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Original Article

The population dynamics and stock status of African catfish *Clarias gariepinus* (Burchell, 1822) in Ribb Reservoir, Lake Tana Sub-Basin, Ethiopia

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Abstract: The African catfish, *Clarias gariepinus*, is of great economic importance in Ethiopian fisheries. The species is hardy and fast-growing in any aquatic environment. This study aimed to investigate growth parameters and exploitation rates of *C. gariepinus* to support effective fisheries management. For this study, a twelve-month gillnet catch was employed. The FiSAT II software was used to examine the population dynamics of C. gariepinus in Ribb Reservoir using length–frequency structured data. The VBGF parameters were estimated as: L_∞ = 99.75 cm, K = 0.98/year, and t_0 = -0.148 year. The total, natural, and fishing mortality coefficients were 3.23, 1.17, and 2.06 per year, respectively. The relative yield-per-recruit (Y'/R) analysis predicted Emax = 0.406 and revealed that *C. gariepinus* is overexploited, with $E_{0.5}$ = 0.267, which is lower than the current exploitation rate ($E_{current}$ = 0.64). The analysis of the probability of length at first capture indicated 71.35 cm, implying that the species is on the verge of overexploitation. Therefore, management measures need to target protecting growth from overfishing. To ensure the effectiveness of any fisheries management regulation, all stakeholders and policymakers need to establish a robust co-management program to conserve essential fish stocks.

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Introduction

Inland small-scale fisheries (SSF) play an important role in the economies of developing countries. For landlocked nations, freshwater fishing is the primary source of animal protein (Tesfaye and Wolf, 2015). The African catfish, *Clarias gariepinus* (Burchell, 1822) is being intensively studied in African inland fisheries. The species is valued for its meat quality and affordability, particularly in Africa and Asia (Barasa and Ouma, 2024). This growing interest in the African catfish has led to increased research on its breeding, feeding, and management practices. As a result, enhancing the sustainability of these fisheries could significantly improve food security and economic resilience in developing regions.

According to Oyakhilomen and Zibah (2013) and Ozigbo et al. (2014), *C. gariepinus* is the most widely cultivated species among catfish groups, exhibiting a broad range of acceptability, adaptability, and selling volume. Generally, *C. gariepinus* has contributed considerably to fisheries development in Africa (Satia, 2011), being the most cultivated fish, next to the Nile tilapia, *Oreochromis niloticus* (Linnaeus, 1758). In some African countries (e.g., Uganda), however, *C. gariepinus* production currently surpasses that of *O. niloticus* in aquaculture (FAO, 2022). In Nigerian fisheries, the catfish accounts for about 80% of aquaculture production (Anetekhai, 2010). Ethiopian SSF considers both *O. niloticus* and *C. gariepinus* as the main food fish species in wild and cultured settings (Tesfaye and Wolf, 2015; Eyayu et al., 2023). Despite the economic and ecological importance of *C. gariepinus*, many freshwater bodies in Africa that host this species have been heavily impacted by a wide range of harmful human activities (Tesfaye and Wolf, 2015; Şimşek et al., 2022; Barasa and Ouma, 2024).

Freshwater biodiversity is threatened by a range of interacting anthropogenic stressors, including the

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introduction of invasive species, pollution, climate change, and overexploitation (Dudgeon et al., 2006; Roshni et al., 2020). Of these, biodiversity overexploitation is apparently widespread and threatens freshwater systems (Tesfaye and Wolf, 2015), reducing commercial catches and affecting associated livelihoods (Şimşek et al., 2022; Eyayu et al., 2023; Barasa and Ouma, 2024).

Dams and reservoirs built across rivers are important for development through power generation and fisheries (FAO, 2022). The resulting artificial dam could favor fisheries development, which is responsible for the socioeconomic issues for nearby communities (Liu et al., 2022). Indeed, reservoir fisheries create jobs for the youth on the African continent (Eyayu et al., 2023). In Africa, reservoir fish is a more accessible source of animal protein for poor people because it is less expensive than meat (Tesfay and Teferi, 2017). However, in developing countries, reservoirs experience several perturbations, including overfishing (Tesfaye and Wolf, 2015; Mequanent et al., 2022). According to Tesfaye and Wolf (2015) and Tesfay and Teferi (2017), the utilization of aquatic resources has increased dramatically due to population growth, prompting greater demand for healthy animal products and the adoption of effective fishing gear.

Ribb Reservoir remains among the latest Ethiopian man-made impoundments. The reservoir is home to 11 economically and ecologically important fish species (Mequanent et al., 2022). Thus, aside from providing water for irrigation, the reservoir is a mainstay for considerable fishing communities. Despite the reservoir's multipurpose use, the biology and growth parameters of commercially important fish stocks for reservoir management, as well as the ichthyofauna, have not been well explored. The reservoir has been subjected to considerable nutrient enrichment due to poor agricultural practices. This situation is detrimental to fisheries practices by reducing fishing areas and water volume (Liu et al., 2022; Mequanent et al., 2022).

Knowledge of growth patterns, population dynamics, and the well-being of economically important wild fish is essential for their long-term management (Potts et al., 2008; Booth et al., 2010; Wartenberg et al., 2013; Tesfaye and Wolf, 2015). Knowledge of such aspects of fisheries would assist in the effective management of brood stocks in capture fisheries (Tesfaye and Wolf, 2015; Mehanna et al., 2018). Nevertheless, fish growth dynamics could vary across habitats and fish strains (Asiedu et al., 2023).

For subsequent assessment in fish population dynamics, specimens of *C. gariepinus* could be obtained from wild and cultured environments (Mehanna et al., 2018). Therefore, to produce data to support the effective management of *C. gariepinus* stocks in Ribb Reservoir, we investigated growth, mortality, and exploitation using collections from experimental and commercial gillnets. This scientific endeavor would produce up-to-date information to properly utilize this stock in the Ribb Reservoir.

