Population dynamic of the Shield-head catfish*Synodontis schall*(Bloch & Schneider, 1801)in Upper Atbara and Setit dam complex, Sudan.

Abstract:

This study aimed to assess important population bio-parameters of *Synodontis schall*in the Upper Atbara and the Setit dam complex(Sudan), comprising asymptotic length, growth curvature, length at maturity, optimum length, growth performance index, and mortality rate. The study was based on the need to assess capture fisheries; whose success depends on understanding the species' population structure. For five months (September 2019 and January 2020), 500 specimens of *S. schall* were collected randomly using gillnet from fishermen monthly.Morphometric parameters were taken in the field.The length-weight relationship demonstrated a strong correlation coefficient of r = 0.902, indicating a negative allometric growth pattern with a b-value of 2.619.The von Bertalanffy growth function was used in estimating population parameters obtained from length-frequency data; The asymptotic length (L_∞) was 36.75 cm, the growth curvature (K) was 0.78 $yr.^{-1}$, and the optimum length (L_{opt}) was 23.09 cm. The total mortality (Z) was 2.09 $yr.^{-1}$; exploitation rate (E) = 0.34 $yr.^{-1}$, natural mortality (M) and fishing mortality (F) = 1.39 and 0.7 $yr.^{-1}$, respectively. The overall growth performance index of 3.023 indicated a slow rate of growth.The results suggest that this species and other commercial species require further research on population dynamics.

Keywords:Shield-head catfish, Population dynamic, Upper Atbara, Mortality and Recruitment.

Introduction:

Nile River represents a vital ecosystem for many freshwater fish species in Sudan, but recent research related to the stock assessment and population dynamics of Nile fish within Sudanis still poorly advanced (Abdalla *et. al*., 2024a, 2024b; Shuaib and Abdalla, 2024).

The genus *Synodontis* is particularly widespread across the African continent; primarily being located in tropical aquatic environments such as the Nile basin, Chad, Niger, and vast areas of West Africa (Willoughby, 1974; Paugy and Roberts, 1992). There are over 112 species within this taxonomic group and an individual can represent up to 40% of total landings by weight in some areas of Africa (Daget *et. al*., 1991; Sanyanga, 1996; Willoughby and Tweddle, 1978).

Synodontis schall, of the family Mochokidae, is one of Africa's most adaptable and widely distributed species (McConnell and Lowe-McConnell, 1987; Dadebo*et. al*., 2012).It is popular for its hardiness as it thrives in many habitats and has low spoilage rates after capture, thus enhancing its marketability despite its fairly modest size. Consequently, *S. schall* has attracted significant attention from fisheries scientists in the tropics.Research has been conducted on the different aspects of the species, especially on its age and growth parameters. For example, Abowei and Hart (2009) studied ten species, including *S. schall* in the Lower River Nun.On the other hand, Akombo *et. al*., (2015) and Araoye *et. al*., (2002)worked on age determination using analysis of hard structures in Nigerian freshwater ecosystems; However, there is a critical dearth of studies using the length-frequency method in assessing the age and growth of *S. schall* in the Lower River Benue. While Bishai and Abu Gideiri (1965) demonstrated that vertebrae are the most reliable skeletal components for determining age in *Synodontis* while otoliths, opercular bones, and dorsal spines are less reliable; they found a strong correlation between age and length, noted that females are generally longer than age-matched males, observed non-uniform growth patterns with rapid increases in the first and third years and slower growth in the second and fourth years, and reported that weight increments occur primarily in the first three and fifth years while a decline is seen in the fourth and sixth years, with varying growth rates among different *Synodontis* species. Hence, Halimand Guma (1989) studiedsome aspects of the reproductive biology of *Synodontisschall* from the White Nile near Khartoum (Sudan).

Fisheries management in the Lower River Benue faces challenges in monitoring catches for sustainable yields as expressed in King (1997) due to the disjointed composition of fishing communities;The research aims to compare traditional length-frequency methods for estimating age and growth highlighting the differences in results obtained. According to Guerreiro *et. al*., (2018) knowledge of fish growth is essential for stock assessment and ecological sustainability. They also emphasize the lack of growth parameter data for most tropical fish species such as *Synodontis* in databases like FishBase.org.

