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Stock Assessment of *Oreochromis niloticus* (Nile tilapia) from a Tropical Reservoir

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ABSTRACT

Artisanal fisheries in reservoirs sustain livelihoods and employment in developing countries like Nigeria, where fish is a primary source of animal protein. Using length composition data, a study on aspects of the stock status of the commercially important *Oreochromis niloticus* in Asejire Reservoir, Southwestern Nigeria, was conducted to promote the sustainability of both the species' benefits and the reservoir's ecosystem functions. A random sample of *O. niloticus* was collected each month from January to December 2023. The Total Length (TL) of each fish was measured in centimeters. Monthly length-frequency data were then analyzed using the TropFishR package within the RStudio environment. *Oreochromis niloticus* (n = 465) ranged from 6.0 to 26.5 cm TL, (16.38 ± 3.8 cm), and exhibited a length-frequency distribution with three modes at 10.2 cm, 14.4 cm, and 19.3 cm, corresponding to age groups 0^+, 1^+, and 2^+ years, respectively. The species exhibited a moderate growth rate (K = 0.75) influenced by seasonal variations (seasonal coefficient C > 0.5), reaching an asymptotic total length (L_∞) of 32.18 cm and a lifespan of 3 years. Estimated lower natural mortality rate (1.06 $year^{-1}$) than fishing mortality (2.56 $year^{-1}$) coupled with an exploitation rate that surpassed the optimum level of 0.5 confirming overexploitation of the species in the reservoir. An exploitation status exceeding the optimum threshold and fishing mortality surpassing natural mortality indicate that the *Oreochromis niloticus* stock is susceptible to overfishing, emphasizing the necessity for targeted conservation and management efforts for the species in the reservoir.

Key Words: Growth, Mortality, Stock status, Size composition, Nile tilapia, Asejire Reservoir.

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INTRODUCTION

Reservoir fisheries exhibit distinctive attributes that are different from those observed in diverse sectors within the fishing industry, with a notable illustration of the predominance of artisanal practices therein (Welcomme, 2001). Artisanal fisheries, particularly in reservoirs of developing countries, play a crucial role in food security, livelihood, and local economies (Novaes et al., 2013, Cintra et al., 2016, De-Almeida et al., 2018, Nogueira et al., 2018, Abache and Owusu-Frimpong, 2019). The global construction of reservoirs has been extensive, with the total area covered by reservoirs worldwide surpassing 400,000 km2 (Avakyan and Iakovleva, 1998), particularly in tropical regions where they significantly contribute to sustaining productive fisheries (Oglesby, 1985, Fernando and Juraj, 1991; Katre et al., 2004). Apart from industrial fishing and aquaculture ventures, most of the fish supply in Nigeria is sourced from artisanal subsector, comprising reservoirs, inland rivers, lakes, and costal and brackish water (Otubusin, 2011). Artisanal fisheries in developing nations, including those in Nigerian reservoirs, provide a cost-effective source of protein for local populations. These fisheries also serve as a vital source of livelihood, income, and employment opportunities for indigenous households. Participation in these fisheries displays a gender bias, where men are typically involved in fishing activities, while women dominate post-harvest enterprises (Abache and Owusu-Frimpong, 2019). This division of labour shows the socio-economic significance of artisanal fisheries.

Notwithstanding the inherent potential and existing

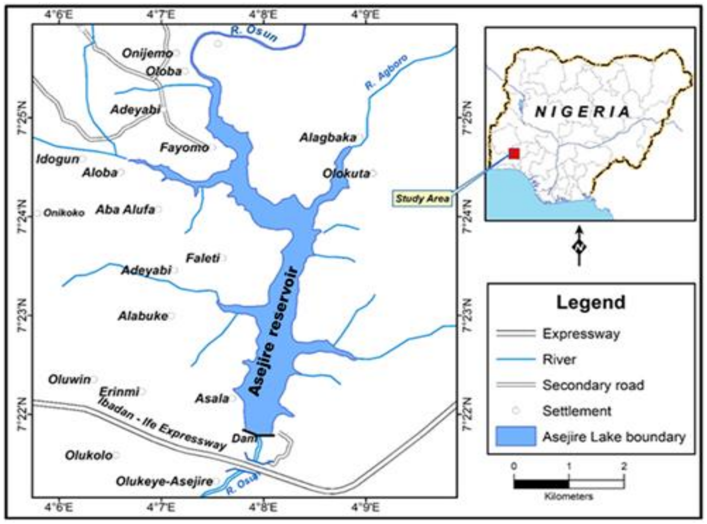

Figure 1: Study site showing Asejire reservoir.

