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Under threat in North African reservoirs: The decline of the Algerian barb, *Luciobarbus callensis* (Actinopterygii, Cypriniformes, Cyprinidae), in Tunisia as a case study

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Abstract

Despite numerous studies on stocked freshwater fishes in Tunisian reservoirs, the population status of native species remains poorly documented. This study aims to address a critical knowledge gap by assessing the decline in the population of the endemic Algerian barbel, *Luciobarbus callensis* (Valenciennes, 1842), in Tunisian reservoirs. Standardized fishing operations involving multi-mesh gillnets conducted across 21 reservoirs between 2013 and 2023 revealed that *L. callensis* was present in only 11 of these reservoirs. This indicates a significant reduction in the species' range compared to historical records.

The species exhibited alarmingly low catch rates (CPUE < 50 fish per 1000 m^{-2} of nets), except in Bir Mcherga reservoir. The application of data-limited stock assessment methods (CMSY++ and LBB) demonstrates widespread overexploitation across all the reservoirs studied. Length-frequency analysis revealed critical mismanagement: while most of the specimens caught were below the biological maturity threshold, they remain legally exploitable under Tunisia's outdated minimum size limit.

The decline of *L. callensis* stocks is primarily driven by unsustainable fishing pressure, facilitated by outdated regulations and habitat degradation. These findings highlight the urgent need for a comprehensive conservation management plan to prevent the continued decline of this important native species.

Keywords

fish population, *Luciobarbus callensis*, decline, global changes, Tunisia

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Introduction

The majority of streams and reservoirs in Tunisia are located in the north of the country (Fig. 1). Fisheries in these reservoirs target a large number of fish species (Ben Rejeb Jenhani et al. 2019; Chargui et al. 2025). It plays a vital economic role, especially in the economically less developed areas of the country (Mili et al. 2015; Hajlaoui et al. 2025). As these fisheries resources are increasingly important, effective management is needed. This activity can only be maintained and developed by monitoring freshwater fish stocks in reservoirs.

While several studies have investigated the biology of stocked freshwater fishes in Tunisian reservoirs, data on the population status of native species remain scarce. Early foundational work by Losse et al. (1991) and Kraiem (unpublished[1]) documented several autochthonous species, including the Algerian barb, *Luciobarbus callensis* (Valenciennes, 1842); the European eel, *Anguilla anguilla* (Linnaeus, 1758); the phoxinel, *Tropidophoxinellus callensis* (Guichenot, 1850); as well as the North African cichlids, *Astatotilapia desfontainii* (Lacepède, 1802) and *Coptodon zillii* (Gervais, 1848). More recently, Mili et al. (2021, 2026) focused on the population status of the key native cyprinids, *L. callensis* and *T. callensis*, highlighting their vulnerability.

A research-development project was initiated in 2013 due to limited data on native fish populations and the need for effective management. This project was a collaboration between the Technical Centre of Aquaculture in Tunis and the Higher Institute of Marine Sciences in Bizerte (Mili et al. 2021). This project aims to update the freshwater fish database for Tunisian reservoirs and to develop a management plan for autochthonous and introduced fish in these reservoirs. The preliminary results presented by Mili et al. (2015, 2016, 2021) provided information about the freshwater fish in Tunisian reservoirs.

The genera *Barbus* (Cuvier, 1817) and *Luciobarbus* (Heckel, 1843) belong to the Cyprinidae family, which is one of the most abundant and diverse families in freshwater ecosystems (Zaccara et al. 2019). With more than 800 species, this group has one of the highest levels of species diversity among fish (Howes 1991; Doadrio 1994; Kraiem 1994; Freyhof et al. 2020; Fricke et al. 2025). The family is widely distributed across Africa, Europe and Asia (Kraiem 1998). Using osteological methodologies, Doadrio (1994) proposed the division of *Barbus* sensu lato into these two distinct genera. It is thought that the genus *Luciobarbus* originated in Asia, spreading to Africa and then, via the southern Mediterranean route, to the Iberian Peninsula and the Middle East (Kraiem 1998; Freyhof et al. 2020). Historically, taxonomists have relied on morphological and meristic features to distinguish between species within these genera (Boulenger 1911; Pellegrin 1939; Touil et al. 2019; Freyhof et al. 2020; Kraiem unpublished[1]).

