Limnology and Freshwater Biology 2025 (5): 1102-1109 DOI:10.31951/2658-3518-2025-A-5-1102

Original Article

LIMNOLOGY FRESHWATER BIOLOGY

Assessing the sustainability and management implications of Nile Tilapia, *Oreochromis niloticus* (Pisces: Cichlidae; Linnaeus 1758)

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ABSTRACT. The Nile tilapia (*Oreochromis niloticus*) was introduced into the Al Massira Dam Lake with the aim of developing profitable fisheries, as a commercially significant species for local populations. However, the stocks of this species have declined in this reservoir due to overfishing pressure, ecological variations, and the effect of other invasive fish species. An assessment of the population dynamics of this species is necessary to develop appropriate fisheries management. This research aimed to determine the state of Nile tilapia stock applying length-based data-limited methods. The von Bertalanffy growth model served to evaluate the sustainability of fisheries. The annual total mortality (Z) and natural mortality (M) rates were determined as respectively 1.79 year^{-1} and 0.67 year^{-1}. The calculated fishing mortality rate (F = 1.12 year^{-1}) exceeds of the maximum sustainable yield (F_{max} = 1.06 year^{-1}), representing the fishing mortality rate ensuring maximum production of equilibrium recruits. Additionally, the current exploitation rate is 0.63, above the reference level (E > 0.5), implying that the Nile tilapia stock in the Al Massira Dam Lake is subject to fishing pressure. Therefore, the stock is overexploited, exceeding optimal levels, and is currently in decline. The findings of this study provide valuable new information about the *Oreochromis niloticus* stock, enabling better management efforts. To ensure sustainable exploitation of this species, considered vulnerable in Al Massira Reservoir, it is imperative to reduce unregulated fishing and more effectively control overfishing practices.

Keywords: *Oreochromis niloticus*, Al Massira Dam Lake, stock status, sustainability, exploitation

For citation: Bousseba M., Ferraj L., Droussi M., Hasnaoui M. Assessing the sustainability and management implications of Nile Tilapia, *Oreochromis niloticus* (Pisces: Cichlidae; Linnaeus 1758) // Limnology and Freshwater Biology. 2025. - № 5. - P. 1102-1109. DOI: 10.31951/2658-3518-2025-A-5-1102

1. Introduction

Tilapias, belonging to the cichlid family, are fish originally from the Middle East and Africa. Various tilapia species were successfully introduced into over 90 countries for aquaculture purposes (Casal, 2006). Among them, the Nile tilapia is in the top ten farmed aquatic fish species globally, accounting for over 70% of total tilapia production (Casal, 2006). This species is particularly valued by fish farmers due to its ease of cultivation, rapid growth, and high-quality flesh.

The Nile tilapia (*Oreochromis niloticus*) has been brought to Morocco by the northern-based company 'Pisciculture du Nord' located in Tangier as part of an initiative to promote national aquaculture. Subsequently, the species was released into natural habitats, leading to the establishment of sustainable wild populations (Louizi et al., 2019). Currently, *O. niloticus* has spread to various reservoirs in Morocco, notably Al Kansra, Sidi Mohamed Ben Abdellah, El Hansali and Al Massira reservoirs (Ainou et al., 2021).

As an invasive species, *O. niloticus* causes social, economic, and environmental impacts (Vicente and Fonseca-Alves, 2013). However, the introduction of Nile tilapia has been beneficial in several pays, providing protein, improving the living conditions of local populations, and contributing to job creation in rural areas. Nevertheless, it is essential to establish rigorous management of this species' stocks to prevent long-term negative consequences. Poor management of fishery resources, particularly commercially important species, can lead to stock collapses, thereby jeopardizing food security and fishing activities (Worm et al., 2006). Implementing reliable stock assessments provides cru-

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Received: June 15, 2025; ***Accepted:*** September 29, 2025; ***Available online:*** October 31, 2025

cial information for diagnosing population status and developing sustainable management strategies (Ecoutin et al., 2005). Traditional stock assessment approaches rely on data relating to catch and fishing effort.