contributions of artisanal fisheries within Nigerian reservoirs, their sustainability is imperiled by some factors, such as the overexploitation of natural stocks, environmental fluctuations, seasonal variability, and deficiencies in fishing regulations, exacerbated by the implementation of destructive artisanal methods by fishers (Chilaka et al., 2014; Sogbesan and Kwaji, 2018). Environmental changes and human interventions, such as reservoir management can threaten fishery resources, affect fish stocks and impact local economies (Abache and Owusu-Frimpong, 2019). Additionally, the use of different fishing gear types and seasonal variations can influence fishery production in reservoirs. This shows the importance of location and gear selection in determining catch rates and economic benefits (Philippsen et al., 2019). Sustainable management practices and participative approaches are essential to maintain valuable fish stocks and ensure the economic viability of artisanal fisheries in reservoirs.

Stock assessment methodologies have garnered recognition as viable mechanisms for discerning optimal fishing strategies (Cadrin and Dickey-Collas, 2014, Fisch et al., 2021; Lancker et al., 2023). However, traditional age-based stock assessment methods, ideal for temperate species, are unsuitable for tropical regions because of the challenges posed by species with indeterminate fecundity and complex spawning behaviors, which are common in the tropics (Lachica, 2017). Limited data availability and a lack of detailed fishery-independent information hinder the application of advanced stock assessment methods in tropical regions (Kumar et al., 2022). Also, reliance on age-structured catch data and the assumption of in variant annual number of batches across age groups can lead to over estimation of biological reference points used for setting harvest rates, especially in species where spawning frequency and duration increase with age or size (Lancker et al., 2023). Nevertheless, with a focus on addressing localized and species-specific management needs, length-based approaches like length-based Bayesian Biomass and length-based stock assessment can be more suitable for data-poor tropical fisheries, providing insights into stock status and abundance despite the lack of detailed time-series catch and effort data (Van Beveren et al., 2019). In the absence of age composition data-controlled experiments and tagging data, length composition data are usually applied to estimate stock status and population dynamics, especially in tropical fisheries (Sparre and Venema, 1998). This study aims to evaluate the population dynamics of the Nile tilapia, *Oreochromis niloticus* stock, utilizing length-frequency distribution data. It focuses on estimating critical parameters, including growth and mortality rates of the species to enhance sustainable fisheries management practices within the Asejire reservoir. This study is predicated on the hypothesis that randomly sampled length-frequency distribution of the fish populations accurately reflects the overall population structure, allowing for reliable estimation of growth and mortality rates of the population. Specifically, it is hypothesized that the observed length distributions will align with predicted patterns based on established von Bertalanffy growth models and that variations in length frequencies over time will indicate significant changes in recruitment and mortality rates.

MATERIALS AND METHODS

The study area

The freshwater reservoir selected for this study is the Asejire Reservoir (Figure 1), located at the geographical coordinates of 07º 21′N latitude and 04º 07′E longitude, within 30 km East of Ibadan, Oyo State of Nigeria. Covering a surface area of 525 ha and at an elevation of 137m above sea level, the Asejire Reservoir was constructed on the Oshun River in 1970 in the Egbeda Local Government Area of Oyo State, Southwestern Nigeria. It was constructed primarily for domestic purposes with a capacity of approximately 80 million litres of water per day (Ipinmoroti. and Iyiola, 2023). Besides providing raw water to the Asejire and Osegere water treatment plants in Ibadan, the reservoir supports thriving artisanal fisheries that are vital to the local communities, comprising twenty-four species belonging to 10 families: Cichlidae, Claroteidae, Latidae, Schilbeidae, Alestidae, Hepsetidae, Mochokidae, Cyprinidae, Mormyridae, and Channidae, with Cichlidae (66.82%) being the most abundant family, represented by four species: *Coptodon marie*, *Coptodon zillii*, *Sarotherodon galilaeus* and *Oreochromis niloticus* in the reservoir (Ayoade and Fagade, 2006).

