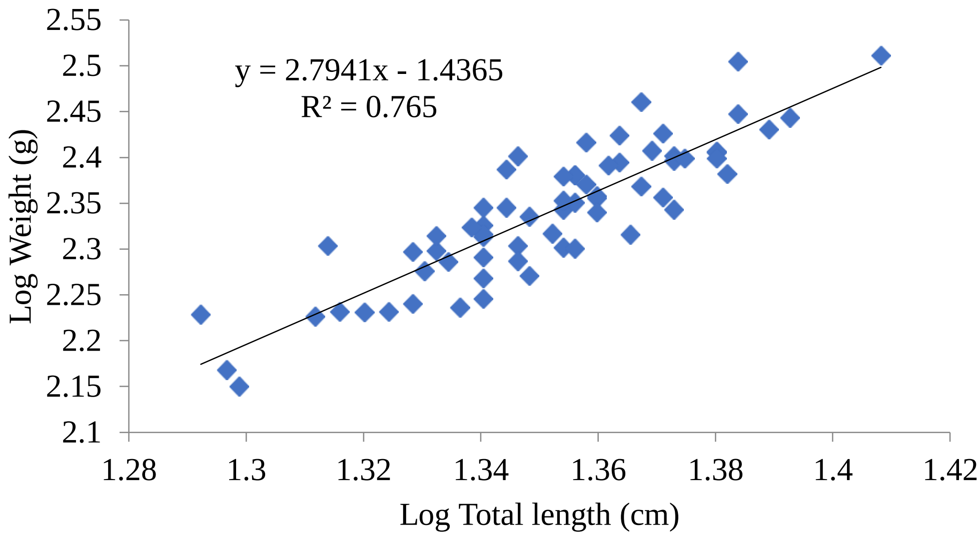


Figure 2. Graph of length-weight relationship of *O. niloticus* at Yalelo fishery. Graph depicting the logarithmic relationship between fish length and fish weight at Yalelo fishery. There was a significant correlation between fish growth and fish weight (R^2 = 0.765). The graph shows a positive correlation between fish length and fish weight.
Source: Authors.

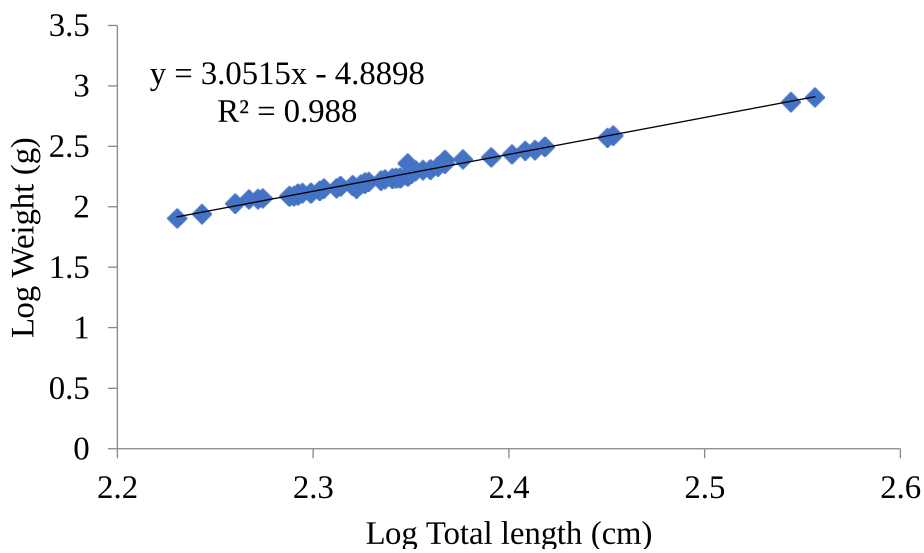


Figure 3. Graph of length-weight relationship of *O. niloticus* at Choombwe fishery. Graph depicting the logarithmic relationship between fish length and fish weight at Choombwe fishery. There was a significant correlation between fish growth and fish weight (R^2 = 0.988). The graph shows a positive correlation between fish length and fish weight.
Source: Authors.

0.000). Linear regression equation of fish length and fish weight at Choombwe fishery was described by the mathematical model: log Weight = -4.89 + 3.052 log Total length. The growth exponent coefficient 'b' at Choombwe fishery was 3.052. The graphical representation of the length-weight relation is given in Figure 3.

