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Research Article

Population Dynamics of the Common Carp (*Cyprinus carpio* L. 1758) Stock in Lake Arekit, Ethiopia: Implications for Management and Conservation

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Cyprinus carpio is a widely distributed and commercially important fish species in Ethiopia. Effective management is essential to sustain fisheries and provide benefits to local communities. This study aims to estimate the growth, mortality, and exploitation rate of *C. carpio* using length-frequency data. A total of 194 *C. carpio* specimens (117 females and 77 males) were collected between June 2022 and May 2023. The population parameters were determined using FISAT (ELEFAN I) software. The Von Bertalanffy growth function estimations were $L_{\infty} = 51.45$ cm total length, $K = 1.1\ \text{year}^{-1}$; $t_0 = -0.124$ year, and growth performance index (Φ') = 3.464. The total mortality rate (Z), natural mortality rate (M), and fishing mortality rate (F) were 2.55 year^{-1}, 1.58 year^{-1}, and 0.97 year^{-1}, respectively. The estimated potential longevity ($t_{\max}$) and average age at which *C. carpio* attains length at the optimum cohort biomass or yield per recruit ($L_{\text{opt}} = 34.79$) in Lake Arekit were calculated as 2.60 years and 1.29 years, respectively. The Z/K ratio (2.32), exploitation rate ($E = F/Z = 0.38$), and highest permissible yield per recruit for *C. carpio* ($E_{\max} = 0.421$) suggest enhancing fishery production by increasing the exploitation rate of the underexploited *C. carpio* in Lake Arekit. The results of this study provide information on the stock of *C. carpio*, which can be used to guide management efforts. The fish catch in Lake Arkeit is currently far lower than it could be. Therefore, the fish harvest should be boosted through the use of permitted nets, the establishment of groups of fishermen who can catch fish effectively, and the linking of the benefits of fish farming's supply chain to the potential of fisheries.

1. Introduction

The common carp (*Cyprinus carpio*, Linnaeus 1758) is frequently cultivated and has a significant commercial value as a food fish in its natural range and in the areas where it has been introduced [1]. *Cyprinus carpio* was initially brought to Ethiopian waterways in 1936 for aquaculture [2, 3].

Small-scale fisheries require the most immediate action, particularly regarding rules and policies governing food security and nutrition [4]. Small-scale fisheries, which also provide many local people in developing countries with a source of employment and food security, employ over 90% of all catch fishers [4, 5]. Nearly half of the fish caught worldwide in developing countries are caught in small-scale fisheries. Furthermore, 90–95% of small-scale landings are made to be used by local people [4, 6, 7]. Small-scale fisheries are therefore essential for immediately increasing the supply of nutrient-dense foods for local, national, and international markets while acting as a sizable source of income for those who work in the sector both directly and indirectly [4]. Despite their significance and potential, numerous small-scale fishing communities such as Lake Arkeit, the focus of this study remains marginalized, and their impact on nutrition and food security is still neglected [8]. Proper assessment and management are essential for maintaining fisheries and the advantages they provide to society [5–7]. Understanding species life histories, population dynamics, and the sustainability of fisheries depends on understanding fish growth. Growth is correlated with several life-history features, such as the natural mortality rate [9], which are known to affect how a fish species reacts to exploitation [10]. The maximum sustainable yield (MSY) and fishing effort in lakes have also been determined through stock assessments.

Although numerous studies on *C. carpio* population characteristics, including growth parameters, reproductive biology, age determination, and population dynamics, have been carried out in various water bodies in Ethiopia [3, 4, 11, 12], there have been no studies on the population growth parameters, mortality, and exploitation rate in Lake Arekit. The fishing of *C. carpio* in this lake has been managed in accordance with data on other carp populations in the same area, including Lake Langano and the Koka Reservoir. The management of the fisheries in these bodies of water generally includes establishing fishery cooperatives, raising awareness, providing off-farm opportunities, implementing integrated conservation efforts, reducing wetland farming, and becoming familiar with social networks.

The general state of the Lake Arekit fishery is unknown. However, the study's preliminary assessment did show that the fishing potential in the lake is poor. The biological characteristics of *C. carpio* and their stocks in Lake Arekit should be studied and frequently evaluated for efficient fishery management. Therefore, the *C. carpio* population in Lake Arekit was examined for various population features, including the length-weight relationship, growth parameters, death rates, the exploitation rate, and stock analysis.

2. Materials and Methods

2.1. Study Area. This study was carried out in Lake Arekit (Ethiopia). The lake is situated between 38°04′30″ and 38°05′0″ E latitude and 7°57′0″ and 7°58′0″ N longitude at an elevation of approximately 2870 m above sea level (Figure 1). It is 2.5 km long (from north to south) and 1.1 km wide (from east to west), respectively. The lake's maximum depth was determined to be 3.2 m. Lake Arekit is a shallow freshwater ecosystem, with an average depth of 2.5 m, in Ethiopia's rift valley basin. It is a lake that is rather small in size, with a surface area of approximately 150 hectares. This lake is located in the Southern Nation Nationality People Regional State (SNNPRS), 220 km from Addis Ababa, the capital city of Ethiopia. The lake does not have an outlet and receives its water from adjacent watersheds and direct rainfall. Lake Arekit is a productive lacustrine ecosystem that is alkaline, turbid, and rich in nutrients (phosphate and nitrate) [13]. The watershed of the lake is significantly impacted by anthropogenic effects, and eutrophication is brought on by nutrient influxes. The lake also provides irrigation services to the community. During the study's reconnaissance survey, it was found that the common carp (*Cyprinus carpio*) was the only species of fish habiting Lake Arekit.