Measurements of biometric data

Total length (TL), taken as the distance from the anterior-most part of the fish to the tip of the longest caudal-fin ray when the caudal fin is compressed, of randomly sampled *Oreochromis niloticus* was measured using a fish measuring board graduated in centimeters at the Asejire Reservoir landing site. Fish were captured using monofilament gillnets with stretched mesh sizes ranging from 16 to 20 mm. Sampling was conducted monthly from January to December 2023 encompassing both the dry and wet seasons. Individual species were identified by the presence of regular vertical stripes on their caudal fins (Olaosebikan and Raji, 2013).

Estimation of stock parameters

Designation of cohorts from raw length-frequency composition data:

Cohorts were identified based on raw length frequency data by visualizing the monthly length data through frequency histograms. Various modes representing cohorts (corresponding to age in years) were validated using a density plot. Add citation

Growth parameters

The growth of *O. niloticus* was modeled according to the seasonally oscillating von Bertalanffy growth function described by Somer (1988) as:

$$L_t = L_\infty[1-(\exp - K(t-t_o)+s(t)-s(t_o))] \quad (1)$$

where L_t is the length of the fish at age t, L_∞ is the asymptotic length (size or maximum length of the average at which growth is zero), K is the growth coefficient, and t_0 is the theoretical age at length zero (now t_{anchor}). In addition, s(t) = (CK/2π) sin 2π (t - ts), where C is the intensity of the sinusoidal oscillation, which normally ranges from 0 to 1 (C value greater than 1 suggests periods of shrinkage in size dimension), and the summer point (ts) is the fraction of a year, relative to the age of recruitment where the sine wave oscillation begins. The seasonalized parameters for the von Bertalanffy Growth Function for the species were estimated using Electronic Length Frequency Analysis (ELEFAN) optimized by genetic algorithms (ELEFAN G.A) (Taylor and Mildenberger, 2017, Mildenberger et al., 2017). The Electronic Length Frequency Analysis allows the estimation of growth parameters from length-frequency composition data by restructuring the data and fitting growth curves through the restructured monthly length-frequency data. Uncertainties in the growth parameter estimates were computed using the jackknife technique which allows the estimation of a confidence interval around the seasonalized von Bertlanffy growth model (soVBGF) parameters (Turkey, 1958).

Life span of the species

Longevity (T_{max}) of the species was estimated using the formula proposed by Pauly (1983) as follows:

$$\text{tmax} = \frac{3}{K} + t_o \quad (2)$$

Where K is the growth coefficient and t_o is the hypothetical age at length zero.

Growth performance index

The growth performance index (Φ′, phi-prime) of the species was calculated based on Munro and Pauly (1983):

$$\Phi' = Log\ (K) + 2 * Log\ (L_\infty) \quad (3)$$

Mortality parameters

The total mortality (Z) of the Nile tilapia population and associated age at first capture were estimated using the length-converted catch curve (Munro, 1984), while the instantaneous natural mortality (M) was estimated from Pauly's empirical equation (Pauly, 1980), given as:

$$Log\ (M) = -0.0066 - 0.279 * Log\ (L_\infty) + 0.6543 * Log\ (K) + 0.4634 * Log\ (T) \quad (5)$$

Thereafter, fishing mortality (F) was obtained based on the empirical relationship (Gulland, 1971).

Table 1: Descriptive statistics of Oreochromis niloticus' total length from Asejire reservoir.

