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Assessing Growth and Stock Status Parameters of African Catfish (*Clarias gariepinus* Burchell, 1822) from Lake Abaya, South Ethiopia

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ABSTRACT: The African catfish, *Clarias gariepinus*, is one of the most commercially important fish species in Lake Abaya, South Ethiopia Regional State. Maintaining the fisheries and benefiting the fishing communities requires effective management. However, little information is known about the growth and stock status of *C. gariepinus* in Lake Abaya. This study was aimed at determining the length-weight relationship, Fulton's condition factor, sex ratio, growth, and stock status of *C. gariepinus* in Lake Abaya. The length-weight and sex data were collected from a total of 1846 fish samples from September 2022 to August 2023 from the commercial fishery of Lake Abaya. The collected data were summarized using descriptive statistics and analyzed with Microsoft Excel, SPSS, and FiSAT II. The length-weight was computed using the power function and obtained as $TW = 0.0025 \times TL^{3.27}$; $R^2 = 0.9404$; $TW = 0.0018 \times TL^{3.34}$; $R^2 = 0.9278$; and $TW = 0.0021 \times TL^{3.30}$; $R^2 = 0.9358$; for females, males, and combined sexes, respectively. The mean Fulton's condition factor was 0.77±0.042, 0.75±0.030, and 0.76±0.029 for females, males, and combined sexes, respectively, and did not significantly differ between sexes or months' interactions ($P > 0.05$). The overall sex ratio was found to be 1:1, and there was no significant difference between sexes and months; interactions ($\chi^2 = 0.00$; $P > 0.05$). The von Bertalanff growth parameters were estimated as $L\infty$ = 127.05 cm, K = 0.21yr^{-}1, t_o = -0.54, Φ' = 3.53, and $W\infty$ = 18.55 kg. The mortality-related parameters were estimated as Z = 1.14 yr^{-1}, M = 0.20 yr^{-1}, F = 0.94 yr^{-1}, E = 0.82, E_{max} = 0.61, Z/K = 5.43, M/K = 0.95, Lc/ $L\infty$ = 0.44, Lc = 56 cm, and L_{50} = 65 cm. This study found about 48.3% of the fish was caught before they reached the length at first maturity and facing growth overfishing. The overall result revealed that the *C. gariepinus* in Lake Abaya was overexploited and the well-being of the fish was not in a suitable condition. We recommended that fisheries management should include restriction of the fish caught lower than L_{50} as well as reduction of fishing gear to ensure the sustainability of this commercially important fish species in Lake Abaya.

Keywords: Condition factor, Growth parameter, Growth pattern, Length-weight relationship, Mortality parameter, Sex ratio, Stock status parameters.

INTRODUCTION

The African catfish, *Clarias gariepinus,* is a freshwater fish that is highly prized for its nutritional content and is one of the most significant animal sources of protein, particularly in Africa. It is currently the subject of extensive research for both aquaculture and food purposes (Satia, 2011; 2017). Throughout Africa and the Middle East, *C. gariepinus* is a major freshwater fish found in freshwater lakes, rivers, and swamps, as well as in artificial habitats such as oxidation ponds and even municipality sewage systems (Froese and Pauly 2017). It is a cheap source of animal protein consumed by humans as well as a source of income and livelihood for fishing communities.

The fish population's dynamics and the stock status assessment are essential for the management of fisheries resources. Indeed, the stock status assessment of a fishery is necessary to know if the fishing pressure has to be alleviated towards the sustainability of the fishery. For stock assessments of tropical fish species, the analysis of length-frequency data coupled with a small number of age readings by counting daily rings is recommended. However, methods using daily ring structures require expensive specialized equipment and large numbers of personnel, making them unlikely to be used in some locations. Thus, the most widely used method for estimating growth and mortality parameters is that involving length-frequency data that are quick and less expensive to collect (Sparre and Venema 1996). Several methods have now been developed to meet the needs of fisheries with limited data. Among these methods, the length-based biomass estimation method is the most employed in the study of the biology and dynamics of exploited stocks (Palomares *et al*., 2018).

Studying fish biology requires the use of quantitative characteristics of fish, such as the length-weight relationship, condition factor, sex ratio, growth, recruitment, and mortality (Rimzhim and Umesh 2014). Measurements of length and weight can provide details about the composition, growth, mortality, life span, and productivity of the stock (Kumar *et al*., 2014). A helpful technique for assessing fisheries is the length-weight relationship, which may be used to predict weight from the length needed for biomass calculations and yield assessments (Martin-Smith, 1996). The length-weight relationship has been used to make morphometric comparisons between species and populations as well as determine yield and weight at a given age (Bayer, 1987; Pauly, 1993; Morato *et al*., 2001; Ozaydin *et al*., 2007; Gupta and Banerjee 2015).