2.2. Data Collection. Fish samples from Lake Arekit were collected using gill nets with stretched mesh sizes of 6 cm, 8 cm, and 10 cm between June 2022 and May 2023 from 3 different sites (Figure 1). Throughout the sampling periods, 194 *Cyprinus carpio* samples (117 females and 77 males) were gathered. Data for the examination of the length-weight relationship of fish were generated from the captures by measuring the length and weight of fish. Individual fish were weighed to a precision of 1 g, and their total length was measured using a measuring board to a precision of 0.1 cm.

2.3. Data Analysis

2.3.1. Length-Weight Relationships. The relationship between length and weight of the fish was examined by using correlation analysis and simple linear regression. The fish's length-weight relationships were computed using the methods presented by Ricker [10] to determine whether their growth pattern was isometric ($b = 3$) or allometric ($b \neq 3$). The relationships between the length and weight of *Cyprinus carpio* in each sex category were calculated using the following equation:

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

where TW = total weight of fish (g), TL = total length (cm), and a and b = constants.

The log transformed relationship ($\mathrm{TW} = \mathrm{aTL}^{b}$) gives the regression equation; Log $W = \log a + b \log L$. "a" and "b" values and linear representations of the graphs were carried out using MS Excel 2010.

Using the Student's t test at a 95% confidence level, the equation's constant value, b, was checked for accuracy against a value of $b = 3$. The fish growth pattern was isometric if the test results did not deviate from the constant value of $b = 3$, while when the test results produced b values other than 3, the fish had an allometric growth pattern.

2.3.2. Growth Parameters. A length frequency analysis was used to estimate the growth parameters (L_∞, k, t_0) using Von Bertalanffy's growth function model [14] are described as follows:

$$\mathrm{Lt} = L_\infty * \left(1 - e^{-K(t - t_0)}\right), \quad (2)$$

where Lt = length of the fish at age t, L_∞ = asymptotic length (maximum length of the average), K = coefficient of growth, and t_0 = theoretical age at length 0 cm. The asymptotic length (L_∞) and growth coefficient (K) were calculated using FISAT [8]. The theoretical age at length zero (t_0) was estimated using Pauly's [15] empirical equation shown as follows:

$$\mathrm{Log}(-t_0) = -0.3922 - 0.275 * \mathrm{Log}(L_{\infty)} - 1.038 * \mathrm{Log}(K)). \quad (3)$$

Also, the reliability of these growth parameters was tested by applying the growth performance index (Φ′, phi-prime), which was computed from the Munro and Pauly [16] equation, as indicated in the following equation:

$$\Phi' = \mathrm{Log}(K) + 2 * \mathrm{Log}(L_\infty). \quad (4)$$

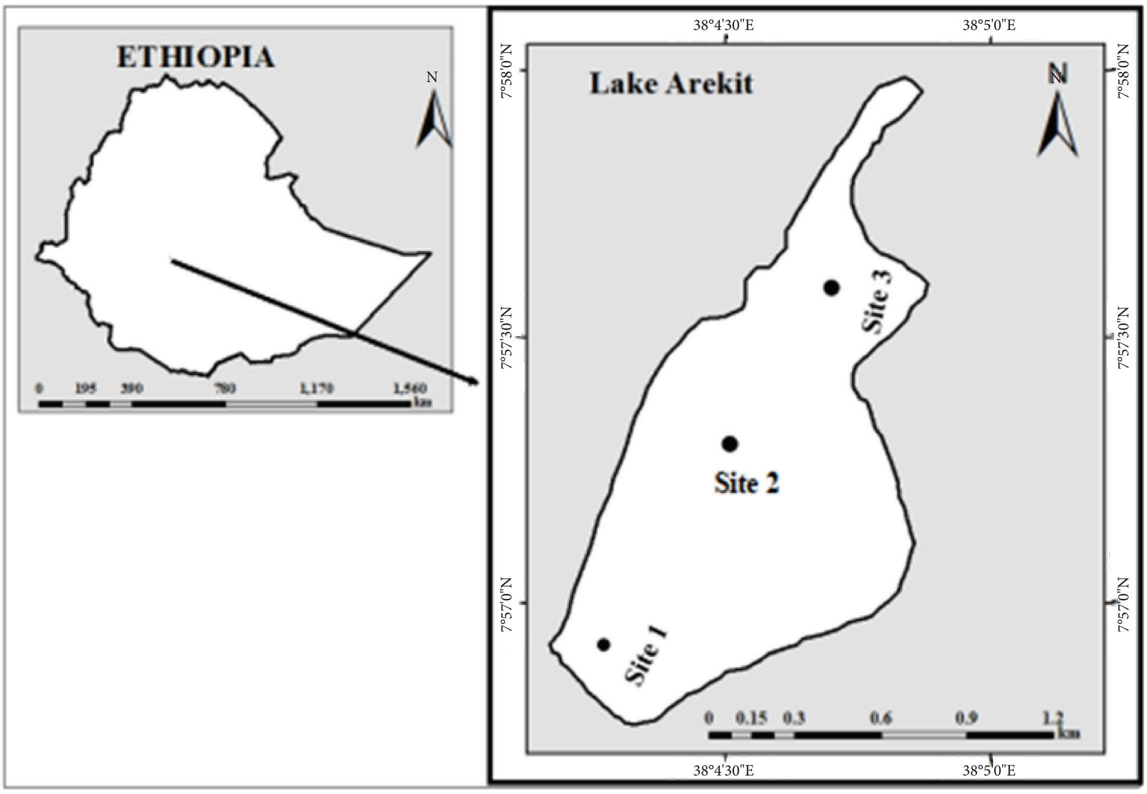

Figure 1: Map of the study area (Lake Arekit) and the sampling sites.