		Total length (cm)				
Months in 2023 year	n	Min	Max	Mean ± SD	95% CL	CV
January	33	12.70	21.60	17.29 ± 2.57	16.38 to 18.21	15.00%
February	40	11.90	19.50	14.73 ± 2.43	13.95 to 15.51	17.00%
March	39	9.20	17.50	13.03 ± 2.37	12.27 to13.81	18.00%
April	38	9.80	15.60	12.11 ± 2.05	11.44 to 12.79	17.00%
May	45	18.10	26.40	22.04 ± 2.08	21.42 to 22.67	9.00%
June	38	14.90	22.20	18.15 ± 1.83	17.55 to 18.75	10.00%
July	40	12.00	21.70	16.49 ± 2.06	15.83 to 17.15	13.00%
August	41	12.20	21.20	16.29 ± 2.76	15.42 to 17.16	17.00%
September	33	8.50	23.30	17.90 + 3.40	16.70 to 19.11	19.00%
October	28	8.10	23.30	17.56 ± 3.14	16.34 to18.78	18.00%
November	34	8.50	26.50	16.45 ± 4.07	15.04 to17.88	25.00%
December	56	6.00	23.50	14.95 ± 3.88	13.91 to 15.99	26.00%

Notes: n, sample size; Min: minimum; Max: maximum; SD: standard deviation; CL: confidence limit; CV: coefficient of variation.

$$Z = M + F$$

Stock Status

The level of exploitation (E) of the species fishery was calculated by the equation: E = F/Z {34}

Data analyses

Statistical analyses were performed using R version 4.3.3 within the RStudio environment, version 12.1. The raw total length-frequency data were subjected to descriptive statistical analysis and visualized through frequency histograms and density plots utilizing the "ggplot2" package. The length-frequency data were categorized into 32 length classes with a bin size of 1 cm, encompassing 12 sampling dates throughout 2023. Reconstructed length-frequency distributions, seasonalized von Bertalanffy growth parameters, mortality estimates, stock status concerning exploitation levels, and cohort analysis were implemented using the TropfishR package.

RESULTS

Population size structure and distribution

The size distribution of Nile tilapia (*Oreochromis niloticus)* is as follows: Sample size: 465 individuals; Total Length Range (TL): 6.0 to 26.5 cm; annual mean total length (TL): 16.28; 95% confidence interval: [16.04, 16.73] (Table 1). Noteworthy fluctuations in the average TL were observed across months, particularly pronounced in November and December 2023, as indicated by the coefficient of variability (Table 1). The length-frequency distribution exhibited three modes at mean lengths of 10.2, 14.4, and 19.3 cm, corresponding to age groups 0^+, 1^+, and 2^+ years, respectively (Figure 2). In addition, the length-frequency distribution of *O. niloticus* in Asejire Reservoir approximates normality.

Seasonal Oscillatory von Bertalanffy Growth parameters

Nile tilapia in Asejire Reservoir exhibited moderate growth (K = 0.75), which was influenced by season, indicated by a seasonal coefficient of (C) = 0.56. The species reached an asymptotic TL ($L\infty$) of 32.18 cm. Figure 3 shows the graphical fit of the estimated growth curves overlaid on the reconstructed length-frequency data. A growth performance index (Φ′) of 2.81 was estimated for the species with a life span of two years.

Stock status: Mortality and Exploitation rates

The total mortality (Z) and age at first capture (t_{50}) for the population of Nile tilapia in Asejire Reservoir were 3.62 year−1 and 0.9 years, respectively (Figure 4); age at first capture corresponds to 16 cm. The estimated natural mortality (M) for the species of 1.06 per year was less than fishing mortality (F) of 2.56 year−1, indicating overfishing. In addition, the exploitation rate (E) value of 0.71 exceeded the optimum value of 0.5, which is also suggestive of overfishing.
The selectivity function of the length-converted catch curve estimated a length at 50% probability of capture (L_{50}) of 16.06 cm

DISCUSSION

In Asejire Reservoir, we found that the Nile tilapia's population comprised three size groups, with the oldest cohorts aged 2. These findings reveal the population structure of the fish stock, unveiling the latent interplay

