Int. J. Aquat. Biol. (2026) 14(6): 50-61
ISSN: 2322-5270; P-ISSN: 2383-0956
Journal homepage: www.ij-aquaticbiology.com
© 2026 Iranian Society of Ichthyology

Original Article

Length-based stock assessment of largemouth bass (*Micropterus salmoides* Lacepède, 1802) in Al Massira Reservoir, Morocco

Loubna Ferraj[*1], Meriem Bousseba[2], Mustapha Hasnaoui[1]

[1]Environmental, Ecological and Agro-Industrial Engineering Laboratory, Department of Biology, Faculty of Sciences and Techniques, Sultan Moulay Slimane University, 23020 Beni Mellal, Morocco.
[2]Biotechnology, Environment and Georesources Research Laboratory, Higher School of Technology, Sultan Moulay Slimane University, 54000 Khenifra, Morocco.

Abstract: The largemouth bass (*Micropterus salmoides*) represents one of the most economically important freshwater fish species exploited by artisanal fisheries in Moroccan reservoirs. However, information regarding its stock status and exploitation level remains limited. This study aimed to evaluate the population dynamics and exploitation status of *M. salmoides* in Al Massira Reservoir using length-frequency data and length-based stock assessment models. A total of 855 specimens were collected from commercial catches between September 2020 and August 2021. Growth parameters were estimated using the von Bertalanffy growth model, while mortality and exploitation indices were calculated to assess fishery sustainability. The estimated total mortality (Z) and natural mortality (M) rates were 1.85 year^{-1} and 0.69 year^{-1}, respectively. The current fishing mortality (F) and exploitation rate (E) exceeded the biological reference points associated with maximum sustainable yield. In particular, the exploitation rate (E = 0.63) was substantially higher than the optimal threshold (E = 0.50), indicating clear overexploitation of the reservoir stock. These findings demonstrate that the current fishing pressure threatens the sustainability of the largemouth bass population in Al Massira Reservoir. Therefore, immediate management measures, including regulating fishing effort and strengthening monitoring programs, are urgently required to ensure the long-term conservation and sustainable exploitation of this fishery resource.

Article history:
Received 4 September 2026
Accepted 4 October 2026
Available online 25 December 2026

Keywords:
Length-frequency analysis
Exploitation rate
Overfishing
Sustainable fisheries management

Introduction

The largemouth bass (*Micropterus salmoides*) is a centrarchid freshwater fish inhabiting temperate and subtropical aquatic ecosystems. Native to the east-central United States and northern Mexico (Brown et al., 2009), this apex predator has been intentionally introduced into numerous countries to support recreational and sport fisheries (Brown et al., 2009; Pereira and Vitule, 2019). Owing to its high adaptive capacity and considerable ecological impacts, *M. salmoides* is currently recognized among the world's most invasive fish species by the International Union for Conservation of Nature (IUCN) (Lowe et al., 2000). This species preferentially inhabits shallow lakes, reservoirs, and marshy freshwater habitats with moderate water temperatures (Lorenzoni et al., 2002). Its worldwide distribution largely resulted from successive introductions between the late nineteenth and early twentieth centuries (Bruslé and Quignard, 2001). In Morocco, *M. salmoides* was first introduced in 1934 and successfully acclimatized in the Middle Atlas lakes (Mouslih, 1987). Following its successful establishment, both juveniles and adults were subsequently introduced into several natural and artificial freshwater ecosystems throughout the country.

Fish stock assessment is based on the analysis of fish population dynamics, fisheries surveys, and commercial catch data. It relies on quantitative and mathematical approaches to evaluate exploitation patterns, estimate stock evolution under different management strategies, and support fisheries management decisions (Punt et al., 2014). Conventional stock assessment methods generally require extensive biological and fisheries data (Shi and Chen, 2019). However, researchers have

[*]Correspondence: Loubna Ferraj
E-mail: ferraj01.loubna@gmail.com
DOI: https://doi.org/10.22034/ijab.v14i6.3034

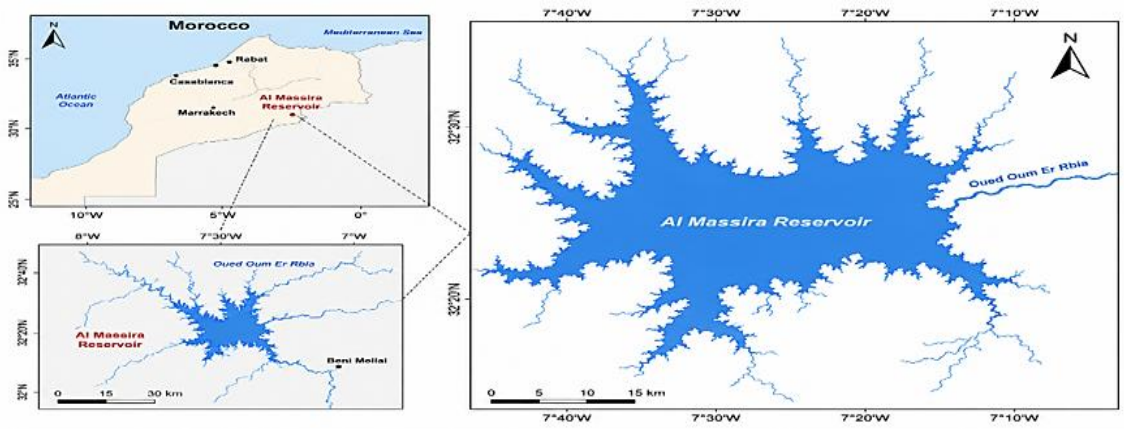


Figure 1. Location of Al Massira Reservoir in Morocco.

conducted comprehensive assessments for only a small proportion of fish species worldwide (Costello and Ovando, 2019). Most traditional stock assessment approaches depend on long-term datasets including catch statistics, age structure, size composition, biomass estimates, gonadal development, and life-history parameters (Methot and Wetzel, 2013). In many small-scale fisheries, the lack of reliable, continuous datasets prevents the use of conventional assessment models and limits estimates of key biological indicators such as biomass and mortality rates (Costello et al., 2012; Dowling et al., 2016). Such fisheries are commonly referred to as data-limited fisheries and require alternative approaches to ensure sustainable exploitation and biodiversity conservation (Chrysafi and Kuparinen, 2016). In recent decades, length-based assessment models have emerged as effective tools for evaluating stock status in data-limited fisheries (Quinn and Deriso, 1999; Costello et al., 2012; Cope et al., 2023). These approaches require relatively limited biological information while providing reliable estimates of growth, mortality, and exploitation parameters, thereby supporting sustainable fisheries management (Dowling et al., 2016).

