**Growth, mortality, and yield per recruit of *Synodontis schall* (Bloch and Schneider, 1801) in Roseries reservoir, Sudan**

**Abstract**:

This study assessed the population bio-parameters of shield-head catfish Synodontis schall (Bloch & Schneider, 1801) in the Roseries Reservoir (Sudan), using length-frequency data analyzed with FiSAT software. The von Bertalanffy growth parameters were determined as an asymptotic length (*L∞*) of 50.4 cm, and a growth curvature (*K*) of 0.17 yr.⁻¹. Mortality rates were calculated with total mortality (Z) at 0.63 yr.⁻¹, natural mortality (M) at 0.46 yr.⁻¹, and fishing mortality (F) at 0.17 yr.⁻¹, resulting in an exploitation rate (E) of 0.28 yr.⁻¹. The species exhibited continuous recruitment, with a maximum exploitation rate (E*max*) of 0.409. Results indicate low fishing pressure on S. schall in the reservoir, which is a relatively low level of productivity. The relationship between total length and body weight also revealed a negative allometric growth pattern (*b* = 2.193) with a moderate correlation (*r* = 0.764).

**Keywords:** Population dynamics, *Synodontis*, Fisheries, FiSAT, and Exploitation rate.

**Introduction**:

The availability of limited resources influences the abundance of fish populations (Hayes *et. al.*, 1996); these populations exhibit renewal characteristics regulated by density-dependent growth and survival mechanisms (Allen and Hightower, 2010). Fish stock assessment and analysis are critical for effective management (Jover, 2022), conservation, and sustainability of fish populations (Gebremedhin *et. al.,*2021).

Stock status can be categorized into several classifications, including under-exploited, optimum exploited, overfished, and rehabilitated fisheries (Ernawati *et. al.,* 2024). To determine the stock status, biomass measurements are utilized to assess whether a stock is overfished (Sathianandan *et. al.,*2021). Additionally, fishing mortality rates are analyzed to evaluate the potential for overfishing, which occurs when the fishing mortality rate exceeds a threshold of 0.5 (Pham *et. al.*, 2023). The phenomenon of widespread overfishing has led to sequential depletion of fish stocks, resulting in stagnation and eventual decline of global fishery catches since the late of 1980s (Kleisner *et. al.*, 2013).

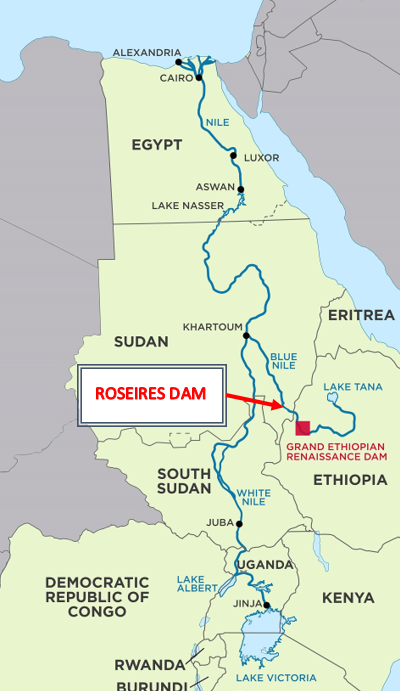
Traditional assessment methods often require extensive statistical and survey data, including catch data, abundance indices, and age structure information (Chrysafi and Kuparinen, 2016). However, many exploited fisheries, particularly in developing countries, lack the data required for these traditional methods and are classified as data-poor (Costello *et. al*., 2012).

The Mochokidae family is a Pan-African fish (Day *et. al.,*2013, and Pinton *al.,*2013); the genus *Synodontis*, which belongs to this family, is particularly prevalent across Africa, primarily inhabiting tropical aquatic environments (Yongo *et. al.*, 2019); these genera were represented by 131 species (Fricke *et. al.,* 2019). The previous research has focused on various aspects of these species, particularly their age and growth parameters, in locations such as the Lower River Nun in Nigeria and the Jebel Aulia reservoir on the White Nile in Sudan, as investigated by (Abowei and Hart, 2009; Araoye *et. al*., 2002; Akombo *et. al*., 2015; and Halim and Guma, 1989).

