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Population Dynamics and Yield Estimation of Common Carp (*Cyprinus carpio*, Linnaeus, 1758) in Ayalew Reservoir, Gamo Zone, Southern Ethiopia

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ABSTRACT

Common carp (*Cyprinus carpio*) is an imported fish species in Ayalew reservoir. The study was intended at estimating important population dynamics parameters and production potential in the reservoir. Total length (TL) and total weight (TW) data were collected from a total of 276 fish samples (141 females and 135 males). The obtained data were analyzed using FiSAT II software. The population and production potential were assessed by using Jones length based cohort analysis model and length-based Thompson and Bell yield prediction models. The average total length was 26 cm and the dominant length groups ranged from 17 to 33 cm were 87%. The length-weight relationship parameters were ($TW = 0.0565TL^{2.53}$, $R^2 = 0.95$) and the condition factor $K = 1.29$. The parameters of von Vertalanffy growth curve were $L\infty = 41$ cm, $k = 0.52$, $t_o = -0.29$, $\theta = 2.9$ and A0.95 = 5.5 years. The assessed values of the total, natural and fishing mortalities were Z = 1.23, $M = 0.55$ and F = 0.68, respectively. The current exploitation rate, 0.55, indicates slightly overexploitation. The estimated fish population and the annual fish yield were 59,304 and 1.5 tons, respectively. However, investigation on reproductive biology, limnolocal aspects and stock enhancements should be required for the sustainability of these resources.

INTRODUCTION

Common carp (*Cyprinus carpio*) is considered to be a very important aquaculture species in many Asian and some European countries. It is widely distributed and frequently considered a nuisance species outside its native range (Penne and Pierce, 2008; Mohammad, 2015). The Common carp is one of the most common freshwater fish invaders worldwide, creating adverse effects on water quality and impacting ecosystem structure and function (Letvin *et al*., 2017). It is highly adaptable to new environments and can alter the biotic and abiotic integrity of aquatic ecosystems (Bajer *et al*., 2012).

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In Ethiopia, *Cyprinus carpio* was first introduced to Aba Samuel Dam (Awash River basin) in 1940 from Italy (Getahun, 2017). Later, it has been introduced in Lake Ziway in the late 1980s (FAO, 1997; Abera *et al*., 2015). For food security purpose, *C. carpio* was introduced in highland lakes such as Ashengie, Ardibo, and Maybar and the introduction was successful (Golubtsov and Darkov, 2008).

Ayalew reservoir is one of the highland water bodies in Gamo Zone Chencha woreda. According to gathered information from Chencha woreda, *C. carpio* was introduced in Ayalew reservoir in the late 1980s by National Fishery and Aquatic Life Research Center. After some years later, the fish was adapted and has been observed by the local community in the reservoir. Since then, there was no any documented information about the population dynamics of *C. carpio* in Ayalew reservoir. For sustainable management and utilization, information on the population dynamics and production potential is very important for this species. Therefore, the objective this study was to estimate the population dynamics and production potential of *C. carpio* in the reservoir.

MATERIALS AND METHODS

Description of the study area

Ayalew reservoir is found in Chencha woreda in Gamo Zone. It is situated at the coordinates of 06°25′068″N latitude and 037°57′368″E longitude with an elevation of 2861 meters above sea level. The area of the reservoir is about 4.37 ha or 0.0437 km^2 with a maximum depth of 5.3 meters.

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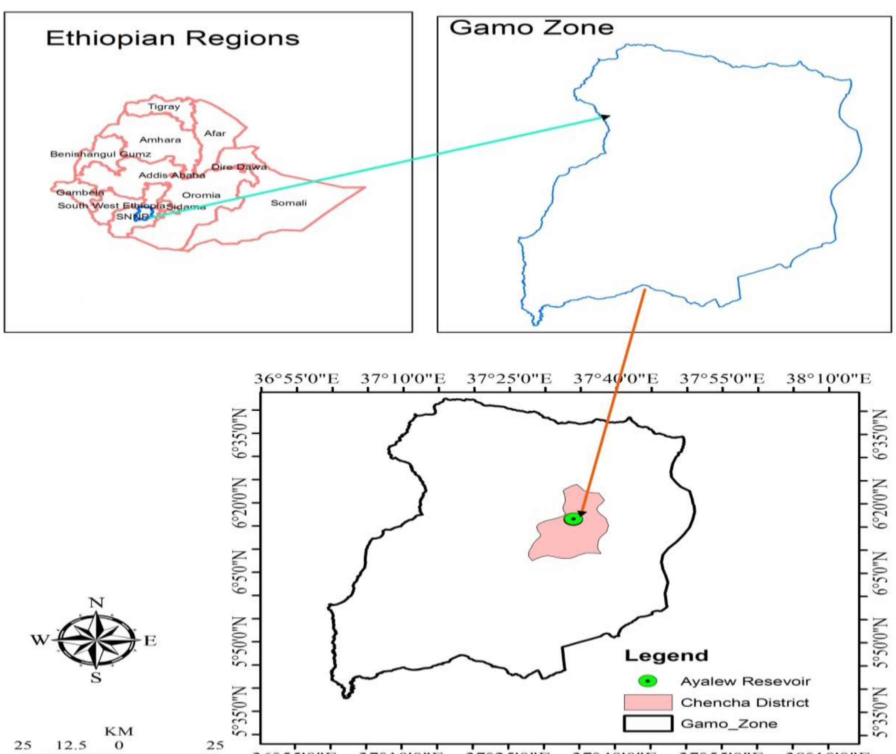