Good growth, low growth overfishing, and year-round recruitment significantly contribute to the successful productivity of *C. gariepinus* in Ribb Reservoir and possibly throughout its natural home range. Although it is important to ensure sustainable productivity of this stock in the reservoir, a resilient population can be maintained through effective management strategies that capture only mature fish. Given the socio-economic importance of the Ribb Reservoir to fisheries, strategies targeted at stock management should be developed for fishing activities. Thus, this study was intended to examine the population dynamics and growth patterns of *C. gariepinus* in Ribb Reservoir to produce baseline data useful to effectively manage capture fishery resources.

Materials and Methods

Study area: The Ribb Reservoir (Fig. 1) was formed by the construction of a dam across the Ribb River, a cardinal tributary of Lake Tana (the largest lake in Ethiopia). The Ribb Reservoir area stretches between 11°42′34″–12°13′45″N and 37°36′6″–38°14′20″E (Ayalew and Bharti, 2020). The dam is an earth-rock foundation with a height and length of 73 and 800 m, respectively (Mequanent et al., 2022). The reservoir supports irrigation agriculture and provides fisheries

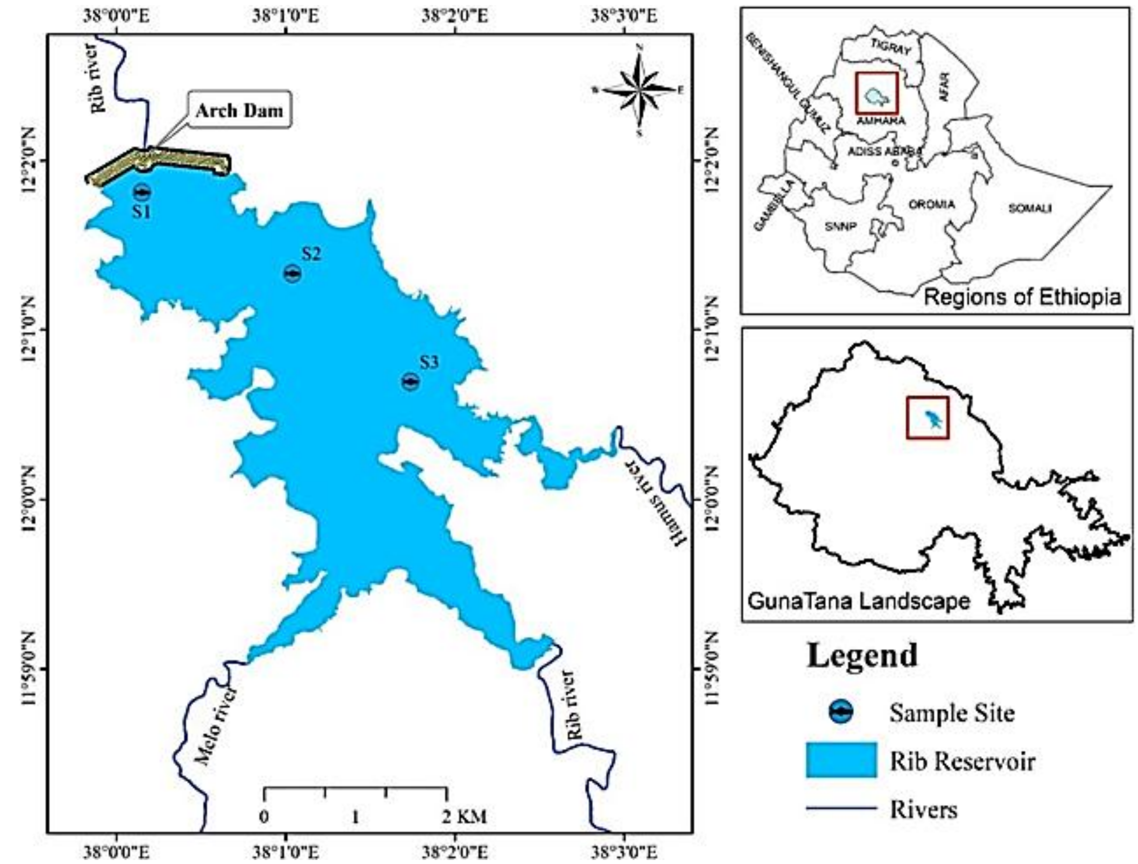

Figure 1. The location of Ribb Reservoir and sampling stations (S1, S2, and S3).

resources to maintain livelihood opportunities in nearby communities in the South Gondar District. The reservoir has a total surface area of 234 m^2 and an average annual inflow of 216 m^3 (Ministry of Water and Energy, 2010). The reservoir is fed by three permanent tributaries (Ribb, Hamus Wonz, and Mello Rivers) and could be used for full irrigation during the dry months (January to May).

The main rainy season in the Ribb area is from June to October. The annual rainfall in the area ranges from 816 to 2344 mm. The annual average temperature in the area ranges from 7.26 to 23.4°C. The highest annual average temperatures occur in March, April, and May, while the lowest occur during the effective rainy months (July, August, and September).

Fish and fisheries in Rib Reservoir: The reservoir has a storage capacity of 234 million cubic meters and serves as a new fisheries development area for the local population, though the dam has impacted the natural fish population. The dam has blocked the upstream migration of native fish species, reducing fish diversity relative to the pre-dam state of the Ribb River. The reservoir created a new source of livelihood, with fisheries production increasing significantly after restocking with *O. niloticus* and the natural adaptation of other important food fish species, including the African catfish and the large upstream migratory *Labeobarbus* spp. of Lake Tana. flocks. A cooperative and organization-based fishery has been operated since 2018. Currently, the reservoir is a mainstay of 76 individual fishers and over 100 fisher cooperatives (Mequanent et al., 2022). Following the full completion of the Ribb Reservoir, fishers established four associations, each comprising 25 individuals, and started fishing in a relatively organized manner. The total annual production was estimated at roughly 148.5, 1028.3, 1034.1, 1043, and 1056 tons for 2018-2022, indicating an upward trend over the period (Source: South Gondar Zone Livestock Resource Development and Promotion Agency, 2023). However, the reservoir's sustainability is threatened by overfishing, significant sedimentation, and soil erosion within its catchment. High rates of sediment deposition from the watershed, driven by factors such as soil erosion and poor farming practices, pose a major threat to the reservoir's lifespan and water quality.