A fish's physiological condition is reflected by the condition factor, which is an index that represents interactions between biotic and abiotic components. It displays the well-being of the populace at different points in its life cycle (Blackwell *et al*., 2000; Ozaydin *et al*., 2007). Based on the idea that heaver fish of a given length are in better condition, the condition factor gives information on the physiological status of fish in relation to their welfare (Bagenal and Tesch 1978; Getso *et al*., 2017). The condition factor is another helpful indicator for tracking the age, growth rate, and intensity of fish feeding (Oni *et al*., 1983). The condition factor is also a measure of a species' current physical and biological state and can change as a result of interactions between physiological variables, parasite infections, and feeding circumstances (Le Cren, 1951). A comprehensive understanding of the conditions of fish species in a water body is an important management tool for the sustainable exploitation of fish. Regular biological surveys of fish species are thus very important in the management of fisheries (Oladipo *et al*., 2018).

The African catfish, *Clarias gariepinus*, is one of the most commercially important fish species in Lake Abaya. Among the lakes in Ethiopia's Rift Valley, Lake Abaya is the most important for its contribution to fish production for both national and local markets. About four commercially important fish species are in Lake Abaya: Tilapia; *O. niloticus*, Nile perch; *L. niloticus*, African catfish; *C. gariepinus*, and Bagrus; *Bagrus docmac*. Despite its significant contribution to the country's economy and livelihood for the fishing communities around the lake, except for *L. niloticus* and *O. niloticus*, which are investigated and documented by Buchale (2022 and 2024), respectively, there is no recent information for the other fish species. In this context, biological parameters such as the growth and stock status parameters of fish needs to be investigated in order to understand the population dynamics of *C. gariepinus* in Lake Abaya for the sustainable benefit of the fishing communities that substantially depend on fishing for their livelihood. In order to provide the information required for sustainable exploitation of fishery resources in Lake Abaya, the present study was aimed at identifying length-weight relationship parameters, Fulton's condition factor and sex ratio, estimating growth and mortality parameters, and determining the stock status of *C. gariepinus* in Lake Abaya.

MATERIALS AND METHODS

A. Description of the study area

Lake Abaya is located in southern Ethiopia and is a part of the Ethiopian Rift Valley lakes (Fig. 1). According to the Ethiopian Mapping Agency (1988), Lake Abaya is the largest lake in the Ethiopian Rift Valley and is situated between 5º3′19″N and 6º45′11″N latitude and 37º18′55″E and 38º7′55″E longitude. Its maximum dimensions are 79.2 km in length, 27.1 km in width, and 2600 km^2 in surface area. It is situated at an average altitude of 1,235 meters above sea level and has a maximum depth of 24.5 meters (Seleshi, 2001).

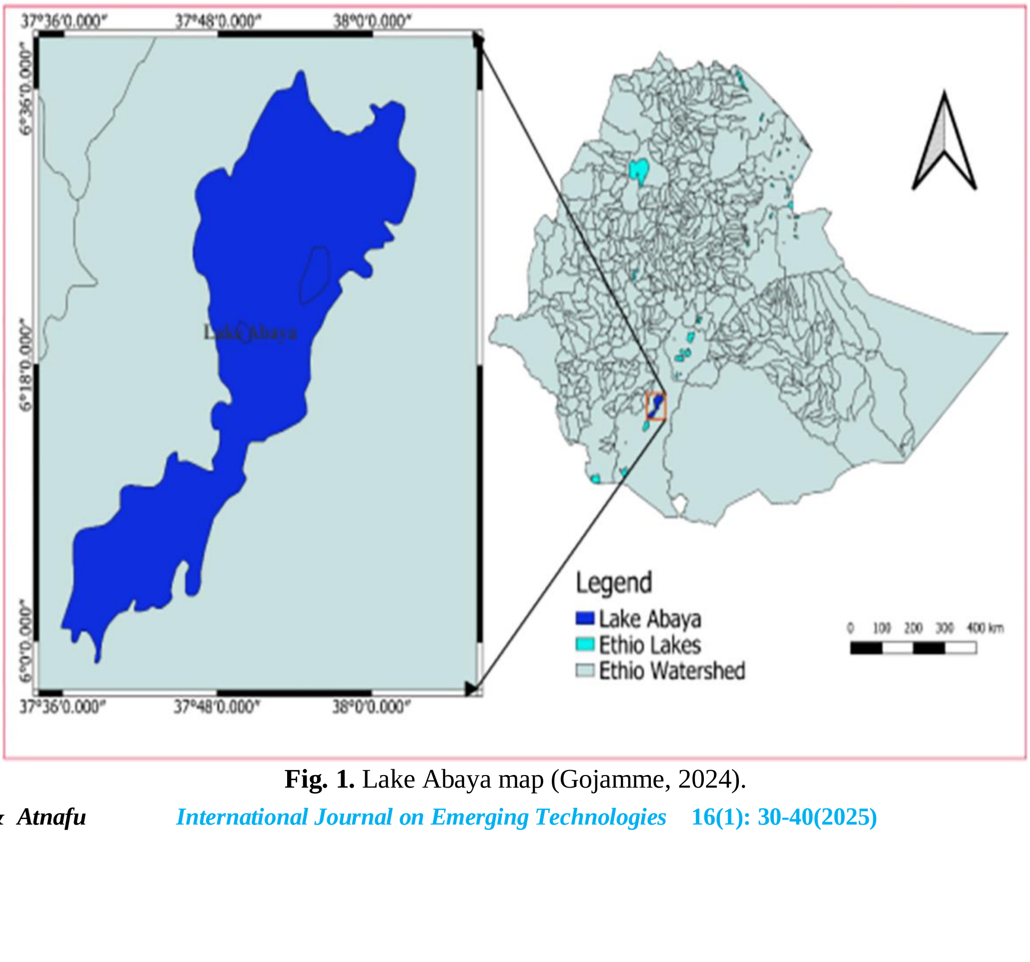

Fig. 1. Lake Abaya map (Gojamme, 2024).

