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Estimates of Life-History Parameters and Population Dynamics of *Bagrus Docmak* (Forsskål, 1775) in Lake Abaya, South Ethiopia

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Abstract:
Sufficient knowledge is necessary for the responsible exploitation of inland fisheries. However, decision-making for fisheries management is unreliable since many inland fisheries lack monitoring. The purpose of this study was to estimate life-history parameters and population dynamics of B. docmak from Lake Abaya. The length-weight data were collected from a total of 1033 fish samples from commercial fisheries of Lake Abaya. The life-history parameters and population dynamics were analyzed with SPSS, and FiSAT II software. An estimate of the length-weight relationship was $W = 0.0085L^{3.04}$; $R^2 = 0.9118$. *The mean condition factor was 0.99, 1.01, and 1.00 for females, males, and combined sexes, respectively, and it was highly significant by months' interaction (P = 0.000). The estimated growth parameters were asymptotic length* $L\infty = 99.75$ *cm, growth rate* $K = 0.55\ yr^{-1}$, *theoretical age* $t_o = -0.21$, *growth performance index* $\Phi' = 3.74$ *and life-span* $t_{max} = 5.24$ *years. The mortality related parameters were estimated as* $Z = 1.43\ yr^{-1}$, $M = 0.57\ yr^{-1}$, $E = 0.60$, *and* $Z/K = 2.6$. *The length at first maturity* (L_{50}), *the length at first capture (Lc), and the optimum length* (L_{opt}) *was 52.02 cm, 44.27 cm and 64.37cm, respectively. With biannual pulses in March and September, the recruitment pattern was year-round. It was also estimated that the length at first recruitment (Lr) was 32 cm, and the corresponding age at first recruitment (Tr) was 0.5 years. About 39.5% of the fish in this study were caught before reaching their length at first maturity* (L_{50}), *and they were subject to overfishing in terms of both recruitment and growth. The exploitation rate (E) in the current investigation was 0.60, while the exploitation rate derived from Y′/R for* $E_{0.5}$ *was 0.35. The current rate of exploitation suggested that B. docmak from Lake Abaya was overexploited. From the management point of view, the exploitation rate should be reduced from 0.60 to 0.35 (42%) to obtain sustainable yield from the fishery of Lake Abaya.*

Keywords: *Condition factor, Exploitation rate, Growth pattern, Life-history parameters, Population dynamics*

1. Introduction

The availability and productivity of many natural aquatic resources have drastically decreased as a result of human disturbance; some have even been forced to the brink of collapse (Pauly *et al*., 2002; Myres and Worm, 2003; Welcomme *et al*., 2010; Huo *et al*., 2015; Lorenzen *et al*., 2016). Fish population parameter estimation is crucial for determining the health of fish stocks and for subsequently organizing their sustainable management (Quist, 2007; Camargo *et al*., 2015). Because of fluctuating environmental factors and shifting fishing pressures, natural fish populations are dynamic (McRae and Diana, 2005). Fish population dynamics are primarily determined by recruitment, growth and mortality rates (Gulland, 1982; Pope *et al*., 2010). If growth and recruitment rates are higher than mortality losses, the size of the fish population increases; if mortality are higher, the population size decreases. Environmental factors and fish species' life-history strategies have an impact on fish population meters (Silvestre and Graces, 2004).

Fish life-history parameters, including maximum length (L_{max}), fecundity, mortality rates, asymptotic length ($L\infty$), growth curvatures (K), longevity, and the length at maturity (L_{50}), are crucial indicators of population dynamics. According to Sa-Oliveira *et al*. (2015), species with longer lifespans have larger asymptotic lengths ($L\infty$), lower natural mortality rates (M), and lower growth curvatures (K), whereas species with shorter lifespans have smaller asymptotic lengths, higher natural mortality rates and higher growth curvatures.

One of Ethiopia's Rift Valley lakes, Lake Abaya, supplies about 8% of the country's and local markets with catch fisheries (Gashaw and Wolff, 2014). Four commercially significant fish species, including the Nile tilapia (*O. niloticus*), Nile perch (*L. niloticus*), African catfish (*C. gariepinus*) and *Bagrus docmak* are found in the lake. Fish population dynamics and life-history research are essential for managing fish stocks sustainably. There are insufficient life-history parameters and population dynamics for *B. docmak* in Lake Abaya. It is impossible to accurately estimate population status and productivity when life-history and population dynamics data are lacking. Reliable and up-to-date fish life-history and growth parameters could be used to determine the state of overexploited stocks and assist in making decisions that would enhance fishery management and species conservation. Therefore, the purpose of this study was to determine the *B. docmak* growth parameters, mortality rates, recruitment patterns, and exploitation status in Lake Abaya.

2. Materials and Methods

2.1 The study area

Lake Abaya is one of the two southernmost lakes in the rift valley and the second largest lake in Ethiopia after Lake Tana, which is a highland lake. It is situated in south Ethiopia regional state, between latitudes 5°55'9" and 6°35'30" N and longitudes 37°36'90" and 38°03'45" E (Fig. 1). The lake has an area of 1200 square kilometers with 60 km long and 20 km wide. It is the largest lake in the rift valley with a maximum depth of 13 m and located at 1268 m above sea level. The largest island in the lake is Aururo; the others are Gidicho, Welege, Galmaka and Alkali. The town of Arba Minch is located on its southwest shore, while the southern banks are part of Nech Sar National Park. The main perennial rivers that flow into Lake Abaya are Galana, Bilate,