Length-weight relationships (LWR) are essential tools in fisheries management for assessing growth patterns of fish populations. They provide critical insights into the growth and condition of fish stocks, reflecting the well-being of species and their communities. LWRs operate on the premise that growth can be isometric, with length and weight increasing at the same rate, or allometric, where these traits grow at different rates. Additionally, understanding LWRs is crucial for fisheries stock assessment and management, as well as for analyzing fish population dynamics, distribution, mortality, and morphology of species (Eagderi *et. al*., 2020; Akter*et. al*., 2019; Jafari-Patcan *et. al*., 2018; Kebede *et. al*., 2018; Rábago-Quiroz *et. al*., 2017andAdeboyejo *et. al*., 2016).

This study attempts to unravel the growth rates, mortality coefficients, and exploitation rates of *Synodontis schall* in the Upper Atbara and Setit complex dam in Eastern Sudan, using length-frequency data for the analysis. Emphasis is placed on estimating growth metrics and sizes at first capture and sexual maturity and mortality rates, all of which are key to proper fish stock management. These results will enable the conservation of efforts and allow the maximum sustainable yields to be formulated to ensure the long-term sustainability of this important species.

Material and Methods:

Study area:

Upper Atbara and Setit complex damconsists of two separate dams: The Rumela Dam on Upper Atbara and the Burdana Dam on Setit also known as Tekezé River. It is located geographically at 14°11'59"N latitude, 35°53′49″Elongitude, and 591 melevation (above sea level); and about 20 km from the confluence of the Atbara-Setit rivers which streams into the Nile and about 80 km southward from Khashm El-Girba Dam.The height of the Rumela Dam is 55 meters and that of Burdana is 50 meters. These two interconnected structures stretch over 13 km. The complex has one reservoir with a gross storage of approximately 2.7 billion cubic meters. The maximum fill elevation is about 517.5 meters above sea level(Adam & Hamad, 2021).

Samples collection:

A total of 500 fish specimens were collected monthly from fishermen at the Upper Atbara and Setit dam complex between September 2019 and January 2020. The fish was identified following Neumann *et. al*., (2016). The total length was measured to the nearest 0.1cm from the snout tip to the upper lobe of the caudal fin using a standard measuring board. Fish body weight was recorded to the nearest 1.0 g with a digital balance (model FRUIT 2000B).

Length-Weight Relationship:

The length-weight relationship for *S. schall* was determined according to Le Cren (1951) equation:

$$\text{Log (W)} = \log(a) + b\log(L)$$

where W represents total weight, L is total length, a is the intercept, and b is the regression coefficient.

Growth Parameters

The von Bertalanffy growth model is widely utilized to analyze the growth patterns of fish, specifically in terms of average length or weight.Growth parameters including asymptotic length (L_∞) and growth coefficient (K) were derived from the von Bertalanffy growth function (vBGF), based on Pauly (1979):

$$L_t = L_\infty \, (1-e^{-k(t-t0)})$$

The theoretical age at zero length (t0) was calculated as:

$$\log_{10}(-t_0) = -0.3922 - 0.2758 \times \log_{10} L_\infty - 1.038 \times \log_{10} K.\text{(Pauly, 1979).}$$

Longevity (T_{max}) was computed as 3/K + t_0, and the growth performance index was evaluated using the formula:

$$2 \times \log L_\infty + \log K.\text{(Moreau } \textit{et. al.}\text{, 1986)}$$

Mortality Parameters

The total annual instantaneous mortality rate (Z) was estimated using the length-converted catch curve. Natural mortality (M) was calculated following Pauly (1980):

$$\log_{10}M = -\,0.0066 - 0.279 \times \log_{10} L_\infty + 0.6543 \times \log_{10} K + 0.4634 \times \log_{10} T$$

Where, M = instantaneous natural mortality, L_∞ asymptotic length, T mean surface temperature (26 °C) K = growth rate.