Recent research confirms that the genus *Luciobarbus* is highly diverse and widespread across North Africa. It has been described as the most abundant and widespread genus of fish in many freshwater ecosystems of the Maghreb (Brahimi et al. 2017). This diversity is the result of a complex biogeographical history, including rapid radiation following significant geological changes to the Mediterranean region (Tsigenopoulos et al. 2003; Zaccara et al. 2019). This has been further elucidated by the description of numerous new species in Algeria and Morocco (Casal-López et al. 2015; Doadrio et al. 2016; Brahimi et al. 2018).

Luciobarbus callensis is an endemic species of North Africa, distributed across Morocco, Algeria, and Tunisia, primarily occurring from north to south of the Atlas Mountains (Zaccara et al. 2019; Kraiem unpublished[1]). Its name originates from Lake La Calle in Algeria, where the first specimen was found. While occasionally referred to by the vernacular name Tunisian barbel in local contexts (Losse et al. 1991), the species is more widely known as the Algerian Barb (Freyhof et al. 2020). On a global scale, it is categorized as Least Concern on the IUCN Red List (Freyhof and Ford 2022) due to its widespread presence in the region. This general status is reflected in Tunisia, where, despite the country's low native fish diversity, harboring only two species, *L. callensis* is common and widely distributed (Freyhof et al. 2020; Mili et al. 2021, 2026; Kraiem unpublished[1]; Laouar unpublished[2]). Its Tunisian range extends from the Ichkeul basin and Tabarka in the north to Kasserine in the south, at the upper limit of the arid zone. The species can be found in most rivers, often alongside other species (mainly *T. callensis*), and is frequently dominant. It inhabits the Mejerda stream and its tributaries, as well as the Miliane, Joumine, Melah, Sajnene (which flow into Lake Ichkeul), and the Oued Abid at Cap-Bon. In other watercourses, such as Oued Nebhana (north of Kairouan), Oued Hatab (Kasserine region), Oueds Zeroud, and Merg Ellil (south of Kairouan), *L. callensis* is the only native fish species present (Mili et al. 2017; Kraiem unpublished[1]). The other native Tunisian species is the rare desert barbel *Luciobarbus antinorii* (Boulenger, 1911), which is restricted to a southern oasis (Kraiem 1998).

According to Tunisian legislation (JORT 1995), the minimum legal catch size for this species is set at 15 cm. On the other hand, the size at which the fish reach sexual maturity is 26.5 cm in Tunisia and 27.7 cm in Algeria (Ould Rouis et al. 2012; Kraiem unpublished[1]).

This paper aims to assess population trends of the native species *L. callensis* in reservoirs formed by dam construction in Tunisia, and to examine the relationship between these trends and habitat alterations.

[1] Kraiem MM (1994) Systématique, biographie et bio-écologie de *Barbus callensis* Valenciennes, 1842 PhD thesis, University of Tunis, Tunisia.

[2] 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, Tunisia, 133 pp.

Material and methods

Sampling. Fish sampling was carried out using multi-mesh gill nets according to the methods used in the European prEN 14575 (CEN 2015) standard for lake fish monitoring. These nets, adapted to Tunisian reservoirs, have been used in Tunisia since 2013 (Mili et al. 2023; Laouar unpublished[2]). Sampling was performed with 20 m long and 1.5 m deep multi-mesh gillnets with eight different mesh sizes (18, 24, 28, 35, 40, 55, 70, and 80 mm, knot to knot) (Mili et al. 2021, 2023). This is the first time that the European standard method (Deceliere-Vergès and Guillard 2008; Argillier et al. 2013) has been used in Tunisian reservoirs.