Despite the ecological and economic importance of *M. salmoides* in Moroccan inland fisheries, information regarding its population dynamics and exploitation status remains scarce. To date, no stock assessment study has been conducted on Moroccan populations of this species. Therefore, the present study aimed to evaluate the population dynamics and stock status of *M. salmoides* in Al Massira Reservoir using length-based models. The findings are expected to provide valuable information for fisheries management and contribute to the sustainable exploitation of this fishery resource.

Materials and Methods

Study area and fish sampling: The Al Massira Reservoir is located at 32°28′32″N and 7°32′15″W, approximately 120 km southeast of Casablanca, Morocco (Alaoui et al., 2000). With a storage capacity of approximately 2.8 billion m³, it represents the second-largest reservoir in Morocco (Alaoui et al., 2000). The reservoir is situated on the Oued Oum Er Rbia River basin within an arid climatic zone characterized by temperate winters (Emberger, 1955). In addition to its ecological importance, Al Massira Reservoir is a major freshwater resource used for domestic water supply, irrigation, fisheries, and hydroelectric power production for surrounding communities (Darwall et al., 2014) (Fig. 1).

Fish sampling: A total of 855 *M. salmoides* specimens were randomly collected from commercial catches between September 2020 and August 2021. Fish sampling was performed monthly from artisanal fisheries operating in the reservoir. Specimens were captured using gill nets with mesh sizes ranging from 25 to 65 mm (Bousseba et al., 2025). All collected specimens were transported to the laboratory for morphometric measurements. Total length (TL, cm) was measured to the nearest 0.1 cm using a graduated ichthyometer, and total weight (TW, g) was recorded

to the nearest 0.1 g using a digital electronic balance.

Growth analysis: Length-frequency data for *M. salmoides* were collected monthly from commercial catches and assumed to represent the size structure of the exploited population. Growth parameters of the von Bertalanffy growth function (VBGF), including asymptotic length (L∞), growth coefficient (K), and anchoring parameter (tanchor), were estimated from length-frequency distributions using the ELEFAN_GA algorithm implemented in the TropFishR package (Mildenberger et al., 2017). This method follows the formula developed by Pauly (1980): $Lt = L\infty \{1-e^{-[K(t-t0)+S(t)-S(t0)]}\}$, where Lt is the fish length at time t, $L\infty$ is the asymptotic length (cm), K is the growth coefficient (year^{-1}), and $t0$ represents the theoretical age at which fish length equals zero. This study did not consider seasonal growth oscillations. Consequently, $S(t) - S(t_0)$ was assumed to be equal to zero. In the TropFishR package, *t0* is replaced by tanchor, which corresponds to the time of year when the von Bertalanffy growth curve crosses zero length (Taylor and Mildenberger, 2017).

The maximum observed length (Lmax) was estimated as the mean length of the largest 1% of sampled individuals. The asymptotic length ($L\infty$) was subsequently approximated according to Pauly (1984) as follows: $L\infty = Lmax / 0.95$. The growth performance index (Ø′) was calculated from the estimated values of K and $L\infty$ using the equation proposed by Pauly and Munro (1984): $Ø' = \log_{10} K + 2 \log_{10} L\infty$. This index is commonly used to compare the growth performance of fish species with similar body shapes based on length growth (Gayanilo and Pauly, 1997).

Mortality parameters were estimated using a length-converted catch curve derived from length-frequency data and previously estimated von Bertalanffy growth parameters. The total mortality rate (Z) was obtained from the descending slope of the linearized catch curve (Pauly, 1983). Given the difficulty and ecological importance of accurately estimating natural mortality (M) (Jørgensen and Holt, 2013), we applied the updated empirical model proposed by Then et al. (2015) as follows: $M = 4.118 \times K^{0.73} \times L\infty^{-0.333}$, based on a meta-analysis of growth data from multiple fish species, instead of the original Pauly (1980) equation. The fishing mortality rate (F) was calculated as $F = Z-M$. The exploitation rate (E) was then estimated as the ratio of fishing mortality to total mortality ($E = F/Z$). The estimated exploitation rate was compared with the reference threshold of 0.5 proposed by Gulland (1971), which represents the optimum level for sustainable exploitation.

The probability of capture was estimated from the length-converted catch curve using the method of Pauly and Munro (1984). This approach extrapolated the descending right arm of the catch curve for each length class. The probability of capture was calculated as the ratio of the observed number of individuals (N) to the available number of fish (N/P), allowing estimation of the length at first capture (Lc) (Pauly, 1987).

Biological reference points were estimated using the relative yield-per-recruit (Y'/R) model of Thompson and Bell (1934) to determine the stocks' optimal exploitation level. The following reference points were calculated: (a) fishing mortality and exploitation rates corresponding to the maximum yield per recruit (Fmax and Emax); (b) fishing mortality and exploitation rates reducing the spawning stock biomass to 50% of the unexploited stock (F0.5 and E0.5); and (c) fishing mortality and exploitation rates corresponding to 10% of the initial slope of the Y'/R curve (F0.1 and E0.1).

The length-weight relationship (LWR) was described using the equation proposed by Le Cren (1951): $Wt = a\ Lt^b$, where a denotes the intercept, and b represents the slope of the regression line (Froese, 2006). By transforming the above equation to logarithmic form ($\log(Wt) = \log(a) + b\log(Lt)$), the a and b coefficients were estimated using linear regression analysis (Zar, 1999). These parameters were then used as input for the YPR model analysis.

Statistical analysis: Differences in total length and body weight between males and females were evaluated using Student's t-test after verifying data normality. We used the Mann–Whitney U test to determine whether the allometric coefficient (b)

Table 1. Summary statistics of *Micropterus salmoides* collected from Al Massira Reservoir, Morocco.