Fishing mortality (F) was derived from the equation by Beverton and Holt (1957):

$$F = Z - M$$

The exploitation rate (E) was obtained using Gulland's (1971) relationship:

$$E = F \div Z = F \div M + F$$

Length at First Capture and Maturity

Length at first capture (L_c) was determined based on the Beverton and Holt (1957) equation, while length at first maturity (L_m) was calculated using data on mature fish, following Gunderson and Sample (1980). The ELEFAN I method assessed to estimate age at first capture (t_c)according to(Gayanilo *et. al.*, 2005).

$$L_c = \bar{L} - K \times (L_\infty - \bar{L}) \div Z. \text{ (Beverton and Holt, 1957)}$$

Where: $\bar{L}$=mean length of the fish catch; K= growth coefficient; L_∞= asymptotic length and Z= the total mortality.

First maturity (L_m or L_{50}): The L_m from the mature fish (stages III+) data per length class was calculated based on Gunderson and Sample (1980) as follows: P = 1÷1+e (b L + a)

Where: P=the proportion of mature fish at length class x, a= intercept and b=slope.

The L_{m50} was then derived from the relationship of a and b as follows: L_m = -a÷b

The length at first maturity (L_m):

Based on first maturity (above) the % of specimens in the catches larger than the length at maturity (L_m); the % of fish between $L_m$and 10% the length at optimum cohort biomass (L_{opt}=) and the % of fish beyond this L_{opt} range (mega-spawners) were determined following Froese (2004).

The recruitment pattern:

The age at first capture (tc) was determined from the estimated growth parameters (L_∞, K, and t_0) using the ELEFAN I method following (Gayanilo *et. al.*, 2005). The "Percent of sample total" option in FiSAT was used to estimate the recruitment pattern when the samples had dissimilar sizes.

Maximum fishing effort (F_{max}) was determined as:

$$0.67\times K/0.67\text{-}L_c \text{ (Hoggarth, 2006).}$$

The precautionary limit reference point (F_{limit}) was determined as:

$$\tfrac{2}{3}\times M \text{ (Patterson, 1992).}$$

The precautionary target reference point (F_{opt}) was calculated as:

0.4×M (Pauly, 1984).

Virtual Population Analysis

The structured virtual population analysis (vPA) was conducted using FiSAT II software (Gayanilo *et. al*., 2005), incorporating parameters such as L_∞,K,M,F,and the regression coefficients.

Biological reference points were estimated through Beverton and Holt's model, with the length at optimum cohort biomass calculated using the formula:

$$L_{opt} = L_\infty \times (3 \div 3 + M \div K)$$

Data Analysis

For the length-weight relationship, data analysis was performed using Microsoft Excel (2016) according to Abdalla *et. al.*, (2024a), while population parameters were estimated using FiSAT software following the methodologies of Gayanilo *et. al.*, (1996) and Pauly and Morgan (1987).

Results:

The length frequency distribution of *S. schall* was plotted with fish length (Fig. 1) revealing the number of specimens collected across different length categories. The histogram indicated that the majority of the catch fell within the 17.5-32.5 cm range.

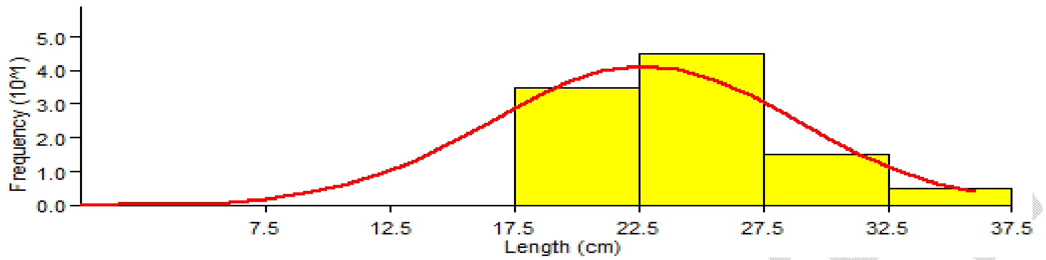

Fig (1). Length frequency distribution of *S. schall* from Upper Atbara and Setit complex dam.

The length-weight relationship of *S. schall* exhibits a negative allometric growth pattern with a high correlation coefficient of r = 0.902, as illustrated in Figure (2).