Fish sampling: Fish samples were collected from three sampling locations in the Ribb Reservoir over one year (April 2021 to March 2022) (Fig. 1). Mono- and multifilament gillnets with 4-12 cm stretched mesh sizes were used to collect fish samples. Gillnets had lengths of 25, 50, and 75 m and a depth of 1.5 m. Fish samples collected by local fishers were also measured after their consent. The fishers set gillnets by 5:00 p.m. and retrieved them the following morning by 7:00 a.m. Each sample was measured for length (total and standard) using a measuring caliper and weighed on a sensitive balance. Monthly length frequency (SL and TL, cm) was compiled from the length measurements of fish samples. Data were grouped into 10 cm length classes to obtain a length-frequency table and stored in FiSAT II (Gayanilo et al., 1994) for subsequent analysis.

Estimation of growth parameters: The Von Bertalanffy growth function (VBGF), which has been used to assess the growth of most fish species, was expected to apply to the target species' growth (Von Bertalanffy, 1938; Sparre and Venema, 1992). The growth parameters (L_∞ and K) of VBGF for standard length (SL) at age (t) were estimated using the ELEFAN I module in FiSAT II (Pauly, 1984; Sparre and Venema, 1992), using the formula of $Lt = L_\infty\{1– \exp[^{-}K(t–t_o)]\}$, where L_∞ is the asymptotic length of fish, K = the growth coefficient, and t_o = theoretical age at zero length. t_o was calculated from the empirical formula of Pauly (1979): $Log_{10}(t_o) = 0.392–0.275 Log_{10} L_\infty–1.038 Log_{10} K$.

Total mortality estimation: FiSAT II (Gayanilo et al., 1994) was used to estimate the overall mortality (Z) of *C. gariepinus* from a linearized length-converted catch curve analysis of length-frequency data (Pauly, 1984; King, 1995). The slope of the decreasing right arm of the length-converted catch curves was used to calculate the species' yearly total mortality coefficient (Z).

Natural mortality estimation: The natural mortality (M) was determined by the empirical formula of Pauly (1980), which relates M, L_∞, K, and the mean annual environmental temperature using the formula of $Log(M) = - 0.0066 – 0.279 \log(L_\infty) + 0.6543 \log(K) + 0.463 \log(T^oC)$, where M = natural mortality, K and L_∞ are growth parameters from VBGF, and $T\,^oC$ is the annual mean surface water temperature.

Estimation of exploitation rate (E): The present value of the instantaneous fishing mortality coefficient (Fpresent) was estimated by subtracting M from Z. The exploitation rate (E) was then computed (King, 1995) using the formula of E = F/Z.

Estimation of length at first capture (Lc): Using fish catch data from gillnets of mesh sizes 4, 6, 8, 10, and 12 cm during the study period, the procedures of Sparre and Venema (1992) and Pauly (1984) were used to estimate the mean length at first capture (Lc or $L_{50\%}$), which is the mean length at which 50% of the fish entering the gillnets caught.

Estimation of Φ': In fisheries biology, the phi-prime index (Φ') is a species-specific body growth parameter and can be calculated from the VBGF parameters of K and L_∞ as follows: $\Phi' = \log_{10}(K) + 2 * \log_{10}(L_\infty)$.

Recruitment patterns: FiSAT II software consistently simulated recruitment pulses by analyzing time-series length-frequency data to calculate the annual count of recruitment pulses and their corresponding intensities. As used in Mehanna et al. (2018), seasonal recruitment patterns for particular species were displayed by projecting the growth parameters (L_∞ and K) onto the time axis of the sample series, following a trajectory given by the VBGF.

Relative yield-per-recruit (Y'/R) analysis: The yield-per-recruit (Y'/R) model developed by Beverton and Holt (1988) and later modified by Pauly and Soriano (1986) formed the basis for this model, and the procedure assumed knife-edge selection based on capture probabilities. Inputs for fitting this model included the ratios Lc/L_∞ and M/K. Optimal fishing strategies were determined at two exploitation rates (i.e., $E_{0.1}$ and E_{max}). $E_{0.1}$ represents the rate of exploitation at 10% of the marginal growth of Y'/R under minimal exploitation, while E_{max} corresponds to the exploitation rate yielding maximum Y'/R (Bandara et al., 2020). Analysis of these two parameters was conducted using FiSAT II software (Gayanilo et al., 2005). The stock status of *C. gariepinus* at Ribb Reservoir was assessed by comparing the current exploitation rate ($E_{current}$) with the biological target reference points, $E_{0.1}$ and E_{max}. Additionally, $E_{0.5}$ represents the exploitation rate, where biomass dropping to half the virgin biomass level was considered as a comparative analogy.

The optimum cohort biomass or yield-per-recruit (L_{opt}) was calculated following Beverton and Iles (1992) as follows: $L_{opt} = L_\infty*(3/(3+M/K))$.

The generation time (t_g) was calculated as the average age of the parents at the time the young fish were born. This was based on the typical age at which fish lay their eggs, known as the fish's average age at L_{opt} (Beverton and Iles, 1992). The t_g was estimated using the equation: $t_g = t_{opt} = t_0 – \ln [1-(L_{opt}/L_\infty)]/K$.

