Biodiversity Research Journal

Biodiversity Research Journal, 2025,

Volume 3, Issue 2, 229-251

Assessment of The Exploitation Status and Potential of The Main Fish Stocks in Tunisian Reservoirs

AUTHORS

Tahani Chargui[1], Rym Ennouri[2,3], Siwar Agrebi[4], Fehmi Boufahja[5,*], Houcine Laouar6, Sami Mili[4,7*]

AFFILLIATIONS

[1]University of Carthage, National Agronomic Institute of Tunis, 43, Street Charles Nicolle 1082, Mahrajène, Tunis, Tunisia.

[2] University of Carthage, Higher Institute of Marine Sciences of Bizerte, Errimel, B.P. 15,7080 Bizerte, Tunisia.

[3] Laboratory of Ecology, Biology and Physiology of Aquatic Organisms, Faculty of Sciences of Tunis, University of Tunis El Manar, Tunis, Tunisia.

[4] University of Carthage, Faculty of Sciences of Bizerte, Zarzouna, 7021 Bizerte, Tunisia.

[5] Biology Department, College of Science, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh 11623, Saudi Arabia.

[6] Technical Center of Aquaculture, Tunis, Tunisia.

[7]University of Carthage, Laboratory of Fisheries Sciences, National Institute of Marine Sciences and Technologies, 28 rue du 2 mars 1934, Salammbô 2025, Tunis, Tunisia.

* CORRESPONDENCE

sami.mili@fsb.ucar.tn

CITATION

Chargui T, Ennouri R, Agrebi S, Boufahja F, Laouar H, Sami Mili S. Assessment of The Exploitation Status and Potential of The Main Fish Stocks in Tunisian Reservoirs. Biodiversity Research Journal, 2025 (3) 2, 229-251

ABSTRACT

Assessing the status and potential of fish stocks in Tunisian reservoirs is essential for the sustainable management of inland fisheries, which play a vital role in rural development and food security. This study aims to estimate biomass and evaluate the exploitation status of six key species: common carp (Cyprinus carpio), thin-lipped grey mullet (Chelon ramada), barbel (Luciobarbus callensis), pikeperch (Sander lucioperca), rudd (Scardinius erythrophthalmus), and roach (Rutilus rubilio), across eight major Tunisian reservoirs: Bir Mcherga, Sidi Saad, Siliana, Kasseb, Sidi Barrak, Sidi Salem, Mellegue, and Lahjar.Standardized scientific gillnet sampling was conducted between 2013 and 2016. Population parameters ($L\infty$, K, t_0, and natural mortality, M) were estimated using FISAT II software. Stock status was assessed through a yield-per-recruit (Y/R) model implemented in VIT software.The results indicate a general pattern of under-exploitation across most fish stocks, suggesting considerable potential for increased sustainable yields. However, notable variability was observed among species and reservoirs. Common carp were found to be near optimally exploited in Sidi Saad (E = 0.48), but under-exploited in Bir Mcherga (E = 0.30). Thin-lipped grey mullet exhibited very low exploitation levels (E = 0.09), indicating that stocking efforts are not being fully utilized. Despite relatively high fishing mortality (F exceeding 60% of total mortality) in species such as barbel and pikeperch, yield-per-recruit analysis still classified these stocks as under-exploited due to their high biological productivity.In conclusion, Tunisian reservoirs possess significant underutilized fisheries potential. The findings highlight the need for site- and species-specific management strategies, including a controlled increase in fishing effort for under-exploited stocks, in order to maximize sustainable yields while ensuring long-term resource conservation.

KEYWORDS: Stock assessment, yield per recruit, inland fisheries, reservoir management, Tunisia

INTRODUCTION

Located in a climatic transition zone between Mediterranean and Saharan influences, Tunisia is characterized by marked rainfall irregularity and increasing structural aridity toward the south (Soudoud, 2006; Snoussi et al., 2002). Historically, these water constraints have driven policies aimed at mobilizing surface water resources through the construction of retention infrastructures (Losse et al., 1992; Louati et al., 1998).

As results, Tunisia has developed a substantial network of hydraulic infrastructures, including 29 large dams, more than 200 hill dams, and over 1,000 hill lakes, with a total storage capacity exceeding 2.9 billion m^3 (Soudoud, 2006; Louati et al., 1998; DGBGTH, 2021). Although initially designed for drinking water supply, irrigation, and industrial use, these reservoirs also function as artificial aquatic ecosystems with significant potential for inland aquaculture development (Losse et al., 1992; Mili et al., 2021).

In addition, Tunisian reservoirs are subject to multiple environmental pressures, including fluctuations in water quality, temperature, and nutrient loading, all of which can significantly influence fish health and stock productivity (Talas et al., 2014; El Babli et al., 2010; Malik et al., 2020; Carter, 2025; Mustafa et al., 2025).

Fisheries exploitation in Tunisian reservoirs is relatively recent, becoming organized in the late 1980s, particularly through the Tunisian–German cooperation project initiated at Sidi Salem Reservoir (Losse et al., 1992; Kraiem, 1998). In the context of stagnating marine catches, which remain around 100,000 tonnes per year (DGPA, 2023), inland fisheries have emerged as a strategic alternative for diversifying national fish production and enhancing food security.

Beyond their quantitative contribution, inland fisheries play a crucial socio-economic role in rural areas. They support the stability of local populations by generating employment opportunities and providing stable income sources for fishing communities (Mili et al., 2015), thereby contributing to integrated territorial and water resource development (Losse et al., 1992; Louati et al., 1998; Mtimet, 2010; Hajlaoui et al., 2022).

Fish populations in Tunisian reservoirs result primarily from stocking programs and repeated species introductions (Losse et al., 1992; Mili et al., 2015). These populations include both native species, such as barbel (Luciobarbus callensis), mullet (Mugil cephalus), and thin-lipped grey mullet (Chelon ramada), and non-native species introduced to enhance fisheries. The latter include common carp (Cyprinus carpio), pikeperch (Sander lucioperca), roach (Rutilus rutilus), and rudd (Scardinius erythrophthalmus) (Mili et al., 2015; Laouar, 2019).

The productivity of these ecosystems depends heavily on annual stocking programs managed by the Technical Aquaculture Centre (CTA), particularly for species that are unable to complete their reproductive cycle in freshwater reservoirs, such as mullets and Chinese carp (Mili et al., 2021).

However, despite an initial period of growth, the sector is currently facing sustainability challenges. Official statistics indicate a significant decline in catches, decreasing from 998 tonnes in 2013 to 693 tonnes in 2023 (DGPA, 2023). Although the economic value has slightly increased, this downward trend raises concerns regarding stock health and fishing pressure (Mili et al., 2022).

Sustainable management of inland fisheries requires robust scientific assessments of fish populations (Buslé & Quignard, 2001; Cadima, 2002; King, 2007). These assessments rely on the analysis of key population parameters such as biomass, exploitation rates, and size structure (Pauly, 1984; Sparre & Venema, 1998).

Nevertheless, studies focusing on quantitative stock assessment in Tunisian reservoirs remain limited and fragmented, often restricted to descriptive analyses (Djemali et al., 2009; Mili et al., 2021). To accurately diagnose exploitation status and develop adaptive management strategies, it is essential to apply analytical stock assessment models tailored to local conditions (Poulet et al., 2012; Ricker, 1975; King, 2007).

The present study aims to address this gap by conducting an integrated assessment (Cadima, 2002) of biomass and exploitation status for key freshwater fish species—namely pikeperch, carp, mullet, barbel, roach, and rudd-across a representative set of Tunisian reservoirs (Siliana, Bir Mcherga, Sidi Saad, Lahjar, Kasseb, Sidi Barrak, and Sidi Salem).