The present investigation aimed to establish the von Bertalanffy growth model, total (Z), natural (M), and fishing (F) mortality rate, exploitation rate (E), length of first maturity (*Lm*), and the length at optimum cohort biomass (*Lopt*) for *Synodontis schall* in the Roseries reservoir (Sudan).

**Material and Methods**:

**Study area**: The Roseires Dam is located on the Blue Nile River in Sudan (Map. 1) and is a critical water storage facility for agricultural irrigation and hydroelectric power generation. Situated approximately 550 km from Khartoum, the dam was initially constructed in 1966. A second construction phase raised its height from 68 m to 78 m, increasing storage capacity from 3.0 billion m³ to 7.3 billion m³. The reservoir now supports local fisheries, providing livelihoods, employment, and income for nearby communities. Fish samples were collected from four designated sites (Table 1).



Map. 1. Roseires Dam in Sudan, Africa (11°47′53″N 34°23′15″E﻿ / ﻿11.79806°N 34.38750°E﻿ / 11.79806; 34.38750). From Ayn network (https://3ayin.com/en/sudan-authorities-support-while-affected-communities-fear-africas-largest-dam/)

**Table 1. The coordinates of the fish sampling sites in Roseires Reservoir (Blue Nile, Sudan) and the distance from the Damazin City.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Site** | **Distance (km)** | **Coordinate** | **Elevation (m)** |
| **Awal Bab** | 4 | 11°45'14"N 34°21'51"E | 487 |
| **EL Regiba** | 16 | 11°38'39"N 34°20'51"E | 497 |
| **Kirma** | 43 | 11°41'09"N 34°30'35"E | 506 |
| **Wad EL Mahi** | 80 | 11°25'27"N 34°40'17"E | 507 |

**Samples collection:** A total of 416 fish specimens were collected monthly from the four sites (Table 1) between January to December 2022. Gillnets with stretched mesh sizes of 2 cm, 4 cm, 6 cm, and 8 cm were used, with lengths of 50 m, 90 m, 95 m, and 100 m and depths of 2 m, 4 m, and 4.5 m, respectively (Table 2). Fish identification followed Neumann *et. al*., (2016). Total length (TL) was measured to the nearest 1.0 mm from the snout tip to the end of the caudal fin using a measuring board. Body weight was recorded to the nearest 1.0 g using a digital balance (FRUIT 2000B).

**Table 2. Specifications of gillnets used for fish sampling.**

|  |  |  |  |
| --- | --- | --- | --- |
| **Gear No.** | **Length (m)** | **Depth (m)** | **Mesh size (cm)** |
| **2** | 50 | 2 | 2 |
| **12** | 90 | 4 | 4 |
| **12** | 95 | 4 | 6 |
| **12** | 100 | 4.5 | 8 |

**Length-Weight Relationship:** The length-weight relationship for S*. schall* was determined using the Le Cren equation: W = a L b, where W represents total weight, L: total length, *a*: the intercept, and *b*: the regression coefficient.

**Growth Parameters:**

The von Bertalanffy growth model was applied to estimate growth patterns, with key parameters including asymptotic length (*L∞*) and growth coefficient (*K*) derived from the von Bertalanffy growth function: *Lt* =*L∞* (1-e-k(t-t0)).

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

log10 (−*t*0) = − 0.3922 − 0.2758 × log10 *L∞*− 1.038 × log10 *K*. (Pauly, 1979).

**Longevity T*max***was estimated as 3/*K* + *t*0*.*

**The growth performance index (*ϕ* ′)** was calculated as: *ϕ* ′ = 2 *log10* *L∞* + log10 K. (Moreau *et. al*., 1986).

**Age at first sexual maturity (*tm50*)**: The commonly used equation of von Bertalanffy (Bertalanffy, 1938) is calculated as follows: *t(L)* = *t0-*1/*K* Ln(1-*L*/*L∞*), where *t(L)* is the age at length *L*, *t0*, *K*, and *L∞* are population growth parameters.

**Length at first maturity (*Lm*)**: *Lm* was estimated from Froese and Binohlan (2000) as:

*log10 Lm* = 0.8776 × log10 *L∞*-0.38.

**Mortality Parameters:**

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

*log10* M = - 0.0066 - 0.279 × *log10 L*∞+ 0.6543 × *log10* K + 0.4634 × *log10* T.

Where: M = instantaneous natural mortality, *L∞* asymptotic length, “T” mean surface temperature (24.5 °C), and “*K*” = growth rate.