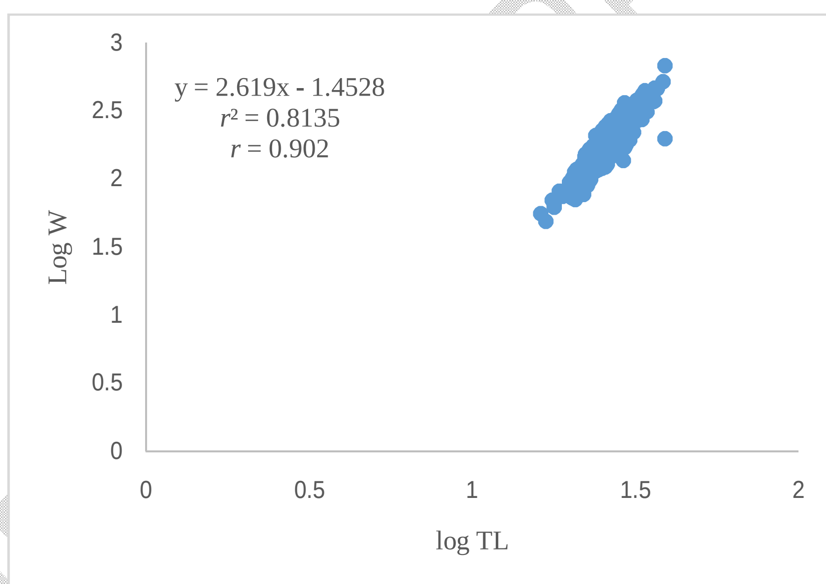

Fig. (2): length-weight relationship of *S. schall* in Upper Atbara and Setit complex Dam.

Growth parameter:

Table (1) summarizes the calculated growth parameters for *S. schall* with an estimated asymptotic length (L_∞) of 36.75cm, a curvature coefficient (K) of 0.78 yr^{-1}, and a theoretical length at age zero (t_0) of -0.712 yr^{-1}. The growth performance index (Φ') was calculated as 3.023 and longevity (T_{max}) reached 3.13 years. The von Bertalanffy growth equation was derived accordingly:

$$L_t = 36.75 \times 1\text{-}\exp(-0.78\times(t+0.712)).$$

The lengths at first capture (L_c) and maturity (L_m) were determined to be 17.4 cm and 13.65 cm, respectively, indicating that L_c is less than L_m,as shown in Table (1).

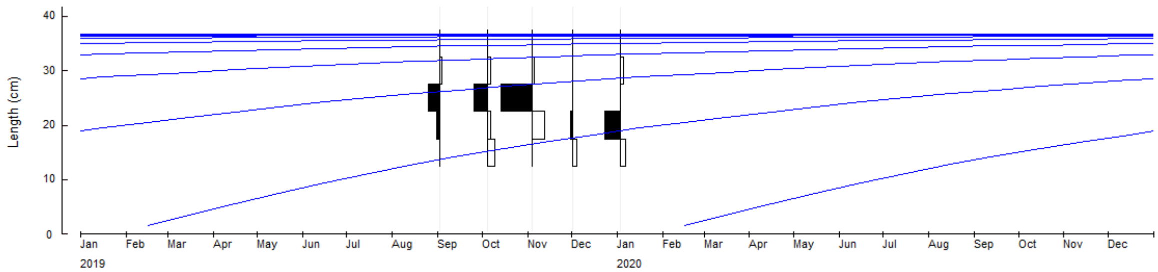

Fig. (3) von Bertalanffy growth curve.

Mortality

The length-converted catch curve from FiSAT indicated total mortality (Z) of 2.09 yr^{-1}, natural mortality (M) of 1.39 yr^{-1}, and fishing mortality (F) of 0.7 yr^{-1} (Fig. 4 and Table 1). The calculated total mortality was represented by the black dots in Fig. (4).

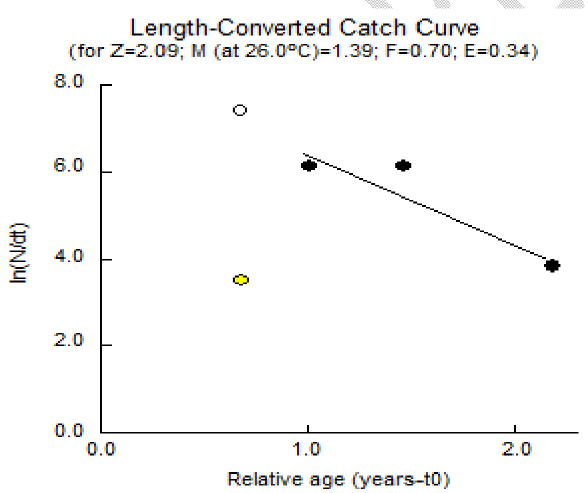

Fig. (4). Total, natural, and fishing mortality using length-converted catch curve from FiSAT output.