Figure 1. Location of Ayalew reservoir in Chencha woreda, Gamo zone, Southern Ethiopia

Methods of sampling and data collection

Ten youths were trained about fish catching and data recording systems. For the trained youths a boat and four monofilament gill nets with 3.5 mesh sizes were delivered for the research activities. Two data collectors were selected based on their skill and involved in data collecting process. The gillnets were deployed with plastic bottles as floats across the reservoir at 5:00 PM and collected at 7:00 AM the next morning. Immediately following capture, the total length (TL) and weight (TW) of the fish were measured, using a measuring board and sensitive balance, to the nearest 0.1 cm and 1 g, respectively. Data were collected weekly for eight months, from October 2021 to May 2022.

Length-weight relationship and condition factor

Length-weight relationship was calculated using power function (Le Cren, 1951).

$TW = aTL^b$ -- [1]

Where,

TW = total weight (g), a = the intercept, TL = total length (cm), b = the slope of length-weight regression

The Fulton's condition factor (*K*) is often used to reflect the nutritional status or well-being of an individual fish. It was calculated by using the formula described by Fulton (1904) which indicated below.

$K = \frac{TW}{TL^3} * 100$ --- [2]

Where,

K = Fulton's condition factor

TW = total weight of fish in gram (g)

TL = total length of fish in centimeter (cm)

Data summarization and analysis

Catch data were compiled and summarized in a format suitable for the Jones length-based cohort analysis and the length-based Thompson and Bell yield prediction models. Microsoft Office Excel (2010) was employed for both data summarization and subsequent analysis.

Estimating growth parameters

The K-scan technique available in the ELEFAN I module of the FiSAT II software was utilized to estimate asymptotic length (L∞) and growth rate (k) from the length-frequency data. Pauly's empirical formula (1979) was then applied to calculate the theoretical age at length zero (t_0)

$\log(-t_o) = -0.392 - 0.275 * \log L_\infty - 1.038 * \log k$ ---[3]

Where,

t_o = is the theoretical age at which fish would have at zero length.

L∞ = asymptotic length, k = von Bertalanffy growth rate constant

Growth performance indexes were calculated as Munro and Pauly (1983):

$\theta = \log(k) + 2 \times \log(L_\infty)$ ------------------------ [4]

Where, θ = growth performance index

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

$\log(L_{50}) = 0.8979 \times \log(L_\infty) - 0.0782$ ------------- [5]

Estimating mortality parameters based on length composition data

For the estimation of total mortality rates, linearized length converted catch curve method was applied and the mortality parameters were calculated based on the following formula (Pauly, 1984).

$\Delta t = 1/k*Ln[(L\infty - L_1)/[(L\infty - L_2)]$ -----------------[6]

$t\ (L_1+L_2)/2 = -1/k\{Ln[(1-(L_1+L_2)/2/(L\infty)]$ --------[7]

$Ln\{[C(L_1, L_2)]/[\Delta t(L_1, L_2)]\} = a- Z*t(L_1+L_2)/2$ ---[8]

Where: Δt = is age interval between L_1 and L_2 or the time taken by fish of length L_1 to reach length L_2

$t(L_1+L_2)/2$ = age of the average consecutive length groups (X variable)

$Ln\{[C(L_1,L_2)]/[\Delta t(L_1, L_2)]\}$ = Y variable

The natural mortality coefficient (M) was estimated using Taylor's method (1958) as follows:

$M = -ln(1-0.95)/A0.95$------------------------------ [9]

Where, A0.95 = longevity, the age at which 99% of the cohort would be dead as a result of natural means (Spare and Venema, 1997).