The longevity (also called maximum age) (t_{max}) was obtained from the Pauly [17] equation, as indicated in the following equation:

$$t_{max} = \frac{3}{k} + t_0. \quad (5)$$

2.3.3. Mortality and Exploitation Rates. The total mortality (Z) was calculated using the length-converted catch curve analysis [10] from the FISAT II software suite (equation (6)), and natural mortality (M) was estimated in accordance with Pauly [18] and Pauly [17] empirical formula (equation (7)). Using the mean annual surface water temperature (T), Pauly's empirical formula (1980) was used to estimate natural mortality (M) as follows:.

$$\text{Log}(M) = -0.0066 - 0.279 * \text{Log}(L_\infty) + 0.6543 * \text{Log}(K) + 0.4634 * \text{Log}(T), \quad (6)$$

where L_∞ = asymptotic length, K = growth coefficient, and T = the average temperature of the waters of Lake Arekit (26.1°C).

The rate of fishing mortality (F) was calculated by the following Gulland [19] equation:

$$F = Z - M, \quad (7)$$

where Z is the total mortality, F is the fishing mortality, and M is the natural mortality.

The exploitation level (E) of the study fish was obtained from an equation proposed by Pauly [18].

$$E = \frac{F}{Z}, \quad (8)$$

where E is the exploitation rate; F is the fishing mortality, and Z is the total mortality.

If the exploitation rate values are under 0.5, the fish stocks are easily exploited, while if the E values are between 0.5 and 1, the stocks are overexploited.

The Jackknife approach was used to determine the best-fit growth curves using mean growth parameters. This method enabled us to measure the impact of fluctuations in the input data and the degree of uncertainty in the growth parameter approximations.

2.3.4. Yield per Recruit (Y'/R) and Biomass per Recruit (B'/R). The model of Beverton and Holt [20], as updated by Pauly and Soriano [21], was used to forecast the species' relative yield per recruit (Y'/R) using the knife-edge analysis incorporated into the FISAT software. $E_{0.1}$ (the exploitation point at which the related increase in yield per recruit reached 1/10 of the related increase computed at a very devalued value of E), $E_{0.5}$ (the exploitation rate corresponding to 50% of the unexploited relative biomass per recruit (B/R)), and E_{max} (the exploitation point that gives the maximum relative yield per recruit) were estimated using L_c/L and M/K values. The stock status was indicated by the biological target reference points ($E_{0.1}$ and E_{max}) and the current exploitation rate (E) [22].

The length at optimum cohort biomass or yield per recruit (L_{opt}) was calculated by Beverton and Iles [23] as follows:

$$L_{opt} = L_\infty * \left(\frac{3}{(3 + M/K)}\right), \tag{9}$$

where L_∞ and K are as defined above and M is the natural mortality coefficient.

The average age of the parents at the time of birth of young fish was calculated as the generation time (tg). It was estimated as the fish's average age at L_{opt}, since this is when fish produce the most eggs on average, according to Beverton and Iles [23].

$$t_g = t_{opt} = t_0 - \ln\frac{[1-(\text{Lopt}/L_\infty)]}{K}. \tag{10}$$

2.3.5. Virtual Population Analysis (VPA). VPA allows for reconstruction of population from total catch data by length. The initial step was to estimate the terminal population (N_t), followed by the successive estimation of F values, and finally, the population sizes are computed for each length class (midpoint). This length-structured virtual population analysis (VPA) was carried out using relevant information and cohort analysis [8]. The input parameters used were L_∞, K, M, and F and constants of length-weight relationship (a and b) were used as inputs to VPA analysis for the species. The initial step is to estimate the terminal population (N_t) given the inputs, from the following equation:

$$N_t = C_t * \frac{(M + F_t)}{F_t}, \tag{11}$$

where C_t is the terminal catch (i.e., the catch taken from the largest length class).

Then, starting from N_t, successive values of F are estimated, by iteratively solving:

$$C_i = N_{i+\Delta t} * \left(\frac{F_i}{Z_i}\right) * (\exp(Z_i * \Delta t_i) - 1), \tag{12}$$

where $\Delta t_i = (t_i + 1 - t_i)$ and $t_i = t_o - (1/K) * \ln(1\text{-}(L_i/L_\infty))$, and where population sizes (N_i) are computed from the following equation:

$$N_i = N_{i+\Delta t} * \exp(Z_i). \tag{13}$$

The last two equations are used alternatively, until the population sizes and fishing mortality for all length groups have been computed [8]. An F-array representing the fishing mortality for each length group, the reconstructed population (in numbers), and the mean stock biomass by length class were made using FiSAT II. The results of the VPA analysis were the biomass (tons), the yield (tons), total and fishing mortality, and exploitation ratios.

3. Results

3.1. Length-Weight Relationships. The length-weight relationship equation obtained for 194 *C. carpio* individuals was $\text{TW} = 0.0381\text{TL}^{2.79}$, $r^2 = 0.97$. For the fish species studied, a high coefficient of determination ($r^2 = 0.97$, $p < 0.05$) showed accurate weight prediction. The regression coefficient "b" value from the pooled data indicated a negative allometric growth of the combined sexes (2.79), females (2.77), and males (2.80) *C. carpio* in Lake Arekit as the values were less than 3 (Table 1, Figure 2).

3.2. Growth Parameters (L_∞, K, t_0, Φ, and t_{max}). The Von Bertalanffy growth parameters for *C. carpio* were $L_\infty = 51.45$ cm and $K = 1.1$ year^{-1} (Table 2, Figures 3 and 4). Furthermore, the age at length 0 cm (t_0) value obtained from the Von Bertalanffy parameters was found to be −0.124 years. The maximum age (t_{max}) was calculated to be 2.60 years, and the values of the growth performance index were equal to $\Phi' = 3.464$ for *C. carpio* in Lake Arekit (Table 2). The equation of the Von Bertalanffy growth model for *C. carpio* in Lake Arekit was $L_t = 51.45 * (1 - e^{-1.1(t+0.124)})$ (Table 2).