The methodology combines standardized scientific sampling using multi-mesh gillnets, in accordance with the CEN (2015) standard, to analyze population structure (Rousseau et al., 1985), alongside the use of commercial catch data to estimate fishing mortality (Nelson, 1994; Guillard, 1991; Hewitt et al., 2007). Cohort analysis models (e.g., Powell–Wetherall) and length–weight relationships are applied to estimate growth parameters, mortality rates, and exploitation levels (Gulland, 1983; Pauly, 1980; Hewitt et al., 2007). The results of this study are expected to provide a solid scientific basis for developing management strategies aimed at optimizing fishery yields while ensuring long-term sustainability.

Methods and Materials

Study Area and Sampling Periods

The study was conducted in eight Tunisian reservoirs that are representative of the country's main artificial lakes and account for a significant proportion of national inland fishery production: Lahjar, Bir Mcherga, Sidi Salem, Sidi Barrak, Kasseb, Siliana, Sidi Saad, and Mellegue (Figure 1) (Soudoud, 2006).

Sampling surveys were carried out over a three-year period (2013–2016), during both spring and autumn seasons at each site, in order to capture seasonal variability in fish communities (Rousseau et al., 1985; Poulet et al., 2012; Laouar, 2019).

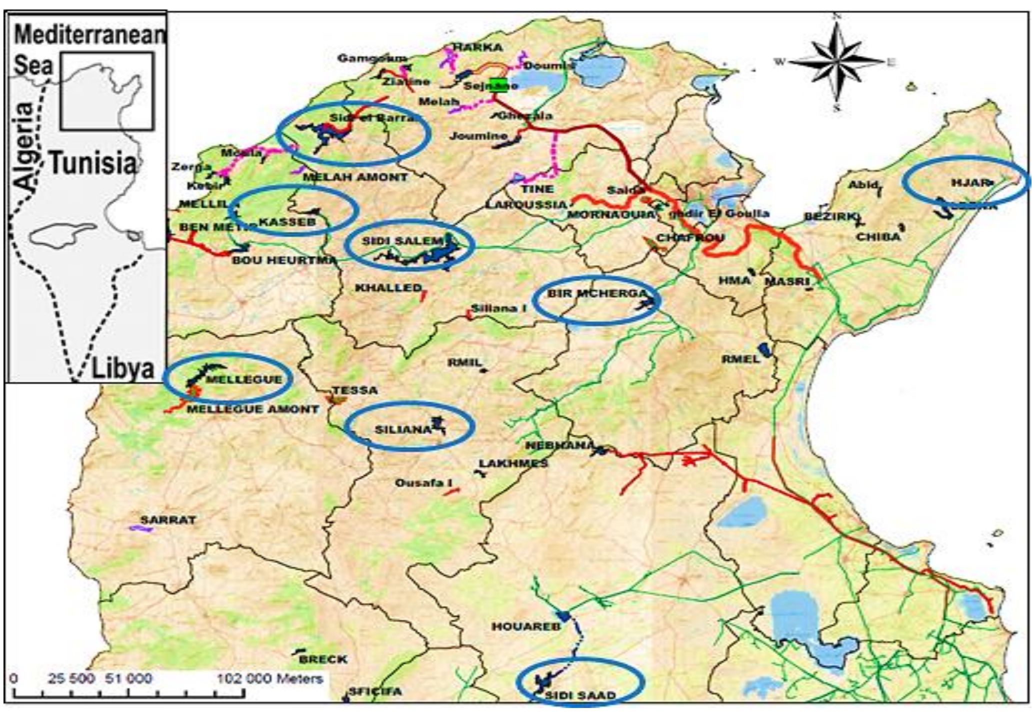

Figure 1: Geographical map of the main dam reservoirs in Tunisia, highlighting the eight study sites.

Ichthyological sampling

Fish community assessment was conducted using multi-mesh gillnets, a standardized passive sampling method widely applied for the quantitative assessment of freshwater fish communities (CEN, 2015; Appelberg et al., 1995). This approach was adapted from protocols developed in Scandinavia and subsequently applied to lentic ecosystems in North Africa (Rousseau et al., 1985; Guillard, 1991; Djemali et al., 2009; Mili et al., 2016).

Two types of gillnets were employed:

- **Benthic gillnets:** Measuring 20 m in length and 1.5 m in height, composed of eight contiguous panels with stretched mesh sizes of 18, 24, 28, 35, 40, 55, 70, and 80 mm.
- **Pelagic gillnets:** Deployed within the water column to target pelagic species, with a height of 6 m and identical mesh size ranges (Mili et al., 2016).

All reservoirs were sampled following a standardized protocol. During each sampling event, both benthic and pelagic multi-mesh gillnets were used. Nets were set at dusk and retrieved at dawn, corresponding to approximately 12 hours of soaking time, in order to capture the nycthemeral activity peaks of fish species. This ensured consistency in sampling effort in terms of gear type, soaking duration, and seasonal coverage.

The nets were deployed using a stratified design to effectively sample different habitats and depth zones within each reservoir.

Catch processing

For each captured individual, the following parameters were recorded: Species identification, Total length (Lt), measured to the nearest millimetre, Total weight (W), measured to the nearest 0.1 g, Sex, Gonadal maturity stage. Species identification was carried out using the taxonomic keys of Kraïem (1998).

Population parameter analysis

Length-frequency data constituted the basis for population dynamics analyses. These analyses were performed using FISAT II (FAO-ICLARM Stock Assessment Tools), version 1.2.2 (Gayanilo et al., 2005; FAO, 2005).

Growth

Individual growth was modelled using the von Bertalanffy (1938) growth equation:

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

where: L_t is the length at age t; $L\infty$ is the theoretical asymptotic length. K is the growth coefficient ($year^{-1}$). T_0 is the theoretical age at zero length.

Initial estimates of L∞L_\inftyL∞ and KKK were obtained using the Wetherall plot method, and subsequently refined using the ELEFAN I algorithm integrated within FISAT II (FAO, 2005).

Length-weight relationship

The relationship between length (L in cm) and weight (W in g) was established for each species and site using the equation (Nelson, 1994): $W = aL^b$

The coefficients a (condition factor) and b (allometric growth exponent) were estimated using linear regression on logarithmically transformed data ($\log W = \log a + b \log L$).

Mortality

Total mortality (Z) was estimated using the linearised catch curve method (Pauly, 1984), based on length frequencies converted to relative ages (Hewitt et al., 2007). Natural mortality (M) was estimated using two complementary approaches for greater robustness:

- The empirical equation of Pauly (1980): $\log_{10}(M) = -0.0066 - 0.279 \log_{10}(L\infty) + 0.6543 \log_{10}(K) + 0.4634 \log_{10}(T)$, where T is the mean annual water temperature (°C).
- The formula of Then et al. (2015) is as follows: $M = 4.899\ t_{max}^{-0.916}$; where t_{max} is the maximum observed age for the species. This is a recent method that is considered to be more reliable.
- When multiple estimates of natural mortality were available (e.g., from Pauly 1980 and Taylor 1959), the final M value used in stock assessment was taken as the arithmetic mean of the two estimates, as recommended for data-limited assessments to reduce method-specific bias.

Finally, fishing mortality (F) was derived by difference: $F = Z - M$ (Hewitt et al., 2007).

Stock assessment

The exploitation status of the stocks was assessed using the yield per recruit analytical model (Beverton & Holt, 1957), implemented via the VIT software (version 1.1, IEO-CSIC) (Lleonart & Salat, 1992; Cadima, 2002). This model is particularly suited to situations with limited data.

The following parameters were used as inputs: growth parameters ($L\infty$, K, t_0), natural mortality (M), mean length at first capture (Lc), and mean length at recruitment (Lr) (Nelson, 1994; Hewitt et al., 2007). The model allows the calculation of Yield per recruit (Y/R), biomass per recruit (B/R), and exploitation rate ($E = F/Z$). Stock status was interpreted by comparing the current exploitation rate (E) to conventional reference points.