Recruitment

Annual recruitment of *S. schall* from the dam (Fig. 5) showed two main recruitment periods coinciding with the rainy season. Recruitment peaked during April/May, with a subsequent decline noted in June and July. During August/October, the newly recruited fish were too small to be captured by the nets in use.

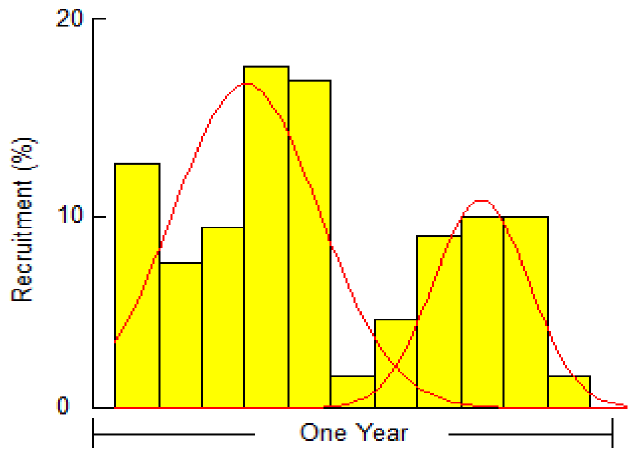

Fig. (5). The annual recruitment pattern of *S. shall.*

Probability of capture

The probability of capture at lengths L_{25}, L_{50},and L_{75} was recorded at 13.65 cm, 17.4cm, and 21.17cm, respectively (Table 1 and Fig. 6).

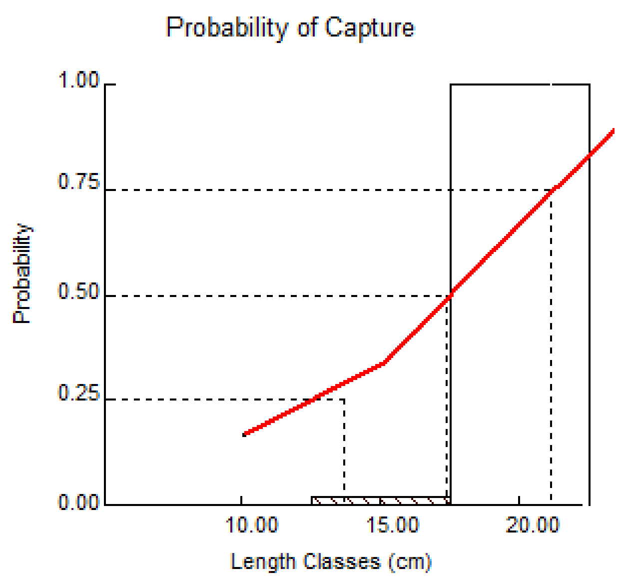

Fig. (6). Capture probability of *S. schall*.

Relative yield and relative biomass per recruit

The relative yield per recruit (Y/R) and relative biomass per recruit (B/R) were calculated based on exploitation ratios. A Y/R value of 0.06 was observed at an exploitation ratio of$E_{01}$and E_{05} was0.355–0.278 (Fig. 7).While an exploration rate (E) and maximum exploration(E_{max}) were recorded at 0.34 and 0.421, respectively (Table,1 and Fig. 4 and 7).