**Fishing mortality (F)** was derived as (Beverton & Holt, 1957): F = Z – M.

**The exploitation rate (E)** was calculated using the formula provided by Gulland (1971): E = F/Z.

**Relative Yield and Biomass per Recruit:**

The model by Pauly & Soriano (1986) was used to predict Y′/R, while relative biomass per recruit (B′/R) was estimated following Gayanilo *et. al*., (2005). Key reference points included:

**Maximum exploitation rate** (E*max*),

**Exploitation rate at 10% virgin biomass** (E0.1),

**Exploitation rate at 50% virgin biomass** (E0.5).

**Length at First Capture,** *Lc*​, was determined using Beverton and Holt's equation:

*Lc* = *L̄*-*K* × (*L∞* - *L̄*) ÷ Z. Beverton and Holt, (1957).

Where: *L̄* = mean length of the fish catch; *K* = growth coefficient; *L*∞ = asymptotic length; and = the total mortality.

**The age at first capture (*t****c*) was determined from the estimated growth parameters (*L∞*, *K*, and *t*0) using the ELEFAN I method following Gayanilo *et. al*., (2005).

**Recruitment Patterns** were analyzed using FiSAT’s "Percent of sample total" option. When the samples had dissimilar sizes.

**Maximum fishing effort (F*max*)** was determined as: 0.67×*K*/0.67-*L*c (Hoggarth *et. al*., 2006).

**The precautionary limit reference point (F*limit*)** was set at: ⅔×M (Patterson, 1992).

**Precautionary target reference point (F*opt*)** was calculated as: 0.4×M (Pauly, 1984).

**Virtual Population Analysis:**

Structured virtual population analysis was conducted using FiSAT II software, incorporating parameters such as *L∞*​, *K*, M, and *F*. Biological reference points were derived from Beverton and Holt’s model (1992).

**Optimum cohort biomass** **length** was calculated as: *Lopt* = *L∞* × (3÷3 + M÷*K*).

**Data Analysis:** Microsoft Excel was used to estimate the Length-weight relationships, while population parameters were estimated using FiSAT (Gayanilo *et. al*., 1996; Pauly & Morgan, 1987).

**Results**:

During this investigation, a total of 416 specimens of *Synodontis schall* were collected monthly from four sites in Roseries reservoir from January to December 2022. The total length (TL) of specimens ranged between 8.5 cm to 47 cm with an average of 20.176 ± 5.417 cm, as appears in Fig. (1).

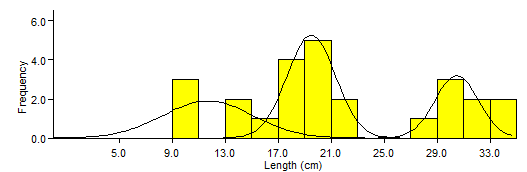


Fig. (1): Decomposition of composite distribution using Bhattacharya's methods.

In the present study, the length-weight relationship of *S. schall* exhibited a negative allometric growth pattern (b-value 2.193) with moderate correlation (*r =* 0.764), as shown in Fig. (2).

Fig. (2): Length-weight relationship of *S. schall* in Roseries reservoir.

In this study, the growth was determined according to von Bertalanffy equation using ELEFAN nodule in FiSAT; yielded an asymptotic length (*L∞* = 50.4 cm), growth curvature (*K* = 0.17 yr. -1), and theoretical age at length zero (*t*0 = -0.063), while growth performance index (Փ') calculated to be 2.635; the longevity (T*max*) reach 17.58 years, as shown in (Fig. 3 & Table 3). The estimated length at first maturity (*Lm50*) for the shield-head catfish *S. schall,* which inhabits the Roseries reservoir, was 13.003 cm; converting these lengths to the corresponding age at first sexual maturity (*t*m50) using the von Bertalanffy formula gave 2.25 yr.-1, as shown in Table (3).

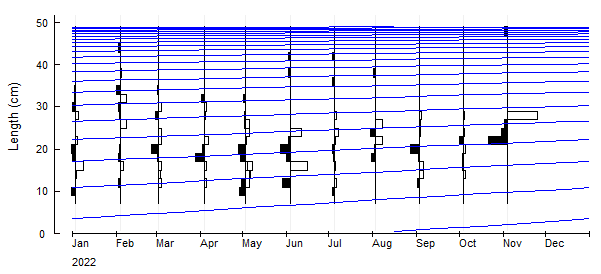


Fig. (3): von Bertalanffy growth curve for *S. schall* in Roseries reservoir.