A stratified sampling method was employed to account for the uneven spatial distribution of fish in reservoirs. In line with the CEN standard, depth ranges were categorized into five different strata: 0–3 m, 3–6 m, 6–12 m, 12–18 m, and >20 m. Each reservoir was divided into several localities along its longitudinal axis to capture the fish distribution gradient, which follows the nutrient concentration from the tributary to the dam (Vašek et al. 2004; Šmejkal et al. 2015). The number of nets deployed in each reservoir was determined based on the depth and surface area.

Following the CEN standard, the surveys were conducted during the spring season (from April 2013 to May 2023), a period when fish exhibit high mobility. To assess the spatial distribution and abundance of *L. callensis*, the surveys were conducted once in each reservoir, except for six reservoirs, where follow-up surveys were carried out after several years (Table 1). Fishing with multi-mesh nets was carried out in 21 reservoirs, located in different areas of Tunisia (Table 1, Fig. 1).

Nets were set in the late afternoon when fish swim intensively (Prchalová et al. 2010; Baran et al. 2021), left for approximately 12 h following the CEN standard, and removed the following morning.

Captured specimens were identified using Laouar (unpublished[2]) datasheets and FishBase (Froese and Pauly 2025), counted, and the total length was measured to the nearest millimeter. For each reservoir, catch per unit effort (CPUE) was calculated as the number of fish caught per 1000 m^2 of net.

Stock assessment. The two data-poor models used in this study, a total Length-based Bayesian model (LBB, Froese et al. 2017) and a Catch Maximum Sustainable Yield model (CMSY++, Froese et al. 2018), have been validated for data-poor fisheries (Froese et al. 2017; Froese et al. 2018; Froese et al. 2023).

The Length-based Bayesian Biomass (LBB) model represents a significant advancement in fishery science, offering a data-driven approach to estimating fish populations and informing sustainable management practices. In data-poor fisheries, like *L. callensis* in reservoirs, length-frequency data are often the primary type of data collected because they are relatively inexpensive and easy to collect (Chong et al. 2020).

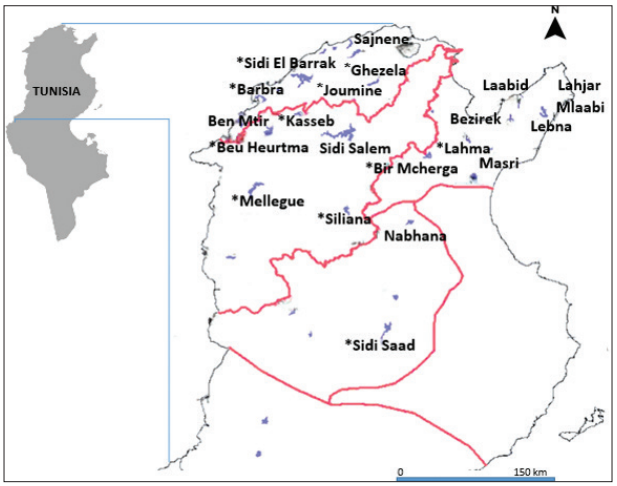

Figure 1. Location of Tunisian reservoirs and hydrological basins sampled in this study. Red line marks the border of hydrological basin; * denotes reservoirs where *Luciobarbus callensis* has been recorded.

The LBB model is a cornerstone of sustainable fisheries management, providing valuable insights into ecosystem health and resilience (Froese et al. 2018; Pons et al. 2019; Zhang et al. 2021; Meissa et al. 2021; Liao et al. 2022). Using length-based approaches, the LBB model provides reliable insights into the abundance and dynamics of *L. callensis* stocks in Tunisian reservoirs, which are critical for effective fisheries management and conservation efforts (Froese et al. 2017, 2018; Al-Mamun et al. 2022). This method was only used in 6 reservoirs (Bir Mcherga, Ghezela, Siliana, Kasseb, Sidi Saad, and Sidi Barrak) where reliable data on length frequencies were obtained. No commercial fishery exists for *L. callensis* in Tunisian reservoirs, and it is considered a bycatch species. In this data-limited context, we relied on standardized experimental gillnet fishing following the EN14757 protocol (CEN 2015), a method specifically designed for representative sampling in lentic systems.