- $E < 0.5$: under-exploitation
- $E = 0.5$: optimal exploitation (corresponding to E_{max}, Maximum Sustainable Yield (MSY)).
- $E > 0.5$: over-exploitation

Data analysis

Statistical analyses and restructuring of length-frequency distributions were performed using FISAT II (FAO, 2005) and R software (version 4.0.2). Results are presented as mean ± standard deviation.

Results

I. Population dynamics and stock assessment of common carp (C. carpio) in Sidi Saad and Bir Mcherga reservoirs

Growth and Mortality Parameters

The key biological parameters used for the stock assessment of C. carpio in Sidi Saad and Bir Mcherga reservoirs are presented in Table 1. The results indicate similar growth patterns between the two populations, with an estimated asymptotic length (L∞L_\inftyL∞) of 60.05 cm. The growth coefficient (K=0.157K = 0.157K=0.157 year^{-1}) and the theoretical age at zero length (t0=−0.920t_0 = -0.920t0=−0.920) suggest a moderate growth rate, which is typical for this species in freshwater reservoir environments. Natural mortality (M) was estimated using two empirical models. Taylor's method (1959) produced a consistent estimate of 0.17 year^{-1} for both reservoirs. In contrast, Pauly's model (1980), which incorporates environmental temperature, yielded slightly higher values of 0.36 year^{-1} for Sidi Saad and 0.34 year^{-1} for Bir Mcherga. The final values retained for analysis were the averages of these estimates: 0.26 year^{-1} for Sidi Saad and 0.25 year^{-1} for Bir Mcherga (Table 1). The differences between estimation methods highlight the influence of environmental variability on mortality rates and emphasize the importance of using multiple approaches for more reliable assessment.

Table 1: Biological parameters of C. carpio in Sidi Saad and Bir *Mcherga reservoirs*.

Parameter	Value
L∞ (cm)	102.2
K (year^{-1})	0.23
t_0	-0.055
a	0.0106
b	2.937
M (Taylor, 1959)	0.231
M (Pauly, 1980)	0.391
M (Average)	0.31

*(M = natural mortality).

Stock structure and dynamics

Analysis of the Cyprinus carpio population in Sidi Saad Reservoir in 2015 estimated the stock size at 7,806 individuals, with a total biomass of 238.99 tonnes. The critical length and age corresponding to the maximum cohort biomass were estimated at 30 cm and 3.47 years, respectively. In the absence of fishing pressure, these values would increase to 37 cm and 5.15 years, indicating the impact of exploitation on population structure.

Stock dynamics are primarily driven by individual growth, which accounts for 90.33% of biomass gains, while recruitment contributes only 9.67%. Biomass losses are almost equally distributed between natural mortality (M = 51.51%) and fishing mortality (F = 48.49%), reflecting substantial fishing pressure on the stock. The annual biomass renewal rate (turnover) is estimated at 51.34%. Spawning stock biomass (SSB), a key indicator of reproductive capacity, is relatively high at 208.78 tonnes.

In contrast, the carp stock in Bir Mcherga Reservoir is considerably smaller, with an estimated population of 1,118 individuals and a mean biomass of 42.08 tonnes. The critical length and age (32 cm and 3.90 years, respectively) are slightly higher than those observed in Sidi Saad. However, the corresponding values for an unfished (virgin) stock remain identical (37 cm and 5.15 years), suggesting similar biological growth potential but differing exploitation regimes.

As in Sidi Saad, biomass gains in Bir Mcherga are predominantly driven by growth (91.84%), with recruitment playing a minor role. However, the mortality structure differs markedly, as natural mortality dominates (70.01%) compared to a lower contribution from fishing mortality (29.99%). The biomass renewal rate is also lower, at 43.82%. Spawning stock biomass (SSB) is estimated at 38.64 tonnes, indicating a reduced reproductive capacity relative to Sidi Saad.

3. Exploitation status assessment

Analysis of yield per recruit (Y/R) using the Beverton and Holt (1957) model, implemented in VIT software, provides a robust framework for assessing stock exploitation status.In Sidi Saad Reservoir, the current yield per recruit (Y/R = 109.36) lies on the ascending portion of the yield curve. When combined with an exploitation rate (E = F/Z) of 0.48, this indicates that the stock is approaching optimal exploitation (E ≈ 0.5), which corresponds to the Maximum Sustainable Yield (MSY). However, as this threshold has not yet been reached, the results suggest that a moderate increase in fishing effort could enhance yields without immediately compromising stock sustainability.

In Bir Mcherga Reservoir, the yield per recruit (Y/R = 113.94) also falls within the ascending phase of the yield curve, while the exploitation rate is notably lower (E = 0.30). This clearly indicates a state of under-exploitation. Furthermore, the biomass per recruit (B/R) is substantially higher in Bir Mcherga (614.66) compared to Sidi Saad (439.27), confirming that a significant portion of the stock's productive potential remains underutilized. The analysis of spawning stock biomass per recruit (SSB/R) relative to total biomass per recruit (B/R) reveals distinct dynamics between the two reservoirs (Table 2). These differences likely reflect variations in population structure, as well as differences in fishing pressure and selectivity, particularly with respect to the size classes being targeted.

Table 2: Key indicators of *C. carpio* stock status in Sidi Saad and Bir Mcherga reservoirs.

Indicator	Sidi Saad	Bir Mcherga
Population size (individuals)	7,806	1,118
Mean biomass - B (t)	238.99	42.08
Spawning biomass - SSB (t)	208.78	38.64
Fishing mortality (F)	0.27	0.23
Natural mortality (M)	0.26	0.25
Exploitation rate (E = F/Z)	0.48	0.30
Yield per recruit - Y/R	109.36	113.94
Diagnosis	**Optimal exploitation**	**Under-exploitation**

A comparison between the two reservoirs highlights clear differences in the structure and exploitation patterns of Cyprinus carpio stocks.

The substantially higher biomass per recruit (B/R) observed in Bir Mcherga suggests more favorable environmental conditions, potentially linked to higher trophic productivity or lower fishing pressure. This under-exploited status indicates a capacity to increase fishing effort; however, it also raises important questions regarding potential limiting factors, such as recruitment variability, habitat constraints, or management inefficiencies that may be restricting optimal stock utilization.

In contrast, the stock in Sidi Saad, although characterized by a significantly larger total biomass, exhibits a lower biomass per recruit, reflecting a higher level of exploitation. With an exploitation rate approaching the optimal threshold, this stock appears to be managed at or near optimal levels. This suggests that current fisheries management practices at this site are relatively effective in balancing exploitation and sustainability.

Nevertheless, the relatively high contribution of fishing mortality (48.49%) warrants careful monitoring. Any further increase in fishing pressure could shift the stock toward over-exploitation. Therefore, maintaining current effort levels, combined with continuous monitoring and adaptive management, is essential to prevent stock depletion and ensure long-term sustainability.

II. Population dynamics and stock assessment of thin-lipped grey mullet (C. ramada) in Sidi Saad and Siliana reservoirs

Growth and Mortality Parameters

The biological parameters of C. ramada are presented in Table 3. Growth is identical in both reservoirs, with an asymptotic length ($L\infty$) of 39.7 cm and a growth coefficient (K) of 0.164 year^{-1}, indicating a similar growth pattern for this species in both ecosystems.

However, the length-weight relationships differ notably, particularly concerning the parameter a (0.0169 in Sidi Saad and 0.0053 in Siliana), which suggests that there are differences in body condition and morphology that are potentially related to variations in the availability of food sources between the two sites. Natural mortality (M) was estimated using both Taylor's (1959) and Pauly's (1980) methods. Pauly's method, which incorporates temperature, yields higher and more variable values, likely reflecting its better suitability to local environmental conditions. The average values obtained were 0.28 year^{-1} for Sidi Saad and 0.29 year^{-1} for Siliana (Table 3).

Table 3: Biological parameters of *C. ramada* in Sidi Saad and Siliana reservoirs.