Length-weight relationship and condition factor at Fwanyanga fishery

Weight measurements ranged from 56.6 to 226 g with a mean of 123.5 g at Fwanyanga fishery. Length measurements ranged from a low of 152 mm to a high of

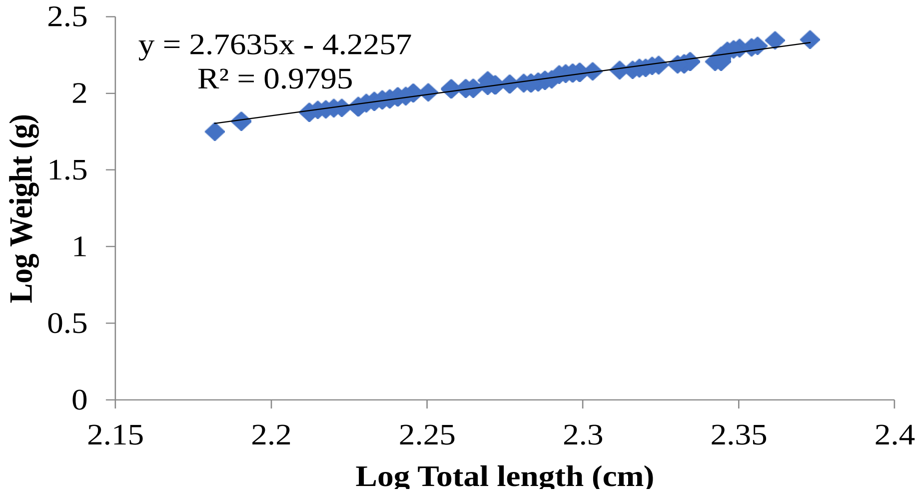


Figure 4. Graph of length-weight relationship of *O. niloticus* at Fwanyanga fishery. Graph depicting the logarithmic relationship between fish length and fish weight at Fwanyanga fishery. There was a significant correlation between fish growth and fish weight (R^2 = 0.98). The graph shows a positive correlation between fish length and fish weight.
Source: Authors.

236 mm with a mean of 191.2 mm. Fulton's condition factor was 1.77 at Fwanyanga fishery. There was significant correlation between fish length and fish weight ($r_{80,\ 0.01}$ = 0.990). The adjusted R^2 was 0.980. ANOVA results showed a significant regression of length on weight (P = 0.000). The Linear regression equation of fish length and fish weight at Fwanyanga fishery was described by the mathematical model: log Weight = -4.23 + 2.76 log Total length. The growth exponent coefficient 'b' at Fwanyanga fishery was 2.76. The graphical representation of the length-weight relation is given in Figure 4.

Combined results from Lake Kariba culture fisheries

Combined weight measurements of sampled fish specimens at Lake Kariba culture fisheries ranged from 56.6g to 809.5g with a mean of 206.5g. Combined length measurements ranged from a low of 152mm to a high of 360mm with a mean of 210.1mm. The overall Fulton's condition factor was 1.89. There was significant correlation between fish length and fish weight ($r_{210,\ 0.01}$ = 0.980). The adjusted R^2 was 0.728. ANOVA results showed a significant regression of length on weight (P = 0.000). The Linear regression equation of combined fish length and fish weight for sampled fish at Lake Kariba culture fisheries was described by the mathematical model: log Weight = -4.97 + 3.093 log Total length. Thus, the overall growth exponent coefficient 'b' for Lake Kariba culture fisheries was 3.093 (Figure 5).

Combined results from Lake Kariba capture fisheries

Cumulative weight measurements at Lake Kariba capture fisheries ranged from 13.2 to 785.6 g with a mean of 300 g. Length measurements ranged from a low of 93 mm to a high of 426 mm with a mean of 250 mm. The cumulative Fulton's condition factor at Lake Kariba capture fisheries was 1.90. There was significant correlation between fish length and fish weight ($r_{197,\ 0.01}$ = 0.558). The determination coefficient (Pearson's adjusted R^2) was 0.555. The regression ANOVA that was constructed in order to determine significant regression (P =0.05) of length on weight gave the results that are given in Table 2.