	N	Lt (cm)		Wt (g)	
		Min-Max	Mean±SD	Min-Max	Mean±SD
♀	556	17.5-46	29.65±7.08	62.3-978	427.98±290.98
♂	299	18-41	28.47±5.52	115-837	438.61±258.58
Total population	855	17.5-46	29.24±6.60	62.3-978	490.45±229.37

♂ = Males, ♀ = Females, N= Individuals Number, SD= Standard deviation.

Table 2. Length–weight relationship parameters of *Micropterus salmoides* from Al Massira Reservoir, Morocco.

	a	*b*	R^2	Growth type	*p*-value
Male	-2.30	3.12	0.98	+ allometry	< 2.2e-16***
Female	-2.34	3.16	0.99	+ allometry	< 2.2e-16***
Total population	-2.31	3.13	0.98	+ allometry	< 2.2e-16***

****P*<0.001.

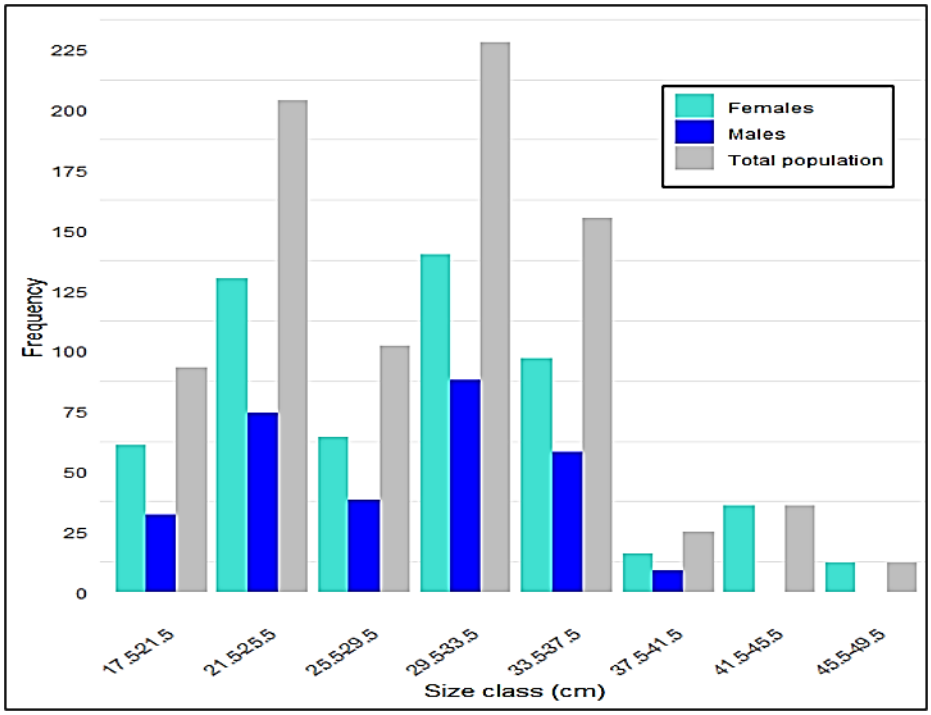


Figure 2. Length-frequency distribution of *Micropterus salmoides* population in Al Massira Reservoir, Morocco.

differed significantly from the theoretical value of 3 (Froese, 2006). Stock assessment analyses were conducted using the TropFishR package in R (Mildenberger et al., 2017). All statistical analyses were performed in RStudio (version 4.2.2).

Results

Length composition analysis: Total length ranged from 17.5 to 46.0 cm, with a mean value of 29.24±6.60 cm (Table 1). The highest frequencies were observed in the 21.5-24.5 cm and 29.5-32.5 cm length classes, comprising 204 and 228 individuals, respectively (Fig. 2). No significant difference in mean total length was detected between males and females (Mann–Whitney *U* test, $P>0.05$). Similarly, body weight did not differ significantly between sexes ($P>0.05$).

Length-weight relationship: Table 2 summarizes the LWR parameters for *M. salmoides*. The estimated allometric coefficient (*b*) was 3.16 for females, 3.12 for males, and 3.13 for the combined population, indicating positive allometric growth in both sexes and the overall population. The results showed that the estimated *b*-values differed significantly from the theoretical isometric value of 3 (*t*-test, $P<0.001$) (Table 2).

Growth parameters, mortality and yield-per-recruit analysis: Table 3 presents the von Bertalanffy growth parameter results. The asymptotic length ($L\infty$)

Table 3. Growth parameters and scores derived using the Genetic Algorithm (ELEFAN G.A).

Parameter	Male	Female	Total population
Asymptotic Length (L∞) (cm)	45.04	52.22	51.21
Growth Coefficient (K) (Year^{-1})	0.78	0.85	0.80
t_{anchor}	0.29	0.71	0.38
Growth Performance Index (∅′)	3.20	3.36	3.32