Parameter	Sidi Saad	Siliana
L∞ (cm)	39.7	39.7
K (year^{-1})	0.164	0.164
t_0	-1.513	-1.513
A	0.0169	0.0053
B	2.777	3.189
M (Taylor, 1959)	0.179	0.179
M (Pauly, 1980)	0.390	0.400
M (Average)	0.28	0.29

*(M = natural mortality).

Stock structure and dynamics

The Chelon ramada population in Sidi Saad Reservoir is estimated at 118,997 individuals, corresponding to a substantial mean biomass of 199.03 tonnes. The population dynamics are almost entirely driven by individual growth, which accounts for 99.5% of biomass gains. This pattern is consistent with the species' biological characteristics, as it does not reproduce in freshwater environments and is therefore fully dependent on stocking operations for population maintenance.

Mortality is predominantly natural (91.22%), while fishing mortality remains low (F = 8.78%), indicating minimal exploitation pressure. The annual biomass renewal rate (30.7%) is entirely reliant on stocking, further emphasizing the artificial regulation of this population.

In Siliana Reservoir, the mullet population is considerably larger, with an estimated 585,646 individuals and a mean biomass of 469.96 tonnes. Similar to Sidi Saad, stock dynamics are primarily driven by growth (71.82% of biomass gains), while mortality is largely natural (90.75%). Although fishing pressure remains low (9.25%), it is slightly higher than that observed in Sidi Saad.

The biomass renewal rate in Siliana (31.96%) is comparable to that in Sidi Saad, reflecting a similar management strategy based on continuous stocking. Overall, these findings confirm that C. ramada populations in both reservoirs are highly dependent on artificial stocking rather than natural recruitment processes.

Exploitation Status Assessment

Yield-per-recruit (Y/R) analysis indicates a pronounced state of under-exploitation for Chelon ramada in both reservoirs (Table 4).

In Sidi Saad Reservoir, the current yield per recruit is relatively low (Y/R = 6.27), while the corresponding biomass per recruit remains substantial (B/R = 232.39). This combination reflects a lightly exploited stock with considerable scope for increasing fishing effort without immediately compromising sustainability.

In Siliana Reservoir, a similar pattern is observed, but with significantly higher production potential. The current yield per recruit (Y/R = 17.53) exceeds that of Sidi Saad and remains on the ascending portion of the yield curve, indicating that the stock has not yet reached its optimal exploitation level. Moreover, the exceptionally high biomass per recruit (B/R = 592.62) highlights a largely untapped capacity for sustainable yield enhancement (Table 4).

In both reservoirs, spawning stock biomass per recruit (SSB/R) is markedly lower than total biomass per recruit (B/R). This pattern is consistent with the biological characteristics of the species, which does not reproduce within freshwater reservoirs. As a result, recruitment is entirely dependent on artificial stocking and remains independent of local spawning biomass.

Table 4: Key indicators of the *C. ramada* stock status in Sidi Saad and Siliana reservoirs.

Indicator	Sidi Saad	Siliana
Population size (individuals)	118,997	585,646
Mean biomass - B (t)	199.03	469.96
Fishing mortality (F)	0.09	0.10
Natural mortality (M)	0.28	0.29
Exploitation rate (E = F/Z)	0.09	0.10
Yield per recruit - Y/R	6.27	17.53
Biomass per recruit - B/R	232.39	592.62
Diagnosis	**Under-exploitation**	**Under-exploitation (high potential)**

Comparing the two reservoirs highlights the success of stocking operations, particularly in Siliana, where the stock biomass is substantial. Similar growth parameters suggest favourable and comparable environmental conditions for Mugil cephalus (or the target mullet species) in both reservoirs. However, C. ramada stocks remain under-exploited. Fishing mortality accounts for only 9% of total mortality, indicating that the majority of produced biomass is not being harvested. This represents a loss of zootechnical resources (fingerlings) and a missed economic opportunity.

The extremely high biomass per recruit in Siliana indicates that this reservoir provides optimal trophic conditions for the species. A rational and controlled increase in fishing effort, specifically targeting mullet, would allow the exploitation rate (E) to approach 0.5 (E_{max}), thereby increasing yields without compromising stock sustainability. A site-specific management strategy based on these quantitative assessments is therefore essential to optimise the socio-economic contribution of this fishery.

III. Population dynamics and stock assessment of barbel (L. callensis) in Sidi Barrak, Kasseb and Bir Mcherga reservoirs

Growth and Mortality Parameters

The biological parameters of L. callensis are presented in Table 5. Sidi Barrak and Kasseb reservoirs exhibit identical growth parameters ($L\infty$ = 68.25 cm; K = 0.076 $year^{-1}$), indicating comparable environmental conditions for growth at these two sites. Bir Mcherga reservoir shows slightly different values ($L\infty$= 71.01 cm; K = 0.077 $year^{-1}$), indicating distinct growth potential.

Table 5: Biological parameters of L. callensis in Sidi Barrak, Kasseb and Bir Mcherga reservoirs.

Parameter	Sidi Barrak	Kasseb	Bir Mcherga
$L\infty$ (cm)	68.25	68.25	71.01
K ($year^{-1}$)	0.076	0.076	0.077
t_0	1.858	1.858	2.075
A	0.0227	0.0227	0.0196
B	2.984	2.984	2.816
M (Taylor, 1959)	0.073	0.073	0.073
M (Pauly, 1980)	0.21	0.21	0.224
M (Average)	0.14	0.14	0.15

*(M = natural mortality).

The natural mortality (M) estimated according to Pauly (1980) is higher than that estimated by Taylor (1959), which reflects the influence of temperature on this parameter. The average values used in the analyses were 0.14 per year for Sidi Barrak and Kasseb, and 0.15 per year for Bir Mcherga (Table 5).

2. Stock Structure and Dynamics

The barbel population in Sidi Barrak is estimated at 177,452 individuals, with an average biomass of 51.29 tonnes. It is a slow-growing population (K = 0.076 $year^{-1}$) with a high longevity, as reflected by an average age at capture of 10.55 years. Stock dynamics are primarily driven by growth (58.75% of gains) rather than recruitment. Fishing mortality (57.76%) slightly exceeds natural mortality (42.24%), indicating considerable fishing pressure on this stock.

In Kasseb, the population is larger in number (191,360 individuals) but exhibits a much lower biomass (14.99 tonnes), suggesting a population structure dominated by younger age classes. Unlike Sidi Barrak, biomass dynamics are mainly driven by recruitment (59.63%). Fishing pressure is particularly intense, with fishing mortality accounting for 70.09% of total mortality.

Bir Mcherga hosts the largest barbel population (848,683 individuals) and shows an intermediate biomass of 21.01 tonnes. As in Sidi Barrak, biomass gains are predominantly driven by growth (82.62%). Fishing pressure remains high, with fishing mortality representing 66.3% of total mortality.

Exploitation status assessment

Yield per recruit (Y/R) analysis reveals contrasting situations among the three reservoirs (Table 6). Sidi Barrak shows the highest yield per recruit (Y/R = 530.27), yet the stock remains under-exploited despite relatively high fishing pressure. The exceptionally high biomass per recruit (B/R = 2,769.49) indicates a robust stock with strong production potential.

Kasseb presents an intermediate situation, with an under-exploited stock and a more moderate biomass per recruit (B/R = 547.75). In contrast, Bir Mcherga exhibits the lowest yield (Y/R = 81.78) and biomass per recruit (B/R = 277.12), indicating a low level of exploitation but also reduced stock productivity compared with the other reservoirs.

Table 6: Key indicators of L. callensis stock status in Sidi Barrak, Kasseb and Bir Mcherga reservoirs.

Indicator	Sidi Barrak	Kasseb	Bir Mcherga
Population size	177,452	191,360	848,683
Mean biomass - B (t)	51.29	14.99	21.01
Fishing mortality (F)	0.19	0.33	0.29
Natural mortality (M)	0.14	0.14	0.15
Exploitation rate (E = F/Z)	0.58	0.70	0.66
Yield per recruit - Y/R	530.27	179.69	81.78
Biomass per recruit - B/R	2769.49	547.75	277.12
Diagnosis	**Under-exploitation**	**Under-exploitation**	**Under-exploitation**

Comparing the three reservoirs reveals considerable variation in the structure and dynamics of L. callensis populations. The Sidi Barrak stock stands out due to its high biomass per recruit, suggesting that environmental conditions are favourable for the growth of this species.