B. Sampling methods and data collection

The study employed a total of 1846 *C. gariepinus* samples, which were collected from commercial fisheries in Lake Abaya. Two landing sites were selected based on their accessibility, and the data was collected for twelve days monthly. The samples were randomly collected from September 2022 to August 2023. The selected fish samples were weighed to the nearest grams (g) using a hanging balance and total length (cm) was measured using a measuring board. The total length (TL) of each fish sample was measured to the nearest 0.1 cm to calculate size-frequency distribution and to estimate growth parameters. The total body weight (TW) of each sample was also measured to the nearest 0.1 g using a hanging balance. Sex determination was also made visually based on external sexual characteristics as well as by dissecting the abdomen and observing the gonads.

C. Data analysis

Length-weight relationship and condition factor. The relationship between the length and weight of *C. gariepinus* was done by Le-Cren (1951) as follows.

$$TW = aTL^{b} \quad (1)$$

Where, TW = total weight (g)

TL = total length (cm)

a = constant value (intercept) and

b = the slope of the length-weight relationship

$$W_{\infty} = a{*}L^{b}{}_{\infty} \quad (2)$$

Where, W_{∞} and L_{∞} are the asymptotic body weight (g) and body length (cm) while a and b are as defined above.

Fulton's condition factor (FCF) is often used toreflect the nutritional status or well-being of anindividual fish and was calculated by using theformula described by Fulton (1904) which isindicated below.

$$FCF = \frac{TW}{TL^{3}}{*}100 \quad (3)$$

The data analyses were done using Microsoft Office Excel (2010) and SPSS (Version 16.0) software. A chi-square test (□^{2} test) was employed to determine if the sex ratio varies between the male and female *C.gariepinus*.

Estimation of growth parameters. Monthly collected values of total length (TL) are grouped into classes of 2 cm according to Wang *et al.* (2020). An empirical approach was used to estimate the population's demographic parameters. The asymptotic length (L∞) and the coefficient of growth (K) were estimated using the electronic length frequency analysis method (ELEFAN). Using Pauly's empirical formula (Pauly, 1979), the theoretical age at zero (t_o) was computed as:

$$\text{Log}(-t_0) = -0.3922 - 0.2752 * \text{Log}(L\infty) - 1.038 * \text{Log}(k) \quad (4)$$

Where, t_o = the theoretical age at which the fish have at zero length

L∞ = asymptotic length, and k = Von Bertalanffy growth constant

The value of length at first maturity (L_{50}) was computed as Froese and Binohlan's (2000) equation:

$$\text{Log}(L_{50}) = 0.8979 * \text{Log}(L\infty) - 0.0782 \quad (5)$$

The longevity (A0.95%), defined as the time the individual takes to reach 95% of the asymptotic length was estimated based on the formula proposed by Taylor (1960):

$$t_{max} = to + \frac{2.996}{K} \quad (6)$$

Where, t_{max}= is the time the individual takes to reach 95% (A0.95%), t_o and K are as defined above.

The growth performance index was computed as Munro and Pauly (1983):

$$\Phi' = \text{Log}(k) + 2 * \text{Log}(L\infty) \quad (7)$$

Stock status parameters. The stock status was estimated using the length-based biomass (LBB) method which is a recent approach developed by Froese*et al.* (2018). A completely new equation to determine the optimal length at first capture (L_{c_opt}) and the age at which optimal fish capture (t_{c_opt}) corresponding to L_{c_opt} are computed (Froese *et al.*, 2016):

$$L_{c\_opt} = \frac{L\infty(2+\frac{3F}{M})}{(1+\frac{F}{M})(3+\frac{M}{K})} \quad (8)$$

$$t_{c\_opt} = t_o + \frac{\ln(\frac{Z(3K+M)}{M(Z+K)})}{K} \quad (9)$$

Where, F = is fishing mortality, M = is natural mortality and Z = is the total mortality while the other parameters are as defined above.