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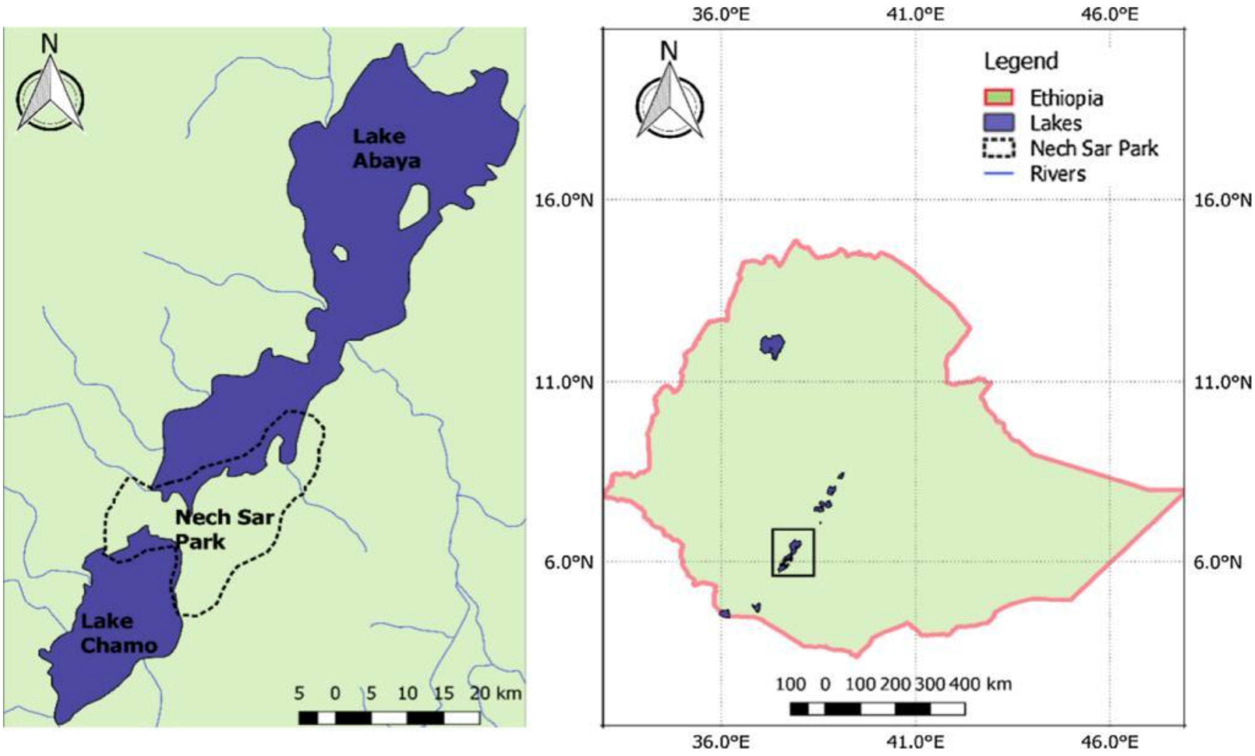

Gidabo, Hamassa and Harre.

Figure 1. Lakes Abaya and Chamo outline map (www.maplibrary.org)

2.2 Data collection

Fish samples were collected from four prominent landing sites on a monthly basis for the period of 12 moths (September 2023-August, 2024) from commercial fisheries of Lake Abaya. The four landing sites were: Hillo, Langama, Gubena and Ella. The fish were sampled randomly and its morphometric measurements (Total length and Total weight) were measured using measuring board and electronic sensitive balance to the nearest of 0.1cm and 0.1g, respectively.

2.3 Data analysis

2.3.1 Length-weight relationship and condition factor

The relationship between length and weight of the fish was analyzed by measuring the lengths and weights of the sampled fish specimens. The statistical relationship between these parameters of the fish was established by using the following equation (Froese, 2006):

$$W = aL^b \quad \text{———} \quad (1)$$

Where, W = weight of fish (g), L = length (cm), *a* = intercept and *b* = slope of length-weight regression.

The condition factor is used for comparing the condition, fatness or wellbeing of fish based on the assumption that heavier fish of a given length are in better condition. The coefficient of the condition factor, K was calculated by using Fulton (1904):

$$CF = \frac{W}{L^3} * 100 \quad \text{———} \quad (2)$$

Where, W = weight in grams, L = length in cm, and 100 is a factor to bring the value of CF near unity (Froese, 2006).

2.3.2 Growth parameters and mortality rates

The collected length frequency data were used to determine growth parameters which intended to be used for the estimation of mortality rates and stock status. Initial estimates of the von Bertalanffy growth parameters such as the asymptotic length (L∞) and the growth coefficient (*K*) were obtained by using ELEFAN incorporated in FiSAT II software (Gayanilo and Sparre, 2005). The theoretical age at zero length (t_o) was calculated from Pauly's empirical equation (Pauly, 1979) given below:

$$\text{Log}(-t_o) = -0.3922 - 0.2752 * \text{LogL}\infty - 1.0381 * \text{LogK} \text{———} (3)$$

Where, t_o = the theoretical age at zero length, L∞ = asymptotic length (cm) and *K* = the von Bertalanffy growth coefficient.