The ANOVA table showed that there was significant regression of fish length on weight (P = 1.51E-36). The linear regression equation of fish length and weight was described as:

Log Weight = -1.15 + 2.57 log Total length. The value of the growth exponent coefficient 'b' at Lake Kariba capture fisheries was 2.57. The length-weight relationship of *O. niloticus* at Lake Kariba capture fisheries was represented graphically as shown in Figure 6.

Length-weight results of female *O. niloticus* from Lake Kariba capture fisheries

Weight measurements of female *O. niloticus* fish specimens at Lake Kariba capture fisheries ranged from 64.1g to 786g with a mean of 350g. Length measurements of sampled specimens ranged from a low of 152mm to a high of 390mm with a mean of 262mm. Fulton's condition factor of female *O. niloticus* fish specimens at Lake Kariba capture fisheries was 1.95. There was significant correlation between fish length and fish weight ($r_{72,\ 0.01}$ = 0.924). The determination

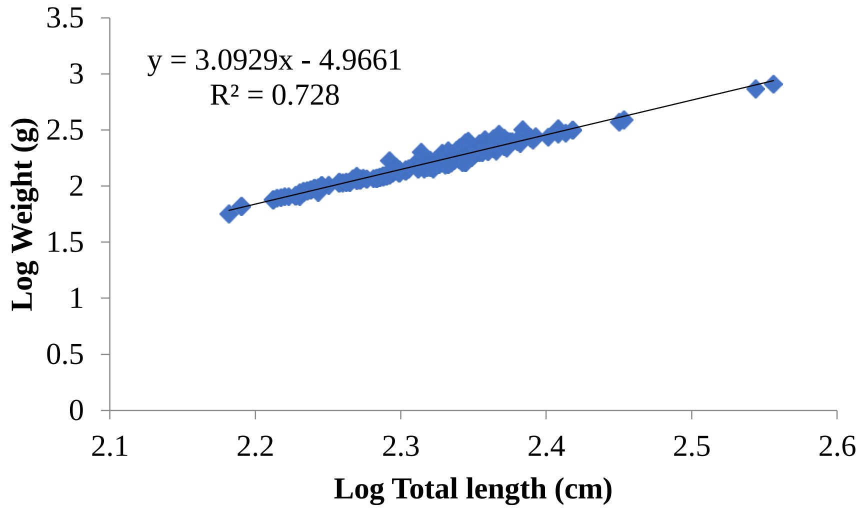


Figure 5. Graph of length-weight relationship of *O. niloticus* at Lake Kariba culture fisheries. Graph depicting the logarithmic relationship between fish length and fish weight at Lake Kariba culture fisheries. There was a significant correlation between fish growth and fish weight (R^2 = 0.728). The graph shows a positive correlation between fish length and fish weight.
Source: Authors.

Table 2. Length-weight regression ANOVA results at Lake Kariba capture fisheries.

	Df	SS	MS	F	Significance F
Regression	1	5.998018	5.998018	246.9382	1.51313E-36
Residual	196	4.760751	0.02429		
Total	197	10.75877			

Df means degrees of freedom, SS means sum of squares, MS means mean sum of squares and F means the computer-generated comparison value. ANOVA means analysis of variance.
Source: Authors.

coefficient (Pearson's adjusted R^2) was 0.915. The regression ANOVA that was used to determine significant regression of length on weight, if any, (P = 0.05) gave the results in Table 3.

The ANOVA Table showed that there was significant regression of fish length on weight (P = 1.15E-39). The linear regression equation of fish length and weight was described as:

Log Weight = -1.47 + 2.799 log Total length. The value of the growth exponent coefficient 'b' for female *O. niloticus* fish specimens at Lake Kariba capture fishery was 2.80. The female fish length-weight relationship was represented graphically as shown in Figure 7.

Length-weight results of male *O. niloticus* from Lake Kariba capture results

Weight measurements of male *O. niloticus* fish specimens at Lake Kariba capture fisheries ranged from 32.2 to 684 g with a mean of 266 g. Length measurements of sampled specimens ranged from a low of 93 mm to a high of 426 mm with a mean of 245 mm. Fulton's condition factor of male *O. niloticus* fish specimens at Lake Kariba capture fisheries was 1.41.