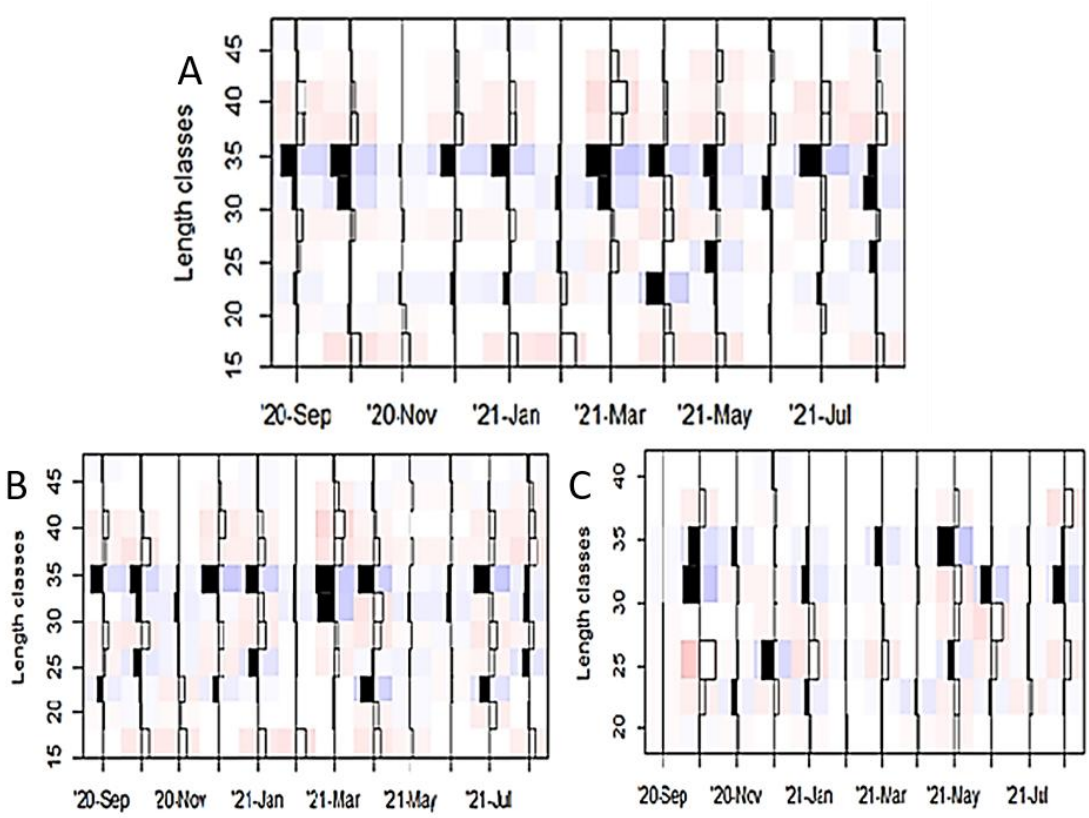


Figure 3. Monthly restructured length-frequency distributions of *Micropterus salmoides* estimated using the ELEFAN_GA routine for (A) total population, (B) females, and (C) males in Al Massira Reservoir, Morocco.

was estimated at 45.04 cm for males, 52.22 cm for females, and 51.21 cm for the combined population. The growth coefficient (*K*) was estimated at 0.78 year^{-1} for males, 0.85 year^{-1} for females, and 0.80 year^{-1} for the total population (Fig. 3). ∅′ was estimated at 3.20 for males, 3.36 for females, and 3.32 for the combined population.

Mortality and exploitation parameters: Total mortality (*Z*) was estimated from the length-converted catch curve and was 1.85 year^{-1}. Natural mortality (*M*) was estimated at 0.69 year^{-1} using the empirical model proposed by Then et al. (2015). Fishing mortality (*F*) was then calculated as the difference between Z and M, yielding 1.16 year^{-1}. The exploitation rate (*E*) was estimated at 0.63. *Lc*, obtained by back-projecting the catch curve, was estimated at 21.50 cm, indicating a 50% probability of capture under the current fishing gear selectivity pattern (Table 4).

Table 4 presents the biological reference points estimated from the yield-per-recruit (YPR) analysis. The model indicated that the maximum yield per recruit would be achieved at a fishing mortality (*F*max) of 0.79 year^{-1} and an exploitation rate (*E*max) of 0.43. The exploitation level corresponding to 50% of the unexploited stock biomass was estimated at *F*0.5 = 0.35 year^{-1} and *E*0.5 = 0.19. Furthermore, the biologically optimal exploitation level was estimated at *F*0.1 = 0.51 year^{-1} and *E*0.1 = 0.28.

Discussions

The present study provides the first assessment of the population dynamics and exploitation status of

Table 4. Mortality, exploitation, and biological reference points estimated for *Micropterus salmoides* in Al Massira Reservoir, Morocco.

Parameters	Value
Total Mortality (Z) (year^{-1})	1.85
Natural Mortality (M) (year^{-1})	0.69
Fishing Mortality (F) (year^{-1})	1.16
$F_{0.1}$ (year^{-1})	0.51
F_{max} (year^{-1})	0.79
$F_{0.5}$ (year^{-1})	0.35
Current Exploitation (E)	0.63
$E_{0.1}$	0.28
E_{max}	0.43
$E_{0.5}$	0.19
Length at First Capture (Lc) (cm)	21.50

M. salmoides in Moroccan freshwater ecosystems, particularly in Al Massira Reservoir, using length-based stock assessment approaches. The generated information contributes to understanding the stock status of this species and provides valuable data for fisheries management and conservation strategies. In addition, these findings establish a scientific basis for future investigations on ecological interactions and fishing impacts within Moroccan inland aquatic ecosystems.

The length–weight relationship analysis revealed that the allometric coefficient of *M. salmoides* was significantly higher than the theoretical isometric value of 3, indicating positive allometric growth for the combined population. This growth pattern suggests that body weight increases proportionally faster than body length. Similar positive allometric growth patterns have previously been reported for *M. salmoides* in several freshwater ecosystems, including the Ebro River in Spain (Leunda et al., 2006), Rift Valley lakes in Kenya (Britton and Harper, 2006), the Doñana Marshlands in Spain (Moreno-Valcárcel et al., 2012), the Saemangeum Reservoir in South Korea (Kim et al., 2015), and the Daechung Reservoir in South Korea (Baek et al., 2015). Conversely, isometric growth patterns have been reported from Lake Elmdale in the United States (Zdinak et al., 1980), the Tibagi River in Brazil (Garcia et al., 2014), and the Nakdong River in South Korea (Lee et al., 2015). In contrast, Mabika et al. (2024) reported negative allometric growth for some populations inhabiting Tugwi-Mukosi Dam in Zimbabwe. Variations in length-weight relationship parameters among populations may be attributed to several biological and environmental factors, including habitat characteristics, seasonal variability, food availability, reproductive status, and environmental conditions (Zhong et al., 2018; Ding et al., 2025). Such variability likely explains the differences observed among geographic regions and aquatic ecosystems.