The body weight, W_{opt} where unexploited cohort biomass reaches a maximum was estimated by Holt's (1958) equation as:

$$W_{opt} = W_{\infty}*(\frac{K}{K+\frac{M}{3}}) \quad (10)$$

The length,L_{opt} corresponding to W_{opt}, and the age at the peak of unexploited cohort biomass t_{opt} are computed as Beverton (1992):

$$L_{opt} = L\infty * (\frac{3}{3+\frac{M}{K}}) \quad (11)$$

$$t_{opt} = t_o + \frac{\ln(\frac{3+M}{M})}{K} \quad (12)$$

The total mortality (Z) was estimated using a linearized length-converted catch curve (Sparre and Venema, 1992). The natural mortality coefficient (M) was estimated using Taylor's method (1958) as:

$$M = \frac{-\ln(1-0.95)}{A0.95} \quad (13)$$

Where,A0.95 is the age at which 95% of the population would die from natural causes. The fishing mortality (F) was calculated as (Qamar *et al.*, 2016).

$$F = Z - M \quad (14)$$

The exploitation rate (E) was calculated as (Georgiev and Kolarov, 1962). The length at first capture (Lc) was estimated from the equation of Beverton and Holt (1957) which applies the growth constant of vBGF, the mean length of the catch ($\bar{L}$), and the total mortality parameter (Z).

$$E = \frac{F}{Z} \quad (15)$$

$$Lc = \bar{L} - k(\frac{L\infty - \bar{L}}{Z}) \quad (16)$$

The relative yield per recruit (Y' /R) and relative biomass per recruit (B' /R) were computed by Beverton and Holt's (1966) method as modified by Pauly and Soriano (1986). The predicted Y' /R and B' /R of the fish were computed as the following formula:

$$Y'/R = EU^{\frac{M}{K}}\left(1-\left(\frac{3U}{1+m}\right)+\left(\frac{3U^2}{1+2m}\right)-\left(\frac{U^3}{1+3m}\right)\right) \quad (17)$$

Where, $U = 1-\left(\frac{Lc}{L\infty}\right)$, is the fraction of growth to be completed by the fish after entry into the exploitation phase; m = is the ratio of growth constant to total mortality (K/Z) and E = is the exploitation rate.

$$B'/R = (Y'/R)/F \quad (18)$$

Then we computed E_{max} (the value exploitation rate E giving the maximum relative yield per recruit), $E_{0.1}$ (the value of E at which marginal increase in Y' /R is 10% of its value at E = 0) and $E_{0.5}$ (the value of E at 50% of the unexploited relative biomass per recruit) using knife-edge selection function of exploitation rate (E) incorporated into FiSAT II software (Gayanilo *et al*., 2005).

RESULTS AND DISCUSSIONS

Sex ratio. We sampled 1846 individuals of *C. gariepinus* from the commercial fishery of Lake Abaya. Among the sampled individuals, the overall sex ratio was found to be 1:1 (χ^2 = 0.00). The monthly sex ratio of both sexes was also found to be statistically insignificant (Table 1; P > 0.05). The finding indicated the presence of an expected natural distribution of sexes, which revealed the stable population of *C. gariepinus* in Lake Abaya. This is in agreement with the natural laws of genetic recommendation. This indicates the availability of mature males and females of *C. gariepinus* expected to spawn in the lake.

The sex ratio reveals the aggregation of males and females in accordance with environmental conditions, the differential behavior of sexes, and the fishing effect (Khan *et al*., 2013). The results found in the present study were in agreement with the results recorded for the overall sex ratio of *C. gariepinus* in Ribb Reservoir (Agumassie *et al*., 2023), Lake Babogaya (Lemma *et al*., 2014), and Lake Baringo (Elijah *et al*., 2014). On the other hand, the overall sex ratio of *C. gariepinus* was not equally distributed in Lake Lugo (Endalh *et al*., 2019), Lake Ziway (Lemma *et al*., 2014), Lake Babogaya (Lemma, 2007), Lake Hertale (Alemayehu *et al*., 2023), and Lake Naivasha (Medhanit, 2016).

Table 1: Sex ratio of *C. gariepinus* from Lake Abaya.

Months	Females	Males	Total	Sex ratio (M:F)	Chi-square (χ^2)	P-value
September	44	49	93	1:0.90	0.13	0.60
October	75	70	145	1:1.07	0.09	0.68
November	86	91	177	1:0.94	0.07	0.71
December	52	44	96	1:1.18	0.33	0.41
January	100	74	174	1:1.35	1.94	0.05
February	72	67	139	1:1.07	0.09	0.67
March	100	103	203	1:0.97	0.02	0.83
April	88	86	174	1:1.02	0.01	0.88
May	98	103	201	1:0.95	0.06	0.72
Jun	81	94	175	1:0.86	0.48	0.33
July	63	76	139	1:0.82	0.61	0.27
August	64	66	130	1:0.97	0.02	0.86
Total	**923**	**923**	**1846**	**1:1**	**0.00**	**1.00**

Length-weight relationship. The length-weight relationship regression was computed as a power function for females, males, and combined sexes of *C. gariepinus* (Fig. 2). The total length and total weight of the fish ranged from 41 cm to 121 cm and 500 g to 15000 g, respectively. The estimated values of regression coefficient b for females, males, and combined sexes were recorded as 3.27, 3.34, and 3.30, respectively. The length-weight relationship of *C. gariepinus* for females, males, and combined sexes was equated as $TW = 0.0025 \times TL^{3.27}$, $TW = 0.0018 \times TL^{3.34}$, and $TW = 0.0021 \times TL^{3.30}$, respectively. The analysis of variance revealed that there was a significant difference between the regression coefficient *b* and the expected cubic value of *b* (P < 0.05). The analysis of the length-weight relationship for both combined sexes revealed that *C. gariepinus* from Lake Abaya had a positive allometric growth pattern. Fish undergoing positive allometric growth is an indication of the stoutness of the body with an increase in length.