Figure 4 shows the length frequency distributions for *C. carpio* in Lake Arekit and the best-fit growth curves using the mean growth parameters obtained from the jackknife approach. According to the length frequency statistics, the 34–38 cm total length range dominated the *C. carpio* population, with a frequency of 34.02%, followed by the 29–33 cm total length, with a frequency of 26.23% (Figure 4).

3.3. Mortality and Exploitation Rates. In comparison to the estimated fishing mortality (F) of 0.97 year^{-1} and the natural mortality (M) of 1.58 year^{-1}, *C. carpio* had a total mortality coefficient (Z) of 2.55 year^{-1} in Lake Arekit (Table 3, Figure 5). The exploitation rate (E) of 0.38 year^{-1} for *C. carpio* appeared to be less than the anticipated level of exploitation ($E = 0.50$) (Figure 5). The length class of the maximum biomass was determined to be 34.79 cm (Table 3, Figure 6). In Lake Arekit, the age at which *C. carpio* reaches its maximum cohort biomass or yield per recruit (L_{opt}) was calculated to be 1.29 years age, on average (Table 3).

3.4. Virtual Population Analysis (VPA). The results of the virtual population analysis (VPA) of *C. carpio* in terms of natural losses, survival, and fishing mortality are shown in Figure 6. With an increase in length and fishing mortality, the natural losses and survivorship of the fish population declined. The highest number of *C. carpio* harvested ranged between 34 and 38 cm TL (Figure 6), indicating that the fishing mortality value of the species was inconsistent. The VPA results showed there were differences in fishing mortality rates with regards to the mean length. At

Table 1: Length-weight relationship of *C. carpio* from Lake Arekit from June 2022 to May 2023.

Sex	N	$TW = a \times TL^b$	$\text{Log TW} = \log a + b \times \log TL$	a	b	r^2
Female	77	$TW = 0.0432TL^{2.77}$	$\text{Log TW} = -0.0432 + 2.77 \times \log TL$	0.0432	2.77	0.96
Male	117	$TW = 0.0392TL^{2.80}$	$\text{Log TW} = -0.0392 + 2.8 \times \log TL$	0.0392	2.80	0.97
Combined	194	$TW = 0.0381TL^{2.79}$	$\text{Log TW} = -0.0381 + 2.79 \times \log TL$	0.0381	2.79	0.97

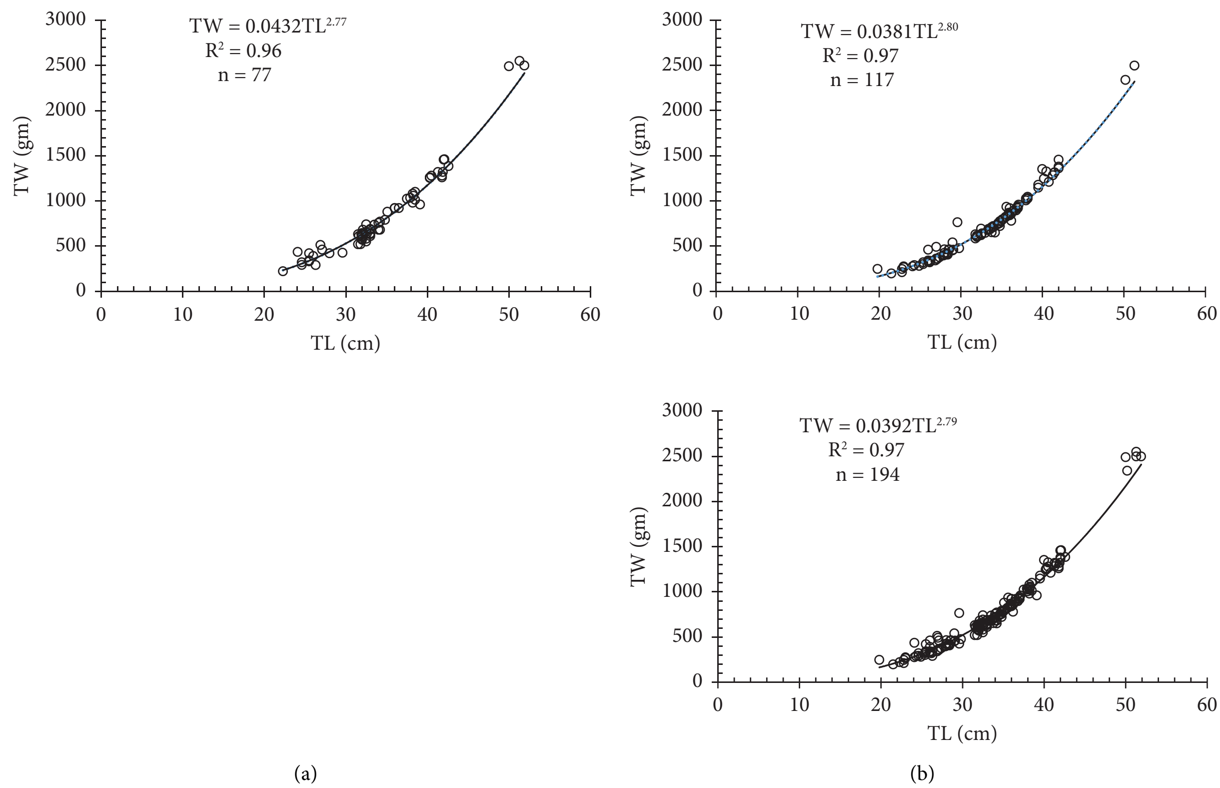

Figure 2: Length-weight relationship of *C. carpio* at Lake Arekit.

Table 2: Growth parameters of *C. carpio* from Lake Arekit.

	Growth parameters					
	L_∞ (cm)	K (yr^{-1})	t_0 (yr)	Φ	t_{max}	Von Bertallanffy equation
C. carpio	51.45	1.1	−0.124	3.464	2.60	$L_t = 51.45 * (1 - e^{-1.1(t+0.124)})$

midlength (34.79 cm TL), the fishing mortality rate peaked ($F = 2.53\ \text{year}^{-1}$). $F_t = 0.97\ \text{year}^{-1}$ was the terminal fishing mortality rate (Figure 6, Table 4).