The growth performance index ($\varnothing'$) estimated for females was higher than that of males, indicating that female *M. salmoides* exhibited a relatively faster growth rate. Similar sex-related differences in growth performance have been reported for *M. salmoides* populations in Lake Trasimeno (Lorenzoni et al., 2002) and the Mankazana impoundment (Taylor and Weyl, 2017). In contrast, Beamish et al. (2005) in Lake Manyame, Rodriguez-Sánchez et al. (2009) in Primera de Palos Lake, and Taylor and Weyl (2017) in the Wriggleswade impoundment reported comparable growth patterns between males and females (Table 5). The growth performance indices ($\varnothing'$) estimated for *M. salmoides* populations in Flint Creek Reservoir (Galloway and Kilambi, 1988), Nishinoko and Shorenji lakes (Yodo and Kimura ,1996), Lake Bracciano (Scalici et al., 2009), and Lake Goe-san (Zhang et al., 2013) were lower than those observed in the present study. Conversely, higher $\varnothing'$ values were reported from Lake Chicamba (Weyl and Hecht, 1999), reservoirs in southern Brazil (Schulz and Leal, 2005), and Lake Naivasha (Britton et al., 2010) (Table 5).

Variability in growth performance among populations of the same species may result from

Table 5. Comparison of von Bertalanffy growth parameters reported for *Micropterus salmoides* populations from different regions worldwide.

Region	Sex	L_∞	K	Ø'
Flint Creek Reservoir, Arkansas, USA[a]	♀ + ♂	48.0	0.52	3.08
Lake Nishinoko, Japan[b]	♀ + ♂	36.2	0.46	2.78
Lake Shorenji, Japan[b]	♀ + ♂	34.1	0.50	2.76
Lake Chicamba, Mozambique[c]	♀ + ♂	46.6	1.17	3.40
	♂	39.40	0.42	2.81
Lake Trasimeno, Italy[d]	♀	46.88	0.33	2.86
	♂	37.22	0.66	2.96
Lake Manyame, Zimbabwe[e]	♀	48.16	0.41	2.97
	♀ + ♂	40.54	0.55	2.95
A Reservoir in Southern Brazil[f]	♀ + ♂	43.91	0.99	3.28
Primera de Palos' Lake, Spain[g]	♂	50.36	0.19	2.68
	♀	51.26	0.18	2.67
Lake Bracciano, Italy[h]	♀ + ♂	31.0	0.49	2.67
Lake Naivasha, Kenya[i]	♀ + ♂	55.4	0.61	3.27
Lake Goe-san, Korea[j]	♀ + ♂	45.9	0.126	2.42
	♂	36.4	0.45	2.78
Wriggleswade impoundment, South Africa[k]	♀	47.2	0.27	2.78
	♀ + ♂	42.0	0.33	2.77
	♂	63.2	0.23	2.96
Mankazana impoundment, South Africa[k]	♀	59.8	0.28	3.00
	♀ + ♂	73.9	0.18	2.99
	♂	45.04	0.78	3.20
Al Massira Reservoir, Morocco[l]	♀	52.22	0.85	3.36
	♀ + ♂	51.21	0.80	3.32

Symbols correspond to Table 4. [a]Galloway and Kilambi (1988), [b] Yodo and Kimura (1996), [c] Weyl and Hecht (1999), [d] Lorenzoni et al. (2002), [e]Beamish et al. (2005), [f] Schulz and Leal (2005), [g]Rodriguez-Sánchez et al. (2009), [h]Scalici et al. (2009), [l]Britton et al. (2010), [j]Zhang et al. (2013), [k]Taylor and Weyl (2017), [l]Current study

interactions among several environmental, biological, and management-related factors. Water temperature plays a fundamental role in fish metabolism and growth. Diana (1984) demonstrated that fluctuating thermal regimes may promote faster food consumption and improved growth performance in *M. salmoides* compared with constant thermal conditions. Salinity may also influence fish growth by affecting physiological processes and biochemical composition. According to Su et al. (2025), optimal salinity conditions are essential for maintaining normal growth and physiological performance in fish populations. Water quality constitutes another important factor affecting fish growth and population dynamics. Environmental parameters such as pH, dissolved oxygen concentration, and ammonia levels directly influence fish physiology and feeding activity. Degraded water quality conditions may induce physiological stress, reduce feeding efficiency, and consequently limit growth performance (Aljehani et al., 2023). In addition, management practices and hydrological fluctuations can strongly influence habitat quality and food availability. Seasonal or anthropogenic fluctuations in water level may modify nutrient availability and alter aquatic food-web structure. Que et al. (2021) demonstrated that such fluctuations can affect food resources and species diversity, potentially reducing fish growth during periods of limited food availability. Population density may also affect growth performance through density-dependent mechanisms. High population density generally increases competition for food and dissolved oxygen, reducing growth and increasing physiological stress. Conversely, low population density may lead to underutilization of available food resources and altered social interactions within fish populations (Aljehani et al., 2023).

The estimated total mortality (Z) of *M. salmoides* in the present study (Z = 1.85 year^{-1}) was higher than values previously reported for subtropical populations, including 1.27 year^{-1} in Mozambique (Weyl and Hecht, 1999) and 0.89 year^{-1} in Puerto Rico (Waters et al., 2005). Similarly, the estimated Z value exceeded the mean mortality rate of 0.73 year^{-1}

reported for 45 aquatic ecosystems in Florida (Allen et al., 2002), as well as 0.49, 0.55, and 0.80 year^{-1} observed in three small impoundments in Georgia (Bonvechio et al., 2014). Taylor et al. (2015) also reported lower mortality values ranging from 0.36 to 0.50 year^{-1} in Wriggleswade Dam, South Africa. Conversely, Allen et al. (2008) reported higher mortality rates for *M. salmoides* populations in Rum Creek and Lake Tobesofkee, North America. Variability in mortality estimates among populations may partly result from differences in environmental conditions, exploitation levels, and methodological approaches used to estimate mortality parameters (Degsera et al., 2021).

The comparison between fishing mortality (F) and natural mortality (M) clearly indicated that fishing mortality represented the dominant source of mortality in the Al Massira Reservoir population (F = 1.16 year^{-1} > M = 0.69 year^{-1}). This result strongly suggests substantial fishing pressure on the stock. Moreover, the exploitation rate (E = 0.63) exceeded the optimal exploitation threshold proposed by Gulland (1971) (Eopt = 0.50), indicating overexploitation. The estimated Z/K ratio also exceeded 1, reflecting a mortality-dominated stock structure and further supporting the hypothesis of excessive fishing pressure.