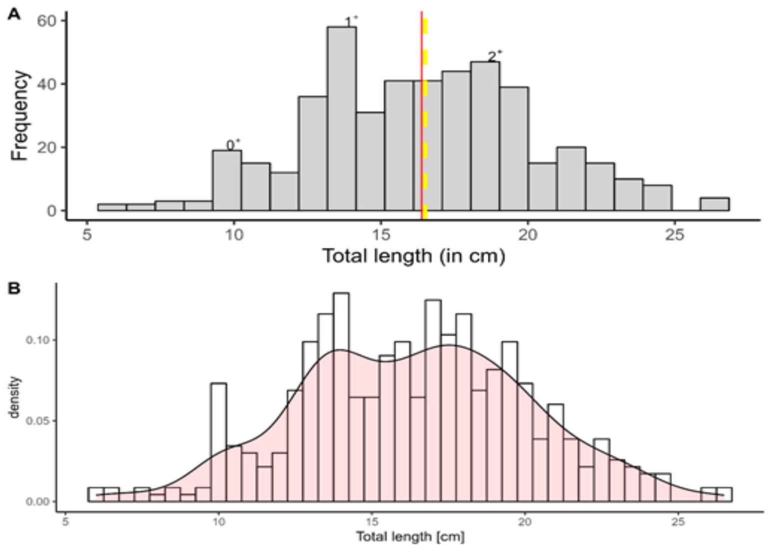

Figure 2: Length-frequency distribution for the Nile tilapia, *Oreochromis niloticus* from Asejire reservoir. (A) shows length frequency histograms for the stock of the Nile tilapia sourced from Asejire reservoir, overlaid with a vertical red line indicating the mean length and yellow-dashed line indicating median length as well as designation of ages (in years) by numbers (0^+, 1^+ and 2^+). (B) shows density plot, exhibiting three prominent modes suggesting three cohorts with fewer individuals as fish get larger.

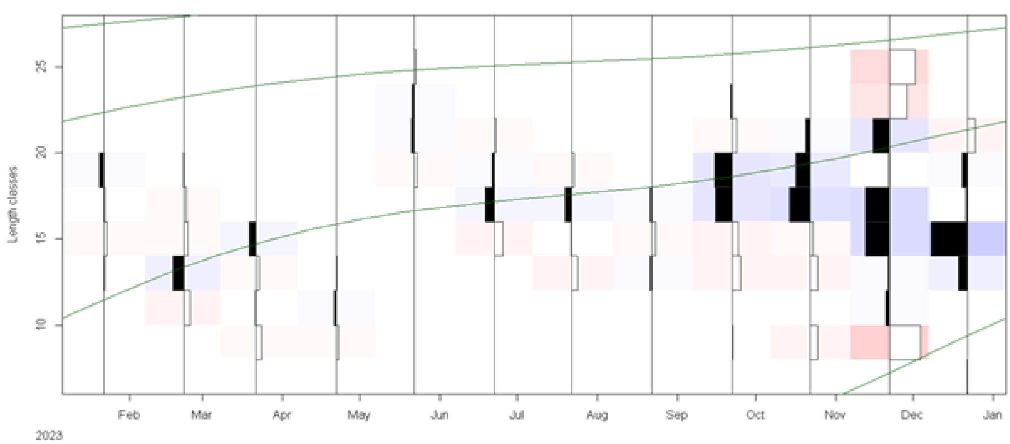

Figure 3: Graphical fit of estimated growth curves plotted through the length frequency data. The growth curves with green curves represent the curves of ELEFAN_GA.

between recruitment, growth, and mortality rates. This was possibly caused by the periodic influx of new individuals into a population, known as recruitment, which is responsible for the fluctuations observed in length-frequency data. Recruitment is characterized by peaks and troughs of the fish stock in the Asejire Reservoir, which is common in the tropics, where two or more recruitment pulses occur per year (Gulland, 1969). This population structure is characterised by an immature cohort comprising more than 60% of the total catch-age 0.9 years, with an average body size of 16 cm which paralleled the average annual size.