The growth performance index Phi (Φ′) was calculated as Pauly and Munro (1984):

$$\Phi' = \text{LogK} + 2 * \text{LogL}\infty \text{———} (4)$$

The von Bertalanffy growth functions (VBGF) were fit to length at age data using the original equation of von Bertalanffy (1938) with size at birth L_o rather than t_o. The length at age zero (L_o) calculated as:

$$L_o = L\infty\left(1 - exp^{(Kto)}\right) \text{———} (5)$$

The longevity (t_{max}), defined as the time the individual takes to reach 95% of asymptotic length (L∞) was estimated based on the formula proposed by Natanson *et al*. (2006):

$$\text{Longevity } (t_{max}) = \left(\frac{1}{K}\right) * ln\left(\frac{L\infty - Lo}{L\infty(1-X)}\right) \text{———} (6)$$

Where, $X = (1 - \frac{Longevity}{L\infty}) = 0.95$

The length-converted catch curve approach which was used in FiSAT II was applied to estimate the total instantaneous mortality rate (Z). Using Tailor's method, the instantaneous natural mortality rate (M) was calculated as follows:

$$M = \frac{-\ln(1-0.95)}{tmax} \text{———} (7)$$

The instantaneous fishing mortality rate (F) was deduced from the expression F = Z-M, and the exploitation rate (E) from E = F/Z (Pauly, 1980).

The length at first capture (Lc) is the length at which 50% of fish is retained by the fishing gear was estimated from the equation of Beverton and Holt (1957) while the corresponding age at first capture (Tc) was computed by converting Lc to age using the von Bertalanffy equation (Gulland and Holt, 1959) as follows:

$$Lc = \bar{L} - K\left(\frac{L\infty - \bar{L}}{Z}\right) \text{———} (8)$$

$$Tc = to - \frac{1}{K} * \ln\left(1 - \frac{Lc}{L\infty}\right) \text{———} (9)$$

Where, Lc = the length at first capture, and $\bar{L}$ = is the mean length of fish in the catch sample, Tc = is the age at first capture while, K, L∞, Z and t_o are as defined above.

The length at first maturity (L_{50}) at which 50% of the fish is matured, the corresponding age at first sexual maturity (T_{50}), and the optimum length (L_{opt}) were estimated the following equation (Froese and Binholan, 2000):

$$\text{Log}(L_{50}) = 0.8979 * \text{Log}(L\infty) - 0.0782 \text{———} (10)$$

$$T_{50} = to - \frac{1}{K} * \ln\left(1 - \frac{L50}{L\infty}\right) \text{———} (11)$$

$$\text{Log}(L_{opt}) = 1.042 * \text{Log}(L\infty) - 0.2742 \text{———} (12)$$

2.3.3 Recruitment patterns

From a time series of length-frequency data, the recruitment patterns routine in FiSAT II was used to calculate the number of pulses annually and the relative intensity of each pulse. As inputs, the growth parameters L∞ and K were employed. The frequencies were backward projected onto the time axis of a time series of samples along a trajectory given by the vBGF to create the graphic illustrating the seasonal pattern of recruitment into the fishery (Dadzie *et al*., 2007). The following formula was used by Beverton and Holt (1957) to estimate the age at first recruitment (Tr):

$$Tr = to - \frac{1}{K} * \ln\left(1 - \frac{Lr}{L\infty}\right) \text{———} (13)$$

Where, Lr = is the smallest length in the collected sample.

2.3.4 The Beverton and Holt Y′/R and B′/R analyses

The relative yield per recruit model was used based on the Beverton and Holt model (1966), modified by Pauly and Soriano (1986). The option assuming knife-edge selection was utilized based probabilities of capture and Lc/L∞ and M/K ratios were used as inputs. The relative yield per recruit (Y′/R) was computed as the following equation:

$$Y'/R = EU^{\frac{M}{K}}\left(1 - \frac{3U}{(1+m)} + \frac{3U^2}{(1+2m)} - \frac{U^3}{(1+3m)}\right) \text{———} (14)$$

Where, E = F/Z, Z = F+M; U = 1-(Lc/L∞); m = (1-E)/(M/K) = K/Z

Where, the other parameters are as previously stated, and E stands for the exploitation rate, F for fishing mortality, and Z for total mortality. The following formula was used to estimate the relative biomass per recruit (B′/R):

$$B'/R = \frac{(Y'/R)}{F} \text{———} (15)$$

The first derivative of this function was used to estimate the biological reference points, $E_{0.1}$, and $E_{0.5}$. The exploitation rates at maximum sustainable yield (MSY), maximum economic yield (MEY), and optimal exploitation rate are denoted by the letters E_{max}, $E_{0.1}$, and $E_{0.5}$, respectively.

3. Results and discussions

3.1 The length-weight relationship and condition factor

The present investigation was conducted on a total sample of 1033 specimens of *Bagrus docmak*. The length of the fish ranged from 29 to 98 cm total length, and the weight between 217 and 11000 g. Out of the total samples, 84.32% of the catches were placed between 44 and 74 cm, however the remaining 7.36% and 8.33% were less than 44 cm and greater than 74 cm, respectively. The mid-length of 50 cm has great contribution in the catch (23.81%) followed by the mid-length of 62 cm which has contributed about 19.17% (Fig. 2).