The LBB analysis was run using the default settings within the bsmart R package (TropFishR package), which requires only the catch-length frequency data. The analysis assumes a logistic selectivity pattern and a standard value of the life-history parameter $M/k = 1.5$ [M = natural mortality rate (year^{-1}) and k = von Bertalanffy growth coefficient (year^{-1})], which is typical for teleost fishes (Froese et al. 2018; Hou et al. 2021). The R statistical software (R Core Team 2018) was used to apply the length-based Bayesian (LBB) model, using the LBB_33a.R script developed by Froese et al. (2018) (source: https://github.com/SISTA16/LBB).

The Catch Maximum Sustainable Yield model (CMSY++) provides a comprehensive insight into the health and sustainability of a fishery resource (Kuriyama et al. 2019). The model has demonstrated its versatility and utility (Lin and Shullman 2017), having been applied in fisheries management and conservation planning. The CMSY++ model is based on a time series of catches, an assumed value of the intrinsic population growth rate

Table 1. Characteristics of the reservoirs surveyed in Tunisia.

Reservoir	Year of construction	Max depth [m]	Area [ha]	Coordinates	Year of survey	Number of gillnets used
Barbara	1999	30	422	36°44′07″N, 08°32′04″E	2018	24
Bezirekh	1959	21	102	36°43′06″N, 10°37′36″E	2017	24
Bir Mcherga	1971	22	705	36°30′36″N; 10°00′38″E	2016	48
Bni Mtir	1954	78	350	36°44′56″N; 08°44′45″E	2018	64
Bouheurtma	1976	44	800	36°40′30″N, 8°47′21″E	2016	48
Ghezala	1984	40	122	36°03′30″N, 09°32′44″E	2017	24
Joumine	1983	31.5	660	36°59′23″N, 09°36′59″E	2019	48
Kasseb	1968	57.6	437	36°45′32″N, 09°0′20″E	2015, 2021	56
Laabid	2002	14	120	40°92′20″N, 09°32′80″E	2017	24
Lahjar	1960	13	254	36°50′52″N, 11°01′46″E	2017, 2021	24
Lebna	1986	22	650	36°44′01″N, 10°55′08″E	2017	28
Lhma	2002	25	160	36°35′32″N, 10°18′15″E	2019	24
Masri	1968	40	66	36°31′57″N, 10°29′25″E	2019	24
Mellegue	1954	65	1280	36°18′54″N, 08°42′00″E	2016	48
Mlaabi	1967	13.5	98	36°49′44″N, 10°59′07″E	2022	24
Nebhana	1965	62.5	532	36°03′34″N; 09°52′34″E	2018	24
Sajnene	1994	56.5	790	37°10′42″N, 09°28′25″E	2017	36
Seliana	1987	53	600	36°09′26″N, 09°20′55″E	2015, 2021	32
Sidi Barrak	1999	27	2734	37°00′41″N, 09°01′18″E	2013, 2022	64
Sidi Saad	1981	46	1700	36°35′31″N, 09°41′50″E	2016	64
Sidi Salem	1981	57	5521	36°35′26″N, 9°23′44″E	2014, 2023	108

(r_{max}: resilience), the proximity of the biomass to the carrying capacity (k), and qualitative information on the status of the stock at the beginning and end of the time series. The model allows estimation of MSY-producing biomass (B_{MSY}) and associated fishery reference points, including relative stock size (B/B_{MSY}), exploitation (F/F_{MSY}), intrinsic population growth rate (r_{max}) and carrying capacity (k) (Froese et al. 2017, 2018).

The prior for the intrinsic rate of population increase (r_{max}) was set to 1.44–4.4 year^{-1} for *L. callensis*, based on its medium resilience classification following FishBase (Froese and Pauly 2025). The prior for the relative biomass that can produce MSY (B_{MSY}) was set to 0.2–0.6 for teleost fishes, as recommended by Froese et al. (2017) for data-limited methods.

Both CMSY++ and LBB are increasingly recognized as reliable, low-data-input methods (Pons et al. 2019; Chong et al. 2020; Lucena-Frédou et al. 2021).