$A0.95 = t_o+2.996/k$ ------------------------------ [10]

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

k = von Bertalanffy growth rate constant

To obtain total mortality, regression analysis was conducted between X and Y variables as described in formula 7 and 8, respectively.

Total mortality (Z) = fishing mortality (F) + natural mortality (M) --------------------------------------- [11]

Then, the fishing mortality rate (F) was obtained by subtracting *M* from *Z*.

Estimating population sizes and fishing mortalities by length group (Jones, 1984)

Jones length-based cohort analysis model was used to estimate the population size and fishing mortality coefficient of *C. carpio* by length groups. This was done in the following three steps:

i) Population number estimate of the largest length group in the catch.

N(largest L) = C(Largest L)*(Z Largest L/F Largest L) -- [12]

Where, N (largest L) = the population of the largest length group in the catch;

C(largest L) = the catch of the largest length group;

Z(largest L) = the total mortality rate of the largest length group in the catch;

F(largest L) = the fishing mortality rate of the largest length group in the catch;

$C(L_1, L_2)$ = the catch of the length groups of $N(L_1)$

ii) Population numbers estimate of consecutively younger length groups in the catch.

$N(L_1) = [N(L_2) * H(L_1, L_2) + C(L_1, L_2)] * H(L_1, L_2)$ -- [13]

Where, $N(L_1)$ = The population number of L_1 (younger) fish

$N(L_2)$ = The population number of L_2 (older) fish

$H(L_1, L_2)$ = the fraction of $N(L_1)$ fish that survived natural death as it grows from length L_1 to L_2 and computed as the following equation (Jones, 1984).

$H(L_1, L_2) = [(L\infty - L_1)/ (L\infty - L^2)] (M/2k)$ ------- [14]

Where, $L\infty$ = the asymptotic length (cm) of *C. carpio* attained at mature size;

L_1 and L_2 = consecutive length groups of fish (cm) that contributed to the fishery;
K = von Bertalanffy growth rate constant (yr^{-1});
M = the rate of natural mortality coefficient

iii**)** Fishing mortality rate estimate of the respective length groups.

Fishing mortality values for each length group was estimated using the equation as follows:

$F(L_1, L_2) = (1/\Delta t) * \ln[N(L_1)/N(L_2)] – M$ -------- [15]

Where, $F(L_1, L_2)$ = Fishing mortality coefficient pertaining to the respective length group;
$N(L_1)$, $N(L_2)$ and *M* are as defined above.

To know the status of the stock, the exploitation rate (*E*) was estimated from mortality parameters as: *E* = F/Z. The exploitation rate (*E*) equal to 0.5 is considered as optimum level of exploitation; whereas less than 0.5 refers to under exploitation and greater than 0.5 refers to overexploitation (Gulland, 1971).

Thompson and Bell (1934) yield prediction procedure

Step 1) Estimating the total annual yield obtained under the current level of fishing

i) Estimating the yield obtained per year from each length group

Yield from each length group obtained per year ($Y(L_1, L_2)$ - is catch in number per length group per year ($C(L_1, L_2)$ multiplied by the average weight of each length group i.e.,

$Y(L_1, L_2) = C(L_1, L_2) * W(L_1, L_2)$ --------------- [16]

Where, $Y(L_1, L_2)$ = the yield (weight) of fish obtained per year from respective length group;
$C(L_1, L_2)$ = total annual catch of fish obtained from respective length group;
$W(L_1, L_2)$ = the mean weight of each length group estimated using equation

$W(g) = a* L^b$ -- [17]

Where,
W(g) = the average weight of each length group,
L = the average length (cm) of each length group i.e., $L = (L_1+L_2)/2$ in which L_1 and L_2 are the length intervals of consecutive length groups. '*a*' and '*b*' are values of the regression coefficients.