In this investigation, *S. schall* showed instantaneous mortality parameters as: total (Z), natural (M), and fishing (F) mortality as 0.63 yr. -1, 0.46 yr. -1, and 0.17 yr. -1, respectively; reflected exploitation rate (E = 0.28); as shown in (Fig. 4 & Table 3).

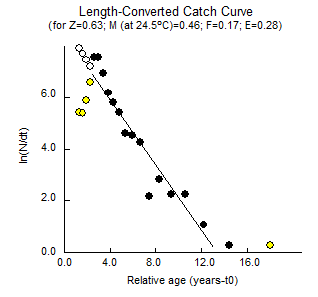


Fig. (4): Von Bertalanffy growth curve (a) (*L∞*= 50.4 cm; *K* = 0.17 yr.-1) overlaid on length-frequency distribution, and (*b*) linearized length-converted catch curve for *S. schall* in Roseires reservoir.

In this study, Shield-head catfish demonstrated continuous recruitment, as shown in Fig. (5).

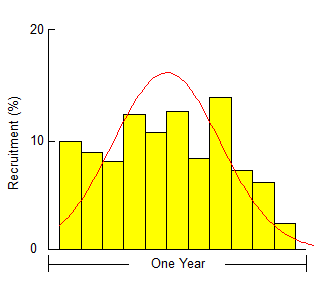


Fig. (5): Recruitment pattern of *S. schall* in Roseries reservoir.

The probability of capture at *L*25, *L50*, and *L*75 was recorded at 13.78 cm, 16.39 cm, and 19.01 cm, respectively; While, the first capture length at 8.5 cm (Fig. 6 & Table 3). Additionally, the maturity age (*tm50*) was estimated as 2.25 yr.-1 as shown in Table (3).

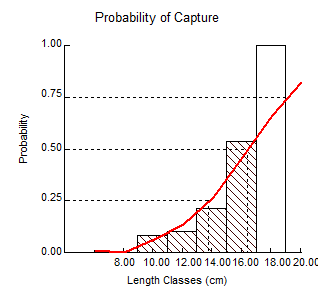


Fig. (6): The probability of capture of *S. schall* in Roseries reservoir obtained from the selective curve.

The relative yield per recruit 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 E01, and E05 was 0.304 – 0.272. While an exploitation rate (E) and maximum exploitation (E*max*) were recorded at 0.28 and 0.409, respectively (Table 3 & Fig. 7). Additionally, the length at optimum cohort biomass (*Lopt*), and length of first maturity (*Lm50*) was determined to be 26.5 cm, and 13.003 cm, respectively (Table, 3).

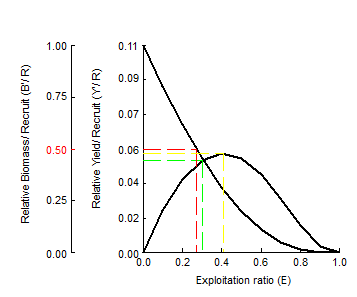


Fig. (7): Beverton and Holt's relative yield per recruitment (Y/R) and biomass per recruit (B/R) for the *S. schall* in Roseires reservoir.

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 18-24 cm. The highest abundance was less than 10 cm (indicated by striped green) and progressively declined with age. Natural mortality was notably high among smaller fish (violet shading), while fishing mortality began at 8 cm, peaking at 19.4 cm (red line) as shown in Fig. (8).

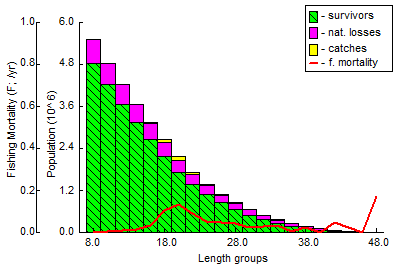


Fig. (8): Length-structured virtual population analysis (VPA) of *S. schall* in Roseires Reservoir, showing survival (green), natural mortality (purple), and fishing mortality (yellow).