The fish's growth patterns and condition are indicated by the length-weight relationship. According to Lemma (2013), it offers crucial information about the composition and dynamics of fish populations. It was utilized not only to help anticipate the average weight of fish at a specific length but also to evaluate the well-being of the fish population in the lake. The study found that *C. gariepinus* in Lake Abaya exhibited a positive allometric growth pattern (b > 3.0). This value deviates significantly from the cubic law proposed by Bagenal and Tesch (1978) and is in line with the values of *b* determined for the same species in Lake Chamo, 3.19 (Elias *et al*., 2011), Lake Naivasha, 3.23 (James *et al*., 2015), Lake Baringo, 3.214 (Britton and Harper, 2006), and Lake Baringo, 3.25 (Elijah *et al*., 2014). However, the finding in this study contradicted the *b* value reported in Lake Ziway, 2.83 (Lemma *et al*., 2014), Lake Babogaya, 2.934 (Lemma *et al*., 2014), Andassa River, 2.4 (Yibeletal and Minwyelet 2020), Lake Tana, 2.678 (Dereje, 2014) and Zobe Reservoir, 2.85 (Sadauki *et al*., 2023), indicating a negative allometric growth. Variations in fish growth patterns could be related to the condition of the species itself, its phenotype, specific geographic location, season, gonad maturity, food availability, health, and environmental conditions (Bagenal and Tesch 1978; Arslan *et al*., 2004; Froese, 2006; Tsoumani *et al*., 2006; Yilmaz *et al*., 2012; Ali *et al*., 2016).

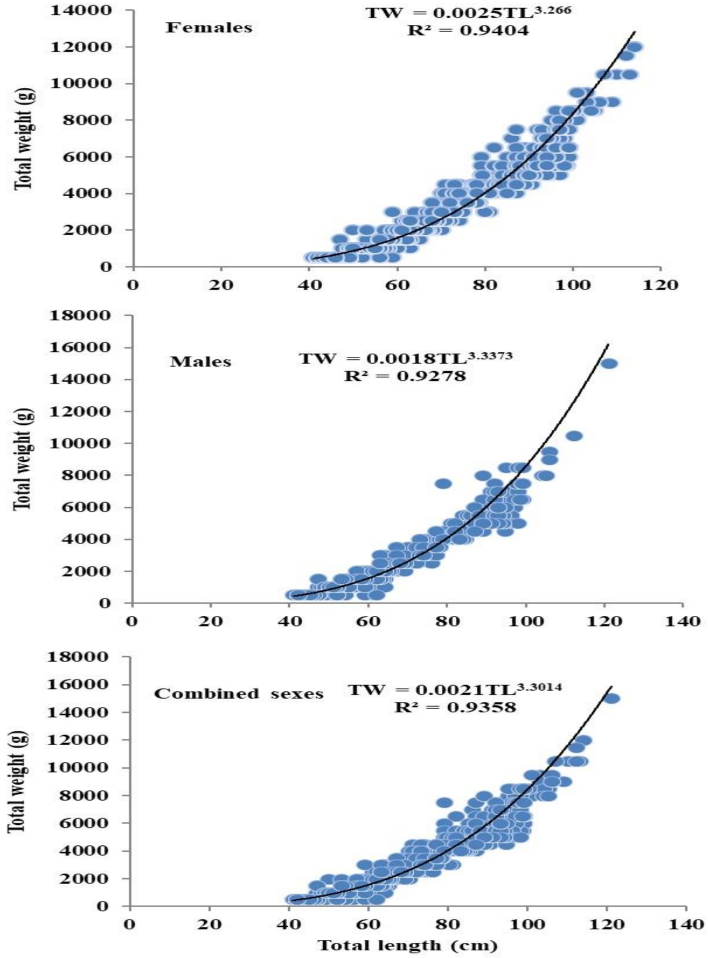

Fig. 2. Length-weight relationship of *C. gariepinus* from Lake Abaya.

Condition factor. The Fulton's condition factor (FCF) varied between 0.73 and 0.88 for females, 0.71 and 0.81 for males, and 0.73 and 0.82 for combined sexes. The mean value with standard deviation was determined to be 0.77±0.042, 0.75±0.030, and 0.76±0.029 for females, males, and combined sexes, respectively (Table 2). The mean condition factor of *C. gariepinus* in Lake Abaya did not significantly differ between the sexes or months' interactions ($P > 0.05$).

The combined mean Fulton's condition factor obtained from this study was comparable with the results recorded in Lake Babogaya, 0.64 (Lemma *et al*., 2014), Lake Hertale, 0.81 (Alemayehu *et al*., 2023), Ribb Reservoir, 0.563 (Agumassie *et al*., 2023), Asi River, 0.7591 (Simsek *et al*., 2022), and Igbokoda River, 0.644 (Omotayo *et al*., 2019). However, the combined mean condition factor obtained from this study deviates from the findings recorded for *C. gariepinus* in Lake Baringo, 1.06 (Elijah *et al*., 2014), Zobe Reservoir, 1.04 (Sadauki *et al*., 2023), and Kontagora Reservoir, 1.98 (Ibrahim *et al*., 2012).