The yield-per-recruit analysis further confirmed the stock's overexploited status, as current fishing mortality and exploitation rates (F = 1.16 year^{-1} and E = 0.63) exceeded the biological reference points associated with maximum sustainable yield (Fmax = 0.79 year^{-1} and Emax = 0.43). These findings indicate that the current exploitation pattern may compromise the long-term sustainability of *M. salmoides* in Al Massira Reservoir.

The estimated length at first capture (Lc = 21.5 cm) was lower than the reported length at sexual maturity (Lm) for *M. salmoides* populations from several geographic regions. Previous studies reported Lm values of 33.7 cm in Mexico (Beltrán Alvarez et al., 2013), 23.2 and 23.9 cm in two temperate African impoundments (Taylor and Weyl, 2017), and 32.6 cm in Kenya (Keyombe et al., 2020). These results suggest that a substantial proportion of immature individuals are currently being harvested in Al Massira Reservoir. The capture of immature fish is likely linked to the extensive use of illegal, non-selective monofilament gillnets with mesh sizes ranging from 25 to 65 mm. This gear captures juvenile and small individuals, increasing fishing pressure on first-time spawners. This may reduce spawning biomass, impair recruitment success, and ultimately threaten the stock's long-term stability and sustainability.

Based on our findings, the *M. salmoides* stock in Al Massira Reservoir appears to be exploited beyond sustainable biological limits. Consequently, effective management measures are urgently needed to reduce fishing pressure and ensure the long-term sustainability of this fishery resource. Reducing fishing pressure could lower the exploitation rate by adopting more selective fishing practices, including increasing gillnet mesh size and prohibiting illegal monofilament nets. These measures would allow juveniles to reach sexual maturity and contribute to stock replenishment before capture. In addition, seasonal fishing restrictions during the reproductive period could enhance spawning success and support natural population renewal. Limiting fishing effort may also reduce fishing mortality and keep exploitation within biologically sustainable thresholds in Al Massira Reservoir.

The effectiveness of these management strategies largely depends on the active involvement of local fishing communities. Strengthening fishermen's awareness regarding minimum catch size regulations, closed fishing seasons, and fishing effort control is therefore essential. Educational programs, workshops, and participatory management initiatives could improve compliance with fisheries regulations and promote sustainable exploitation practices for long-term stock conservation.

Conclusion

The present study provides the first length-based stock assessment of *M. salmoides* in Moroccan freshwater ecosystems, particularly in Al Massira Reservoir. The

results show that current exploitation of this commercially important species exceeds sustainable biological limits, indicating overexploitation. The estimated exploitation and mortality parameters demonstrated that fishing pressure constitutes the main factor affecting the population dynamics of the species in the reservoir. To ensure the long-term sustainability of this fishery resource, effective management measures are urgently required. Such measures should include regulating fishing effort, establishing appropriate minimum catch sizes, prohibiting illegal and non-selective fishing gear, and reinforcing seasonal fishing restrictions during the reproductive period. In addition, awareness programs targeting local fishing communities could help promote more responsible and sustainable fishing practices. Overall, the findings of the present study provide valuable scientific information for fisheries management and constitute an important baseline for future research and conservation strategies concerning inland fishery resources in Morocco.

Ethical statement

All experimental procedures involving fish were conducted in accordance with the European Union Directive 2010/63/EU on the protection of animals used for scientific purposes.

References

Alaoui L., Agoumi A., Moncef M., Mokhliss K. (2000). Étude du régime thermique de la retenue Al Massira (Maroc). Hydroécologie Appliquée, 12 : 183-206. (in French)

Allen M.S., Sheaffer W., Porak W.F., Crawford S. (2002). Growth and mortality of largemouth bass in Florida waters: implications for use of length limits. In: D.P. Philipp, M.S. Ridgway (Ed.). Black Bass: Ecology, Conservation and Management. American Fisheries Society. Bethesda, MD. pp: 559-566.

Allen M.S., Walters C.J., Myers R. (2008). Temporal trends in largemouth bass mortality, with fishery implications. North American Journal of Fisheries Management, 28: 418-427.

Aljehani F., N'Doye I., Laleg-Kirati T.M. (2023). Model-based versus model-free feeding control and water-quality monitoring for fish-growth tracking in aquaculture systems. IFAC Journal of Systems and Control, 26: 100226.

Baek S.H., Jang M.H., Yoon J.D., Kim J.H., Park S.H., Lee J.W., Byeon M.S. (2015). Length-weight relationships of 19 freshwater fishes from the Daechung Reservoir in South Korea. Journal of Applied Ichthyology, 31: 937-938.

Beamish C.A., Booth A.J., Deacon N. (2005). Age, growth and reproduction of largemouth bass *Micropterus salmoides* in Lake Manyame, Zimbabwe. African Zoology, 40: 63-69.

Beltrán Alvarez R., Sánchez Palacios J., Ramírez Lozano J.P., Ortega Salas A.A. (2013). Reproducción de *Micropterus salmoides* (Pisces: Centrarchidae), en el embalse Gustavo Díaz Ordaz, Sinaloa, México. Revista de Biología Tropical, 61: 1313-1325. (in Spanish)

Bonvechio T.F., Bowen B.R., Wixson J.M., Allen M.S. (2014). Exploitation and length limit evaluation of largemouth bass in three Georgia small impoundments. Journal of the Southeastern Association of Fish and Wildlife Agencies, 1: 33-41.

Bousseba M., Ferraj L., Ouahb S., Droussi M., Hasnaoui M. (2025). Quantitative fishery assessment of data-limited *Sander lucioperca*: tools for fisheries management and conservation. Turkish Journal of Fisheries and Aquatic Sciences, 25: TRJFAS26223.

Britton J.R., Harper D.M. (2006). Length-weight relationships of fish species in the freshwater Rift Valley lakes of Kenya. Journal of Applied Ichthyology, 22: 334-336.

Britton J.R., Harper D.M., Oyugi D.O. (2010). Is the fast growth of an equatorial *Micropterus salmoides* population explained by high water temperature? Ecology of Freshwater Fish, 19: 228-238.