3.5. Yield per Recruit (Y'/R) and Biomass per Recruit (B'/R). The relative Y'/R and B'/R analyses of *C. carpio* are shown in Figure 7. The maximum allowable limit of the exploitation level (E_{max}), which yields the maximum relative yield per recruit, was estimated to be 0.421 (Figure 7). The marginal gain in the relative yield per recruit at $E_{0.1}$, the level of exploitation at 10% of the marginal increase estimated for a very low value of E, was 0.355. The relative biomass per recruit at the exploitation level ($E_{0.5}$), or 50% of the relative biomass of the unexploited stock, was 0.278 (Figure 7).

4. Discussion

4.1. Length-Weight Relationship. Table 5 presents the growth coefficient (b) values for *C. carpio* in several geographic locations and shows various growth types. Some studies [24, 26, 27, 30] revealed negative allometric patterns. This is in agreement with the present study. The negative allometric growth of *C. carpio* in the Lake Arekit showed that the fish were not developing properly, presumably as a result of the inappropriate environmental conditions as well as overfishing. However, other studies [25, 28, 31] indicated positive allometric growth patterns (Table 5). The variations in the growth pattern of the same species in different geographical localities may be due to various factors, such as the number and size of specimens examined, stomach fullness, sex

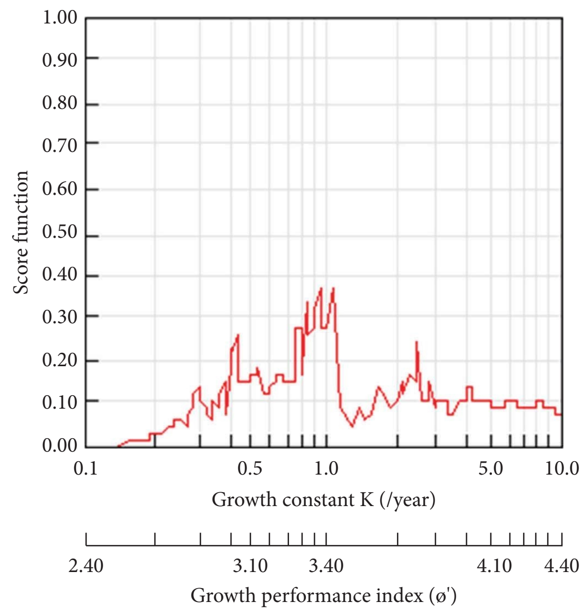

Figure 3: Estimation of L_∞ by the ELEFAN I method for *C. carpio* in Lake Arekit.

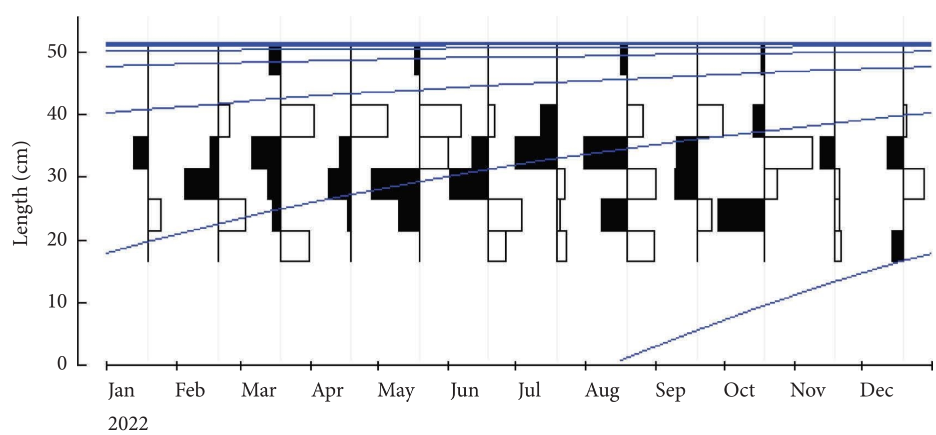

Figure 4: Length frequency distribution output from FISAT with superimposed growth curves for *C. carpio* in Lake Arekit. (L_∞ = 51.45 cm; K = 1.1 yr^{-1}). (Note. Black bars represent maximum monthly-based frequencies, white represents minimum monthly-based frequencies, and blue lines represent growth curves).

Table 3: Estimates of instantaneous rates of total mortality (Z), natural mortality (M), and fishing mortality (F) for *C. carpio* in Lake Arekit.

	Mortality and exploitation rates					
	Z ($year^{-1}$)	M ($year^{-1}$)	F ($year^{-1}$)	E ($year^{-1}$)	L_{opt} (cm)	t_g (year)
Cyprinus carpio	2.55	1.58	0.97	0.38	34.79	1.29

variation, disease and parasite loads, stage of maturity, sampling method, and variations in environmental conditions among different localities [3, 12, 32, 33].