The preponderance of immature cohorts underscores the urgent need for revised fisheries management policies, including stricter catch limits, to ensure the recovery and long-term health of Nile tilapia populations in Asejire reservoir. Our observations of annual fish length can be used to achieve management goals through the use of size limits. Although individuals within the same population can show considerable variation in the length reached at a given age, mean growth is often adequate to describe the characteristics of a fish population (Pilling et al., 2002). The annual mean length of fish plays a crucial role in the development and

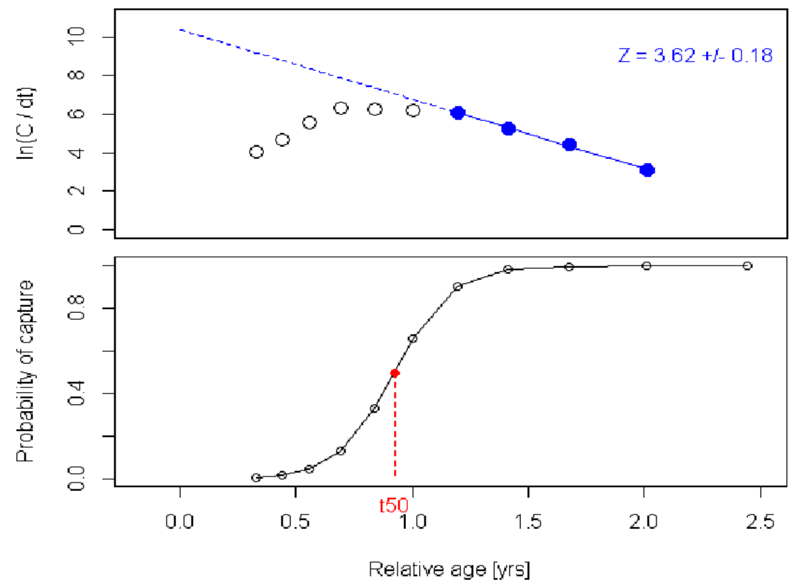

Figure 4: Length-converted catch curve of *Oreochromis niloticus* sampled from Asejire reservoir, indicating the value of total mortaliyt (Z) and mean age at first capture (t_{50}).

implementation of minimum legal-size regulations that help to balance conservation and fishery objectives by maximizing biomass yield, and also maintaining natural age structures and biomass of the spawning stock biomass (Stewart, 2008). These regulations are essential in fisheries to limit overfishing and improve fishing quality by increasing the average size of fish caught (Daniel et al., 2015). By setting a minimum legal size, fishermen can protect juvenile fish, govern the sizes of the fish caught, and maintain spawning stocks for future generations (Frances et al., 1989; Takar and Gurjar, 2020). Methods using length-frequency data to infer the growth pattern of fish assume that the component of the distribution is normally distributed, an assumption underlying length-frequency models that was satisfied by our dataset because the value of the annual average body size approximates the median value of 16.50 cm (Figure 2). The absence of individuals smaller than 6.0 cm and above 26.5 cm TL may be attributed to the selectivity of fishing gear used in the present study.