While all stocks are classified as under-exploited based on the yield per recruit criterion, the relatively high exploitation rates in Kasseb and Bir Mcherga (E > 0.6) approach the conventional threshold for overexploitation (E = 0.5). This apparent contradiction can be explained by the methodology of yield per recruit analysis, which assesses potential yield relative to a theoretical optimum, whereas the exploitation rate reflects current fishing pressure (Table 6). The high proportion of fishing mortality in Kasseb (70.09%) and Bir Mcherga (66.3%) warrants particular attention. Although the stocks are currently under-exploited in terms of production potential, such levels of fishing pressure could threaten long-term sustainability, especially for a slow-growing species such as barbel.

IV. Population dynamics and stock assessment of pikeperch (S. lucioperca) in Siliana reservoir

Growth and mortality parameters

The biological parameters of S. lucioperca in Siliana reservoir are presented in Table 7. Analysis reveals growth characteristics typical of the species, including a high asymptotic length ($L\infty$) of 102.2 cm and a moderate growth coefficient (K) of 0.23 year^{-1}, indicating significant potential for individual growth. The length-weight relationship shows values consistent with those reported in the literature for this species.

Table 7: Biological parameters of *S. lucioperca* in Siliana reservoir.

Parameter	Value
$L\infty$ (cm)	102.2
K (year^{-1})	0.23
t_0	-0.055
a	0.0106
b	2.937
M (Taylor, 1959)	0.231
M (Pauly, 1980)	0.391
M (Average)	0.31

*(M = natural mortality).

Natural mortality (M) was estimated using the same methods. As has been observed for other species, the value obtained using Pauly's method, which incorporates temperature, is higher (0.391 year^{-1} compared to 0.231 year^{-1}). The average value of 0.31 year^{-1} was used for subsequent analyses (Table 7).

Stock Structure and Dynamics

The pikeperch stock in Siliana Reservoir is estimated at 1,630 individuals, with an average biomass of 21.53 tonnes. The population is characterised by a young structure, with a mean length of 25.86 cm and a mean age of 1.27 years. The critical length and age corresponding to maximum cohort biomass are estimated at 44 cm and 2.39 years, respectively.

Stock dynamics are predominantly driven by individual growth (98.22% of biomass gains), while recruitment contributes only marginally (1.78%). Losses are mainly attributable to fishing mortality (60.66%), which substantially exceeds natural mortality (39.34%). The annual biomass renewal rate (turnover) is particularly high at 79.08%, indicating strong productivity. Spawning stock biomass (SSB), which is essential for recruitment, is estimated at 14.22 tonnes.

Exploitation Status Assessment

Yield per recruit (Y/R) analysis using the Beverton and Holt (1957) model indicates that the pikeperch stock is currently under-exploited. The present yield per recruit (Y/R = 162.47) lies within the ascending phase of the production curve, suggesting that a controlled increase in fishing effort could move the stock closer to its maximum sustainable yield (MSY) (Table 8).

However, the exploitation rate (E = F/Z = 0.61) exceeds the conventional threshold of 0.5, which is typically associated with optimal exploitation. This apparent inconsistency with an under-exploitation diagnosis can be explained by the high productivity of the species and the substantial renewal rate of the stock (79.08%), which allows it to sustain relatively high fishing pressure while still retaining unexploited production potential.

The analysis of biomass per recruit (B/R = 338.70) and spawning biomass per recruit (SSB/R = 223.77) shows that spawning biomass represents a substantial proportion of total biomass, although it remains lower than total biomass (Table 8), reflecting the predominantly young structure of the population.

Table 8: Key indicators of S. lucioperca stock status in Siliana reservoir.

Indicator	Value
Population size (individuals)	1,630
Mean biomass - B (t)	21.53
Spawning biomass - SSB (t)	14.22
Fishing mortality (F)	0.48
Natural mortality (M)	0.31
Exploitation rate (E = F/Z)	0.61
Yield per recruit - Y/R	162.47
Biomass per recruit - B/R	338.70
Renewal rate	79.08%
Diagnosis	**Under-exploitation**

Pikeperch is a species of high commercial value in Tunisian reservoirs. The results indicate that the Siliana Reservoir stock is highly productive and retains significant under-exploited production potential. However, the relatively high proportion of fishing mortality (60.66%) and the elevated exploitation rate (E = 0.61) may initially suggest a risk of overexploitation. Nevertheless, its position on the yield-per-recruit curve and its high renewal rate (79.08%) indicate considerable resilience (Table 8).

This resilience can be attributed to the species' biological characteristics, including rapid growth and early maturation, which enable it to withstand relatively high levels of exploitation. The young population structure (mean age of 1.27 years) further supports this interpretation.

V. Population dynamics and stock assessment of rudd (S. erythrophthalmus) in Sidi Salem and Siliana reservoirs

Growth and Mortality Parameters

The biological parameters of S. erythrophthalmus, based on the work of Djemali (2005) and Mili et al. (2017), are presented in Table 9. The species exhibits relatively rapid growth (K = 0.379 year^{-1}) and has a moderate asymptotic length ($L\infty$ = 31.51 cm). The length-weight relationship indicates slightly positive allometric growth.

Table 9: Biological parameters of S. erythrophthalmus according to Djemali (2005) and Mili et al. (2017).

Parameter	Value
$L\infty$ (cm)	31.51
K (year^{-1})	0.379
t_0	0.377
a	0.0107
b	3.068
M (Roff, 1984)	0.25
M (Taylor, 1959)	0.36
M (Average)	0.30

*(M = natural mortality).

Natural mortality (M) was estimated using the methods of Roff (1984) and Taylor (1959), yielding values of 0.25 and 0.36 year^{-1}, respectively. The average value of 0.30 year^{-1} was used for the analyses.

Stock structure and dynamics

The rudd population in Sidi Salem is estimated at 20,039 individuals, corresponding to a substantial biomass of 101.49 tonnes. Individual growth is the primary driver of stock dynamics (98.37% of gains), while recruitment contributes only marginally (1.63%). Fishing mortality (62.17%) significantly exceeds natural mortality (37.83%), indicating considerable fishing pressure. The annual renewal rate is high (79.31%), reflecting strong productivity.

In Siliana, the rudd population is much larger in number (1,608,516 individuals) but exhibits lower biomass (24.74 tonnes), suggesting a population structure dominated by juvenile individuals. As in Sidi Salem, growth is the main contributor to biomass gains (97.62%). Mortality is more balanced between natural causes (53.34%) and fishing (46.66%). The renewal rate remains relatively high at 56.24%.

Exploitation Status Assessment

Yield per recruit (Y/R) analysis indicates under-exploitation in both reservoirs (Table 10). In Sidi Salem, the current yield per recruit (Y/R = 28.68) lies within the ascending phase of the production curve, indicating untapped production potential despite considerable fishing pressure. In Siliana, a similar pattern is observed, with a higher yield per recruit (Y/R = 51.20), which also remains within the ascending phase.

Biomass per recruit (B/R) is higher in Siliana (B/R = 195.13) than in Sidi Salem (B/R = 58.16), suggesting more favourable conditions for biomass accumulation in the former reservoir.

Table 10: Key indicators of *S. erythrophthalmus* stock status in Sidi Salem and Siliana reservoirs.