These approaches require a large amount of data (Shi and Chen, 2019), often including time series of catches, information on length-weight relationships, age structure, relative or absolute population density, gonadal maturity, and detailed life cycle data (Methot and Wetzel, 2013). Due to this data requirement, in recent decades, length-based approaches have been developed as alternatives for assessing the status of stocks of data-limited fisheries (Costello et al., 2012). In many cases, these approaches have proved to be more effective than certain models based on captures (Pons et al., 2019) and have been effectively used in data-limited fisheries across the globe (Cope et al., 2023). They offer dependable estimates (Pons et al., 2019; Santos et al., 2023) and assist in improving effective management practices. The application of length-based methods is a valuable asset for the sustainable development of data-limited fisheries (Dowling et al., 2016), thereby aiding in the adoption of precautionary measures grounded in well-informed decisions. This method provides a practical solution for enhancing the management and preservation of fisheries.

This research aimed to supply updated scientific data on the dynamics of population and stock status of *O. niloticus* in the Al Massira Reservoir. It contributes to the sustainable fisheries development and the conservation of aquatic biodiversity in this region. In the absence of prior data in this field, this is the initial attempt of analysing the state of *O. niloticus* population in Morocco using length-based data-limited methods, especially in Al Massira Reservoir. The findings will serve as a robust foundation for evaluating the current state of fish stocks and setting appropriate catch limits.

2. Material and methods

2.1. Study Area

This survey was performed in Al Massira Dam Lake in Morocco (32° 28′ 32″ North and 7° 32′ 15″ West) (Alaoui et al., 2000). Having a storage capacity of 2,800 million m^3, the Al Massira Reservoir ranks as the second-largest reservoir in Morocco. It is built on the mid-section of the Ouadi Oum Er-Rbia, the country's second-longest permanent river (Bounif et al., 2023). Table 1 (Alaoui et al., 2000) summarizes the principal features of the Al Massira Dam Lake.

Table 1. Principal characteritics of Al Massira Reservoir

Parameter	Value
Watershed area	28500 Km^2
Maximum depth	40 m
Maximum width Length	10 Km 30 Km
Normal elevation	285 NGM
Maximum elevation	287,5 NGM
Volume at normal level	2800 10^6 m^3

Note: (*) i.e. + 10m above the bottom of the Lake (230 NGM).

2.2. Data collection

Fish samples from the Al Massira Reservoir were captured by professional fishermen using stretched-mesh gill nets (25–65 mm). During the sampling periods, 975 *O. niloticus* specimens were randomly sampled monthly in commercial fisheries over January to December 2021. Each individual fish was weighed in the laboratory with an electronical balance accurate to 0.1 g to determine its total weight (TW), and its total length (TL) was recorded with a graduated ichthyometer, accurate to 0.1 cm.

2.3. Growth, mortality parameters and exploitation rate

The analysis was conducted on length-frequency monthly data of Nile tilapia obtained through commercial landings. The 'TropFishR' package (Mildenberger et al., 2017) applied the seasonal von Bertalanffy growth formula to estimate the growth parameters by using ELEFAN_GA algorithm (Schwamborn et al., 2019):

$$Lt = L\infty\{1 - e^{-[K(t-t_0)+S(t)-S(t_0)]}\}, \quad (1)$$

where Lt represents the fish length at time t, L∞ denotes the asymptotic length (cm), K is the growth coefficient ($years^{-1}$), and t_0 refers to the theoretical age when the length is equal to zero. Seasonal growth was disregarded in this research to simplify the analysis. Thus, "$+ S(t) - S(t_0)$" in the previous formula was considered equal to 0. In 'TropFishR', the parameter t_0 is substituted with t_{anchor}, indicating the moment in the year when a cohort's growth curve crosses zero length (Taylor and Mildenberger, 2017).