The Nile tilapia that inhabited Asejire Reservoir exhibited moderate growth (K = 0.75). The growth was impacted by season (C = 0.56), and the species reached an asymptotic TL (L_∞) of 32.18 cm. According to Sparre and Venema , a K value of 1.0 is characteristic of species exhibiting rapid growth, a K value of 0.5 denotes medium growth, and a K value of 0.2 corresponds to slow-growing species. The growth performance index (Φ') of 2.81 estimated for the species indicated multiple spawning patterns within a year (Assefa et al., 2019). A lifespan of three years was estimated for the species. Our study showed strong support for seasonal growth oscillations: parameter C quantifies the magnitude of the seasonal fluctuation in growth, and a value of C equal to zero indicates the absence of seasonal variation, rendering the equation equivalent to the von Bertalanffy model (Taylor and Mildenberger, 2007). Similar to temperate species, seasonal oscillations in growth can also occur in tropical fish. Tropical freshwater fishes, including *O. niloticus*, exhibit seasonal oscillations in growth caused by environmental conditions, such as seasonal changes in water temperature. Seasonal oscillations of growth in freshwater fish may also be due to the alternation of floods caused by rainy and dry seasons. This study makes a noteworthy impact by shedding light on seasonal growth rhythms in tropical fish species from a developing country. It is widely known that certain environmental factors trigger seasonal growth in fish species. However, most tropical fish stock assessments do not consider seasonal changes. This is partly due to the misconception that fish in tropical areas always grow uniformly. Although there is a paucity of seasonalized von Bertalanffy growth parameters for Oreochromis niloticus, several studies have reported these parameters for non-seasonal forms. In Lake Manzala, southwestern Egypt, the parameters were estimated as asymptotic length, L_∞=34.51 cm and the growth coefficient, K=0.38 yr^{-1}K = (Sahar et al., 2020). For *Oreochromis niloticus* in the Lake Tana region (northwest Ethiopia), the von Bertalanffy growth parameters were reported as L_∞=44.1 cm and K=0.44 yr^{-1} (Assefa et al., 2019). The estimated asymptotic lengths are comparable to the findings of this study, but there are differences in the estimated growth coefficients.

The results of this study showed that Nile tilapia was overexploited in Asejire Reservoir as the fishing mortality (F) rate was greater than the natural mortality (M) rate. According to Munro (1984), the natural mortality rate is directly related to the lifespan of a species. Long-lived species with lifespans of 15 or more years have relatively low natural mortality rates (M≤0.2). Short-lived species, with life spans of 5 years or less, have relatively high natural mortality rates (M≥0.7), confirming that the species is short-lived in life with a longevity estimate of 3 years for the species.

For the present dataset, the exploitation rate is equal to 0.71, indicating overfishing (Gulland, 1969). An exploitation rate of 0.7 for a fish stock is considered significantly high, indicating that 70% of the fishable biomass is harvested annually through fishing activities. This elevated exploitation rate is often associated with overfishing, in which the removal rate exceeds the natural replenishment capacity of the fish population. Such practices can lead to a rapid depletion of fish stocks, potentially resulting in population collapse if not effectively managed. Sustainable fisheries management typically advocates lower exploitation rates to maintain the health and stability of fish populations, thus ensuring their long-term sustainability. To address the risks posed by an exploitation rate of 0.7, it is imperative to implement stricter fishing regulations, improve stock assessments, and promote conservation measures to maintain fishery productivity and ecological balance.

Conclusion and Recommendation

Nile tilapia stock is at risk of being overfished in Asejire Reservoir because the exploitation level of the fish stock is beyond the sustainable level. Additionally, fishing mortality is outpaced by natural mortality, indicating overfishing. Thus, it is critical to implement direct management and conservation initiatives to safeguard this fish stock in the reservoir. Fish in tropical regions experience seasonal growth due to environmental changes; however, many assessments ignore seasonal oscillations in growth parameters. Information on seasonal oscillatory growth is an important contribution of this study. Artisanal fisheries in Nigerian reservoirs are data-limited, and reliable age information for the stock assessment remains scare. However, length data are widely collected and are much more readily available for data-poor stocks. Utilizing length-based stock assessment models to obtain useful aspects of species stock assessments could provide informed decisions for the management of fish stocks. To mitigate the overfishing of this Oreochromis niloticus in Asejire Reservoir, it is advisable to establish catch limits informed by sustainable yield estimates and to enforce seasonal fishing restrictions during essential growth and reproductive phases. Regulations concerning size should be instituted to safeguard juvenile and mature breeding individuals, alongside measures to control fishing efforts through the limitation of fishing days, gear restrictions, and permit requirements. A comprehensive monitoring program is essential for the ongoing evaluation of fish population dynamics, thereby facilitating adaptive management strategies. Furthermore, involving local communities in co-management practices and offering education on sustainable fishing techniques are vital for fostering compliance and garnering support for conservation initiatives.

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