There was a significant correlation between fish length and fish weight ($r_{112,\ 0.01}$ = 0.672). The determination coefficient (Pearson's adjusted R^2) was 0.669. The regression ANOVA that was used to determine significant regression of length on weight, if any, (P = 0.05) gave the results in Table 4.

The ANOVA table showed that there was significant regression of fish length on weight (p = 1.3E-28). The linear regression equation of fish length and weight was described as: Log Weight = -1.017 + 2.46 log Total length. The value of the growth exponent coefficient 'b' for male *O. niloticus* fish specimens at Lake Kariba capture fishery was 2.46.

The male fish length-weight relationship was represented

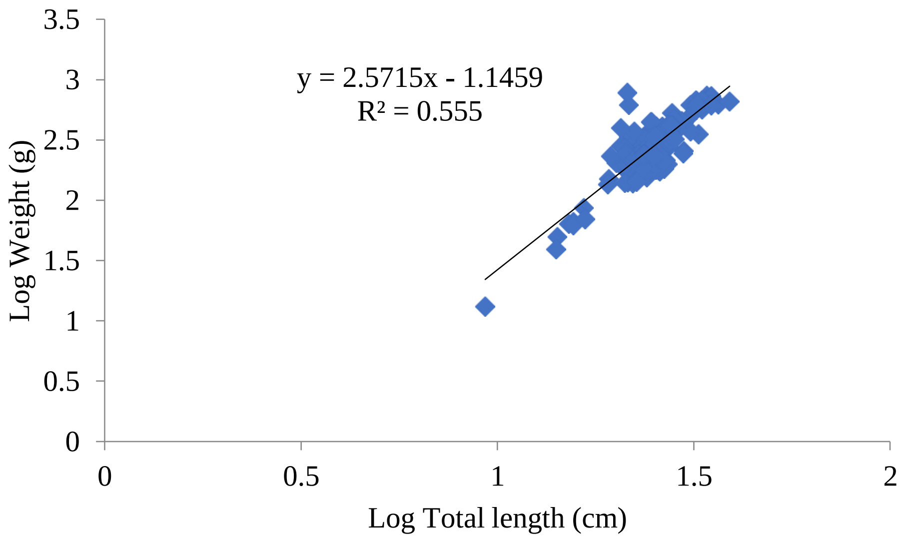


Figure 6. Graph of length-weight relationship of *O. niloticus* fish specimens at Lake Kariba capture fisheries. Graph depicting the logarithmic relationship between fish length and fish weight at Lake Kariba capture fisheries. There was a significant correlation between fish growth and fish weight (R^2 = 0.555). The graph shows a positive correlation between fish length and fish weight.
Source: Authors.

Table 3. Female length-weight ANOVA regression results at Lake Kariba capture fishery.

	Df	SS	MS	F	Significance F
Regression	1	3.941167	3.941167	760.3645	1.14997E-39
Residual	71	0.368011	0.005183		
Total	72	4.309178			

Df means degrees of freedom, SS means sum of squares, MS means mean sum of squares and F means the computer-generated comparison value. ANOVA means analysis of variance.
Source: Authors.

graphically as shown in Figure 8.

Condition factor and natural mortality results

Fulton's condition factors of Lake Kariba culture fisheries and Lake Kariba capture fisheries are given in Table 5.

All sampled study sites had condition factors which were greater than 1.0. Condition factors of sampled fish specimens ranged from a low of 1.77 at Fwanyanga fishery to a high of 1.95 at Yalelo fishery. When fish from all culture fisheries were treated as a single population, the overall condition factor was 2.24. The value of the condition factor when data at both capture fisheries wascombined was 1.93. The histograms that were constructed in order to show the variations among the condition factors of the sampled fisheries is shown in Figure 9.

Allometric condition factors, relative condition factor, form factor and natural mortality results

The results of allometric condition factor, relative condition factor, form factor growth exponent coefficients and natural mortality results are given in Table 6.