The maximum fish length (Lmax) was determined as the average length of the largest 1% of the sample fish. Subsequently, a first estimate for L∞ was obtained by the following equation (Pauly, 1984):

$$L\infty = L\max/0.95. \quad (2)$$

The growth performance index (∅′) was calculated for comparing the various estimates of growth parameters according the equation below (Pauly and Munro, 1984)

$$\varnothing' = \log_{10} K + 2\log_{10} L\infty. \quad (3)$$

To establish mortality parameters, a linearised length-converted capture curve was generated based on length-frequency data and earlier calculated growth parameters. Thus, the mortality rate (Z) has been derived by the slope of the catch curve's descending section (Pauly, 1983). In view of the significance and complexity of accurately estimating natural mortality rate (M) (Jørgensen and Holt, 2013), an up-to-date version of Pauly's (1980) method, based on a meta-analysis of growth data from several fish species, was applied (Then et al., 2015)

$$M = 4.118 \times K^{0.73} \times L\infty^{-0.333}. \quad (4)$$

The fishing mortality rate (F) is expressed by the formula F = Z – M, and the current exploitation rate (E) was estimated using the F/Z function.

2.4. Yield per recruit model

Biological reference levels have been generated using Thompson and Bell (1934) relative yield-per-recruit (YPR) analysis to determine the optimal yield. These reference points included F_{max} and E_{max} (fishing mortality and exploitation levels representing the optimum yield per recruit), $F_{0.5}$ and $E_{0.5}$ (the points where spawning biomass is halved relative to an unfished population), and $F_{0.1}$ and $E_{0.1}$ (representing 10% of the YPR curve's initial slope).

2.5. Length-weight relationship

The length-weight relationship was evaluated through linear regression analysis. It was determined according to the equation described by Le Cren (1951) to establish if the pattern of growth of the individuals was allometric ($b \neq 3$) or isometric ($b = 3$).

$$TW = aTL^{b}, \tag{5}$$

where a = the intercept and b = the slope of regression line.

The log-transformed relationship ($TW = aTL^{b}$) is expressed by the regression formula:, which defines the a and b coefficients (Zar, 1999).

2.6. Statistical analysis

The 'TropFishR' package (Mildenberger et al., 2017) was applied to determine the stock state of *O. niloticus*. The isometric growth hypothesis (Ricker, 1975) was checked by Student's t-test ($p < 0.05$). The software R-Studio version 4.2.2 was utilised to perform all statistical analysis.

3. Results

In the present study, a total of 975 specimens of the two sexes of *O. niloticus* were sampled and examined between January and December 2021. The total length of the individuals was from 10.5 to 49.0 cm. The total weight varied between 50 to 1005 g. The mean length was estimated at 25.11 cm (± 8.80), and the calculated mean weight was 395.07 g (± 273.03).

The a and b parameters of the LWR were estimated from data on length (TL) and weight (TW) by applying equation (5). The established relationship was $TW = -0.94\ TL^{2.40}$ ($R^2 = 0.94$). The value of b demonstrated a notable deviation from isometric growth (t-test, $p < 0.05$), suggesting that *O. niloticus* displays an allometric negative growth (Table 2).

The growth parameters for *O. niloticus* in the Al Massira Reservoir were $L\infty = 53.92$ cm, $K = 0.24$ year^{-1} et $t_{anchor} = 0.65$. Additionally, the performance index was equal to $\varnothing' = 2.85$, with a high level of model estimation quality (Rn = 0.53).

The total mortality (Z) obtained by converting catch curve into catch length (Fig. 1) was calculated to be 1.79 year^{-1}, and the natural mortality (M) was equal to 0.67 year^{-1}. Thus, the fishing mortality was determined to be 1.12 year^{-1} yielding a current exploitation ratio (E) of 0.63. The length at first capture (*Lc*), derived by the retroprojection of the declining part of the capture curve, was estimated at 13.04 cm. This means that fish in this length class have a 50% chance of being vulnerable to capture under the current gear selectivity scheme.