4.2. Growth Parameters (L_∞, K, t_0, Φ, and t_{max}). The growth parameters (L_∞ and K) for *C. carpio* obtained in this study are compared with those obtained from other studies (Table 6). For the same species, the growth parameter values vary across different geographic regions. The asymptotic length (L_∞) of *C. carpio* in the current study was higher than that of the species in some waters [25] but lower than that of the species in other waters [34–38] (Table 6). Different environmental circumstances, food availability, metabolic activity, reproductive activity, fish size, survey technique, and fishing pressure are a few variables that may have an impact on how differently the same species grows in different places [32, 42]. A fish's ability to grow is influenced by three factors: its genetic makeup, the growth-restraining abiotic environment it encounters, and the biotic

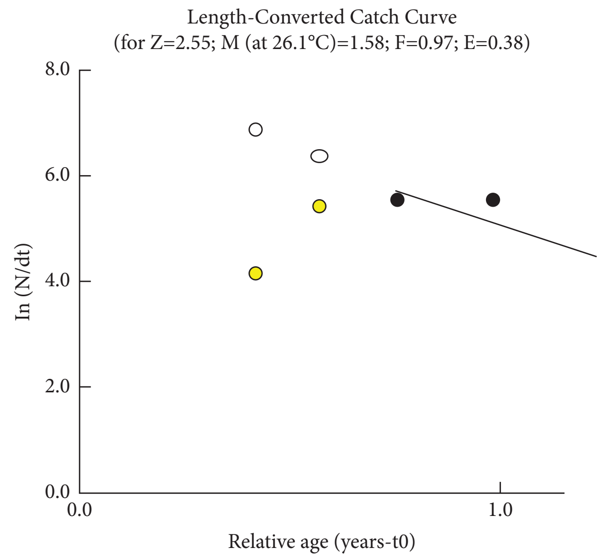

Figure 5: Length converted catch curve of *C. carpio* in Lake Arekit. Yellow and black dots are calculated points. Black dots are used to fit regression line (length-group that are fully recruited into the stock and used in the analysis to calculate mortality). Yellow dots indicate small size fishes and those that were excluded from estimation. Black outlines circles are the extrapolated points to estimate the probability of capture.

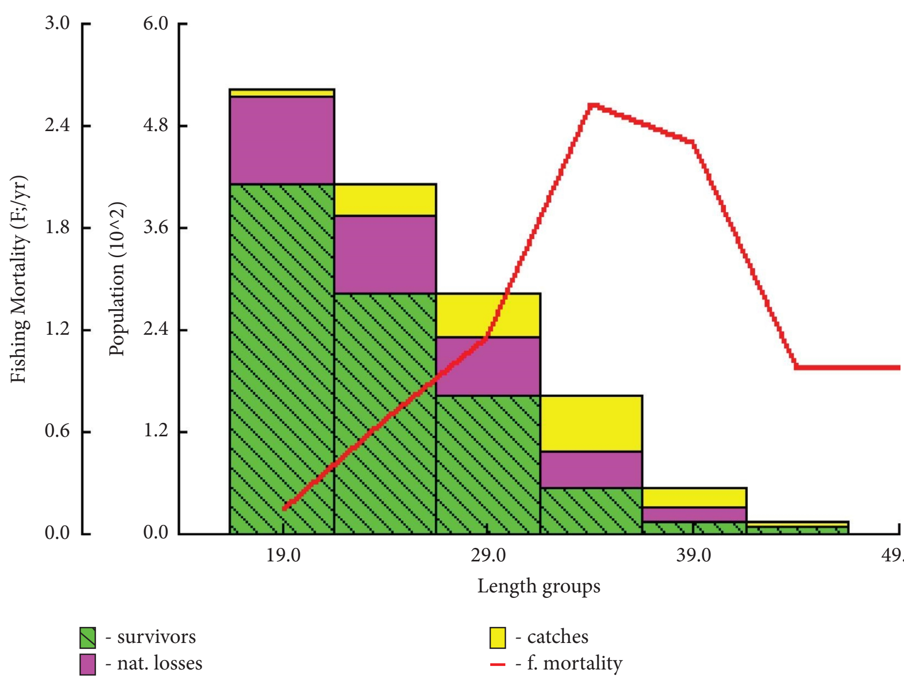

Figure 6: *C. carpio* population estimation in Lake Arekit using the VPA from the FiSAT output.

environment [43]. Moreover, the development rates of related species can vary depending on habitat [32, 44].

Fish lifespan has been linked to the Von Bertalanffy curvature parameter K [45] and longevity has been linked to mortality [46]. Fish species with high K values also had high M values, whereas the opposite was true for fish species with low K values. If natural mortality is high, a slow-growing species (low K) will soon become extinct [47]. The variations in the growth coefficients (K) for *C. carpio* in various geographical locations are shown in Table 6. The varying growth coefficients of the same fish species residing in various waterways are mainly related to the fluctuating water characteristics and ecological circumstances of the aquatic environment. In comparison to *C. carpio* populations in other research locations, the growth coefficient (K) value of the *C. carpio* in the present study represents a faster growth rate (Table 6), owing to high growth rates and short asymptotic lengths [47]. According to Sparre and Venema [47], $K > 1.0$ indicates rapid growth, $K = 0.5$ indicates medium growth, and $K < 1$ indicates slow growth. Given that *C.*

Table 4: FISAT II output of virtual population analysis of *C. carpio* in Lake Arekit.

Midlength	Catch (in numbers)	Population (*N*)	Fishing mortality (*F*)	Steady-state biomass (tons)
19.0	9	523.64	0.1378	0.05
24.0	38	411.45	0.6664	0.08
29.0	51	283.35	1.1540	0.10
34.0	66	162.52	2.5299	0.10
39.0	25	55.30	2.3020	0.06
44.0	5	13.14	0.9700	0.09
49	0	0	0.9700	0.00

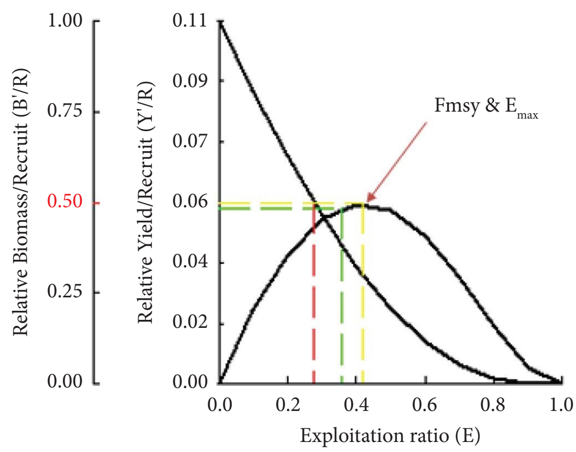

Figure 7: Relative yield per recruit and biomass per recruit (selection ogive) for *C. carpio* in Lake Arekit. $E_{0.1} = 0.355$, $E_{0.5} = 0.278$, and $E_{max} = 0.421$ (yellow dotted line). Current $E = 0.38$. (Note. The red line represents $E_{0.1}$ and yellow line represents *E*-ma. Black lines are either yield per recruit (*Y*/*R*), maximum sustainable yield points (MSY), or biomass per recruit (*B*/*R*)).