To assess the stocks of *L. callensis* caught in Tunisian reservoirs, we obtained catch data from the Fisheries Statistical Yearbook published by the General Directorate of Fisheries and Aquaculture (DGPA 2023) for the period 2010–2022.

Statistical analyses. Statistical analyses were performed using R software (version 4.2.2). Differences in CPUE among reservoirs where *L. callensis* was present were assessed using the non-parametric Kruskal–Wallis test, followed by Dunn's post hoc test with Bonferroni correction for multiple comparisons. Non-parametric tests were chosen due to non-normal data distributions (Shapiro–Wilk test) and heterogeneity of variances (Levene's test). The significance threshold was set at $P < 0.05$ for all analyses.

Temporal changes in CPUE within individual reservoirs (Sidi Barrak, Siliana, and Kasseb) were assessed using paired tests. For comparisons where CPUE dropped to zero (Sidi Barrak and Siliana reservoirs), the non-parametric Wilcoxon signed-rank test was applied. For the Kasseb Reservoir, where both CPUE values were positive, a paired t-test was performed on the raw data after confirming that the differences were normally distributed. A Bonferroni correction was applied to adjust the significance threshold for these three temporal comparisons ($\alpha = 0.0167$). Results were considered significant at $P < 0.05$, unless otherwise stated.

Length frequency distributions were visualized using kernel density estimation (KDE) plots. This method provides a smooth, continuous probability density function of fish lengths, offering a more detailed representation of population structure. The KDE bandwidth was selected using Scott's rule. The differences in length distribution between reservoirs were tested for statistical significance using the non-parametric Kolmogorov–Smirnov test for pairwise comparisons, with a Bonferroni correction applied to account for multiple testing. The size class in each reservoir was analyzed using packages in the R statistical environment (Wood 2006; Züur et al. 2009).

A correlation analysis was performed to assess the relationship between CPUE and various environmental parameters, including reservoir maximum depth, surface area, geographic coordinates (latitude and longitude), construction year, and survey year. Due to non-normal data distribution, Spearman's rank-order correlation was used. The results of this analysis are visualized in a correlation heatmap. Statistical analyses and graphical presentations were performed using R (R Core Team 2019).

Results

The results of fish sampling using multi-mesh gillnets show that eight species of freshwater fish are present in Tunisian reservoirs: Algerian barb, *Luciobarbus callensis*, common carp, *Cyprinus carpio* Linnaeus, 1758; flathead grey mullet, *Mugil cephalus* Linnaeus, 1758; thinlip grey mullet, *Chelon ramada* (Risso, 1827); pike-perch, *Sander lucioperca* (Linnaeus, 1758); phoxinel, *Tropidophoxinellus callensis*; rudd, *Scardinius erythrophthalmus* (Linnaeus, 1758); and roach, *Rutilus rutilus* (Linnaeus, 1758). Among these, only two are strictly freshwater indigenous species, both from the family Cyprinidae: the Algerian barb and the phoxinel.

Individuals of *Luciobarbus callensis* were captured only in 11 of the 21 reservoirs surveyed (Table 2). Field observations showed that the population status of *L. callensis* is alarming, with populations found mainly downstream of the reservoirs. This study reports a low CPUE of this species in the last decade (Table 2). A statistical analysis revealed highly significant differences in CPUE among the different reservoirs ($\chi^2 = 85.34$, df = 11, $P < 0.001$). Dunn's post-hoc test showed that the CPUE at the Bir Mcherga reservoir was significantly higher than at all the other sites ($P < 0.001$). Additionally, the Sidi Barrak (2013) and Kasseb (2015) reservoirs had significantly higher CPUE than the Sidi Saad, Bouheurtma, Mellegue, Joumine, Lhma, and Barbara reservoirs ($P < 0.05$). No other significant differences were observed between the remaining reservoir pairs.