The condition factor is an index reflecting the effect of interactions between biotic and abiotic factors on the physiological condition of fish (Blackwell *et al*., 2000). Fish body condition is known to vary seasonally depending on changes in gonadal development, food availability, and other environmental factors (Pope and Willis, 1996). A fish body condition factor greater or equal to one (≥1.0) indicates a good level of feeding and appropriate environmental conditions (Ayoade, 2011; Ujjania *et al*., 2012). But a value lowers than one indicates the existence of unsuitable environmental conditons (Le Cren, 1951). In the present study, there was no significant condition factor variation between both sexes and months' interactions throughout the study period. However, it was observed that the values of the mean condition factor for *C. gariepinus* from Lake Abaya were less than one (< 1.0), which indicated that *C. gariepinus* is generally not doing well in the lake.

Variations in body conditions are influenced by many biotic and abiotic factors, such as phytoplankton abundance, predation, water temperature, and dissolvedoxygen concentrations, among others (Ahmed *et al*., 2011). Fishes in poor body condition are reported to have less fecundity than those in better condition

(Lowe-McConnell, 1959). When compared to findings from the literature, Dagne *et al.* (2023) reported that turbidity, salinity, nitrates, and soluble reactive phosphorous in Lake Abaya showed an increasing trend based on data from in-situ measurements and laboratory analysis of physic-chemical parameters and the plankton communities. There is also heavy year-round fishing pressure and intensive agricultural practices in the lake's catchment areas that could be responsible for the poor condition of *C. gariepinus* in Lake Abaya.

Table 2: Mean monthly condition factors of *C. gariepinus* from Lake Abaya.

Months	Females	Males	Combined sexes
Sep	0.77	0.75	0.76
Oct	0.78	0.79	0.78
Nov	0.77	0.76	0.76
Dec	0.88	0.76	0.82
Jan	0.82	0.81	0.81
Feb	0.76	0.74	0.75
Mar	0.74	0.72	0.73
Apr	0.74	0.75	0.75
May	0.75	0.73	0.74
Jun	0.77	0.71	0.74
Jul	0.73	0.73	0.73
Aug	0.75	0.78	0.76
Average	0.77±0.042	0.75±0.030	0.76±0.029

Estimated growth parameters. The von Bertalanffy growth model was used to estimate the growth parameters of *C. gariepinus* from Lake Abaya. The predicted asymptotic length ($L\infty$) and the annual growth constant (K) of *C. gariepinus* were 127.05 cm and 0.21 yr^{-1}, respectively. The other estimated growth parameters such as theoretical age at birth (t_o), length at first maturity (L_{50}), and the growth performance index (Φ') were presented as -0.54, 64.71 cm, and 3.53, respectively. The longevity (t_{max}) in which 95% of an individual fish takes to reach asymptotic length ($L\infty$) and removed due to natural cause was estimated at 14.81 years. The asymptotic weight ($W\infty$) when the fish attains its asymptotic length ($L\infty$) was estimated at 18.55 kg in Lake Abaya.

The estimated von Bertalanffy growth parameters were compared with the literature in different areas (Table 3). It is possible that the various water bodies' varying environmental conditions accounted for the differences in estimations of the von Bertalannfy growth parameters when compared to a similar study. The size of the population and how fish adjust throughout their lives are other elements that influence growth. Among several factors, the growth parameters can be influenced by genetics, resource availability, and population density. The fishing pressure is also a factor for change in the asymptotic length of fish in a given water body. If fishing gear is selective and oriented toward harvesting larger individuals, larger individuals may become rare in overexploited fisheries, and the scarcity of these individuals in a given sample will certainly underestimate the growth parameters.

Table 3: Parameters comparison of the von Bertalanffy growth curve and growth performance indices for *C. gariepinus* reported from different areas.

Area	N	$L\infty$ (cm)	K yr^{-1}	t_o	Φ'	Reference
Gölbaşı Lake, Turkey	566	60.24	0.21	-1.61	-	Narin (2003)
Laing River reservoir, Eastern Cape	101	140.67	0.17	-0.16	-	Potts *et al.* (2008)
Kat River Reservoirs, Eastern Cape	134	93.02	0.19	-0.28	-	Potts *et al.* (2008)
Mid-Cross River, Nigeria	1421	80.24	0.49	-3.93	3.10	Idumah (2011)
Darlington Dam, Eastern Cape	175	93.17	0.15	-2.43	-	Wartenberg *et al.* (2013)
Lake Koka, Ethiopia	6025	121.9	0.16	-0.72	3.36	Gashaw and Wolff (2015)
Lower Okavango Delta, Botswana	106	52.87	0.72	-1.35	-	Bokhutlo *et al.* (2015)
Baringo Lake, Kenya	2272	114.30	0.37	-	-	Macharia *et al.* (2017)
Manzalah Lake, Egypt	1241	86.88	0.31	-0.39	-	Mehanna *et al.* (2018)
Periyar Lake, India	344	91.88	0.54	-	3.66	Roshni *et al.* (2020)
OuedTakhamalte, Algeria	84	53.84	0.28	-	-	Behmene *et al.* (2021)
Mai-Ndombe Lake, DRC	2001	55.65	0.28	-0.50	-	Nsapu (2021)
Asi River, Turkey	185	58.2	0.39	-0.40	3.12	Şimşek *et al.* (2022)
Lake Abaya, South Ethiopia	1846	127.05	0.21	-0.54	3.53	Present study