Table 5: Length-weight relationship for *C. carpio* of the previous studies.

Study area	Sex	*N*	*a*	*b*	R^2	Author(s)
Foum El-Khanga Dam	♀	198	0.017	2.865	0.974	Sahtout et al. [24]
	♂	149	0.024	2.765	0.933	
	♀ + ♂	347	0.018	2.859	0.963	
Atatürk Dam Lake	♀	106	0.024	2.847	0.95	Yüce et al. [9]
	♂	125	0.034	2.807	0.95	
	♀ + ♂	231	0.029	2.847	0.95	
Almus Dam Lake	♀ + ♂	307	0.0084	3.32	0.9437	Karataş et al. [25]
Lake Lugo	♀ + ♂	591	0.0189	2.853	0.9269	Mekonnen et al. [26]
Amerti reservoir	♀ + ♂	496	0.022	2.923	0.977	Hailu [27]
Kızılırmak river basin	♀ + ♂	301	0.001	3.138	0.93	Birecikligil et al. [28]
Deroua			0.005	3.423	0.9825	Mert and Bulu [29]
Damsa Dam Lake	♀	63	0.0181	2.9689	0.915	Mert and Bulu [29]
	♂	97	0.0278	2.8507	0.903	
	♀ + ♂	160	0.0219	2.9040	0.900	
Oubeira Lake	♂	322	0.6923	2.3484	0.8239	Sara et al. [30]
	♀	198	0.9712	1.9455	0.7156	
	♀ + ♂	360	0.018	2.802	0.929	
Current study	♀	77	0.043	2.77	0.96	
	♂	117	0.039	2.80	0.97	
	♀ + ♂	194	0.038	2.79	0.97	

carpio in Lake Arekit has a high life span and a high growth coefficient, it is clear that this species grows quickly (Table 6).

The study's age at zero length, t_0 (−0.124), verified that the *C. carpio* from Lake Arekit quickly reached its maximum size. The age at zero length, t_0 in the current study seems to be comparable to that discovered by Stroe et al. [34] in the Danube Delta ($t_0 = -0.077$). The lowest value ($t_0 = -2.423$) was obtained from Keban Dam Lake, Turkey [41], AlMassira Dam ($t_0 = -1.27$) [40], and Almus Dam ($t_0 = -1.922$) [25]. This variance could be caused by several developmental

Table 6: Comparison of on Von Bertalanffy growth parameters, mortality, and exploitation rates for *C. carpio* from different areas of the world.

Location	L_∞	K	Ø	t_0	t_{max}	Z	F	M	E	Reference
Koka, Ethiopia	74.1	0.28	3.19	−0.46		0.83	0.28	0.55	0.34	Tesfaye and Wolff [4]
Danube Delta, Romania	86.1	0.87		−0.077		1.47	0.65	0.82	0.44	Stroe et al. [34]
Southern Caspian Sea, Iran	72.0	0.18	2.97	−0.65	10	0.71	0.42	0.29	0.59	Fatemi et al. [35]
Almus Dam, Turkey	46.39	0.153	5.80	−1.922	7	0.64	0.32	0.32	0.50	Karataş et al. [25]
Lake Karamık, Turkey	130	0.0754	7.15	−0.2452	10	0.40	0.24	0.16	0.60	Balik et al. [36]
Mangla, Pakistan	80.33	0.60	3.588	−0.39		1.22	0.89	0.33	0.27	Mirza et al. [37]
Lake Paniai, Indonesia	61.43	0.32		−0.43		1.17	0.52	0.65	0.44	Kaban [38]
Lake Gariep, South Africa	62.58	0.16		−0.39	7	0.82	0.12	0.70	0.14	Winker et al. [39]
Merdja Sidi Abed Dam, Algeria	36.75	0.46		−0.33	2	1.08	0.26	0.82	0.24	Ferraj et al. [40]
Keban Dam Lake, Turkey	43.09	0.176	2.51	−2.423		—	—	—	—	Çalta et al. [41]
Damsa Dam Lake, Turkey	88.45	0.168	7.18	−0.583	8	0.25				Mert and Bulut [29]
AlMassira Dam, Morocco	44.63	2.60	5.60	−1.27						Ferraj et al. [40]
This study	51.45	1.1	3.464	−0.124	2.60	2.55	0.97	1.58	0.38	

phases and environmental factors such as temperature, organic matter, and food quality.

In the fish stock assessment, which is based on K and L_∞, the use of "Φ" is a more precise estimator [16]. This index is the most accurate technique for determining the average growth parameters of a particular species and should produce results comparable to those for other groups of the same species [47]. The estimates for *C. carpio* in the Southern Caspian Sea ($\Phi = 2.97$) [35] and Koka Reservoir ($\Phi = 3.19$) [4] were both lower than those in the current study. This shows that our estimations of growth parameters were accurate. The results from Lake Karamık ($\Phi = 7.15$) [36] and Almus Dam ($\Phi = 5.80$) [25]were both greater than those of the current study ($\Phi = 3.464$). This difference in the phi prime index between the same species may be due to differences in the size of the largest individuals sampled [36] and various exogenous and endogenous factors affecting fish growth performance and longevity [48].