Virtual population analysis: To reconstruct the population from total catch data by length, the virtual population analysis (VPA) approach was used in this work to perform length-structured VPA (Gayanilo et al., 2005). The 'F' values for each length class were calculated using the FiSAT program. L_∞, K, M, F, and the constants a and b for the length-weight relationship of *C. gariepinus* are input parameters for the VPA analysis. The first step is to compute the final population (N_t) using the equation of $N_t = C_t * (M + F_t)/F_t$, where C_t, or the catch from the longest length class, is the terminal catch.

Subsequent values of ‘F’ are then approximated, starting with N_t, by repeatedly using the equation of $C_i = N_{i+\Delta t} * (F_i/Z_i) * (\exp(Z_i * \Delta t_i)-1)$ (equation 1), where, $\Delta t_i = (t_i+1 - t_i)$, and $t_i = t_o - (1/K) * \ln(1-(L_i/L_\infty))$, and where population sizes (N_i) are computed from the equation of $N_i = N_{i+\Delta t} * \exp(Z_i)$ (equation 2). Until the population numbers and ‘F’ for all length groups were calculated, equations 1 and 2 were applied alternately (Gayanilo et al., 2005). Accordingly, the biomass (tonnes), yield (tonnes), M and F, and exploitation ratios were the outcomes of the VPA model.

Resource status: Estimates of the fishing mortality rate with the target (F_{opt}) and limit (F_{limit}) were compared to biological reference points (BRP), which were established as F_{opt} = 0.5M and F_{limit} = 2/3M (Patterson, 1992). This allowed for the evaluation of resource status.

Data analysis: To meet the data criteria of the FAO ICLARM Stock Assessment Tools (FiSAT II) program, the length-measured data of *C. gariepinus* were first imported into Microsoft Excel 2016 and then categorized into length classes with 10 cm intervals. FiSAT II Software was used to estimate population parameters using the length frequency analysis (ELEFAN I) (Gayanilo et al., 2005).

Results and Discussions

Length frequency distribution: A total of 379 individuals of *C. gariepinus* were sampled from the Ribb Reservoir. Of these, 192 individuals were females, and 187 were males. The sex ratio (F:M = 0.97:1) was slightly biased toward males, but there was no significant difference between the sexes (P>0.05). The fish weighed between 98 and 6000 g (TW) and ranged in size from 30 to 100 cm (TL). Samples taken from the Ribb Reservoir had mean TL and mean TW standard deviations of 54.63±2.46 cm and 1030.8±105.63 g, respectively. More than 75% of the capture in the Ribb Reservoir was between 48.0 and 53.0 cm TL, according to the population structure of *C. gariepinus* (Fig. 2). This suggests overexploitation in the Ribb Reservoir's *C. gariepinus* stock, as the species can reach up to 170 cm TL under optimal circumstances (Mehanna et al., 2018). In Ribb Reservoir, *C. gariepinus* exhibited a negative allometric growth pattern for combined sexes (TW = 0.0105TL2.833; R2 = 0.8532; n = 379), consistent with a comparable study using the same data (Tesfahun et al., 2023). Growth pattern (b), which varies with environmental factors and fish health, may serve as a gauge of the fish's physiological state (Eyayu, 2019). If there is enough prey in reservoirs, fish may be able to grow successfully. Fishing pressure aimed at over-catching the adults can also affect the LWR and the b-value (Pombo-Ayora et al.,

Table 1. Growth parameters of *Clarias gariepinus* from the Ribb Reservoir.

	Growth Parameters					
C. gariepinus	L_∞ (cm)	K (y^{-1})	t_0 (y)	Φ′	t_{max}	VBGF equation
	99.75	0.98	-0.148	3.99	2.91	$L_t = 99.75*(1 - e^{-0.98(t + 0.148)})$

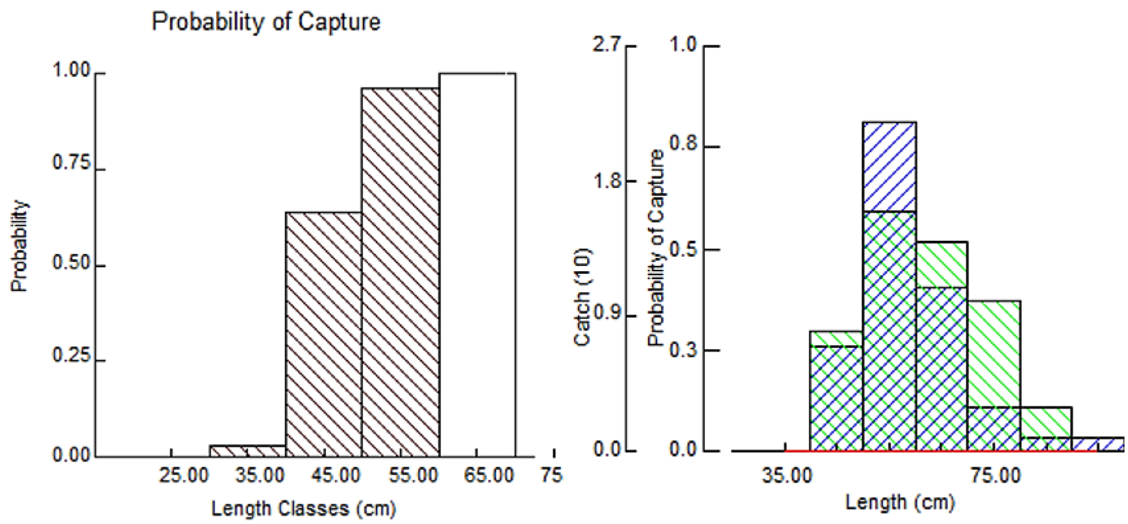

Figure 2. The length-frequency distribution (left) and gear selectivity (right) of *Clarias gariepinus* from Ribb Reservoir.