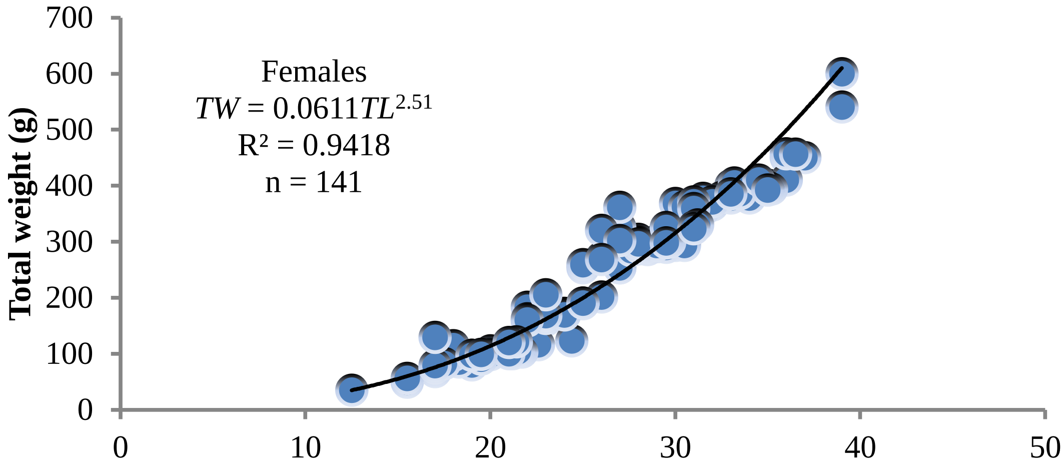
ii. Estimated yield was obtained from all length groups per year by adding up the contribution of each length group.

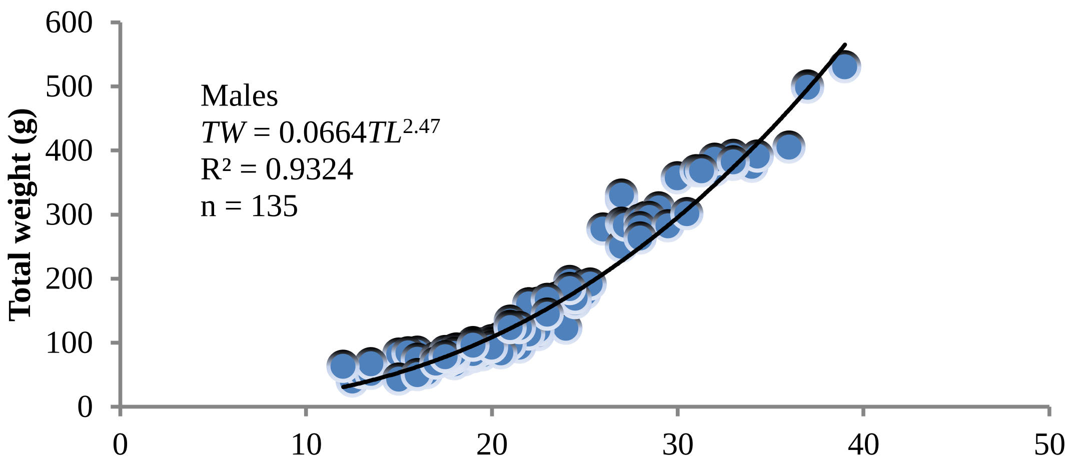
RESULTS AND DISCUSSION

Length-weight relationship and Fulton's condition factor

The values of the regression coefficient "*b*" for females (n =141), males (n =135) and combined sexes (n =276) obtained from the length-weight relationship by using the best-fit regression of power function gave 2.51, 2.47 and 2.53, respectively (Fig. 2). Analysis of variance (one-way ANOVA) showed the significant differences between the regression coefficient "*b*" and the cubic value of "*b"* (3) ($P < 0.05$).

As indicated in Table 1, the t-test also revealed that the presence of significant difference between the regression coefficient "*b*" in female, male and combined sexes (P < 0.05).