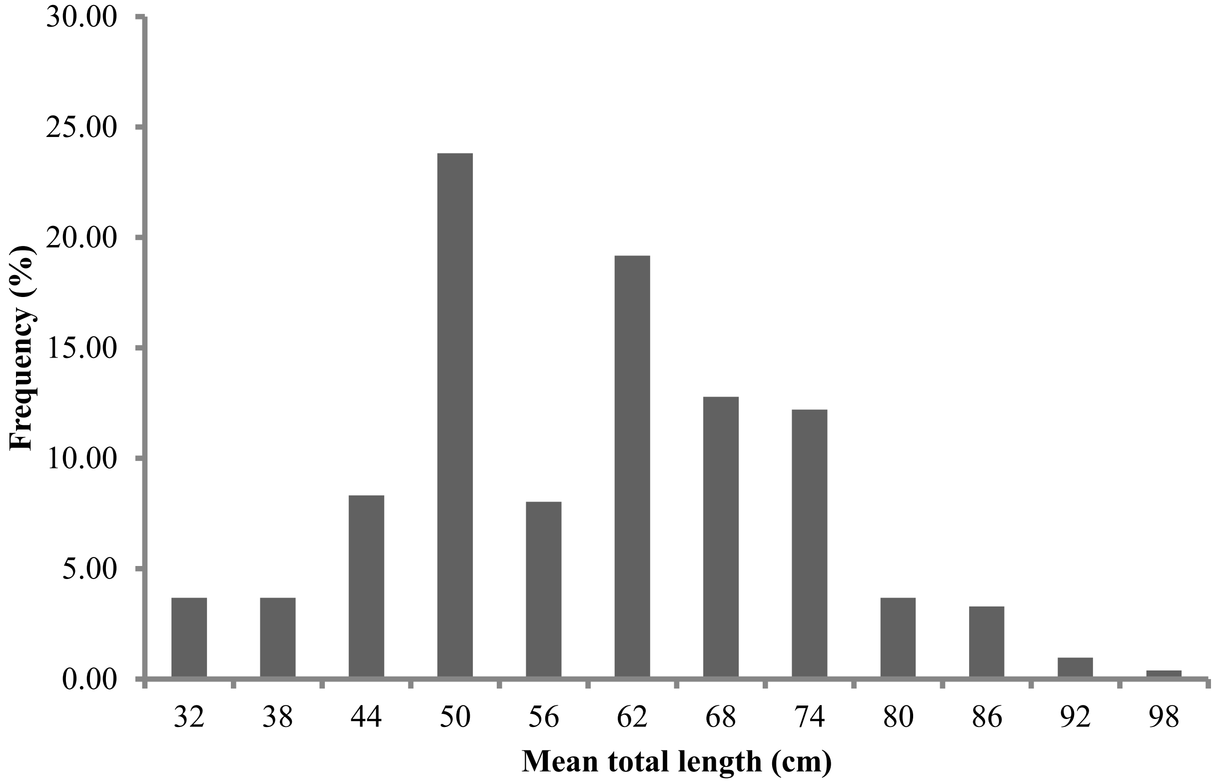

Figure 2: The length structure of *Bagrus docmak* in Lake Abaya

The relationship between the total length and total body weight of *B. docmak* was established with the use of scatter plot diagram and power function (Fig. 3). The *b* value obtained from the length-weight relationship was 3.0428 and was described by the equation $W = 0.0058L^{3.0428}$ ($R^2 = 0.9118$, r = 0.9548). A strong positive correlation was found between the length and weight of *B. docmak* in Lake Abaya (r = 0.9548). The regression coefficient *b* was found to be 3.0428 and did not show a statistically significant difference from the hypothetical value 3.0 ($P > 0.05$).

The growth patterns of the fish might be isometric, negative allometric or positive allometeric. When a fish grows isometrically, its body form does not alter. Positive allometric growth suggests that the fish gets comparatively stouter or deeper in body as it grows, whereas negative allometric growth makes the fish thinner or lighter in weight as it gets longer (Riedel *et al*., 2007).

The isometric growth pattern (*b* = 3.0428) observed in the present study suggests that *B. docmak* in Lake Abaya exhibits no change in body shape as it grows. The high coefficient of determination value (0.9118) obtained in assessing the length-weight relationship indicates a good prediction of curvilinear regression. When comparing the result of the present study with those of previous studies, it indicated that it was in agreement with some other regional and international findings on length-weight relationships while others are not.

The growth pattern observed in this study was consistent with the isometric growth reported by Buchale Shishitu (2024) for *O. niloticus* (b = 3.02) from Lake Abaya and El-Drawany and Elnagar (2015) for *B. docmak* (b = 3.05) from the Muess Channel in Egypt. On the other hand, *B. docmak* from Lake Victoria (b = 2.89) and Lake Akata (b = 2.79) showed negative allometeric growth, according to Yongo and Agembe (2021) and Ikongbeh *et al*. (2012), respectively. Also Buchale Shishitu (2022) and Hailu *et al*. (2009) reported a positive allometric growth b = 3.1 and b = 3.24 for *B.docmak* from Lake Chamo respectively, whereas Eel-Drawany and Elnagar (2015) reported b = 3.1 for *B. bayad* from the Muess Channel in Egypt.

Fish may exhibit distinct growth patterns due to factors such as water quality, food availability, habitat conditions, season and life stages (Yilmaz *et al*., 2012; Ali *et al*., 2016). According to Tsoumani *et al*. (2006), differences in fish growth patterns may also be related to the species' overall health, phenotypic, geographic location, and therefore its habitat. It should also be mentioned that different biotic and abiotic factors might affect a fish species' growth process depending on where they live.