Indicator	Sidi Salem	Siliana
Population size (individuals)	20,039	1,608,516
Mean biomass - B (t)	101.49	24.74
Fishing mortality (F)	0.49	0.27
Natural mortality (M)	0.30	0.30
Exploitation rate (E = F/Z)	0.62	0.47
Yield per recruit - Y/R	28.68	51.20
Biomass per recruit - B/R	58.16	195.13
Diagnosis	**Under-exploitation**	**Under-exploitation**

A comparison of the two reservoirs reveals contrasting population dynamics of rudd. The Sidi Salem stock, although smaller in number, exhibits higher total biomass due to the presence of larger individuals. In contrast, Siliana supports a very large population composed mainly of juveniles, resulting in lower total biomass (Table 10).

Despite the relatively high exploitation rate in Sidi Salem (E = 0.62), the diagnosis of under-exploitation in both sites can be explained by the high productivity of this species, as evidenced by elevated renewal rates (79.31% and 56.24%). This rapid renewal capacity enables rudd populations to withstand substantial fishing pressure while maintaining significant unexploited production potential.

VI. Population dynamics and stock assessment of roach (R. rubilio) in Sidi Salem, Mellegue and Lahjar reservoirs

Growth and Mortality Parameters

The biological parameters of R. rubilio used for stock assessment, as derived from the work of Djemali (2005) and Mili et al. (2017), are presented in Table 11. The species exhibits rapid growth (K = 0.383 year^{-1}) and has a moderate asymptotic length ($L\infty$ = 32.24 cm). The length-weight relationship indicates marked positive allometric growth.

Natural mortality (M) was estimated using the methods of Roff (1984) and Taylor (1959), yielding values of 0.25 and 0.38 year^{-1}, respectively. The average value of 0.31 year^{-1} was used for the analyses.

Stock structure and dynamics

The roach population in Sidi Salem is large in number (10,321,598 individuals), with an average biomass of 147.53 tonnes. Individual growth is the dominant driver of stock dynamics (92.71% of gains). Mortality is relatively balanced between natural causes (47.75%) and fishing (52.25%). The annual renewal rate is high (64.92%), indicating strong productivity.

Table 11: Biological parameters of *R. rubilio* according to Djemali (2005) and Mili et al. (2017).

Parameter	Value
$L\infty$ (cm)	32.24

K (year^{-1})	0.383
t_0	0.088
a	0.0066
b	3.1878
M (Roff, 1984)	0.25
M (Taylor, 1959)	0.38
M (Average)	0.31

*(M = natural mortality).

In Mellegue, the roach population is smaller (28,900 individuals) but exhibits a substantial biomass (5.65 tonnes), suggesting the presence of larger individuals. Growth is the primary contributor to biomass gains (88.45%). Mortality is nearly balanced between natural causes (50.76%) and fishing (49.24%). The renewal rate is 61.07%.

The sampled population in Lahjar is smaller (7,857 individuals), with a biomass of 1.87 tonnes. The relative contribution of recruitment is higher (38.12%) compared with the other sites. Fishing mortality slightly exceeds natural mortality, at 54.72% and 45.28%, respectively. The renewal rate is the highest among the three reservoirs, at 68.46%.

Exploitation Status Assessment

Yield per recruit (Y/R) analysis reveals a state of under-exploitation in all reservoirs (Table 12). In Sidi Salem, the current yield per recruit (Y/R = 52.07) lies within the ascending phase of production. In Mellegue, a slightly higher yield per recruit is observed (Y/R = 58.77), which also remains in the ascending phase. In Lahjar, the highest yield per recruit is recorded (Y/R = 79.25), and it likewise falls within the ascending phase of the production curve.

Table 12: Key indicators of the R. rubilio stock status in Sidi Salem, Mellegue and Lahjar reservoirs.

Indicator	Sidi Salem	Mellegue	Lahjar
Population size (individuals)	10,321,598	28,900	7,857
Mean biomass - B (t)	147.53	5.65	1.87
Fishing mortality (F)	0.34	0.30	0.38
Natural mortality (M)	0.31	0.31	0.31
Exploitation rate (E = F/Z)	0.52	0.49	0.55
Yield per recruit - Y/R	52.07	58.77	79.25
Biomass per recruit - B/R	153.51	195.43	211.56
Diagnosis	**Under-exploitation**	**Under-exploitation**	**Under-exploitation**

A comparison of the three reservoirs reveals contrasting population structures for roach. Sidi Salem supports a very large population with substantial biomass, whereas Mellegue and Lahjar contain much smaller populations composed of larger individuals (Table 12).

Despite relatively high exploitation rates (E = 0.49-0.55), the diagnosis of under-exploitation at all three sites can be explained by the high productivity of this species, as evidenced by elevated renewal rates (61.07–68.46%). This rapid renewal capacity enables roach populations to withstand considerable fishing pressure while maintaining significant untapped production potential.

Discussion

This study represents the most comprehensive assessment to date of the status of the main fish stocks in Tunisian reservoirs. It covers six key species across eight dam reservoirs. The results reveal a complex situation in which widespread under-exploitation coexists with specific management challenges, highlighting the need for a differentiated and adaptive management approach.

The methodological framework, based on standardised protocols (CEN, 2015) and combining complementary assessment techniques such as cohort analysis and production modelling, constitutes a significant improvement over previous studies. The consistency of the results with those of Djemali (2005), Laouar (2019), Mili et al. (2016), and Mili et al. (2021) supports the robustness of the estimates and provides updated reference data for Tunisian inland fisheries.

The use of multiple natural mortality estimation methods (Pauly, 1980; Taylor, 1959; Roff, 1984) helps reduce the uncertainty associated with individual approaches. The resulting values (0.25–0.31 $year^{-1}$) are consistent with both the international literature (Mehner et al., 2005; Boisneau & Mennesson-Boisneau, 2001; Lammens, 2001; Lorenzoni et al., 2002) and studies specific to the Tunisian context (Toujani, 1998; Kraiem, 1994; Djemali, 2005; Mili et al., 2022; Mili et al., 2023).

The observed interspecific and inter-site variability highlights the importance of abiotic and biotic factors in structuring fish communities. As reported by Djemali et al. (2010), Guillard (1991), and Ben Rejeb-Jenhani et al. (2019), reservoir morphometry, trophic productivity, and hydrological connectivity play key roles in determining carrying capacity and stock productivity.

For native species such as barbel, population structure reflects watershed characteristics and connectivity with tributary streams. These findings corroborate the observations of Kraiem (1994) and Mili et al. (2015) regarding the importance of river inputs in sustaining native cyprinid populations.

In contrast, for introduced species such as common carp and pikeperch, successful establishment depends on the degree of match between ecological requirements and reservoir conditions (M'Hetli, 2001; Laouar, 2019). The strong performance of pikeperch in Siliana confirms previous findings (Toujani, 1998; M'Hetli, 2001; Laouar et al., 2016) regarding the species' high potential in large Tunisian reservoirs.

The under-exploitation of these high-value commercial species represents a significant economic opportunity; however, a cautious and controlled management approach is required (Lammens, 2001). As recommended by Mili et al. (2015), Laouar (2019), and Mili et al. (2021), the development of their exploitation should be accompanied by strengthened monitoring systems, including regular assessment of population structure and exploitation rates.

The contrast between successful stocking operations (Mili et al., 2013; Romdhane et al., 2019) and the current under-exploitation of stocks highlights a gap between production efforts and resource utilisation. As emphasised by Mili et al. (2023), improved coordination between the Technical Aquaculture Centre (CTA) and professional fishers is essential to optimise the return on investment.

The under-exploited potential of forage species such as rudd and roach, traditionally considered secondary, offers promising opportunities for diversifying fisheries. Their high productivity (Mili et al., 2017) makes them suitable candidates for sustainable exploitation, provided that appropriate management measures are implemented (Poulet et al., 2012; King, 2007).

Overall, the results support the adoption of an ecosystem approach to fisheries (EAF) for the management of Tunisian reservoirs. This approach should include: (i) differentiated management plans adapted to each reservoir's specific characteristics (morphometry, productivity, and fish community), as recommended by Chargui et al. (2021) and Poulet et al. (2012); (ii) optimisation of fishing effort based on stock-specific reference indicators (Chargui et al., 2021); (iii) economic valorisation of catches through diversification of exploited species and development of adapted marketing chains (Losse et al., 1992; Mtimet, 2010; Hajlaoui et al., 2022); and (iv) integration of conservation objectives, particularly for native species such as barbel, whose populations may be affected by fisheries development (King, 2007).