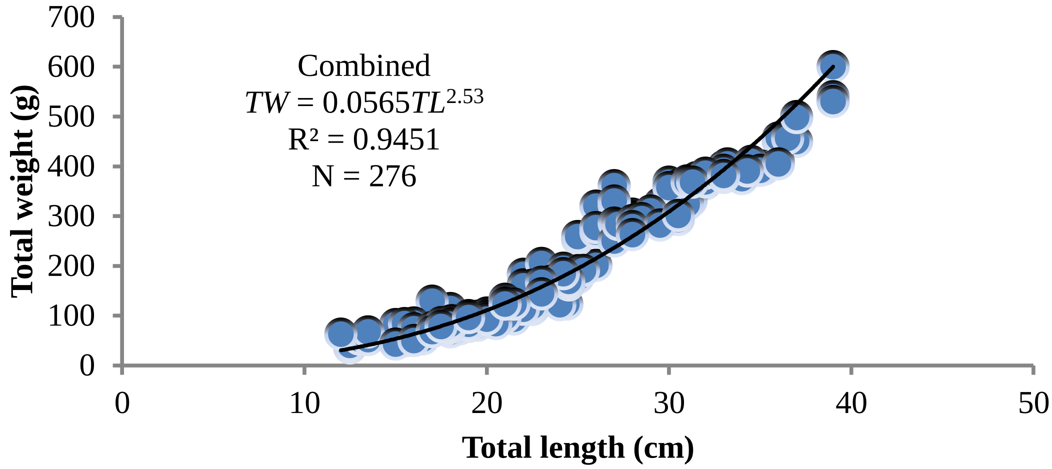


Figure 2. Length-weight relationship of *C. carpio* from Ayalew reservoir

In this study, the length-weight relationship showed that *C. carpio* showed a negative allometric growth. Values of *b* equal to 3 indicate that the fish grows isometrically; values other than 3 indicate allometric growth (Tesch, 1971). The *b* value is often 3.0 and generally between 2.5 and 3.5 (Froese, 2006). The *b* values in fish is species specific and therefore varies with sex, age, seasons, physiological conditions, growth increment and nutritional status of fish (Ricker, 1975; Bagenal and Tesch, 1978). Mert and Bulut (2014), Saylar and Semra (2014), Yilmaz *et al*. (2012), Ünver and Yildirim (2011), and Richard *et al*. (2018) also reported negative allometric growth for *C. carpio* in different water bodies worldwide, and their *b* values were 2.9, 2.8, 2.83, 2.89 and 2.75, respectively.

However, positive allometric growth values for this species were documented by (Karataş *et al*., 2007; Kirankaya and Ekmekçi, 2004), who reported b values of 3.21 and 3.022, respectively. The difference in the results of the current and previous publication might possibly be associated with reasons related to ecosystem and biological phenomena such as seasons, feeding behavior, competition for food, and maturity stages.

Table 1. Regression static parameters of *C. carpio*.

Parameters	Female	Male	Combined
a value	0.0611	0.0664	0.0565
b value	2.5135	2.4698	2.5303
Std. Error (S_b)	28.61	30.05	29.58
R^2	0.9418	0.9324	0.9451
t-calculated	48.62	42.55	69.26
t-critical (5%)	1.97	1.97	1.97
No of observation	141	135	276
Significance	0.000	0.000	0.000

Monthly mean Fulton's condition factor (*K*) ranged from 1.15 to 1.39 for females, 1.16 to 1.44 for males and 1.23 to 1.38 for combined sexes (Table 2). The average *K* value for females, males and combined sexes were 1.28, 1.30 and 1.29, respectively. Females exhibited their lowest condition factor (1.15) in February and their highest (1.39) in May. In contrast, the lowest value for males (1.16) was recorded in November, and the peak value (1.44) occurred in April. For combined sexes, the minimum value (1.23) was recorded in November and the highest (1.38) in April and May. Fulton's Condition factor indices have been widely used as indicators of relative health and depend on the environmental conditions and food availability. April and May are highly rainy season in the study area and might be the reason for the variation in monthly condition factor. The results indicated that there was no significant difference between sexes as well as month's interaction in mean condition factor of *C. carpio* (P > 0.05).

Table 2.The mean monthly Fulton's condition factor of female, male and combined C. *carpio* in Ayalew reservoir.

Moths	Female	Male	Combined
October	1.28	1.21	1.25
November	1.33	1.16	1.23
December	1.23	1.30	1.26
January	1.28	1.38	1.33
February	1.15	1.32	1.25
March	1.22	1.25	1.24
April	1.32	1.44	1.38
May	1.39	1.36	1.38
Average	**1.28**	**1.30**	**1.29**

Morton and Routledge (2006) divided the *K* values into five categories as very bad (0.8–1.0), bad (1.0–1.2), balance (1.2–1.4), good (1.4–1.6) and very good (> 1.6). On the other hand, Ayoade (2011) suggests that the Fulton's condition factor higher than one is a good fish health condition. Based on the five categories above, the condition factor in the present study was not in the range of 1.4-1.6 and *C. carpio* in the reservoir was not in a good health condition. This might be due to anthropogenic factor that affects the limnological aspects of the reservoir.

The length composition of sampled catch and estimated annual catch of *C. carpio*

The mean total length catch composition and yield contribution of *C. carpio* are indicated in Fig. 3. The compositions were ranged from 13 to 39 cm with an average length of 26cm. The mean length ranged from 17 cm to 33 cm were about 87% of the total catch and had a high contribution in fish yield.