Brown T.G., Runciman B., Pollard S., Grant A.D.A., Bradford M.J. (2009). Biological synopsis of largemouth bass (*Micropterus salmoides*). Canadian Manuscript Report of Fisheries and Aquatic Sciences, 2884: 1-26.

Bruslé J., Quignard J.P. (2001). Biologie des poissons d'eau douce européens. Technique and Documentation. Paris. (in French)

Chrysafi A., Kuparinen A. (2016). Assessing abundance of populations with limited data: lessons learned from data-poor fisheries stock assessment. Environmental Reviews, 24: 25-38.

Cope J.M., Dowling N.A., Hesp S.A., Omori K.L., Bessell-

Browne P., Castello L., Chick R., Dougherty D., Holmes S.J., McGarvey R., Ovando D., Nowlis J., Prince J. (2023). The stock assessment theory of relativity: deconstructing the term 'data-limited' fisheries into components and guiding principles to support the science of fisheries management. Reviews in Fish Biology and Fisheries, 33: 241-263.

Costello C., Ovando D. (2019). Status, institutions, and prospects for global capture fisheries. Annual Review of Environment and Resources, 44: 177-200.

Costello C., Ovando D., Hilborn R., Gaines S.D., Deschenes O., Lester S.E. (2012). Status and solutions for the world's unassessed fisheries. Science, 338: 517-520.

Darwall W., Carrizo S., Numa C., Barrios V., Freyhof J., Smith K. (2014). Freshwater key biodiversity areas in the Mediterranean Basin hotspot: Informing species conservation and development planning in freshwater ecosystems. IUCN. Cambridge.

Degsera A., Minwyelet M., Yosef T. (2021). Stock assessment of Nile tilapia *Oreochromis niloticus* (Linnaeus 1758) in Lake Tana, Ethiopia. African Journal of Aquatic Science, 46: 499-507.

Diana J.S. (1984). The growth of largemouth bass *Micropterus salmoides* Lacepede under constant and fluctuating temperatures. Journal of Fish Biology, 24: 165-172.

Ding H., Xiong M., Yang Y., Zhong T., Chen F., Gong Y., Zhang D., Jiang S., Zhang Z. (2025). Variations of length–weight relationships for six fish species from the Lower Yarlung Zangbo River Catchment, Tibet, China. Fishes, 10: 56.

Dowling N.A., Wilson J.R., Rudd M.B., Babcock E.A., Caillaux M., Cope J., Dougherty D., Fujita R., Gedamke T., Gleason M., Gutierrez N., Hordyk A., Maina G.W., Mous P.J., Ovando D., Parma A.M., Prince J., Revenga C., Rude J., Szuwalski C., Valencia S., Victor S. (2016). FishPath: a decision support system for assessing and managing data- and capacity-limited fisheries. In: T.J. Quinn II, J.L. Armstrong, M.R. Baker, J. Heifetz, D. Witherell (Eds.). Assessing and managing data-limited fish stocks. Alaska Sea Grant, University of Alaska Fairbanks. pp: 59-96.

Emberger L. (1955). Une classification biogéographique des climats. Recueil des Travaux du Laboratoire de Botanique, Géologie et Zoologie de la Faculté des Sciences de l'Université de Montpellier, Série Botanique, 7: 3-43. (in French)

Froese R. (2006). Cube law, condition factor, and length–weight relationships: history, meta-analysis, and recommendations. Journal of Applied Ichthyology, 22: 241-253.

Galloway M.L., Kilambi R.V. (1988). Thermal enrichment of a reservoir and the effects on annulus formation and growth of largemouth bass *Micropterus salmoides*. Journal of Fish Biology, 32: 533-543.

Garcia D.A.Z., Costa A.D.A., Leme G.L.A., Orsi M.S. (2014). Biology of black bass *Micropterus salmoides* (Lacepède, 1802) fifty years after introduction into a small drainage of the Upper Paraná River basin, Brazil. Biodiversitas, 15: 180-185.

Gayanilo F.C., Pauly D. (1997). The FAO-ICLARM stock assessment tools (FiSAT): reference manual. FAO. Rome.

Gulland J.A. (1971). The fish resources of the ocean. Fishing News Books. Surrey, UK.

Jørgensen C., Holt R.E. (2013). Natural mortality: its ecology, how it shapes fish life histories, and why it may be increased by fishing. Journal of Sea Research, 75: 8-18.

Keyombe J.L.A., Kevin O., Waithaka E., Nicholas O., Oscar D., Kyule D.N. (2020). Some aspects of fish growth in redbelly tilapia (*Coptodon zillii*) and largemouth bass (*Micropterus salmoides*) in Lake Naivasha, Kenya. Fisheries and Aquaculture Journal, 11: 280.

Kim J.H., Yoon J.D., Won D.H., Byeon M.S., Jang M.H. (2015). Length–weight relationships of 19 fish species from the Saemangeum Reservoir in South Korea. Journal of Applied Ichthyology, 31: 951-953.

Le Cren E.D. (1951). The length–weight relationship and seasonal cycle in gonad weight and condition in the perch (*Perca fluviatilis*). Journal of Animal Ecology, 20: 201-219.

Lee J.W., Yoon J.D., Kim J.H., Park S.H., Baek S.H., Yu J.J., Jang M.H., Min J.I. (2015). Length-weight relationships for 18 freshwater fish species from the Nakdong River in South Korea. Journal of Applied Ichthyology, 31: 576-577.

Leunda P.M., Oscoz J., Miranda R. (2006). Length-weight relationships of fishes from tributaries of the Ebro River, Spain. Journal of Applied Ichthyology, 22: 299-300.

Lorenzoni M., Dorr A.J.M., Erra R., Giovinazzo G., Mearelli M., Selvi S. (2002). Growth and reproduction of largemouth bass (*Micropterus salmoides*) in Lake

Trasimeno (Umbria, Italy). Fisheries Research, 56: 89-95.

Lowe S., Browne M., Boudjelas S., De Poorter M. (2000). 100 of the world's worst invasive alien species: a selection from the global invasive species database. IUCN. Auckland.

Mabika N., Magqina T., Makoni T. (2024). Length-weight relationship and condition factor for five common fish species in a recently constructed reservoir (Tugwi-Mukosi Dam), Zimbabwe. Aquatic Research, 7: 83-92.