The graphical visualisation of the YPR model is presented in Fig. 2. The model results indicate that the optimal values for maximizing yield are a maximum fishing mortality (F_{max}) of 1.0 year^{-1} and a maximum exploitation rate (E_{max}) of 0.59. A yield corresponding to 50% of the biomass of the stock could be attained at a rate of $F_{0.5}$ = 0.39 year^{-1} and $E_{0.5}$ = 0.22. Furthermore, to achieve the biologically optimal yield, the recommended values are $F_{0.1}$ = 10.58 year^{-1} and $E_{0.1}$ = 0.32.

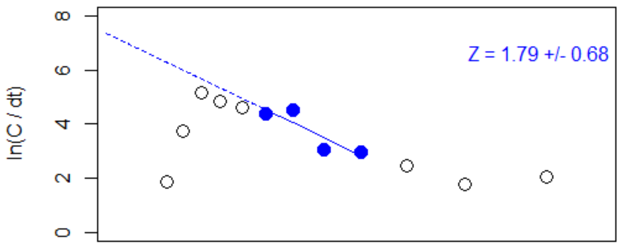

Fig.1. Catch curve based on length data illustrating total mortality rate (Z).

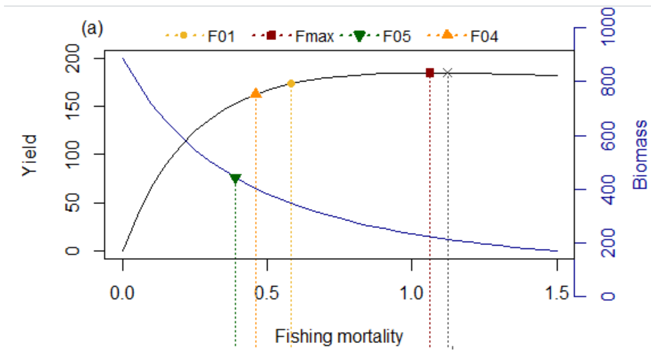

Fig.2. Yield and biomass curve per recruit according to different fishing mortality rates in *O. niloticus*.

Table 2. Length-weight relationships (LWR) of *O. niloticus*

N	*a*	*b*	R^2	*t*-value	*p*-value
975	-0.94	2.40	0.94	36.10	< 2.2e-16***

Note: ***$p < 0.001$

4. Discussion

In Morocco, reservoir fisheries play a major role in the rural economy, providing an accessible source of animal protein for local populations at affordable prices. However, despite their socio-economic importance, these fisheries remain understudied in terms of resource management. This work constitutes the first tentative to assess the population dynamics of *O. niloticus* in Moroccan inland waters, particularly in the Al Massira Reservoir, using methods adapted to limited length-frequency data. These data serve as a basis for assessing stock status and developing sustainable management measures designed to preserve the resource and to guarantee the viability of this essential fishery for rural communities over the long term.

The allometric coefficient *b* of LWR is frequently used to indicate fish growth patterns (Chu et al., 2012). The *b* coefficient for *O. niloticus* in our study was significantly less than 3 ($p < 0.001$), suggesting a negative growth pattern. This indicates that the size of this species increases at a faster rate than its weight. Research carried out by Naeem et al. (2010) in the Indus River (Pakistan), Novaes and Carvalho (2012) in Barra Bonita Reservoir (Brazil), Outa et al. (2014) in Lake Naivasha (Kenya), Abdalla et al. (2020) in Khashm El-Girba Reservoir (Sudan), El-Bokhty and Fetouh (2023) in El-Salam Canal (Egypt), Iyiola et al. (2024) in the Osun River (Nigeria), and Mabika et al. (2024) in Tugwi-Mukosi Reservoir (Zimbabwe) have highlighted negative allometric growth patterns, thus aligning with the findings of our study. However, other studies have highlighted a positive allometric type of growth of *O. niloticus* species in different aquatic zones across various countries (Ojuok et al., 2000; Karrar et al., 2016; Asmamaw et al., 2019; Cuadrado et al., 2019; Mohamed and Al-Wan, 2020; Mabika et al., 2024; Shija, 2024). Additionally, research conducted by El-Bokhty (2006) in Egypt, Kembenya et al. (2014), and Yongo et al. (2018) in Kenya, as well as Reis (2020) in Turkey, revealed isometric allometry for *O. niloticus*. The existence of differences in the values of parameter *b* between various regions may result from several factors, including fish physiology, sexual maturity, sex, temperature, season, growth phase, size range, and sample size, as well as habitat, diet, stomach fullness, and health status (Le Cren, 1951; Froese, 2006; Froese et al., 2011; Mondol et al., 2017).