Estimated stock status parameters. The total mortality rate (Z) was obtained from a linearized length converted catch curve regression analysis. As indicated in Fig. 3, the slope of the regression line (b) was computed to be -1.14, and hence, the estimated total mortality rate was 1.14. The estimated natural mortality rate (M), and fishing mortality rate (F) were 0.20 yr^{-1}, and 0.94 yr^{-1}, respectively. Based on the obtained mortality parameters, the current exploitation rate (E) was estimated at 0.82, which indicated the state of overexploitation. The relative fishing mortality (F/M) was 4.7, which reveals the state of overexploitation.

The overexploited stocks have a relative fishing mortality higher than 1.2. The fully exploited and under-exploited stocks have respective values of 0.8-1.2, and <0.9 (Palomares *et al*., 2018). Fish mortality can be attributed to both natural and anthropogenic factors such as fishing. Most of the natural mortality could be attributed to diseases, old age, and predation factors in the aquatic ecosystem.

The fishing mortality in the present study is higher than the natural mortality, indicating that the primary cause of mortality for *C. gariepinus* in Lake Abaya is attributed to fishing factors. The M/K ratio was 0.95 which is below the Beverton and Holt (1959) range of 1.0-2.50 for fish indicating a poor environmental state.

The estimated Z/K ratio of *C. gariepinus* in the present study was calculated to be 5.43, which indicated a mortality-dominated fish population. The Beverton and Holt (1957) general criteria stated that if the Z/K ratio is <1, then the population is growth-dominated; if it is >1, then mortality-dominated, and if it is equal to 1, then the population is in an equilibrium state where mortality balances growth. Based on the general criteria described above, the Z/K value in the present study suggested that the *C. gariepinus* population in Lake Abaya was highly exploited. This is also revealed by the estimated high exploitation rate (E = 0.82) which indicates the state of overexploitation.

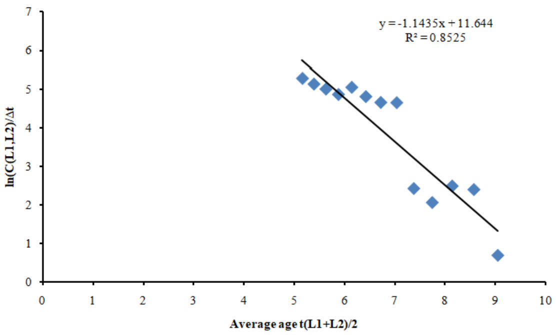

Fig. 3. Linearized length-based catch curve of *C. gariepinus* from Lake Abaya.

As indicated in Fig. 4, the length at first capture (Lc) and the length at first maturity (TL_{50}) of *C. gariepinus* were estimated to be 56 cm and 65 cm, respectively. The optimum length where the maximum yield can be obtained (L_{opt}) and the optimum age (t_{opt}) were estimated with the respective values of 96 cm and 13.7 years. The body weight, W_{opt} where unexploited cohort biomass reaches a maximum was estimated at 14 kg. The optimal length at first capture (L_{c_opt}) and the corresponding age at which the optimal fish capture (t_{c_opt}) was estimated at 90.49 cm and 6.47 years, respectively while, the Lc/L_∞ ratio was also estimated at 0.44. Out of the total catch, about 31.1% of *C. gariepinus* was removed before it reached its length at first capture (Lc) while about 48.3% was caught before its length at first maturity (L_{50}). This result indicated that *C. gariepinus* in Lake Abaya is under heavy growth overfishing.

According to Froese *et al*. (2016), to obtain a maximum yield for a given fishing mortality (F), the Lc can be increased to allow a longer non-exploitable growth phase, until the exploitable biomass and the catch per effort (CPUE) reach a maximum. Therefore, any catch greater than L_{50} and close to L_{c_opt} could make the fishery possible to better reach sustainability in Lake Abaya.

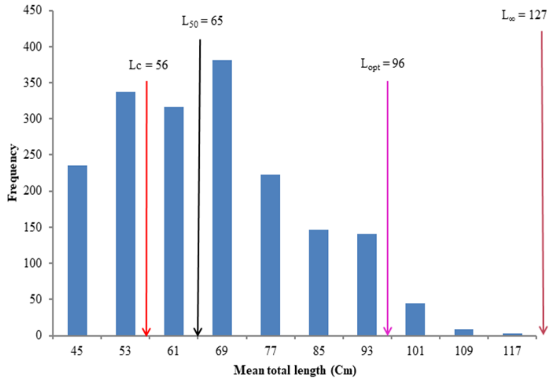

Fig. 4. Size spectrum of *C. gariepinus* from Lake Abaya.