Methot R.D., Wetzel C.R. (2013). Stock synthesis: a biological and statistical framework for fish stock assessment and fishery management. Fisheries Research, 142: 86-99.

Mildenberger T.K., Taylor M.H., Wolff M. (2017). TropFishR: an R package for fisheries analysis with length-frequency data. Methods in Ecology and Evolution, 8: 1520-1527.

Moreno-Valcárcel R., Oliva-Paterna F.J., Arribas C., Fernández-Delgado C. (2012). Length–weight relationships for 13 fish species collected in the Doñana marshlands (Guadalquivir estuary, SW Spain). Journal of Applied Ichthyology, 28: 663-664.

Mouslih M. (1987). Introduction de poissons et d'écrevisses au Maroc. Revue d'Hydrobiologie Tropicale, 20: 65-72. (in French)

Pauly D. (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. Journal du Conseil International pour l'Exploration de la Mer, 39: 175-192.

Pauly D. (1983). Some simple methods for the assessment of tropical fish stocks. FAO. Rome.

Pauly D. (1984). Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM Studies and Reviews, 8: 1-325.

Pauly D., Munro J.L. (1984). Once more on the comparison of growth in fish and invertebrates. Fishbyte, 2: 21.

Pauly D. (1987). A review of the ELEFAN system for analysis of length-frequency data in fish and aquatic vertebrates. In: D. Pauly, G.R. Morgan (Eds.). Length-based methods in fisheries research. ICLARM, Manila and KISR, Safat. pp: 7-34.

Pereira F.W., Vitule J.R.S. (2019). The largemouth bass *Micropterus salmoides* (Lacepède, 1802): impacts of a powerful freshwater fish predator outside of its native range. Reviews in Fish Biology and Fisheries, 29: 639-652.

Punt A.E., A'mar T., Bond N.A., Butterworth D.S., de Moor C.L., De Oliveira J.A.A., Haltuch M.A., Hollowed A.B., Szuwalski C. (2014). Fisheries management under climate and environmental uncertainty: control rules and performance simulation. ICES Journal of Marine Science, 71: 2208-2220.

Que Y., Xie J., Xu J., Li W., Wang E., Zhu B. (2021). Ecological influences of water-level fluctuation on food web network. Water, 13: 2371.

Quinn T.J., Deriso R.B. (1999). Quantitative fish dynamics. Oxford University Press. New York. 542 p.

Rodríguez-Sánchez V., Encina L., Rodríguez-Ruiz A., Sánchez-Carmona R. (2009). Largemouth bass *Micropterus salmoides* growth and reproduction in Primera de Palos Lake (Huelva, Spain). Folia Zoologica, 58: 436-446.

Scalici M., Schiavone F., Marinelli A., Gibertini G. (2009). Growth, longevity, and mortality of the largemouth bass *Micropterus salmoides* (Lacepède, 1802) in a Mediterranean lake (Rome, Italy). Revue d'Écologie (La Terre et la Vie), 64: 51-60.

Schulz U.H., Leal M.E. (2005). Growth and mortality of black bass *Micropterus salmoides* (Pisces, Centrarchidae; Lacepède, 1802) in a reservoir in southern Brazil. Brazilian Journal of Biology, 65: 363-369.

Shi Y.C., Chen X.J. (2019). A review of stock assessment methods on small pelagic fish. Marine Fisheries, 41: 118-128.

Su M., Feng Z., Zhong Y., Ye Z., Zhang J. (2025). Insights into salinity effect on growth of the spotted scat (*Scatophagus argus*): exploring the optimum salinity for its culture. Aquaculture Reports, 41: 102667.

Taylor G.C., Weyl O.L.F., Cowley P.D., Allen M.S. (2015). Dispersal and population-level mortality of *Micropterus salmoides* associated with catch-and-release tournament angling in a South African reservoir. Fisheries Research, 162: 37-42.

Taylor G.C., Weyl O.L.F. (2017). Age, growth and reproduction of non-native largemouth bass *Micropterus salmoides* (Lacépède, 1802) populations in two temperate African impoundments. Journal of Applied Ichthyology, 33: 767-775.

Taylor M.H., Mildenberger T.K. (2017). Extending electronic length frequency analysis in R. Fisheries Management and Ecology, 24: 330-338.

Then A.Y., Hoenig J.M., Hall N.G., Hewitt D.A. (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate using information on

over 200 fish species. ICES Journal of Marine Science, 72: 82-92.

Thompson W.F., Bell H. (1934). Biological statistics of the Pacific halibut fishery. II. Effect of changes in intensity upon total yield and yield per unit gear. Reports of the International Fisheries Commission, 8: 49 p.

Waters D.S., Noble R.L., Hightower J.E. (2005). Fishing and natural mortality of adult largemouth bass in a tropical reservoir. Transactions of the American Fisheries Society, 134: 563-571.

Weyl O.L.F., Hecht T. (1999). A successful population of largemouth bass *Micropterus salmoides* in a subtropical lake in Mozambique. Environmental Biology of Fishes, 54: 53-66.

Yodo T., Kimura S. (1996). Age and growth of the largemouth bass *Micropterus salmoides* in lakes Shorenji and Nishinoko, central Japan. Fisheries Science, 62: 524-528.

Zar J.H. (1999). Biostatistical analysis. 4th edition. Prentice-Hall. Englewood Cliffs, New Jersey. 663 p.

Zdinak A., Kilambi R.V., Galloway M.L., McLanahan J.D., Duffe C. (1980). Estimated growth and standing crop of largemouth bass (*Micropterus salmoides*) from Lake Elmdale. Proceedings of the Arkansas Academy of Science, 34: 101-103.

Zhang M.M., Oh S.W., Lee W.O., Na J.J. (2013). Population biology of the largemouth bass *Micropterus salmoides* from Goe-san Lake, Korea. Journal of Environmental Biology, 34: 747-754.

Zhong S.J., Ma Q.Y., Liu S.D., Wang S.J., Ren Y.P. (2018). Linear mixed-effects models for estimating spatiotemporal variations of length–weight relationships for *Lophius litulon*. Journal of Fishery Sciences of China, 25: 1299-1307.