The estimates of the performance index Ø′ have revealed considerable variation in growth parameters for the population of *O. niloticus* from one geographical area to another (Table 3). Ouattara et al. (2009) in Ivory Coast, Mahmoud et al. (2013) in Egypt, and Amponsah et al. (2020) in Ghana antiquated Ø′ values lower than those obtained in our study. In contrast, other researchers found Ø′ values higher in Bangladesh, Pakistan, and Ethiopia (Ahmed et al., 2003, Mehak et al., 2017; Shija, 2024). Various factors can explain the variations in growth parameters, such as the level of exploitation as well as ecological and environmental differences between regions, including food availability, mortality, and temperature (Torcu-Koc et al., 2004). e fish growth is determined by three factors, namely the biotic environment, the restrictive abiotic environment it experiences, and its genetic composition (Martino et al., 2019). Length-based growth parameters can also be considerably affected by the ecosystem's productivity (Gulland, 1971; Ault et al., 2008) and the selectivity of fisheries (Herrón et al., 2018).

The estimated total and fishing mortality ratios for *O. niloticus* in this study (1.79 $year^{-1}$ and 1.12 $year^{-1}$, respectively) were less than those found by Mehanna et al. (2020) in an earlier study on Lake Manzala ($Z = 2.02$ $year^{-1}$, $F = 1.20$ $year^{-1}$), as well as lower than

Table 3. Von Bertalanffy growth parameters of *O. Niloticus* in diverse geographical regions

Study area	L_∞ (cm)	K ($Year^{-1}$)	Ø′	Author/s
Kaptai Reservoir, Bangladesh	55.59	0.39	3.08	(Ahmed et al., 2003)
Nyanza Gulf of Lake Victoria, Kenya	58.78	0.59	3.31	(Njiru et al., 2007)
Ayamé Reservoir, Ivory Coast	30.7	0.22	2.32	(Ouattara et al., 2009)
Nozha Hydrodrome, Egypt	38.06	0.21	2.49	(Mahmoud et al., 2013)
El-Bahr El-Faraouny Canal, Egypt	37.27	0.29	2.61	(El-Kasheif et al., 2015)
Lac Toho, Benin	41.5	0.30	2.71	(Montcho et al., 2015)
Chashma Reservoir, Pakistan	22.78	0.07	3.56	(Mehak et al., 2017)
Lake Tana, Ethiopia	44.1	0.44	2.93	(Assefa et al., 2019)
Lake Naivasha, Kenya	42	0.21	2.57	(Waithaka et al., 2020)
Halali Reservoir, India	46.73	0.63	3.14	(Johnson et al., 2020)
Garmat Ali River, Iraq	30.49	0.45	2.62	(Salman and Mohamed, 2020)
lagoon Sakumo II, Ghana	19.4	0.54	2.31	(Amponsah et al., 2020)
NamTheun 2 Reservoir, Laos	55.6	0.14	2.63	(Beaune et al., 2021)
Lake Langeno, Ethiopia	35.70	0.32	2.61	(Tesfaye et al., 2022)
Lake Abaya, Ethiopia	49.35	0.36	3.0	(Shija, 2024)
Al Massira Reservoir, Morocco	53.92	0.24	2.85	Present study