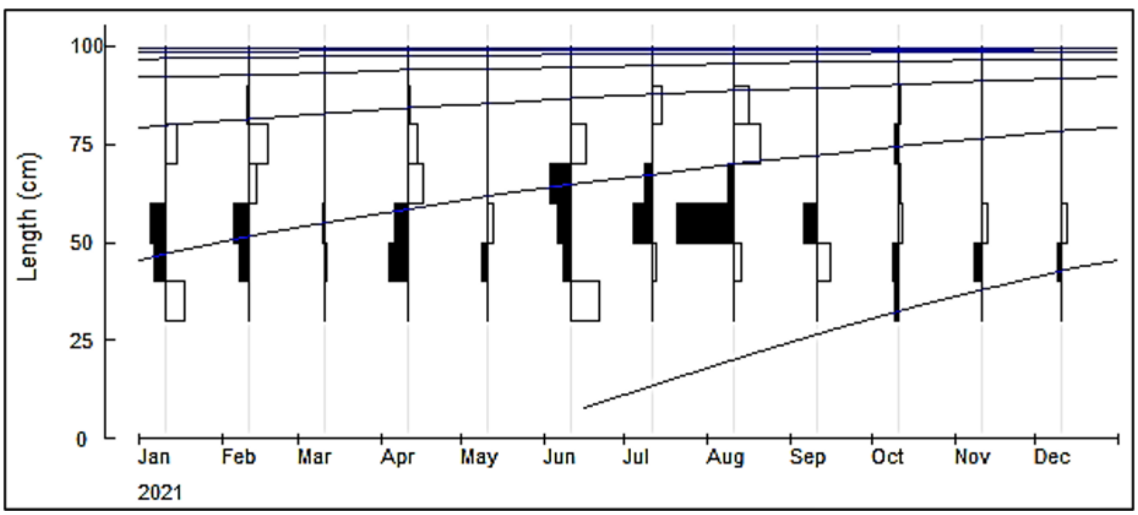

Figure 3. Restructured length-frequency distribution with growth curves superimposed using ELEFAN for *Clarias gariepinus* from Ribb Reservoir (L_∞ = 99.75 cm; K = 0.98 yr−1). (Note. Black bars represent maximum monthly-based frequencies, white bars represent minimum monthly-based frequencies, and blue lines represent growth curves.

2024).

Population parameters: Table 1 and Figures 3 and 4 show estimated growth parameters (L_∞ and K), growth performance indices (Phi prime-Φ′), longevity (t_{max}), and theoretical age at length zero (t_0) for *C. gariepinus* populations sampled from Ribb Reservoir. The projected growth parameters were determined to be K = 0.98/year and L_∞ = 99.75 cm. Furthermore, Table 1 indicates that the Φ′ for *C. gariepinus* in Ribb Reservoir was 3.99, and the predicted t_0 was -0.148 years. The Φ' tends to show little variation between stocks of the same species and serves as an indicator of the reliability of species-specific growth or otherwise of the estimated growth parameters (Okogwu, 2011; Şimşek et al., 2022). The Φ’ values calculated for *C. gariepinus* were similar to those reported in previous studies conducted in different areas (Table 2). The low number of elderly individuals at Rib Reservoir suggests that *C. gariepinus* fisheries are subject to high fishing

Table 2. Parameters' comparisons (L_∞, K, t_0) of the von Bertalanffy growth curve and growth performance index (Φ') for *Clarias gariepinus* individuals reported from different locations.

Area	L∞	*K*	t_0	Φ'	Reference
Lake Manzala (Egypt)	86.66	0.31	-0.39	-	Mehanna et al. (2018)
Bontanga Reservoir (Ghana)	61.95	0.39	-0.07	-	Kwarfo-Apegyah et al. (2008)
Peryar Lake (India)	91.88	0.54	-	3.66	Roshi et al. (2020)
Golbasi Lake (Turkeye)	60.92	0.21	-1.71	-	Narin (2003)
Laing River Reservoir (Eastern Cape)	140.67	0.17	-0.16	-	Potts et al. (2008)
Kat River Reservoir (Eastern Cape)	93.02	0.19	-0.28	-	Potts et al. (2008)
Darlington Dam (Eastern Cape)	93.17	0.15	-2.43	-	Wartenberg et al. (2013)
Gubi Dam (Nigeria)	43	0.65	-1.37	3.08	Abdulkarim et al. (2008)
Mai-Ndombe Lake (DRC)	55.65	0.28	-0.50	-	Nsapu (2021)
Gubi Dam (Nigeria)	43	0.65	-1.37	3.08	Abdulkarim et al. (2009)
Lake Tana (Ethiopia)	87.5	0.2	-	-	Wudneh (1998)
Ribb Reservoir (Ethiopia)	**99.75**	**0.98**	**-0.148**	**3.99**	**Present study**

Note: Dash means no data available; L∞: asymptotic length; *K*: body growth coefficient; t_0: theoretical age at zero length; *Φ'*: phi-prime.