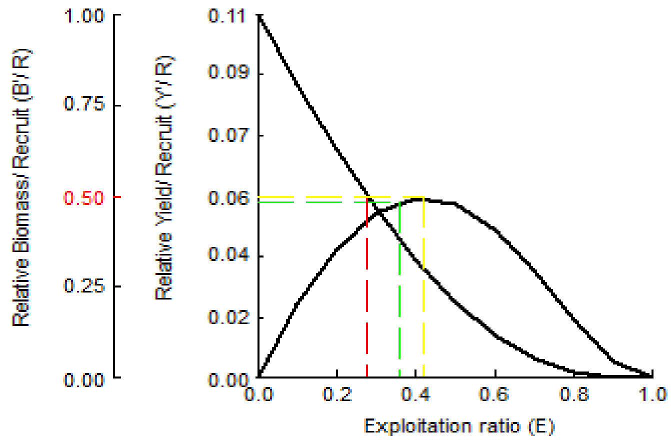

Fig. (7).Relative yield per recruitment (Y/R) and biomass per recruit (B/R) of the *S. schall*.

Population analysis

Population analysis indicated a low catch-to-stock ratio in the reservoir as highlighted by the yellow shading in Fig. (8), particularly in the length range of 17.5-32.5 cm. The highest abundance was less than15 cm (indicated by striped green) gradually declining with age. Natural mortality was notably high among smaller fish (violet shading);While fishing mortality began at 15 cm peaking at 24.7 cm (red line) as appears in Fig. (8).

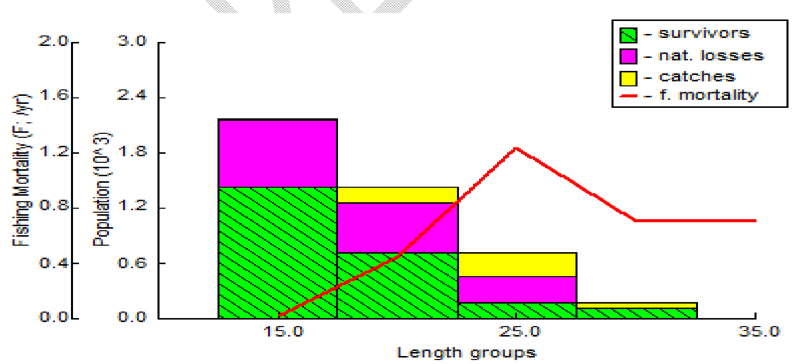

Fig. (8). Length-structured (TL) virtual population analysis of*S. schall* in Upper Atbara and Setit complex dam.

Table (1): shows the bio-parameter of *S. schall* from Upper Atbara and Setit complex dam.

Parameters	Estimated values	Parameters	Estimated values
L_∞ (cm)	36.75	E	0.34
K (year $^{-1}$)	0.78	E_{max}	0.421

Phi (Φ')	3.023	E_{01}	0.355
t_0(year)	-0.712	E_{05}	0.278
T_{max} (year)	3.13	L_c or (L_{50})	17.4 cm
Z (year $^{-1}$)	2.09	L_{25}	13.65 cm
M (year $^{-1}$)	1.38	L_{75}	21.17 cm
F (year $^{-1}$)	0.7	L_{opt}	23.09 cm
L_c / L_∞	0.05	Z/K	2.68
L_m(cm)	13.65	F_{opt}	0.554
F_{max}	0.923	F_{limit}	0.730

The overall mean length of the specimens was 22.7 ± 6.09 cm with observed extremes reaching 35 cm and predicted extremes at 37.45 cm. The 95% confidence interval ranged from 32.74 to 42.17 cm. For the *S. schall* population, the estimated L_∞ was 30 ± 0.2 cm, with a growth coefficient of 1.5 ± 0.2 yr^{-1}. Additionally, L_{50} and L_{75} were found to be 9.5 cm and 12 cm respectively, with a maximum fishing effort (F_{max}) of 0.923.

Discussion:

The analysis of data indicates that the lengths of *Synodontis schall* predominantly range from 17.5 to 30.3 cm (Fig. 1).The relation of length and weight of *S. schall* displays a high correlation coefficient of r = 0.902, and shows a negative allometric growth pattern with b-value of 2.619 as shown in Fig. (2); These results conform with those from various sites such as the Roseires Reservoir, the Upper Atbara and Setit complex dam, the Atbara River and Khashm El-Girba Reservoir (Sudan), the Okpara Stream in the Oueme River (Benin), the Lower Ogun River, and the River Benue (Nigeria) as reported by Hamid *et. al.*,(2024); Adam and Hamad, (2021); Ahmed *et. al.*, (2011); Imorou *et. al.*, (2019); Adeosun *et. al.*, (2017) and Akombo *et. al.*, (2014). Using the FiSAT II software and the ELEFAN I methodtoestimate the von Bertalanffy growth parameters yielding an asymptotic length (L_∞) of 36.75 cm, a growth coefficient (K) of 0.78 yr^{-1}, and a theoretical age at zero length (t_0) of -0.712 $yr.^{-1}$; These findings differfrom Mehanna (2022), who reported an L_∞ of 42.25 cm, K of 0.42 yr^{-1}, and t_0 of -0.36 yr, alongside a growth performance index (Φ') of 2.87. In this study, the calculated growth performance index was 3.023, with maximum longevity (T_{max}) of 3.13 years (Table 1); This suggests that the growth performance and longevity of *S. schall* in the current study agree with Terhemen *et. al.*, (2017) estimated L_∞ for *S. schall* in the lower River Benue (Nigeria) using five different methods, reporting a range from 30.11 cm (Bhattacharya method) to 37.06 cm (von Bertalanffy and van

Zalinge methods); They observed that *S. schall* typically reaches its maximum length by age 3+, indicating a relatively short lifespan. Also, the occurred results are lower than those reported by Mehanna (2022), who noted a maximum lifespan of 4 years based on pectoral fin spine analyses; Such discrepancies may be attributed to geographical variations, differing fishing methods, food availability, and conservation practices. Hence, our findings contrast with those of El-Kasheif *et. al.*, (2012), who indicated that the asymptotic lengths for males, females, and both sexes were 62.74 cm, 64.24 cm, and 63.45 cm, respectively. They reported growth curvatures of 0.1243yr^{-1}, 0.1198yr^{-1}, and 0.1270 yr^{-1} for the same groups. Additionally, the t_0 values varied, measuring -1.0657 $yr.^{-1}$ for males, -1.0732 $yr.^{-1}$ for females, and 0.9729 $yr.^{-1}$ for both sexes. Longevity estimates also differ, as El-Kasheif *et. al*., (2012) noted a maximum lifespan of 6 years for this species, potentially attributed to differences in catch practices and gear types. Hence, Halim and Guma (1989) documented that *S. schall* can live up to 5 years.

Akombo *et. al*., (2021) investigated five *Synodontis* species in the lower River Benue from January 2016 to December 2018; They reported L_∞ values spanning from 18.80 cm in female *S. clarias* to 37.04 cm in female *S. membranaceus*; The t_0 values were negative for the combined sexes of *S. clarias, S. omias, S. gambiensis*, and *S. membranaceus*, while positive t_0 values were observed in both combined sexes of *S. membranaceus* and *S. schall*; Growth rates (*K*) were lower in *S. clarias* (0.301 - 0.497) and *S. omias* (0.171 - 0.310), with higher rates in *S. membranaceus* (0.310 - 0.640) and females of *S. schall* (0.430 - 0.580); The combined growth performance index for *S. schall* was 2.946, indicating a healthy growth potential compared to other species studied.In a prior study, Akombo *et. al*., (2015) found L_∞ values of 30.05 cm for females, 30.00 cm for males, and 28.50 cm for combined sexes. The growth rates were 0.580 for females, 0.570 for males, and 0.430 for both sexes combined. The t_0 values were positive, suggesting a consistent growth pattern across genders.

Our length-converted catch curve analysis indicated total mortality (Z) of 2.09 yr^{-1}, natural mortality (M) of 1.39 yr^{-1}, and fishing mortality (F) of 0.70 yr^{-1} (Fig. 3, Table 1). In contrast, Mehanna (2022) reported total mortality as 1.23, natural mortality as 0.54, and fishing mortality as 0.69 yr^{-1}. Akombo *et. al.*, (2021) found natural mortality rates ranging from 0.5422$yr.^{-1}$, for female *S. omias* to 1.3340$yr.^{-1}$ for male *S. membranaceus*, while fishing mortality was 0.8214$yr.^{-1}$ for combined *S. omias*and 3.0934 for female *S. membranaceus*. Total mortality varied from 1.52$yr.^{-1}$ for combined *S. omias* to 4.078$yr.^{-1}$ for combined *S. membranaceus*. Yet,