DISCUSSION

Data on the population parameters of *O. niloticus* is still very rare in Zambia and Lake Kariba in particular. Literature on natural mortality parameters among cultured fish is equally rare. Hence, the current study focused on the proper description on population parameters including length-weight relationships, length-length relationships, multi-approach condition factors (K_A, K_F, K_R), form factor ($a_{3.0}$) and natural mortality (M_W) of *O. niloticus* at Lake

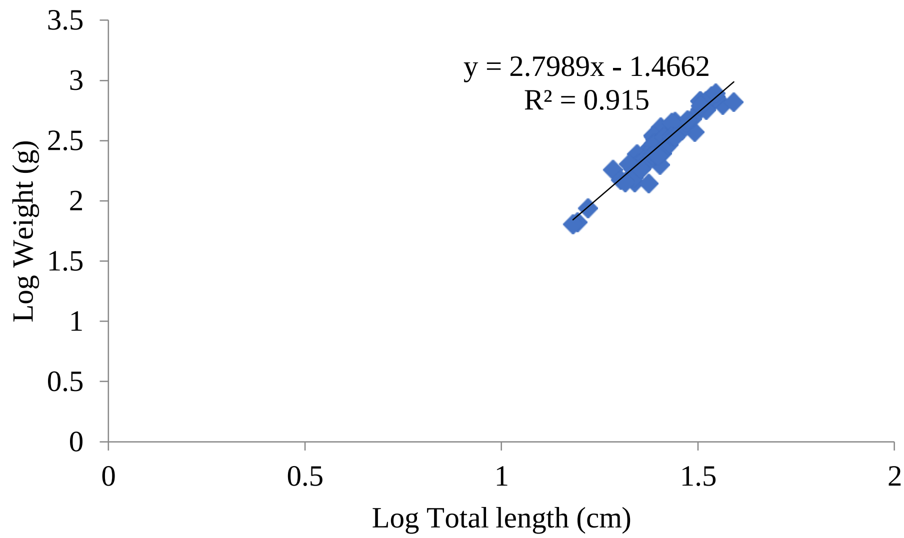


Figure 7. Graph of length-weight relationship of female *O. niloticus* fish specimens at Lake Kariba capture fisheries. Graph depicting the logarithmic relationship between fish length and fish weight of female *Oreochromis niloticus* fish specimens at Lake Kariba capture fisheries. There was a significant correlation between fish growth and fish weight (R^2 = 0.915). The graph shows a positive correlation between fish length and fish weight.
Source: Authors.

Table 4. Male length-weight ANOVA regression at Lake Kariba capture fishery.

	Df	SS	MS	F	Significance F
Regression	1	3.918549	3.918549	227.1236	1.30193E-28
Residual	111	1.915076	0.017253		
Total	112	5.833625			

Df means degrees of freedom, SS means sum of squares, MS means mean sum of squares and F means the computer-generated comparison value. ANOVA means analysis of variance.
Source: Authors.

Kariba.

The growth exponent coefficient (r^2) was higher among fish from culture fisheries (r^2 = 0.960 in Figure 5) than capture fisheries (r^2 = 0.555 in Figure 6). This implied that fish from culture fisheries grow faster than fish from capture fisheries (Ngodhe and Owuor, 2019; Osho and Usman, 2019; Saha et al., 2021). This was expected because reared fish from culture fisheries are exposed to more food resources which are readily available than wild fish from capture fisheries.

The faster growth of culture fish relative to capture fish was further confirmed by larger growth coefficients of cultured fish (b = 3.093) relative to capture fish (b = 2.23). This growth exponent result (b = 2.23) meant that fish at Lake Kariba capture fisheries exhibited negative allometric growth (b is less than 3) implying that the increase in body weight did not match the increase in total length (Dalu et al., 2013; Ndiaye et al., 2015). The value of the growth coefficient among female *O. niloticus* at Lake Kariba capture fisheries was 2.80. This growth exponent value (b = 2.80) meant that female fish at Lake Kariba capture fisheries exhibited negative allometric growth (b is less than 3) implying that the increase in body weight did not match the increase in total length (Dalu et al., 2013; Ngodhe and Owuor, 2019). The value of the growth exponent coefficient for male *O. niloticus* fish specimens at Lake Kariba capture fisheries was 2.46. This value (b = 2.46) meant that male fish specimens at Lake Kariba capture fisheries exhibited negative allometric growth (b is less than 3) implying that the increase in body weight did not match the increase in total length (Dalu et al., 2013; Osho and Usman, 2019; Saha et al., 2021). The previous studies on length-weight of various fish species showed a high degree of correlation between length and weight data. Length-weight relationship results obtained by Mahomoud et al.