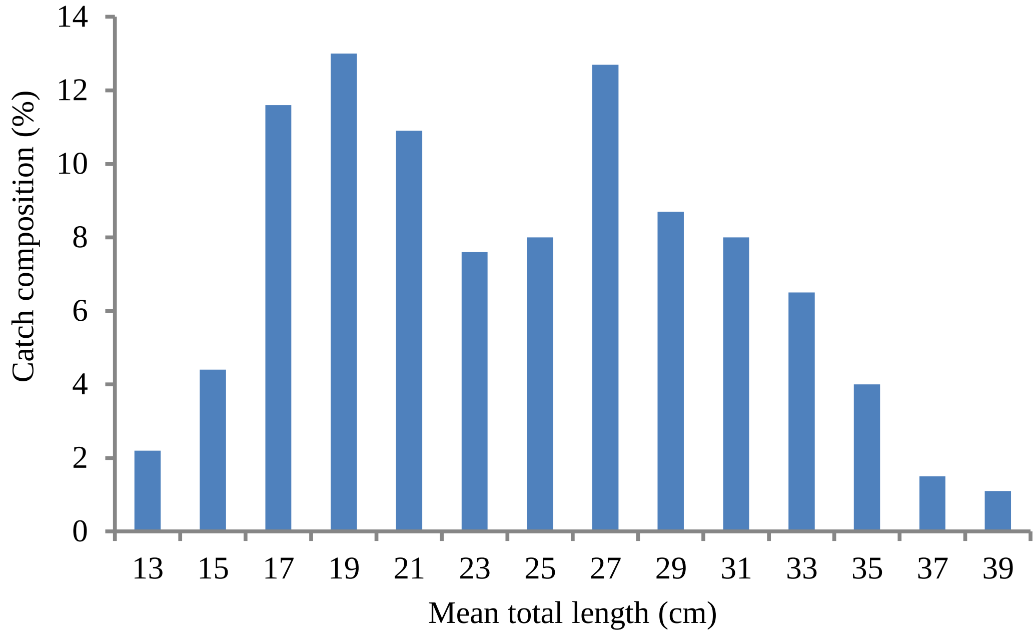


Figure 3. Size structure of *C. carpio* harvested from Ayalew reservoir

Estimation of growth and mortality parameters

The estimated asymptote length (L∞) and the length at first maturity (L_{50}) were 41 cm and 23.44 cm, respectively. The annual growth constant (k) and the growth performance index Phi (θ) were 0.52 yr^{-1} and 2.9, respectively (Fig. 4). The theoretical age at which fish would have at zero length (t_o) was -0.29 and the Longevity (A0.95), the age at which 99% of the cohort would be dead as a result of natural means was 5.5 years.

The fish species with a growth constant (k) value greater than or equal to one (1) is a fast growing fish species (Gulland, 1983; Sparre and Venema, 1998). Besides the genetic makeup which determines the growth potential of the fish species, food availability, environmental conditions and fishing effects could affect the growth performance index of a particular fish species (Getabu, 1992). According to Sambo and Haruna (2012), the growth performance index is a function of L∞ in which increase in L∞ leads to an increase in the growth performance index. The growth constant (k) value ranges from 0.06 to 0.48, 0.12 to 0.75 and 0.11 to 0.69 for *C. carpio* species that live naturally in rivers, lakes and reservoirs, respectively (Fish Base, 2011).

The growth constant (k) of *C. carpio* in Ayalew reservoir was 0.52 $yr^{-1}$and laid into the range of 0.11-0.69 for the *C. carpio* fish populations that live naturally in water of reservoirs.

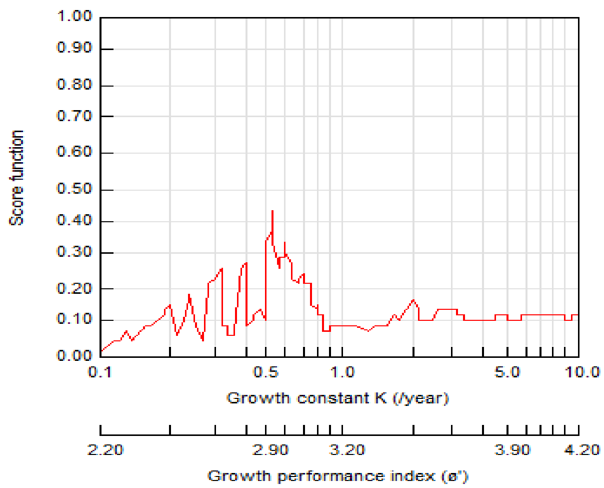


Figure 4. ELEFAN I K- scan routine FiSAT II output for *C. carpio* from Ayalew reservoir.