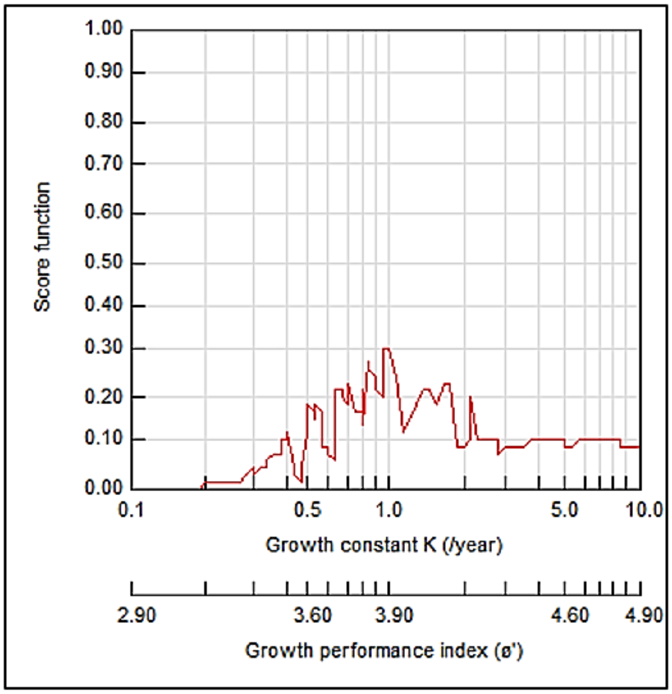

Figure 4. Estimation of L_∞ by the ELEFAN I method for *Clarias gariepinus* from Ribb Reservoir.

pressure (Wartenberg et al., 2013; Pombo-Ayora et al., 2024). Several factors, including but not limited to the location, season, predation, and fishing pressure, can affect growth parameters (Roshi et al., 2020; Şimşek et al., 2022; Pombo-Ayora et al., 2024).

Accordingly, the maximum age (t_{max}) for *C. gariepinus* was calculated to be 2.91 years. Regarding empirical analysis, the VBGF growth model for *C. gariepinus* in Ribb Reservoir was $L_t = 99.75*(1 - e^{-0.98(t + 0.148)})$. The literature in several areas was compared with the VBGF growth parameters (Table 2). Compared with other studies, the growth coefficient (K = 0.98 year^{-1}) and asymptotic length (L_∞ = 99.75 cm) were the highest (Table 2). With regard to L_∞, Potts et al. (2008), Wartenberg et al. (2013), and Roshi et al. (2020) reported the value as 93.02, 93.17, and 91.88 cm in Kat River Reservoir (Eastern Cape), Darlington Dam (Eastern Cape), and Peryar Lake (India), respectively. However, in contradiction to this notation, a large L_∞ (140.67 cm) for *C. gariepinus* was reported from Laing River Reservoir (Eastern Cape) for a sample size of 101 individuals (Potts et al., 2008). Thus, it may be concluded that there is significant pressure on the *C. gariepinus* stocks in the Ribb Reservoir (Wartenberg et al., 2013). In contrast to the findings of Abdulkarim et al. (2009), who assumed that the L_{opt}/L_∞ ratio was constant with an average of 0.62 and minimum and maximum values of 0.323 and 0.938, respectively, for all fish species, the optimum body size (L_{opt}) to asymptotic length (L_∞) ratio (L_{opt}/L_∞) was found to be 0.05.

Compared with other values reported elsewhere, the growth coefficient (K) from this study was high (K = 0.98 year^{-1}). This may be due to the comparatively high mean annual water temperature (23.8°C) in Ribb Reservoir and the preponderance of juveniles in the catches. Additionally, the K-values of fish grown in various water sources vary (Table 2). Young fish (1 year old) had a higher K value, whereas elderly fish (5 years old) showed poor growth (Abdulkarim et al., 2009; Okogwu, 2011).

The age at zero length (t_0 = -0.148) calculated in the

Table 3. Available literature on mortality and exploitation rates of *Clarias gariepinus* stocks from different localities.

Area	Z	M	F	E	Reference
Ribb Reservoir (Ethiopia)	**3.23**	**1.17**	**2.06**	**0.64**	**Present study**
Bontanga Reservoir (Ghana)	1.08	0.79	0.29	0.27	Kwarfo-Apegya et al. (2008)
Peryar Lake (India)	1.34	0.84	0.50	0.37	Roshi et al. (2020)
Gubi Dam (Nigeria)	1.42	1.20	0.22	0.15	Abdulkarim et al. (2009)
Lake Manzalah (Egypt)	0.98	0.37	0.61	0.62	Mehanna et al. (2018)
Mai-Ndombe Lake (DRC)	1.05	0.35	0.70	0.67	Nsapu (2021)

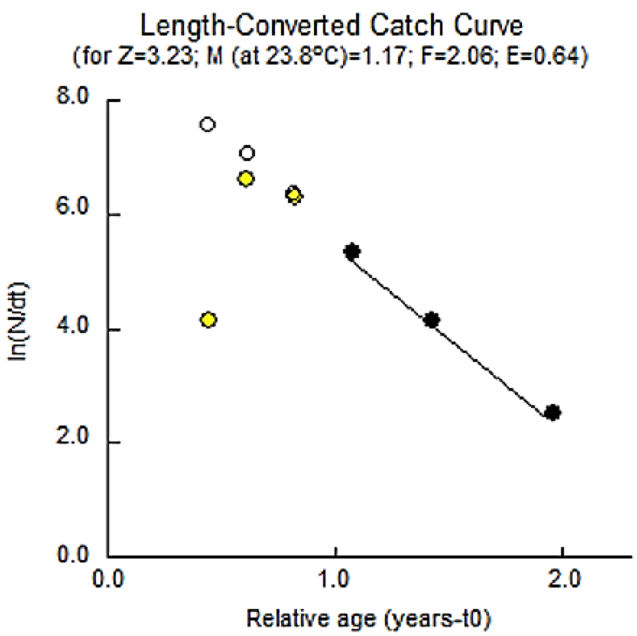

Figure 5. Length-converted catch curves showing mortality rates (Z, M, and F) and exploitation rate (E) of Clarias gariepinus in Ribb Reservoir, Ethiopia.

present study was much higher than reported in the available literature but smaller than reported from Bontanga Reservoir (Ghana) (Kwarfo-Apegyah et al., 2008) and almost equivalent to reports made from Laing River Reservoir (Eastern Cape) (Potts et al., 2008) (Table 2). This variation among similar species can be attributed to environmental and biological factors, such as temperature, food quality, and life-history development (Abdulkarim et al., 2008; Nsapu, 2021). The study's $t_0 = -0.148$ indicated that the *C. gariepinus* population from Ribb Reservoir quickly reached table size. In the Ribb Reservoir, *C. gariepinus* has a maximum lifespan (t_{max}) of approximately 2.91 years. The predicted longevity in this study ($t_{max} = 2.91$) was lower than that of the Mid-Cross River (Nigeria), 6.12 years (Okogwu, 2011), and Lake Manzalah (Egypt), 8 years (Mehanna et al., 2018). According to Okogwu (2011), *C. gariepinus* in lakes and impoundments can live for up to 13 years. However, lifespans may decline to below 9 years due to biological factors such as sex, genetics, diet, reproduction, age, and maturation, as well as environmental factors related to salinity and temperature (Diana and Höök, 2023). All these factors contribute to determining fish lifespan (Dutta, 2023).