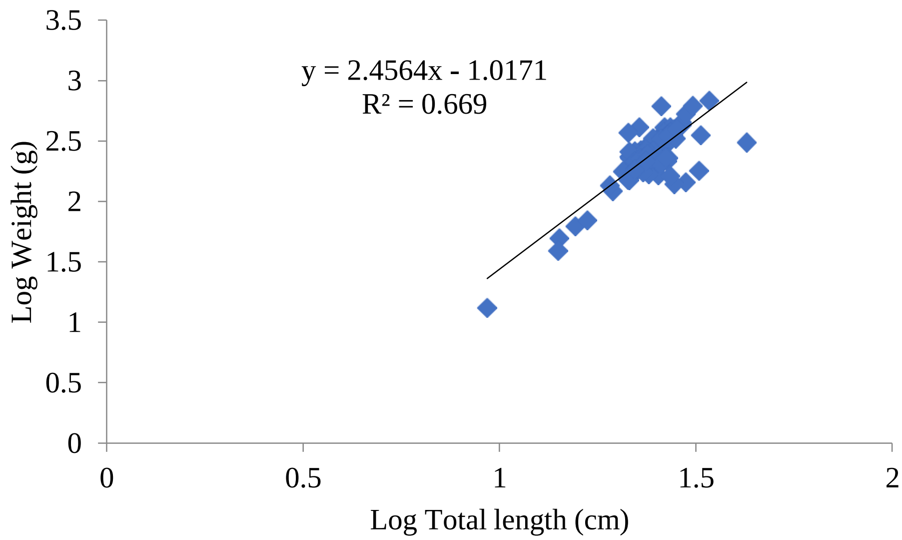


Figure 8. Graph of length-weight relationship of Male *O. niloticus* at Lake Kariba capture fisheries. Graph depicting the logarithmic relationship between fish length and fish weight of Male *O. niloticus* fish specimens at Lake Kariba capture fisheries. There was a significant correlation between fish growth and fish weight (R^2 = 0.669). The graph shows a positive correlation between fish length and fish weight.
Source: Authors.

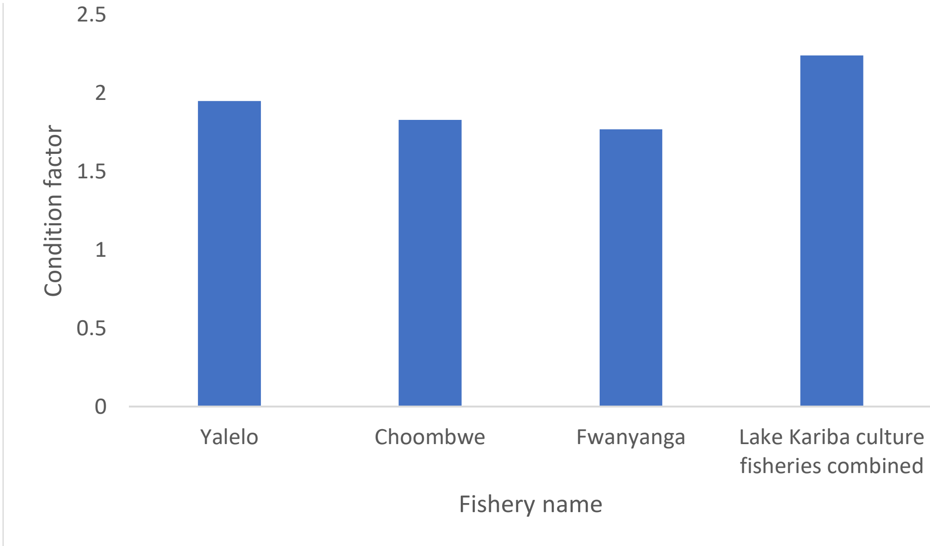
Table 5. Fulton's condition factors of sampled fisheries at Lake Kariba.