A length composition data prepared for a linear regression analysis was established between X and Y variables for estimation of total mortality (Table 3).

Table 3. Parameters for length-based catch curve analysis

Length group (cm)	Annual Catch C(L1,L2)					X	Y
		k	L∞ (cm)	Δt (L1,L2)	(L1+L2)/2	t(L1+L2)/2	Ln(C(L1,L2)/Δt)
16-18	859	0.52	41	0.16	17	1.03	8.59
18-20	967	0.52	41	0.17	19	1.20	8.62
20-22	859	0.52	41	0.19	21	1.38	8.40
22-24	564	0.52	41	0.21	23	1.58	7.88
24-26	591	0.52	41	0.24	25	1.81	7.81
26-28	967	0.52	41	0.28	27	2.07	8.16
28-30	644	0.52	41	0.32	29	2.36	7.60
30-32	591	0.52	41	0.39	31	2.71	7.33
32-34	483	0.52	41	0.48	33	3.14	6.91
34-36	349	0.52	41	0.65	35	3.70	6.29
36-38	107	0.52	41	0.98	37	4.48	4.69
38-40	81	0.52	41	2.11	39	5.81	3.64

Based on the linearized length-based catch curve analysis, the mortality parameters were estimated. As indicated in figure 5, the slope of the regression line (b) is -1.23 and hence, the estimated total mortality rate (*Z*) was 1.23 yr^{-1}. Out of the total mortality, natural mortality rate (*M*) and fishing mortality rate (*F*) were 0.55 yr^{-1} and 0.68 yr^{-1}, respectively. Using these mortality estimates, the exploitation rate (*E*) was computed as 0.55 and indicates that the *C. carpio* is slightly overexploited.

Based on the computed exploitation rate (*E*), the *C. carpio* in Ayalew reservoir was overexploited and the fish population was not abundant enough to utilize the resource sustainably. The exploitation rate (*E*) of a fish stock is at its maximum level and sustainable if the value of *F* was equivalent with or same with the value of *M* or the rate of exploitation (*E*) had value of 0.5 (Gulland, 1983).

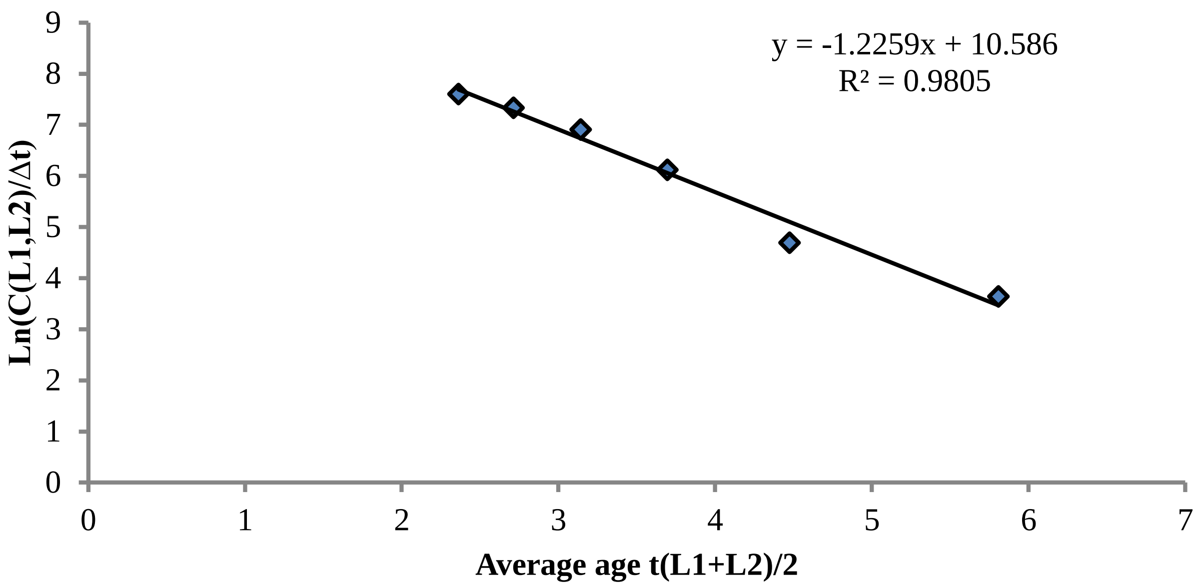


Figure 5. Linearized length-based catch curve of *C. carpio* from Ayalew reservoir