When the result of virtual population analysis (VPA) was considered (Fig. 5), *C. gariepinus* with a total length ranging from 45 cm to 68 cm had more exposure to fishing gears, whereas the fishing mortality was higher for the total length above 70 cm.

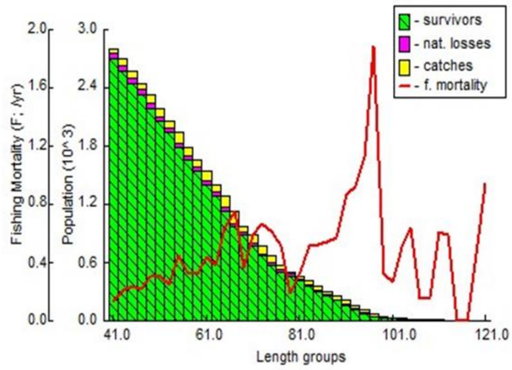

Fig. 5. Virtual population analysis (VPA) of *C. gariepinus* from Lake Abaya.

As indicated in Fig. 6a, the recruitment pattern of *C. gariepinus* in Lake Abaya takes place throughout the year with a single peak period in March. The relative yield per recruit (Y′/R) and biomass per recruit (B′/R) were computed using the knife-edge technique. Based on the computed relative yield per recruit and relative biomass per recruit curve (Fig. 6b), the exploitation rate at which its virgin stock's 10% of its marginal relative yield per recruit rises ($E_{0.1}$), the exploitation rate the stock is diminished to half of its initial virgin biomass ($E_{0.5}$), and the exploitation rate that results in the maximum yield (E_{max}) were 0.50, 0.35, and 0.61, respectively. The current exploitation rate ($E_{current}$) was 0.82 which indicated the *C. gariepinus* in Lake Abaya was overexploited.

The year-round recruitment and breeding are typical features of tropical species because of the relatively stable and elevated water temperatures in the tropics

(Etim and Sankare 1998). The rainfall patterns and water level fluctuations appear to be major influencing factors in the breeding biology of tropical freshwater fish species (Wootton, 1990). The monthly average rainfall in the study area is higher from March to October and could be one of the probable reasons for the occurrence of peak recruitment in March. Yield is not sustainable when fish are harvested before they are allowed to spawn at least once, and when fishing greatly reduces population size (Miranda *et al*., 2000). By comparing the length at first capture (Lc) with the length at first maturity (L_{50}) it is possible to obtain a rough idea of whether yield estimates are sustainable. Any exploited stock is more likely to be sustained if the average length of fish in the harvest is larger than the average length at maturity.

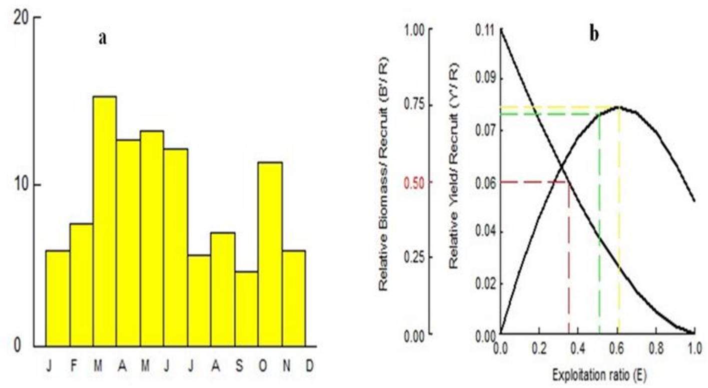

Fig. 6. Seasonal recruitment pattern (a) and Beverton and Holt relative yield per recruit and biomass per recruit (b) of *C. gariepinus* from Lake Abaya.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings, the sex ratio was found to be 1:l and the length-weight relationship of *C. gariepinus* was undergoing a curvilinear and positive allometric growth pattern. *C. gariepinus* in Lake Abaya was not in a suitable condition, as the mean condition factor was recorded to be less than one (K< 1). The predicted growth parameters; the asymptotic length (L∞) and the growth constant (K) were obtained to be 127.05 cm and 0.21 yr^{-1}, respectively. The asymptotic weight (W∞) when *C. gariepinus* attains its asymptotic length was estimated at 18.55 kg while, the longevity was estimated at 14.81 years.

The *C. gariepinus* in Lake Abaya was overexploited as 31.1% of the fish was removed before it reached its Lc, and about 48.3% was caught before its length at first maturity. The current exploitation rate ($E_{current}$) and the exploitation rate that results a maximum yield (E_{max})were estimated at 0.82, and 0.61, respectively.

Generally, the evidence in this study revealed that 79.4% of *C. gariepinus* in Lake Abaya was under heavy fishing pressure with growth overfishing. The fish was not also in good condition and we recommended that the fisheries management of the lake should include restriction of fish caught lower than the length at first maturity as well as reduction of fishing gear to ensure the sustainability of this commercially important fish species.

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Conflict of Interest. None.

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