Table (3): bio-parameters of *S. schall* in Roseries reservoir.

|  |  |  |  |
| --- | --- | --- | --- |
| Parameter | Value | Parameter | Value |
| *L∞* (cm) | 50.4 | E | 0.28 |
| *K* (yr.-1) | 0.17 | E01 | 0.304 |
| *t0* (yr.-1) | -0.063 | E05 | 0.272 |
| Z (yr.-1) | 0.63 | E*max* | 0.409 |
| M (yr.-1) | 0.46 | *L*25 | 13.78 |
| F (yr.-1) | 0.17 | *L*50 | 16.39 |
| Phi (Փ') | 2.635 | *L*75 | 19.01 |
| T*max* | 17.58 | *Lopt* | 26.5 |
| F*max* | 0.307 | *Lc* | 8.5 |
| F*limit* | 0.120 | *Lc*/*L∞* | 0.001 |
| F*opt* | 0.184 | *M*/*K* | 1 |
| *t*m50 (yr. -1) | 2.25 | *Lm* (cm) | 13.003 |

**Discussion**:

In the present study, the total length (TL) of S. schall range between 8.5 cm and 47 cm, with a mean length of 20.176 ± 5.417 cm (Fig. 1). These findings differ from those of Adam *et. al*., (2025), who reported a different length distribution for the same species (17.5 – 32.5 cm) in the Upper Atbara and Setit Dam Complex (Sudan), These differences in length distribution may be attributed to fishing practice, and gears selectivity.

The length-weight relationship of S. schall exhibited a negative allometric growth pattern (*b* = 2.193), with a moderate correlation coefficient (*r* = 0.764) as shown in Fig. (2). These results agree with previous studies by Adam *et. al*., (2025), Adam and Hamad (2021), Lalèyè *et. al*., (2006), Akombo *et. al*., (2014), Hamid *et. al*., (2024), and Ahmed *et. al*., (2017), who also documented negative allometric growth for S. schall in the Upper Atbara and Setit Dam Complex (Sudan), Ouémé River (Nigeria), river Benue at Makurdi (Benin), and Roseries reservoir (Sudan).

In the current study, Growth parameters derived from the von Bertalanffy growth equation revealed an asymptotic length (*L*∞) of 50.4 cm, growth curvature (*K*) of 0.17 yr⁻¹, and theoretical age at zero length (*t*0) of -0.063 yr⁻¹ (Fig. 3 & Table 3). These values were higher than those reported by Adam *et. al*., (2025) for S. schall in the Upper Atbara and Setit Dam Complex (Sudan), where *L*∞ was 36.75 cm, *K* was 0.78 yr⁻¹, and *t*0 was -0.712 yr⁻¹. Similarly, Mehanna (2022) recorded a lower *L*∞ (42.25 cm), higher *K* (0.42 yr.⁻¹), and *t*0 (-0.36 yr⁻¹) for the same species. Terhemen *et. al*., (2017) estimated *L*∞ for S. schall in the lower River Benue (Nigeria) using multiple methods, ranging from 30.11 cm to 37.06 cm; however, Akombo *et. al*., (2021) studied five Synodontis species in the lower River Benue, reporting *L*∞ values between 18.80 cm and 37.04 cm, with varying *t*0 and *K* values among species. Earlier, 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, with positive *t*0 values. These differences may be referring to differences in geographical location, fishing methods, food availability, and conservation practices.

Conversely, our findings were lower than those of El-Kasheif *et. al*., (2012), who reported *L*∞ values of 62.74 cm (males), 64.24 cm (females), and 63.45 cm (combined sexes), with *K* values of 0.1243 yr⁻¹, 0.1198 yr⁻¹, and 0.1270 yr⁻¹, respectively. The *t*0 values also varied, being negative for males (-1.0657 yr.⁻¹) and females (-1.0732 yr⁻¹) but positive for combined sexes (0.9729 yr.⁻¹). These differences may be due to variations in catch practices and gear selectivity.

In this study, the obtained growth performance index (Փ′) was 2.635, and longevity (T*max*) was estimated at 17.58 years (Fig. 3 & Table 3). These findings contrast with Adam *et. al*., (2025) who reported a higher Փ′ (3.023) but lower T*max* (3.13 years) for S. schall in the Upper Atbara and Setit Dam Complex (Sudan). Akombo *et. al*., (2021) documented a growth performance index for combined sexes of S. schall (Փ′ of 2.946). Moreover, Terhemen *et. al*., (2017), who reported a longevity of 3+ years in the lower River Benue (Nigeria), and Mehanna (2022), who recorded a lifespan of 4 years (Փ′ = 2.87). While El-Kasheif *et. al*., (2012) noted a maximum lifespan of 6 years, Hence, Halim and Guma (1989) reported up to 5 years. These variations may result from differences in environmental conditions, fishing pressure, and habitat characteristics.