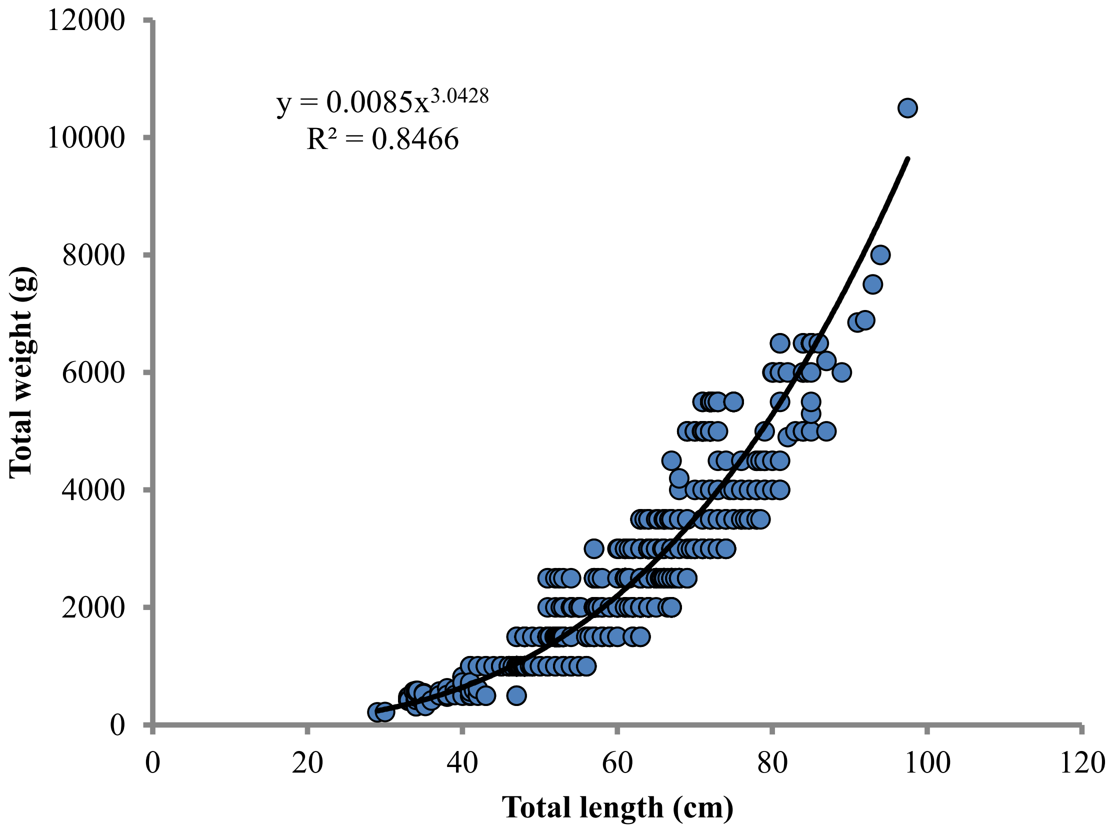

Figure 3: Length-weight relationship of *B. docmak* from Lake Abaya

3.2 Condition factor (CF)

The mean condition factor (CF) was 0.99, 1.01, 1.00, for females, males and combined sexes of *B. docmak*, respectively (Table 1). The mean condition factor was not significantly different between sexes ($P > 0.05$) but the variations of condition factor was highly significant by month's interaction ($P = 0.000$; Table 2).

The condition factor which represents the degree of well-being of the fish in their habitat is expressed by the coefficient of condition, also known as the length-weight factor. It is a measure of various ecological and biological factors, such as degree of fitness, gonad development, and suitability of the environment with respect to the feeding conditions (Murtuza and Ai-Misned, 2013; Yongo *et al*., 2016). When the value of condition factor is equal to or greater than one, it means the fish have attained a better condition (LeCren, 1951; Ayoade, 2011; Ujjania *et al*., 2012).

Based on the mentioned criteria, *B. docmak* sampled from Lake Abaya during the present study was in a good condition, with a mean value of 1.00. This result was comparable with the findings of Yongo and Agembe (2021) for *B. docmak* (CF = 1.0) from Lake Victoria, Buchale Shishitu (2022) from Lake Chamo (CF = 0.99), Mutethya *et al*. (2020) for *S. intermedius* (CF = 1.00), and Yongo and Wairimu (2018) for *S. victoriae* (CF = 1.01) from the Nyanza Gulf of Lake Victoria. However, the result of the present study was not in agreement with the results of Ikongbeh *et al*. (2012) for *B. docmak* from Lake Akata (CF = 1.62), Buchale Shishitu (2022) for *L. niloticus* from Lake Abaya (CF = 1.31), Buchale Shishitu (2024) for *O. niloticus* from Lake Abaya (CF = 1.69), Hail Anja *et al*. (2009) for *B. docmak* from Lake Chamo (CF = 0.4-05), and Buchale Shishitu and Atnafu (2025) for *C. gariepinus* from Lake Abaya (CF = 0.76).

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The condition factor of fish can vary on the bases of the species type, prevailing environmental conditions, and food availability in their occupied habitats (Okach and Dadzie, 1988; Wanyanga *et al*., 2016). The condition factor of fish can also be affected by season, reproductive cycles, fishing pressure, and water quality parameters (Khallaf *et al*., 2003; Buchale Shishitu and Atnafu, 2025).

Table 1: Mean condition factors of *B. docmak* from Lake Abaya

Sex	Mean	Std. Deviation	Std. Error of Mean
Females	0.99	0.113	0.033
Males	1.01	0.113	0.033
Combined sexes	1.00	0.106	0.030

Table 2: Variations of condition factor by months

Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Between groups	.255	11	.023	9.860	.000
Within groups	.028	12	.002		
Total	.284	23			

3.3 Growth parameters and mortality rates

The von Bertalanffy growth model was used to estimate the growth parameters and the estimated parameters of growth for *B. docmak* indicated that asymptotic length ($L\infty$) = 99.75 cm, growth rate (K) = 0.55 yr^{-1}, the age at birth (t_o) = -0.21, the length at birth (Lo) = 10.88 cm, the length at first maturity (L_{50}) = 52.07 cm, the growth performance index (Φ′) = 3.74, and the longevity (t_{max}) was 5.24 years. The optimum length (L_{opt}) at which *B. docmak* attains optimum weight was also estimated at 64.37 cm in Lake Abaya.