Despite these advances, several limitations should be acknowledged. The absence of long-term time series limits the analysis of interannual stock variability (Poulet et al., 2012). In addition, trophic interactions between species require further investigation (Cadima, 2002).

Future research should focus on the development of long-term monitoring programmes, the study of interspecific competition and predation, detailed economic evaluation of management scenarios, and the assessment of climate change impacts on reservoir productivity.

This study demonstrates that Tunisian reservoirs possess significant fishery potential that remains under-exploited. Realising this potential requires a refined, site-specific management strategy based on the ecological and biological characteristics of each system and stock.

The main recommendations are:

- gradual and controlled increase in fishing effort on under-exploited stocks;
- establishment of a permanent monitoring system for key stock indicators;
- development of value chains for all exploitable species;
- training of fishers in selective and sustainable fishing practices;
- integration of local and scientific knowledge into decision-making processes.

Implementing these recommendations would contribute significantly to the socio-economic development of rural areas while ensuring the long-term sustainability of inland fisheries resources in Tunisia.

Acknowledgements

We thank the AMBISEPT project collaborators (Technical Center of Aquaculture, Higher Institute of Marine Sciences of Bizerte, and General Directorate of Fisheries and Aquaculture, Tunisia) for their support, and the ISSMB and FSB students for their valuable assistance in the experimental work.

References

Appelberg, M., Berger, H.M., Hesthagen, T. et al. Development and intercalibration of methods in Nordic freshwater fish monitoring. Water Air Soil Pollut 85, 401–406 (1995). https://doi.org/10.1007/BF00476862

Ben Rejeb-Jenhani, A., Fathalli, A., Djemali, I., Changeux, T., & Romdhane, M.S., (2019). Tunisian reservoirs: diagnosis and biological potentialities. Aquat. Living Resour. 32, 17. https://doi.org/10.1051/alr/2019014

Beverton R.J.H. & Holt S.J., (1957). On the dynamics of exploited fish populations. U. K. Min. Agric. Fish., Fish. Invest. 2 (9): 533 p.

Boisneau P. & Mennesson-Boisneau C., (2001). Inland commercial fisheries management. Fisheries Manag Ecol. 8:303–310

Bruslé J. and Quignard J.P., (2001). Biologie des poissons d'eau douce européens. Collection aquaculture - pisciculture. 625p.

Cadima E-L., (2002). Manuel d'évaluation des ressources halieutiques. FAO Document technique sur les pêches. N° 393. Rome: 160 p.

Carter Rebecca., (2025). The Influence of Water Quality on Freshwater Fish Habitat and Reproduction. J. Fish. Res., 1-2, Allied Academies.

CEN (Comité Européen de Normalisation)., (2015). Water quality - Sampling of fish with multi-mesh gillnets (Norme NF EN 14757).

Chargui, T., Ennouri, R., Rjeibi, M., Fatnassi, M., Laouar, H., Romdhane, N., & Mili, S. (2025). What can fisheries managers learn from spatiotemporal assessment of freshwater fish populations in three Tunisian reservoirs: Lahjar, Kasseb and Siliana? Int. J. Lim., 61(5). https://doi.org/10.1051/limn/2025005

Chargui, T., Fatnassi, M., Ennouri, R., Zarrouk, H., Laouar, H., Romdhane, N., & Mili, S. (2021). Exploring freshwater fish assemblages and population structure in three Tunisian reservoirs for better fishery management. Biodiversity Int J. 2021., 5(2), 37–45. DOI: 10.15406/bij.2021.05.00196.

DGBGTH (Directorate General of Dams and Major Hydraulic Works)., (2021). Hydrological Yearbook of Tunisia. Ministry of Agriculture, Water Resources, and Fisheries of Tunisia. 123p.

DGPA (Directorate General of Fisheries and Aquaculture)., (2021). Directory of Fisheries and Aquaculture Statistics in Tunisia. Ministry of Agriculture, Water Resources, and Fisheries.

DGPA (Directorate General of Fisheries and Aquaculture)., (2023). Directory of Fisheries and Aquaculture Statistics in Tunisia. Ministry of Agriculture, Water Resources, and Fisheries. 145p

Djemali, I., (2005). Évaluation de la biomasse piscicole dans les plans d'eau douces tunisiens: Approche analytique et acoustique (Doctoral thesis in agricultural sciences). National Institute of Agronomy of Tunisia., p. 250

Djemali, I., Laouar, H., & Toujani, R., (2010). Distribution patterns of fish biomass by acoustic survey in three Tunisian man-made lakes. Journal of Applied Ichthyology., 26, 390-396.

Djemali, I., Toujani, R., & Guillard, J., (2009). Hydroacoustic fish biomass assessment in man-made lakes in Tunisia: horizontal beaming importance and diel effect. Aquatic Ecology., 43, 1121-1131.

El Bably, M. A., Emeash, H. H., & N Mohamed, A. (2010). Influence of water quality on fish productivity. J. Vet. Med. Res.., 20(1), 313-318.

FAO: Food and Agriculture Organisation., (2005). Série informatique Pêche: guide d'utilisation de FISAT II.

Gayanilo F-C., Sparre P. and Pauly D., (2005). FAO-ICLARM Outils d'évaluation des stocks II (FiSAT II). Version révisée. Guide d'utilisation. FAO Série informatique. Pêche. No. 8, Version révisée. Rome, FAO. 190 p.

Guillard J., (1991). Etude des stocks pisciaires lacustres par écho intégration : problèmes méthodologiques. Thèse doctorale univ. Lyon I., 148p.

Gulland, J.A., (1983). Fish stock assessment: a manual of basic methods. FAO/Wiley Series on Food and Agriculture.

Hajlaoui, W., Fatnassi, M., Mili, S., Ben Salem, S., Troudi, D., & Missaoui, H., (2022). Characterization of socio-economic fishing activity in Tunisian reservoir: Sidi Saad (centre of Tunisia), a case study. J. aquac. mar. biol., 11(3), 93-98. DOI:10.15406/jamb.2022.11.00342

Hewitt D.A., Lambert D.M., Hoenig J.M., Lipcius R.N., Bunnell D.B. and Miller T.J., (2007). Direct and Indirect Estimates of Natural Mortality for Chesapeake Bay Blue Crab. Transactions of the American Fisheries Society, 136:1030–1040.

King, M. (2007). Fisheries biology, assessment and management. Wiley-Blackwell, 2nd ed.

Kraiem M., (1994). Systématique, biogéographie et bio-écologie de *Barbus callensis* Valenciennes, 1842 (poisson, Cyprinidae) de Tunisie. Doctoral thesis in biological sciences of the Faculty of Sciences of Tunis. 227p.

Kraïem, M.M., (1998). Les poissons d'eau douce de Tunisie: peuplement, répartition et écologie. Bulletin de l'Institut National Scientifique et Technique d'Océanographie et de Pêche de Salammbô, 25, 111-134.

Lammens E.H.R.R., (2001). Consequences of biomanipulation for fish and fisheries, FAO, Fisheries Circular.

Laouar, H., (2019). Assessment of fishery resources in dam reservoirs in Tunisia: Intercalibration of acoustic and gillnet sampling (Doctoral thesis in Agronomic Sciences), National Agronomic Institute of Tunisia. p.133

Laouar, H., Marzouki, M., Briki, H., & Mili, S., (2016). Note technique sur la reproduction contrôlée du sandre *Sander lucioperca* en cages dans les retenues des barrages tunisiennes. Bulletin du CTA: Échos de l'aquaculture, 5, 10-13.

Lieorat J. & Salat J., (1992). VIT: Programa d'analisis de pesquerias. Informes Técnicos de Scientia Marina, 116 p.