Estimated population sizes and current yield by length group

The estimated population number and annual yield of *C. carpio* in the study area were about 59, 304 and 1.5 tons, respectively (Table 4). The recruitment pattern of the fish was year-round with two peak recruitment period in the year. The peak recruitment takes place twice a year, in April and July to August for this particular fish species (Figure 6). The projected annual recruitment of *C. carpio* in the reservoir was about 9,118 as indicated in Table 4 (column 8; row 3). Based on the estimated population, it is possible to obtain about 7.4 tons of fish biomass and 1.5 tons of fish yield per year.

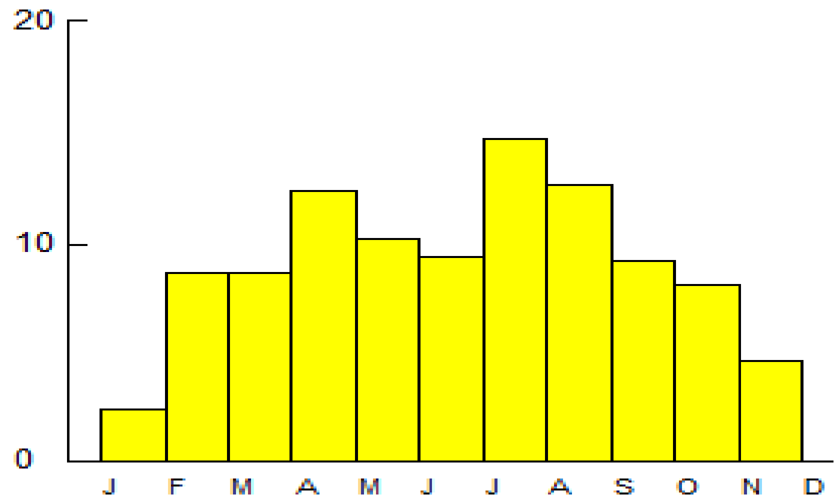


Figure 6. Recruitment pattern output from FiSAT II for *C. carpio* in Ayalew reservoir

Table 4. Estimated population, current yield and other parameters of *C. carpio* by length group

Length group (cm)	Annual catch			x	y			
		Δt (L_1,L_2)	$(L_1+L_2)/2$	$t(L_1+L_2)/2$	$Ln(C(L_1,L_2)/\Delta t)$	H	$N(L_1,L_2)$	Current yield
12-14	161	0.14	13	0.73	7.07	1.01	9118	6
14-16	322	0.15	15	0.88	7.69	1.01	8774	18
16-18	859	0.16	17	1.03	8.59	1.01	8264	64
18-20	967	0.17	19	1.20	8.62	1.01	7220	95
20-22	805	0.19	21	1.38	8.34	1.01	6081	102
22-24	564	0.21	23	1.58	7.88	1.02	5115	89
24-26	591	0.24	25	1.81	7.81	1.02	4400	115
26-28	940	0.28	27	2.07	8.14	1.02	3665	222
28-30	644	0.32	29	2.36	7.60	1.02	2597	182
30-32	591	0.39	31	2.71	7.33	1.03	1847	197
32-34	483	0.48	33	3.14	6.91	1.04	1170	189
34-36	295	0.65	35	3.70	6.12	1.05	623	134
36-38	107	0.98	37	4.48	4.69	1.08	284	56
38-40	81	2.11	39	5.81	3.64	1.17	146	48
Total	**7,410**						**59,304**	**1,517**

CONCLUSIONS & RECOMMENDATIONS

The growth pattern of *C. carpio* was negative allometric which implied that the fish became thinner as its body length increases. The wellbeing of the fish was not in a good health condition. The mean length groups ranged from 17 cm to 33 cm was about 87% of the total catch and had a high contribution in fish yield. The *C. carpio* in Ayalew reservoir can grow up to the maximum length ($L\infty$) 41 cm with growing speed (k) of 0.52 per year. The long lifespan (A0.95) of the cohort and the length at first maturity were 5.5 years and 23.44 cm, respectively. The production potential of the fish was about 7.4 tons of fish biomass and 1.5 tons of yields per year. However, investigation on reproductive biology, limnological aspects and stock enhancement are required in the reservoir.

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Conflicts of interest

The authors declare that there is no conflict of interest in publishing the manuscript in this journal.

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