The growth parameters of *B.docmak* reported by Musinguzi *et al*. (2024) were L∞ = 107.9 cm, K = 0.10 and Φ′ = 3.08 and L∞ = 104.9 cm, K = 0.10 and Φ′ = 3.06 from Lakes Edward and George, respectively. The differences in estimations of the von Bertalanffy growth parameters when compared to similar study were due to variations in environmental conditions of different water bodies. The size of the fish 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 the asymptotic length of fish in a given water body.

The total mortality (Z) of *B. docmak* was estimated from a linearized length converted catch curve regression analysis. The slope of the regression line (b) was computed to be -1.43, and hence, the estimated total mortality rate was 1.43 (Fig. 4). The estimated natural mortality rate (M), and fishing mortality rate (F) were 0.57 and 0.86, respectively. The obtained mortality parameters revealed that, the current exploitation rate (*E*) was estimated at 0.60, which indicated the state of overexploitation. The relative fishing mortality (F/M) was 1.51 that confirms the state of overexploitation. According to Palomares *et al*. (2018), the overexploited stocks have a relative fishing mortality higher than 1.2. Fishing mortality can be attributed to both natural and anthropogenic factors such as fishing. Most of the natural mortality could be attributed to old age, diseases, and predation in the aquatic ecosystem. The estimated Z/K ratio of *B.docmak* was 2.6 which indicated mortality-dominated fish population. According to Beverton and Holt (1957) general criteria, if 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. Based on the finding in the present study, *B. docmak* in Lake Abaya was highly exploited.

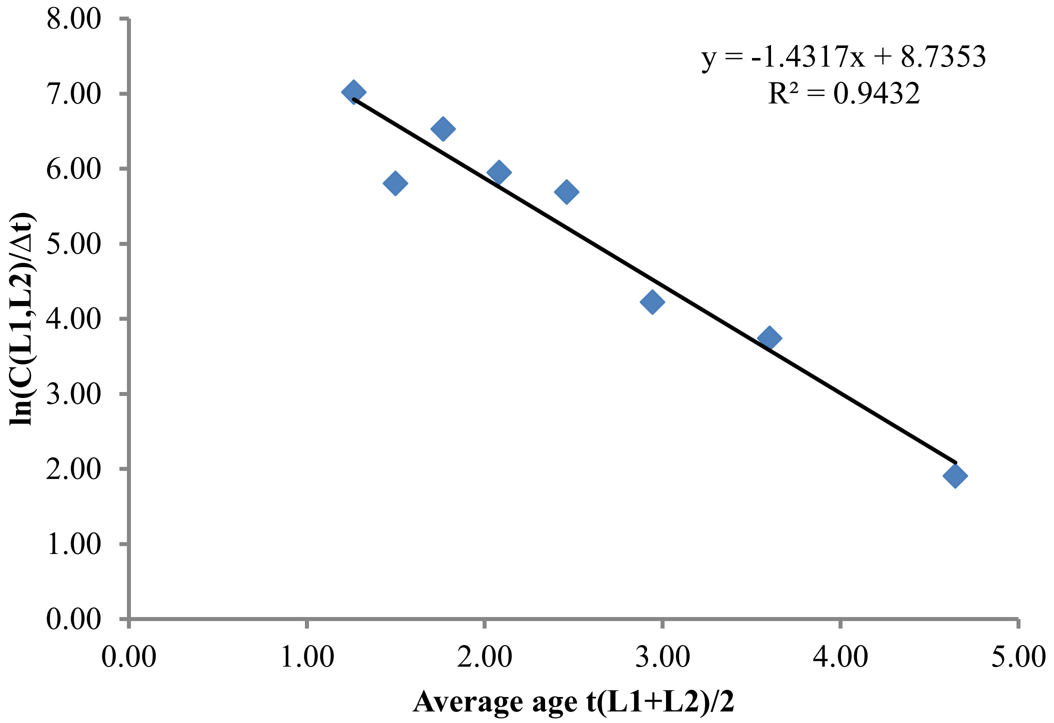

Figure 4: Linearized length-based catch curve of *B. docmak* from Lake Abaya.

The estimated length at first capture (Lc) and the length at first maturity (L_{50}), of *B. docmak* was 44.27 cm, 52.07 cm, respectively (Fig. 5). The age at first capture (Tc) corresponding to the length at first capture (Lc) was estimated at 0.86 years which indicated that *B. docmak* in Lake Abaya was vulnerable for capture at the age of eight months. About 15.69% of the fish was removed before their length at first capture (Lc) while, about 39.5% was caught before its length at first maturity (L_{50}).

The length at first capture (Lc) is used for detecting the appropriate mesh sizes of the applied gears and the length at first maturity (L_{50}) in relation to the length at first capture can be considered as a biological reference point for any target species (Froese and Binohlan, 2000). If the length at first capture (Lc) falls below the length at first maturity (L_{50}), there is a risk of recruitment overfishing. In the present study, the length at first capture (Lc) was less than L_{50} and Lopt indicating growth and recruitment overfishing characterized by small-zed *B. docmak* in Lake Abaya. To obtain a maximum yield from the fishery, any catch greater than L_{50} could make the fishery sustainable in Lake Abaya.