Study site	Weight (g)	Length (mm)	Condition factor (K_F)
Yalelo	222	225	1.95
Choombwe	198	221	1.83
Fwanyanga	123	191	1.77
Lake Kariba culture fisheries combined	177	211	2.24
Siavonga	352	264	1.91
Sinazongwe	241	237	1.81
Lake Kariba capture fisheries combined	300	251	1.93

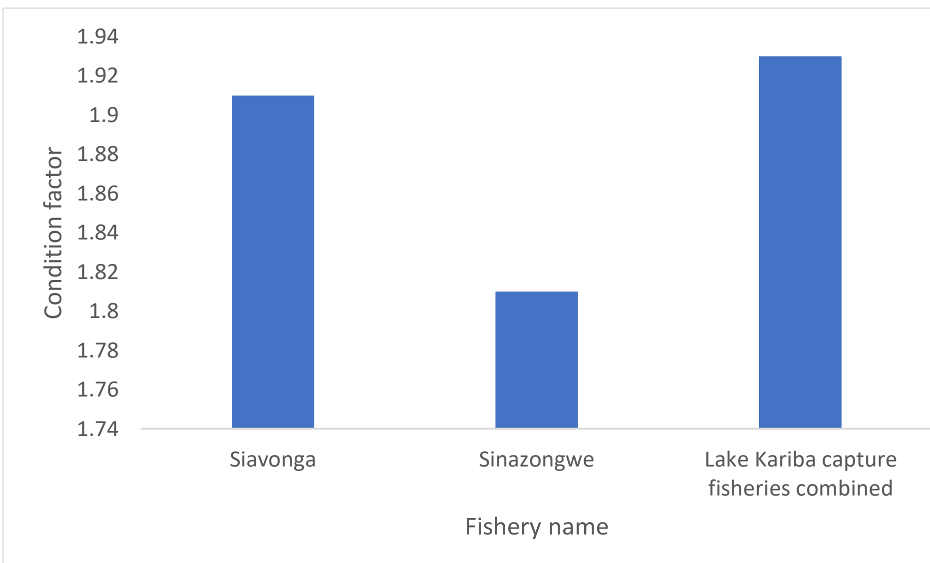
Source: Authors.

(2011) from Lake Timsah, (Egypt) showed that growth exponent (b) for all the sampled specimens were nearly 3; representing isometric values. Pearson's correlation coefficient (r^2) values were significant. The growth exponent results of combined data (b = 3.093) of this study tallies with positive allometric growth coefficients reported by Ngodhe and Owuor (2019) (b = 3.09), in the cages of Lake Victoria (Kenya), in various fish farms of Western Kenya by Musa et al. (2012) (b = 3.44) and in wild *Oreochromis niloticus* of Lake Kariba by Nyirenda (2017) (b = 3.24). The negative allometric growth coefficients obtained were also obtained by Khallaf et al. (2018) (b = 2.999) in the Egyptian Delta region and Amponsah et al. (2020) in the semi-lagoon of Ghana (b = 0.54). The discrepancies between the results of this study and results from other aquatic ecosystems may be attributed to differences among ecological habitats and genetic differences among the studied fish species.

The form factor ($a_{3.0}$) is useful in ascertaining whether or not the body dimension of a group of living organisms in a habitat is considerably different (Froese, 2006). The calculated $a_{3.0}$ for *O. niloticus* was outside the fusiform range of 0.0131-0.0140 (Froese, 2006); suggesting another body form among *O. niloticus* fish at Lake Kariba. This was expected because genus *Oreochromis* has large deep-bodied fish (Skelton, 2001). Due to lack of related reference literature regarding the form factor of genus *Oreochromis* from other aquatic ecosystems in Zambia, it was not possible to make comparisons across the water bodies. The large form factor of *O. niloticus* fish from culture fisheries (0.823) compared to capture fisheries (0.579) indicates that fish from culture fisheries



(a)



(b)

Figure 9. Histogram of condition factors at Lake Kariba culture fisheries (a) and Lake Kariba capture fisheries (b). The y-axis shows the condition factor at each fishery while the x-axis shows the fishery where fish samples were sampling was done. The capture fisheries were Siavonga and Sinazongwe (Figure 9b) while culture fisheries were Yalelo fishery, Choombwe fishery and Fwanyanga fishery (Figure 9a). Yalelo fishery showed the largest condition factor (Figure 9a) because it is a commercial fishery. Overall data showed a larger condition factor among culture fisheries than capture fisheries.
Source: Authors.

are generally larger than their counterparts from capture fisheries. This is expected because cultured fish have access to abundant nutritious food as opposed to fish from the wild where food resources such as diatoms, detritus and algae are scarce (Zengeya et al., 2015).