Lorenzoni M., Dörr A.J.M., Erra R., Giovinazzo G., Mearelli M. & Selvi S., (2002). Growth and reproduction of largemouth bass (Micropterus salmoides Lacépède, 1802) in Lake Trasimeno (Umbria, Italy), Fish. Res., vol 56: 89-95.

Losse G.F., Nau W. and Winter M., (1992). Le développement de la pêche en eau douce dans le nord de la Tunisie. Étude effectuée dans le cadre de la coopération technique Tuniso-Allemande. Éditeurs GTZ Gmbh. 418 p.

Louati M. El H., Khanfir R., Alouini A., El Euchi M. L., Marzouk A. and Frigui L., (1998). Stratégie du secteur de l'eau en Tunisie à long terme (2030), République Tunisienne, Ministère de l'Agriculture. 97 p.

Malik, D. S., Sharma, A. K., Sharma, A. K., Thakur, R., & Sharma, M. (2020). A review on impact of water pollution on freshwater fish species and their aquatic environment. Advances in environmental pollution management: wastewater impacts and treatment technologies., 1, 10-28.

M'Hetli M., (2001). Le sandre *Stizostedion lucioperca* (Linnaeus, 1758), poisson allochtone: Étude biologique et essai d'optimisation des critères de l'élevage. Doctoral thesis in biological sciences of the Faculty of Sciences of Tunis.

Mehner, T., Diekmann, M., Brämick, U. & Lemcke, R., (2005). Composition of fish communities in German lakes as related to lake morphology, trophic state, shore structure and human-use intensity. Freshw. Biol.,50, 70-85.

Mili, S., Bouriga, N., Ennouri, R., Laouar, H., & Missaoui, H., (2013). Identification, répartition spatio-temporelle et caractérisation génétique des alevins de Muges ensemencés dans les retenues de barrages tunisiennes. Cybium, 37(1-2), 67-73.

Mili, S., Ennouri, R., Dhib, A., Laouar, H., Missaoui, H., & Aleya, L., (2016). Characterization of fish assemblages and population structure of freshwater fish in two Tunisian reservoirs: implications for fishery management. Environ. Monit. Assess., 188 (364),1-11.

Mili, S., Ennouri, R., Laouar, H., & Aleya, L., (2017). Optimization of fishing for stock enhancement of Rutilis rutilus and Scardinius erythropththalmus in forage fish-deficient Tunisian reservoirs. Environ. Monit. Assess., 189 (610), 1-12.

Mili, S., Ennouri, R., Laouar, H., & Missaoui, H., (2015b). Étude de l'âge et de la croissance chez deux espèces de Mugilidae (Mugil cephalus et Liza ramada) dans trois retenues de barrages en Tunisie. Bull. Soc. zool. Fr., 140(3), 181-197.

Mili, S., Ennouri, R., Laouar, H., & Missaoui, H., (2015a). Fisheries in the Tunisian dams: diagnosis of the current situation and development opportunities. FAO Fisheries and Aquaculture Proceedings: No. 39, eds. 2015. Rome. 95–106 pp.

Mili, S., Ennouri, R., Laouar, H., Khedhri, I., Zarrouk, H., Chargui, T., Romdhane, N., (2021). Freshwater Fish Farming and Fishery Management in Tunisian Reservoirs: Limitations and Opportunities. In F. Khebour Allouche, M. Abu-hashim & A.M. Negm, (eds), Agriculture Productivity in Tunisia Under Stressed Environment (pp. 309-334). Springer Water. Springer, Cham. https://doi.org/10.1007/978-3-030-74660-5_14

Mili, S., Hajlaoui, W., Ennouri, R., Fatnassi, M., & Laouar, H., (2022). Rapport technique sur l'échantillonnage des peuplements piscicoles au niveau des retenues de barrage en Tunisie moyennant des filets multimailles. Rapport technique transmis au Ministère de l'agriculture, des ressources hydrauliques et de la pêche. p. 217

Mtimet N., (2010). Analyse socioéconomique de la filière de la pisciculture continentale au nord –ouest de la Tunisie. Projet sauvegarder et valorisation socio-économique des ressources environnementale de la région nord-ouest de la Tunisie rapport Ministère l'agriculture et l'environnement Coopération italienne .15-30p.

Mustafa, Muhammad Hasnain, Al Sulivany, Basim. S. A., Albassam, Nuha Hameed, Yousif, Alan I., Al-Taee, Nidhal Tahseen Taha, Saeed, Kaynat, Hassan, Ali, Owais, Muhammad. Acute and Chronic Fluoride Exposure Impairs Blood Physiology, Immunity, and Metabolic Disruptions in Labeo rohita. Egypt. J. Aquatic Biol. Fish., 29 (5): 2429 – 2448, 2025.

Nelson J.S., (1994). Fishes of the world. 3rd ed. John Wiley and Sons, New York, 600 p.

Pauly D., (1980). A selection of simple methods for assessment of tropical fish stocks. Fisheries Circular, FIRM/C, 729: 1-54.

Pauly, D., (1980). On the interrelationships between natural mortality, growth parameters, and mean environmental temperature in 175 fish stocks. J. Cons. Inter. Expl. Mer., 39(2), 175-192.

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

Poulet N., Seon-Massin N. & Basilico L., (2012). Biodiversité aquatique : du diagnostic à la restauration. Synthèse du séminaire. Biodiversité aquatique : quelles pistes pour la gestion des rivières et plans d'eau. Paris, 46p.

Ricker, W.E., (1975). Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Board Can., 191.

Roff D A., (1984). The evaluation of life history in teleosts. Can. J. Fish Aquat. Sci., 41: 989-1000.

Romdhane, M. S., Fassatoui, C., Shaiek, M., Ben Rejeb Jenhani, A., & Changeux, T. (2019). Mugilid fisheries of Tunisian coasts and lagoons. Aquatic Living Resources, 32(6). https://doi.org/10.1051/alr/2019005

Rousseau B., Nelva A., Persat H. & Chessel D., (1985). Constitution d'une base de données ichtyologique par l'échantillonnage ponctuel d'abondance: application aux peuplements du Haut-Rhône français. Cybium, 9 (Z), 157-173.

Snoussi, M., Haïda, S., & Imassi, S., (2002). Effects of the construction of dams on the water and sediment fluxes of the Moulouya and the Sebou rivers, Morocco. Regional Environmental Change, 3(1-3), 5-12.

SOUDOUD., (2006). Large dams in Tunisia (Database). Ministry of Agriculture and Water Resources. Directorate General of Dams and Major Water Works. Tunisia.

Sparre, P., & Venema, S.C., (1998). Introduction to tropical fish stock assessment. Part 1: Manual. FAO Fisheries Technical Paper. No. 306.1, Rev.2.

Talas, Z. S., Gulhan, M. F., Erdogan, K., & Orun, I. (2014). Antioxidant effects of propolis on carp Cyprinus carpio exposed to arsenic: biochemical and histopathologic findings. Dis. Aquat. Organ., 108(3), 241-249.

Taylor, C. C., (1959). Temperature and growth: The Pacific razor clam. ICES Journal of the Conseil (Journal du Conseil International pour l'Exploration de la Mer), 25(1), 93–101. https://doi.org/10.1093/icesjms/25.1.93

Then, A. Y., Hoenig, J. M., Hall, N. G., & Hewitt, D. A., (2015). Evaluating the predictive performance of empirical estimators of natural mortality rate for fishes. ICES J. Mar. Science., 72(1), 82–92. https://doi.org/10.1093/icesjms/fsu136

Toujani, R., (1998). Le sandre (*Stizostedion lucioperca*) de la retenue de Sidi-Salem (Tunisie): Biologie et dynamique de population (Doctoral thesis in biological sciences). University Claude Bernard Lyon I. p.176

Von Bertalanffy, L., (1938). A quantitative theory of organic growth (inquiries on growth laws II). Human Biology, 10(2), 181–213.