Mortality and exploitation rates: The Z/K ratio in this study was 3.29, indicating that the species in the reservoir is being severely overfished. This is because overexploitation is indicated by a Z/K ratio of ≈2 (Etim et al., 1999). The calculated annual death rates were Z = 3.23, M = 1.17, and F = 2.06. For *C. gariepinus*, the projected immediate mortality and exploitation rate was extremely high. When compared to the relatively low value of natural mortality (M = 1.17), the high value of fishing mortality (F = 2.06) in Ribb Reservoir suggested a high rate of *C. gariepinus* exploitation (E = 0.64) (Table 3; Fig. 5). There is significant fishing pressure on *C. gariepinus* in the Ribb Reservoir, as evidenced by the estimated exploitation rate of 0.64, which is greater than the optimum exploitation rate (E_{opt}) of 0.5 and 0.4 as determined by Gulland (1971) and Pauly (1987), respectively. As advised by Gulland (1971), the E-value found in this study suggests that the Ribb fishery is not being utilized to its full potential. F = M, which yields a fixed E = 0.5 for a maximally exploited stock (Pauly, 1984).

Relative yield per recruit: The optimal exploitation rates were determined to be E_{max} = 0.406, E0.1 = 0.308, and E0.5 = 0.267, based on the Beverton-Holt relative yield per recruit assessed using the knife-edge approach (Fig. 6). The present E is significantly greater than the E0.5, which preserves 50% of the biomass of the spawning stock, but it is almost equivalent to the E_{max}. The yield contours forecast

Table 4. The outputs from the VPA of *Clarias gariepinus* in Ribb Reservoir, Ethiopia.

Length class (cm)	Catch (numbers)	Population (N)	F	Biomass (tonnes)
30-39.9	10.00	731.65	0.0955	0.26
40-49.9	140.00	599.12	1.6020	0.44
50-59.9	127.00	356.88	2.2388	0.51
60-69.9	63.00	163.51	2.0104	0.45
70-79.9	27.00	63.84	1.7525	0.33
80-89.9	12.00	18.82	2.0600	0.41
90-99.9	0	0.00	2.0600	0.00

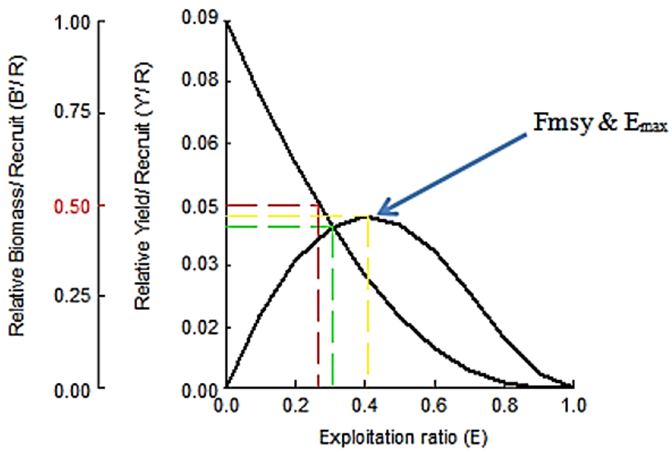

Figure 6. Relative yield per recruit (Y/R)' and biomass per recruit (selection ogive) for *Clarias gariepinus* in Ribb Reservoir, Ethiopia. $E_{0.1}$ = 0.308 (red dotted line), $E_{0.5}$ = 0.267 (green dotted line), $E_{current}$ = 0.64 (yellow dotted line), and E_{max} = 0.406 (yellow dotted line indicated in blue arrow). Black lines are drawn to indicate (*Y*/*R*) and maximum sustainable yield (MSY), or biomass per recruit (*B*/*R*).

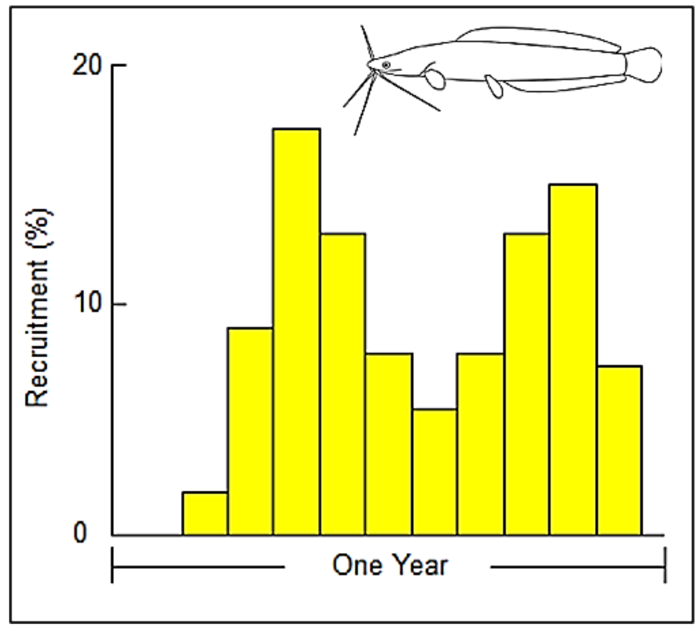

Figure 7. Recruitment patterns of *Clarias gariepinus* from Ribb Reservoir, Ethiopia.

how changes in Lc (length at first capture) and E (exploitation rate) will affect the fish's relative yield per recruit. The Lc/L∞ of 0.050 and the exploitation rate of 0.64 indicate that the smaller fish (juveniles) might be caught at a higher effort level when comparing the yield isopleth diagram in this study with that of Pauly and Soriano (1986).