In the current investigation, the estimated length at first maturity (*Lm50*) was 13.003 cm, corresponding to an age at first maturity (*t*m50) of 2.25 years (Table 3). These results slightly align with Adam *et. al*., (2025), who reported *Lm50* = 13.65 cm. However, Mehanna (2022) found higher values (*Lm* = 24.1 cm, *Lc* = 23.6 cm), suggesting selective fishing pressure on smaller individuals. El-Kasheif *et. al.*, (2012) reported even higher first maturity and capture lengths (31 cm and 28 cm, respectively), likely due to regional differences in fishing regulations and stock conditions.

In this investigation, total mortality (Z = 0.63 yr⁻¹), natural mortality (M = 0.46 yr⁻¹), and fishing mortality (F = 0.17 yr⁻¹) were recorded, with an exploitation rate (E) of 0.28 (Fig. 4 & Table 3). These values were lower than those reported by Adam *et. al*., (2025) (Z = 2.09 yr⁻¹, M = 1.39 yr⁻¹, F = 0.7 yr⁻¹, E = 0.34 yr⁻¹). Akombo *et. al*., (2021) found varying mortality rates among *Synodontis* species, with higher fishing mortality in *S. membranaceus* (3.0934 yr⁻¹) compared to *S. schall*. Akombo *et. al*., (2017) reported elevated fishing mortalities for *S. schall* (2.203–2.360 yr⁻¹), exceeding natural mortalities (1.045–1.235 yr⁻¹). In contrast, El-Kasheif *et. al*., (2012) documented lower mortality rates (Z = 0.59 yr⁻¹, M = 0.35 yr⁻¹, F = 0.25 yr⁻¹), possibly due to reduced fishing pressure.

In the present study, recruitment analysis indicated continuous recruitment (Fig. 5), consistent with Akombo *et. al.,* (2017), who observed two annual pulses. However, Adam *et. al*., (2025) reported two distinct recruitment periods, suggesting seasonal spawning variations.

In the current investigation, the probability of capture at *L*25, *L*50, and *L*75 was 13.78 cm, 16.39 cm, and 19.01 cm, respectively, with first catch length (*Lc*) at 8.5 cm (Fig. 6 & Table 3). These findings agree with Adam *et. al*., (2025) but contrast with Mehanna (2022) (*Lc* = 23.6 cm) and El-Kasheif *et. al*., (2012) (*Lc* = 28 cm), reflecting differences in fishery management and gear selectivity.

In the present investigation, the relative yield per recruit (Y/R) and biomass per recruit (B/R) analysis showed Y/R = 0.06 at E01, with E05 ranging from 0.272–0.304 (Table 3 & Fig. 7). The current exploitation rate (E = 0.28) was below the maximum (E*max* = 0.409), indicating under-fishing. These results were lower than those of Adam *et. al.*, (2025) (E*opt* = 0.5). Mehanna (2022) reported higher exploitation (E = 0.56), while Akombo *et. al*., (2017) found even greater ratios (0.64–0.69), suggesting overfishing risks in some regions. El-Kasheif *et. al*., (2012) recorded an exploitation rate of 41%, further highlighting regional variability.

In the present study, the theoretical maximum effort (F*max*), absolute higher limit to avoid overfished (F*limit*), and target for sustainable yield (F*opt*) were 0.307, 0.120, and 0.184, respectively. The obtained results appear lower than Adam *et. al*., (2025) (F*max* = 0.923, F*limit* = 0.730, F*opt* = 0.554). These differences may reflect varying fishery management strategies and stock conditions.

**Conclusion**:

*Synodontis schall* exhibited moderate growth and high natural mortality, with low productivity potential. The low catch-to-stock ratio suggests a need for careful monitoring and management to ensure that fishing practices do not compromise the long-term viability of *S. schall* in the Roseries Reservoir. Implementing measures to protect smaller fish and optimize exploitation rates will be crucial for maintaining healthy stock levels in the future.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, manuscript.

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