Furthermore, significant temporal declines were observed within specific reservoirs. Catches fell to zero in Sidi Barrak (Wilcoxon test: $P < 0.0167$) and Siliana (Wilcoxon test: $P < 0.0167$) between 2013 and 2022, and between 2015 and 2021, respectively. A significant decrease was also recorded in Kasseb reservoir ($P < 0.0167$), where CPUE declined from 20.02 to 0.83 fish · 1000 m^{-2} between 2015 and 2021.

Analyses of factors affecting *L. callensis* populations. Figure 2 displays a heat map of the correlation matrix for seven parameters, including the year of survey, year of construction, occurrence, maximum depth, longitude, latitude, and the main variable, CPUE. The occurrence of the Algerian barbel in Tunisian reservoirs showed a significant positive correlation with CPUE. Furthermore, a significant negative correlation was found between the year of survey and both the CPUE and occurrence of *L. callensis*, indicating a concurrent decline in its population abundance and distribution over time. Negative correlation was also detected between CPUE and maximum depth, suggesting that *L. callensis* tends to occur in shallower reservoirs. In contrast, CPUE showed weak relationships with reservoir area and year of construction. A strong negative correlation between latitude and occurrence indicates that the species is more frequently recorded in northern reservoirs.

Table 2. Occurrence and CPUE of the autochthonous freshwater fish *Luciobarbus callensis* in Tunisian reservoirs.

Reservoir	Occurrence	CPUE [fish/1000m² of nets]	Total length [cm]	Length range [cm]
Barbara	+	1.13	36.7 ± 1.52	35.0–38.0
Bezirekh	–	0	—	—
Bir Mcherga	+	163.54	22.5 ± 3.50	12.0–33.0
Bni Mtir	–	0	—	—
Bouheurtma	+	1.19	25.5 ± 4.77	20.0–31.0
Ghezala	+	15.00	30.5 ± 1.90	27.5–33.5
Joumine	+	1.22	13.8 ± 1.54	11.9–16.0
Kasseb 2015	+	20.02	35.5 ± 4.05	22.0–45.0
Kasseb 2021	+	0.83	24.1 ± 10.52	13.5–50.0
Laabid	–	0	—	—
Lahjar 2017	–	0	—	—
Lahjar 2021	–	0	—	—
Lebna	–	0	—	—
Lhma	+	0.83	41.5 ± 2.95	38.5–44.5
Masri	–	0	—	—
Mellegue	+	3.65	19.5 ± 3.41	16.0–24.0
Mlaabi	–	0	—	—
Nebhana	–	0	—	—
Sajnene	–	0	—	—
Seliana 2015	+	5.45	23.0 ± 5.05	15.0–31.0
Seliana 2021	–	0	—	—
Sidi Barrak 2013	+	45.83	35.0 ± 2.60	26.0–44.0
Sidi Barrak 2022	–	0	—	—
Sidi Saad	+	1.39	22.0 ± 3.32	17.0–27.0
Sidi Salem 2014	–	0	—	—
Sidi Salem 2023	–	0	—	—

Length values are expressed as the mean ± standard deviation.

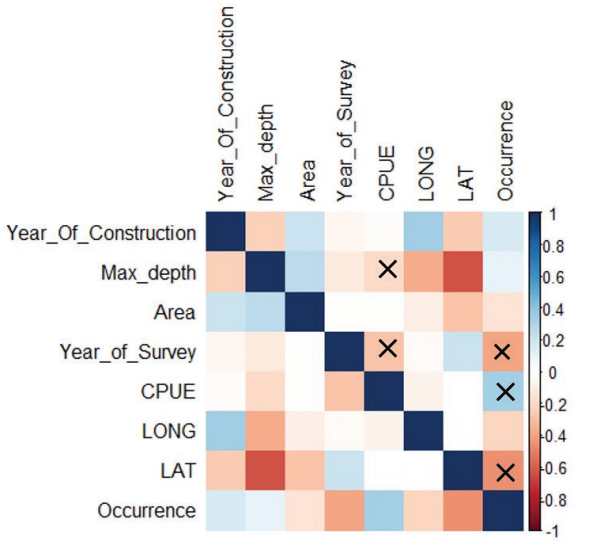

Figure 2. Correlation matrix of *Luciobarbus callensis* CPUE and occurrence, and various reservoir variables. The color gradient of the matrix shows the Pearson correlation coefficient (r) values ranging from –1 to 1: the blue indicates a positive correlation ($0 < r < 1$), and red indicates a negative correlation ($-1 < r < 0$). Each heat map cell's color represents the strength and direction of the correlation between a particular parameter and landing. The symbol × denotes a statistically significant correlation ($P < 0.05$).