Fish exhibit a wide range of life stages. The maximum lifespan (t_{max}) of *C. carpio* in Lake Arekit differs from the 5.49 years reported in Lake Naivasha by Oyugi [49]; as well as those in Lake Karamık (10 years) [36], Damsa Dam Lake (8 years) [29], and Lake Gariep (7 years) [39]. It does, however, slightly exceed the maximum age determined by Ferraj et al. [40] in the Merdja Sidi Abed Dam (2 years), Algeria (Table 6). The differences in the lifespan of the same fish species in varied geographical location may be related to the habitat quality of the fish.

4.3. Mortality Parameters (Z, M, and F). It has been noted that *C. carpio* populations in various locations exhibit variability in their fish mortality rates (Table 6). The mortality rate in fish populations is influenced by age, abiotic conditions, parasitic diseases, carnivorous fishes, food shortages, and hunting [35]. For the carp population sampled from Lake Arekit, total mortality (Z) was significantly higher than that found at other locations such as Koka Lake ($0.83\,yr^{-1}$) [4], Danube Delta ($1.47\,yr^{-1}$) [34], and Lake Paniai ($1.17\,yr^{-1}$) [38]. These findings suggest that the *C. carpio* population in Lake Arekit was not properly managed. The value obtained for the same species in other bodies of water [34, 37, 38, 40] is less than the value hypothesized for *C. carpio* in Lake Arekit (Table 6). The fishing mortality (F) for *C. carpio* in Lake Arekit is greater than for Lake Paniai [38] and the Danube Delta (Stroe et al. [34]; where it was $0.52\,yr^{-1}$ and $0.65\,yr^{-1}$, respectively). It was evident from comparing the estimated values for M and F that natural mortality accounted for the majority of *C. carpio* deaths in Lake Arekit. The total, natural, and fishing mortalities for *C. carpio* in Lake Arekit were high. Fish physiological circumstances and fishing pressure may be responsible for these results.

The M/K ratio in this study is within the range for most species and indicates that the M for *C. carpio* in Lake Arekit was accurately computed. A Z/K ratio calculated in this study likewise pointed to a population with a high mortality rate. This is consistent with the general [45] criteria: if Z/K is less than one, the population is dominated by growth; if it is greater than one, the population is dominated by mortality; and if it is equal to one, the population is in an equilibrium condition where growth and mortality are equal. If the Z/K ratio in a mortality-dominated population is 2, it indicates that the population is being lightly exploited [45]. Therefore, our Z/K results indicate that there may be an unexploited stock in Lake Arekit. This is further supported by the predicted low exploitation rate, which indicates limited exploitation stock. Therefore, our Z/K value indicates underexploited stock.

4.4. Virtual Population Analysis (VPA) and Exploitation Rate at MSY. The present exploitation ratio (E) value found in this study is less than the optimal level of $E = 0.5$ [19]. Sustainable yield is optimal when $F = M$, and the stock is often underexploited when $E < 0.5$ [19]. As a result, the *C. carpio* stock in Lake Arekit is likely to be underutilized. The current study's exploitation rate (E) estimate is greater than those of Lake Koka (0.34) [4], Lake Mangla (0.27) [37], Lake Gariep (0.14) [39], and Merdja Sidi Abed Dam (0.24) [40]. However, the E estimated for *C. carpio* stock in Lake Karamık [25] and the Southern Caspian Sea

[35] reported slight overexploitation of the fish, with values of 0.60 and 0.59, respectively (Table 6).

Fishing mortality rates varied significantly throughout the course of these specimens' lives, with F varying in response to variations in mean lengths. The minimum yield for this fishery was achieved at F_{MSY} (fish mortality at maximum sustainable yield), and it dropped with F values higher than F_{MSY}. With the current fishing mortality for this species, F_{cur} is lower than F_{msy} (but somewhat higher than $F_{0.5}$, the optimum reference point); therefore, the stock may be considered sustainable. $E = 0.38$ was the rate of exploitation. The relative yield and biomass per recruit were used to calculate this rate, which was > $E_{0.1} = 0.355$, $E_{0.5} = 0.0.278$, and $E_{max} = 0.421$ (Figure 7). A midlength of 34.79 cm and an average age of 1.29 years were the length and age ranges for the largest peak in fishing mortality ($F = 2.53\ \text{year}^{-1}$) and the optimal cohort biomass or yield per recruit (L_{opt}) (Figure 6, Tables 3 and 4). The relative yield per recruit (Y/R) and biomass per recruit were calculated as functions of L_c/L_∞ and M/K, respectively. M/K's computed value was 1.44, whereas L_c/L_∞ remained at 0.59. The findings indicated that, in comparison to the current exploitation rate of 0.38, the highest values for yield per recruit for *C. carpio* were at the exploitation level of 0.421. Based on these data, the *C. carpio* stock in Lake Arekit was clearly within sustainable limits. In fact, increasing fatality rates in fishing can increase the level of exploitation. Our research indicates that raising the rate at which Lake Arekit's underutilized *C. carpio* is harvested could boost fishery production.

5. Conclusions and Recommendations

Knowledge of fish population dynamics is essential for making up-to-date decisions and implementing effective management strategies. In this study, we assessed for the first time the growth parameters, mortality rates, rate of exploitation, fishing effort, and maximum sustainable yield (MSY) of *C. carpio* collected from Lake Arekit. Our findings revealed the exploitation rate of *C. carpio* in Lake Arekit is below the ideal value, indicating that the fishery stock is underexploited. It is advised to implement the following fisheries management strategies in order to increase fishing in the study lake: setting up a regular monitoring programme to determine and record the *C. carpio* population, creating more fishermen's associations (at the moment, there is only one with 15 members), creating a social network and raising awareness for fisheries, involving numerous stakeholders, and creating chain values for fisheries, among other things.

Data Availability

The data used to support the findings of the study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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