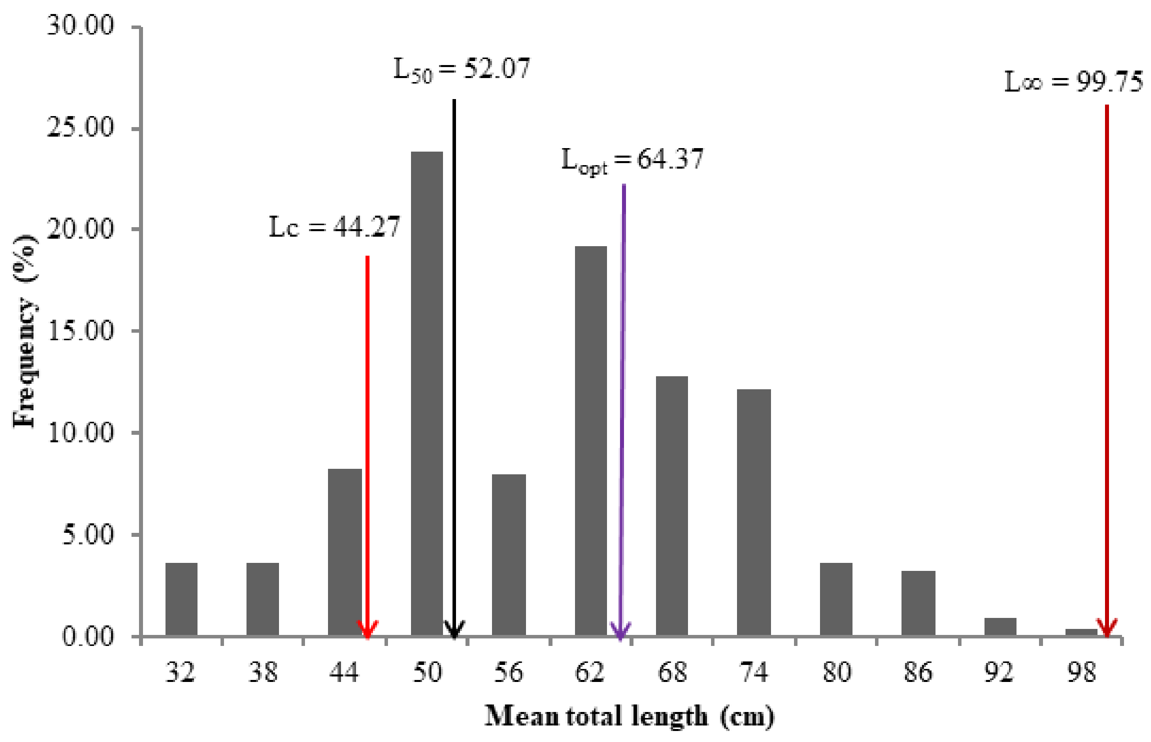

Figure 5: Size spectrums of *B. docmak* from Lake Abaya

3.4 Virtual population analysis (VPA) and recruitment patterns

Based on the result of virtual population analysis (VPA), a total length between 41 cm and 77 cm had more exposure to fishing gears, whereas the fishing mortality was higher for the total length above 65 cm (Fig. 6).

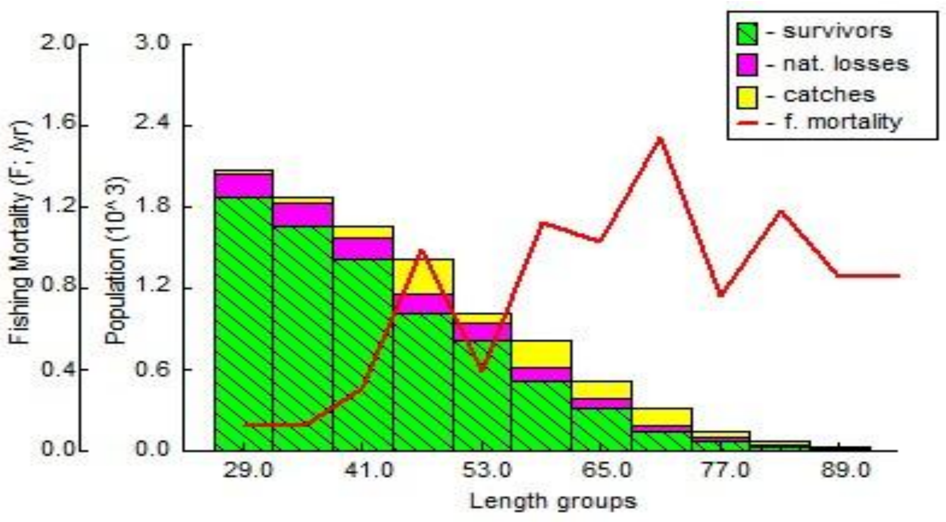

Figure 6: Virtual population analysis of *B. docmak* from Lake Abaya

The length at recruitment (Lr) was determined as the smallest mid-length in the collected sample, while the corresponding age at recruitment (Tr) was the youngest fish in the sample. In the present study, the length at recruitment (Lr) and the corresponding age of recruitment (Tr) was 32 cm and 0.5 years, respectively for *B. docmak* in Lake Abaya. The recruitment pattern takes place throughout the year with biannual peak period in March and September (Fig. 7).

The year-round recruitment and breeding are typical features of tropical fish due to relatively stable and elevated water temperatures in the tropics (Etim and Sankare, 1998). The rain fall 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 occurrences peak recruitment in March and September.