Fish condition factor (K) is useful in measuring various parameters such as habitat productivity, ecological conditions and fish biological factors such as plumpness, gonad maturity and fish adaptability to the environment (Mahomoud et al., 2011; Saha et al., 2021). The overall condition factor of *O. niloticus* fish at Lake Kariba culture fisheries (K = 2.24) was larger than the overall condition factor of *O. niloticus* fish at Lake Kariba capture fisheries (K = 1.97). The observed larger condition among cultured

Table 6. Growth parameters, condition factors and mortality results of *O. niloticus* at Lake Kariba.

Fishery type	N	TL	W	a	LWR		LLR			Condition factors				
					b	r^2	a	b	r^2	$a_{3.0}$	K_A	K_F	K_R	M_W
Culture	211	211	177	-4.97	3.093	0.960	0.1035	0.996	0.933	0.823	0.0142	3.093	0.286	0.122
Capture	198	251	300	-2.93	2.23	0.555	0.5798	0.7785	0.9256	0.579	0.227	2.24	0.904	0.142

N = number of *O. niloticus* fish sampled, TL = mean total length in millimeters, W = mean weight in grammes, a = intercept, b = regression slope, r^2 = coefficient of determination, $a_{3.0}$ = form factor, K_A = allometric condition factor, K_F = Fulton's condition factor, W_S = anticipated standard weight and M_W = natural mortality.
Source: Authors.

fish relative to captured fish can be attributed to the fact that cultured fish are exposed to better nutritious food than fish from the wild. The large condition factor of females relative to males may be attributed to sexual maturation among some female fish. It also implies that females were heavier than males. Musa et al. (2012) reported a lower condition factor (K = 1.12) just like Ngodhe and Owuor (2019) (K = 1.14) and Keri et al. (2011) (K = 1.64 to 1.79). Condition factor values obtained by Nyirenda (2017) (K = 2.108 to 2.191) were higher than the results from the present study. Condition factor results of this study were in the same range with results obtained by Khallaf et al. (2018) in the Egyptian Delta region (K = 1.67 to 2.43). The allometric condition factor and relative condition factor were not considered for analysis because they are not reliable (Saha et al., 2021).

The natural mortality of *O. niloticus* from capture fisheries (M_W = 0.142) was larger than the natural mortality of *O. niloticus* from culture fisheries (M_W = 0.122). This can be attributed to the fact that the habitat in a culture fishery is better than the habitat in a capture fishery. The similarity in values of natural mortality may be due to the fact that the sampled fish were from the same water body. The natural mortality of *O. niloticus* from the Kafue Floodplains obtained by Makeche (2017) was larger (M_W = 2.12) than the values obtained in the current study (M_W for capture fisheries was 0.142 and M_W for culture fisheries was 0.122) due to differences in the habitat and the period of sampling. Natural mortality values of similar fish species (*Trichogaster ladius*) obtained by Saha et al. (2021) from Bangladesh (M_W = 1.28) was different from the current values probably due to the differences in species and habitat.

Conclusion

Length-weight studies revealed that a relationship existed between fish total length and body weight. Growth exponent values obtained from length-weight relationships and condition factors showed acclimatization of cultured fish, hence the above-average condition factors. The allometric growth exponent coefficients obtained from the sampled fish entail that the habitats at the sampled fisheries were within the tolerance range for *Oreochromis niloticus* fish. The findings of the present study have shown that *O. niloticus* can be cultured on a large scale for food to meet the nutritional demand while improving the economic status of fish farmers. This is because all sampled fish from the three culture fisheries had above-optimal condition factors implying that the reared fish were well-adapted to the environment and were in good condition. The present study provides firsthand information about the growth pattern and relative conditions of *O. niloticus* fish species from its ex-situ habitat. This study has provided a feedback on the wellbeing of the reared *O. niloticus* at Lake Kariba.

Recommendations

A similar research needs to be undertaken in other aquatic habitats in Zambia over a long period of time in order to study monthly changes in population parameters among different fish species. A similar study can also be conducted to compare growth and mortality parameters among cultured fish and wild fish in different water bodies in Zambia.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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