Akombo *et.al*., (2017) reported fishing mortalities for *S. schall* of 2.203$yr.^{-1}$, 2.355$yr.^{-1}$, and 2.360$yr.^{-1}$ for females, males, and combined sexes, respectively, all exceeding natural mortalities of 1.235, 1.227$yr.^{-1}$, and 1.045$yr.^{-1}$ for the same groups. Total mortalities were calculated at 3.438$yr.^{-1}$, 3.582$yr.^{-1}$, and 3.405$yr.^{-1}$ for females, males, and combined sexes, respectively. Our findings exceeded those of El-Kasheif *et. al*., (2012), who reported a total mortality rate of 0.59$yr.^{-1}$ for *S. schall*, with natural mortality at 0.35$yr.^{-1}$ and fishing mortality at 0.25$yr.^{-1}$. This discrepancy may be due to variations in fishing pressure and gear types.
Relative yield per recruit (Y/R) and relative biomass per recruit (B/R) were assessed based on exploitation ratios, revealing a Y/R of 0.06 at an exploitation ratio of $E_{0.1}$ and values ranging from 0.355 to 0.278 at $E_{0.5}$ (Fig. 7); current and maximal exploitation rates were noted at 0.34 and 0.421 (Table 1); Mehanna (2022) reported an exploitation rate of 0.56 for *S. schall* in the Nile River (Egypt), while Akombo *et. al*., (2017) found higher exploitation ratios in the lower River Benue (0.64 for females, 0.66 for males, and 0.69 for combined sexes), indicating potential overfishing risks. These findings suggest that current exploitation rates are less than the optimum level indicating fisheries resources are under-fishing.Our findings were lower than the exploitation rate of *S. schall* in Egypt, reported by El-Kasheif *et. al*., (2012) as 41%.

The lengths at first capture (L_c) and maturity (L_m) were determined to be 17.4 cm and 13.65 cm, respectively, indicating that L_c is less than L_m. The probabilities of capture at lengths L_{25}, L_{50}, and L_{75} were recorded at 13.65 cm, 17.4 cm, and 21.17 cm (Table 1, Fig. 6). Mehanna (2022) estimated L_m at 24.1 cm and L_c at 23.6 cm, indicating selective fishing mortality towards smaller fish, leading to detrimental effects on populations. To foster sustainable management, increasing the length at first capture is recommended to ensure adequate spawning biomass and to monitor exploitation levels closely.Furthermore, these results contrast with those of El-Kasheif *et. al*., (2012), who reported first maturity and capture lengths of 31 cm and 28 cm, respectively.

Annual recruitment of *S. schall* from the dam reservoir (Fig. 5) demonstrated two primary recruitment peaks coinciding with the rainy season, with a notable increase in recruitment during April/May, followed by a decrease in June and July. From August to October, newly recruited individuals were often too small for capture with the current fishing gear. Akombo *et. al*., (2017) similarly noted continuous recruitment with two distinct pulses: one at the beginning of the year and another mid-year.

Conclusion:

This study provides valuable background into the population dynamics of *Synodontis schall* in the Upper Atbara and Setit complex dam reservoir. The findings highlight critical aspects of length-weight relationship, growth, mortality, and recruitment patterns, emphasizing the species' ecological and commercial significance.The study revealed a negative allometric growth pattern with a strong correlation. The observed two rounds of recruitment, are crucial for effective management strategies.The results indicate a concerning trend of low catch-to-stock ratios and high natural mortality. The disparity between the lengths at first capture and maturity points to the need for regulatory measures that protect juvenile populations to ensure long-term sustainability.Given the moderate growth parameters and relatively short lifespan of *S. schall*, there is an urgent need for further research focused on enhancing productivity and conservation efforts. Integrating optimal management practices will be essential to balance fishing activities with the preservation of this species and its habitat. Future studies should aim to refine an understanding of the ecological interactions within the reservoir and develop targeted strategies to support the sustainability of both *S. schall* and other commercially important species.

Ethical Issues: Ethics approval and consent to participate, human and animal rights, consent for publication, and availability of data and materials are not applicable.

Disclaimer (Artificial intelligence)

Option 1:

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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