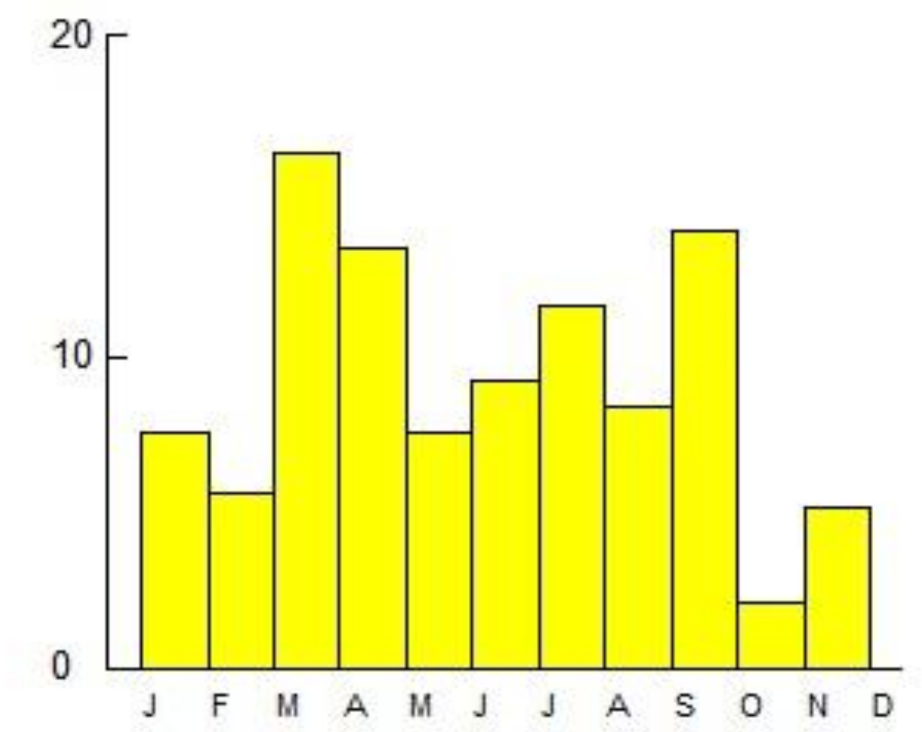

Figure 7: Seasonal recruitment pattern of *B. docmak* from Lake Abaya

3.5 Relative Yield and relative Biomass per recruit (Y′/R, B′/R)

In the present study, the current exploitation rate (E) was 0.60 and the exploitation rates obtained from relative yield per recruit analysis were $E_{0.1}$ = 0.507, $E_{0.5}$ = 0.350 and E_{max} = 0.614 (Fig. 8). The current exploitation rate (E) was almost equivalent to E_{max} which achieves the maximum Y′/R and higher than $E_{0.5}$ which conserves 50% of the spawning stock biomass. The current exploitation rate indicated that *B. docmak* in Lake Abaya was overexploited. From the management point of view, the exploitation rate should be reduced from 0.60 to 0.35 (42%) to obtain sustainable yield from *B. docmak* in Lake Abaya.

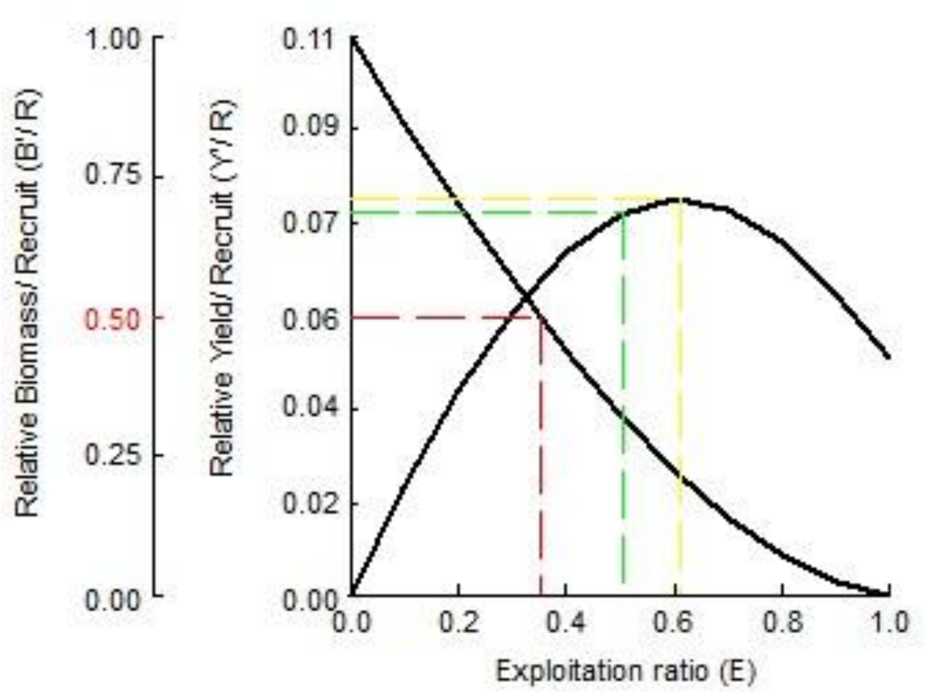

Figure 8: Beverton and Holt relative yield and biomass per recruit of *B. docmak* from Lake Abaya

4. Conclusions and Recommendations

From the results of this study, it was concluded that *B. docmak* in Lake Abaya follows isometric growth pattern (b = 3.04). The growth parameters; asymptotic length (L∞) and growth curvature (K) was estimated at 99.75 cm and 0.55 yr^{-1}, respectively. The fish was overexploited and experiencing recruitment and growth overfishing due to heavy fishing pressure as 39.5% of the fish was removed before they attain the length at first maturity (L_{50}). The length at recruitment (Lr) and the corresponding age of recruitment was 32 cm and 0.5 years, respectively. The recruitment pattern takes place year-round with biannual pulses in March and September. Proper management of this resource requires reduced exploitation and fishing effort by reduction of number of fishing gears and/ or reduction of fishing hours. To enhance sustainability of *B. docmak* in Lake Abaya, the current exploitation rate should be reduced by 42%.

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Conflict of interest

The author declares that there is no conflict of interest.

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