Different scenarios that correspond to variations in mesh size are represented by the Lc/L∞ numbers. Okogwu (2011) asserts that E is equivalent to fluctuations in the F/Z ratio. The recruitment trend (Fig. 7) shows a double-peak pattern each year; the August peak may reflect the recruitment of juveniles bred the year before into the adult population, while the June peak is most likely due to peak recruitment in migratory breeding stock.

Stock status: Fishing mortality rate estimates were compared with the goal (Fopt) and limit (Flimit) biological reference points (BRPs), which were defined as follows: Fopt = 0.5M, so that E = 0.5 (King, 1995), and F_{limit} = 2/3M. This allowed for the evaluation of resource status. The overexploitation of *C. gariepinus* in Ribb Reservoir was demonstrated by the current F, which was significantly higher than F_{opt} and F_{limit}. The overexploitation of this population is caused by fishermen's tendency to reduce net mesh size and intensify their efforts to catch more fish when the reservoir's various fish species decline (Abdulkarim et al., 2009). Therefore, it is imperative that all parties involved—fishers, local communities, researchers, and government agencies—work together to protect the stock in Ribb Reservoir. In light of this, the current study recommends a number of management measures, such as reducing fishing pressure, particularly on spawners and juveniles, lengthening the time to first capture, and identifying

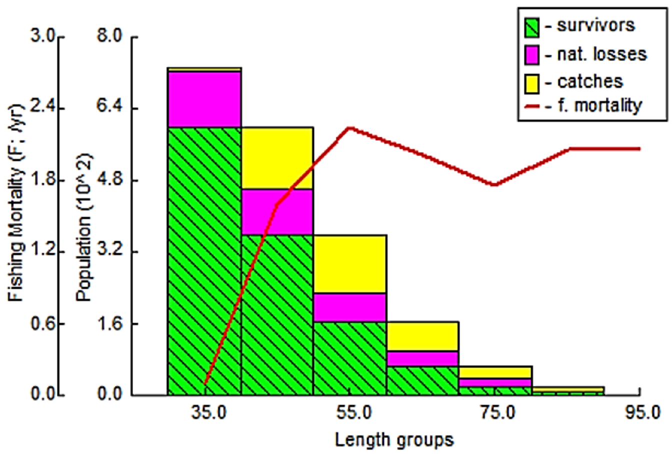

Figure 8. Population estimations of *Clarias gariepinus* in Ribb Reservoir using the VPA from FiSAT output.

and safeguarding specific crucial locations, such as spawning and nursery grounds. Another advantage is keeping an eye on and enhancing the reservoir's water quality.

Length-structured virtual population analysis: Figure 8 presents the findings of the virtual population analysis (VPA) of C. gariepinus for fishing mortality, survival, and natural losses. Consequently, the VPA indicates a low survival rate due to intense fishing pressure. Increasing fishing mortality in the VPA showed that while increased fishing pressure could lead to an exponential decline in the adult population, it would not eradicate the population. Furthermore, increased fishing mortality may significantly affect adults (Roshini et al., 2020).

The fish population's natural losses and survivorship decreased as length and fishing mortality increased. The species' fishing mortality varied across length classes, as indicated by the largest numbers of *C. gariepinus* harvested at TLs of 55-62 cm and 85-95 cm. This suggests that variations in fishing mortality rates with respect to mean length were seen in the VPA results. The fishing mortality rate peaked at 55 cm TL (F = 3.32 year^{-1}). The terminal fishing mortality rate (Ft) was 2.06 year^{-1} (Fig. 8; Table 4).

Conclusion and recommendations

Making informed judgments and implementing management plans requires an understanding of the dynamics of fishing target populations. The purpose of this investigation was to evaluate the stock status of *C. gariepinus* in Ethiopia's Ribb Reservoir. The findings of the study indicated that *C. gariepinus* has a L_∞ of 99.75 cm, a K of 0.98 yr^{-1}, and a t_0 of -0.148 years. With natural mortality (M) at 1.167 years, fishing mortality (F) at 2.06 years, and total mortality (Z) at 3.23 years, the fish shows improved growth in accordance with the VBGF growth model. Overexploitation of the stock is indicated by an exploitation rate (E) of 0.64 ($E_{current}>E_{0.05}$). Fishery managers should enforce species-specific mesh sizes for fishing gear and maintain species-specific size restrictions to support species sustainability and stock recovery. However, it would be challenging to enforce management rules, such as increasing the mesh size. To ensure the sustainability of the C. gariepinus stock, research indicates that lowering fishing pressure, limiting the number and types of fishing vessels, and temporarily closing the fishery should be investigated. Additionally, it is advised that length-frequency and catch data be collected continuously to track broader changes in population dynamics and stock status. Notwithstanding its drawbacks, this study offers baseline data on the *C. gariepinus* population to help address reservoir fishery management challenges in developing nations and to inform the use of efficient management strategies for species-specific reservoir fisheries. To establish the ideal mesh size for sustainable *C. gariepinus* fishing in Ribb Reservoir, a comprehensive additional study of gear and mesh-size selectivity should be conducted. Furthermore, further research may be necessary to fully understand the reproductive biology and ecology of C. gariepinus and their relationship to its demography. This will assist in developing better management practices for this fish in other comparable agroecological settings.

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