the estimates provided by Degsera et al. (2021) in Lake Tana (Z = 1.10 $year^{-1}$, F = 0.49 $year^{-1}$) and by Muhtadi et al. (2022) for *O. niloticus* from Coastal Lake (Z = 3.20 $year^{-1}$, F = 1.93 $year^{-1}$). In contrast, the values obtained for the same species in Lakes Koka and Naivasha (Z = 0.65 $year^{-1}$, F = 0.26 $year^{-1}$ and Z = 1.47 $year^{-1}$, F = 0.80 $year^{-1}$; respectively) are lower than those obtained for *O. niloticus* in Al Massira Reservoir, according to Tesfaye and Wolff (2015) and Waithaka et al. (2020). The inclusion of smaller and larger samples sizes impacts the assessment of growth parameters, which may also affect the calculations of mortality rates. This could, in part, explain the disparities registered in our study and other research (Degsera et al., 2021). Furthermore, the methods used to estimate mortality parameters could also be determining factors for these differences (Tesfaye, 2006; Degsera et al., 2021). Natural and fishing mortality can indicate an overfishing status (Pauly, 1983). The fishing mortality reported in the current research (F = 1.12 $year^{-1}$) exceeds that of natural mortality (M = 0.67 $year^{-1}$). This high value of fishing mortality appears to be the result of intensive fishing pressure practised in the Al Massira Reservoir. Moreover, The Z/K report obtained in this research also highlighted a high mortality rate among the population (Z/K > 1), reinforcing the idea that the *O. niloticus* population is subject to excessive fishing pressure. This is further supported by an exploitation rate exceeding the threshold of E_{opt} = 0.5 (E = 0.63), indicated a high level of exploitation. Comparative evaluation of current and predicted levels of both fishing mortality and exploitation is required for developing a long-term sustainability strategy of a harvested fishery (Alam et al., 2021). The prediction model (YPR) reveals that the current rate of fishing mortality (F = 1.12 $year^{-1}$) exceeds the recommended maximum mortality level (F_{max} = 1.06 $year^{-1}$). Similarly, the current exploitation rate (E = 0.63) surpasses the desired level (E_{max} = 0.59), thereby confirming that the *O. niloticus* population stock is experiencing overexploitation in the Al Massira Reservoir. The calculated value of length at first capture (Lc = 13.04 cm) of Nile tilapia found in our research is below its length at first maturity (Lm), which has been shown in various studies in several different areas. The observed values are 24.6 cm in Ethiopia (Tesfaye and Wolff, 2015), 26.18 cm in Kenya (Njiru et al., 2007), and 47.4 cm in Sri Lanka (Amarasinghe et al., 2017). This suggests that high proportions of juvenile fish are being captured using gillnets. Indeed, fishermen commonly use non-selective, highly destructive, and illegal monofilament gillnets (mesh sizes of 25 to 65 mm), which leads to the capture of much smaller individuals in Al Massira Dam Lake.

The data indicate that the *O. niloticus* population in the Al Massira Reservoir clearly exceeds sustainable limits. Thus, it is essential to develop strategies for reducing fishing pressure in order to protect this population and therefore guarantee the sustainable viability of the fishery in the long term. The findings of this survey show that gillnet fishing for *O. niloticus* in the Al Massira Dam Lake exerts intensive pressure on the population. Therefore, management actions must aim to increase the size of the first capture (Lc). This objective This could be achievable through the implementation of mesh size regulations, which would help improve the rehabilitation of the population by permitting the escape of juvenile fish. Restrictions on gear size, by banning the use of monofilament gillnets, should also be applied urgently and strictly. It is also recommended to close the fishery during breeding seasons to promote the adult reproduction as well as the rebuilding of the population. It is also essential to increase the awareness of the various stakeholders in order to ensure the effective monitoring and implementation of fisheries legislation.

5. Conclusion

It is essential to understand fish population dynamics in order to make informed management decisions and implement successful strategies. In this research, we evaluated for the first one the stock status of *O. niloticus* in Al Massira Reservoir in Morocco. Our results show that the exploitation level of this fish species exceeds the recommended threshold, suggesting that the fish stock is overexploited. To ensure the sustainability of these resources in this Dam Lake, it is imperative to establish management strategies aimed at reducing fishing pressure. This This could be carried out by fixing catch quotas, defining appropriate minimum catch sizes, and encouraging fishers to adopt sustainable and responsible fishing practices.

Conflict of interest

No conflicts of interest have been declared by the authors.

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