Length frequency distribution. A detailed length-frequency analysis was conducted on six reservoirs (Bir Mcherga, Ghezela, Siliana, Kasseb, Sidi Saad, and Sidi Barrak) where multi-mesh gillnet sampling captured a wide size range, providing a representative overview of the *L. callensis* population structure. For all specimens of *L. callensis* across Tunisian reservoirs, total length ranged from 11.9 to 50 cm (Table 2, Fig. 3).

The analysis revealed a clear dichotomy in the population structure. The population was predominantly composed of adult individuals in Kasseb (2015) and Sidi Barrak (2013), as well as in Ghezela, Barbara, and Lhma, where the mean length exceeded the 26.5 cm maturity threshold. In contrast, populations in other reservoirs, such as Bir Mcherga, Mellegue, and Joumine, were predominantly juvenile, with mean lengths below this biological maturity size. Probability density curves showed significant spatial variability in shape ($P < 0.05$), further highlighting the substantial differences in population structure between reservoirs.

Stock assessment (LBB approach). The LBB analysis was applied to the length-frequency data from sampling that produced a sufficient number of individuals to enable robust modelling. For reservoirs with multiple sampling surveys, the dataset with the highest catch rate and most comprehensive length structure was selected. Specifically, data from Sidi Barrak (2013) and Kasseb (2015) were used as the species were poorly represented or absent in subsequent surveys.

The findings reveal stark contrasts in stock status across the studied reservoirs (Table 3). Relative fishing intensity (F/M) exceeded 1 in Siliana (2015), Kasseb (2015), Ghezela and Bir Mcherga, indicating high exploitation rates. This is consistent with the unfished biomass ratio (B/B_0) falling below 0.5 in these reservoirs, which suggests severely depleted biomass. By contrast, Sidi Saad and Sidi Barrak (2013) had healthier stock levels, with B/B_0 above this threshold.

Furthermore, ratios of L_{mean}/L_{opt} and L_C/L_{Copt} below unity (<1.0) in Sidi Saad, Siliana (2015), Kasseb (2015), and Bir Mcherga suggest a truncated population structure and the capture of undersized individuals. Conversely, L_C/L_{Copt} ratios above unity (>1.0) in Sidi Barrak (2013) and L_{mean}/L_{opt} ratios in Ghezela indicate more sustainable fishing patterns. The presence of large specimens is indicated by L_{95th}/L_{inf} ratios close to unity in Kasseb (2015) and Sidi Barrak (2013).

Stock assessment (CMSY++ approach). The CMSY++ analysis presented in Table 4 outlines the status of the Algerian barb fishery across the studied reservoirs. According to CMSY++, resilience for *L. callensis* is classified as low, with the intrinsic growth rate parameter (r_{max}) ranging from 0.05 to 0.5. Initial estimates of prior relative biomass (B/K) at the start and end of the time series (2010–2022), reflecting assumed depletion levels, suggest a medium depletion range of 0.2 to 0.6 for CMSY++.

Across all reservoirs, the biomass (B) was notably lower than biomass at the MSY level (B_{MSY}), indicating stock depletion. Moreover, fishing mortality (F) surpassed fishing mortality at the MSY level (F_{MSY}) in Joumine, Barbara, Bouhertma, and Sidi Barrak, indicating the over-exploitation of *L. callensis* stocks in these reservoirs. Furthermore, the biomass relative to B_{MSY} ratios (B/B_{MSY}) where less than 1 for all reservoirs, providing further evidence that the species' stocks in these reservoirs are overfished.

Interestingly, only seven reservoirs, Lhma, Mellegue, Bir Mcherga, Ghezela, Kasseb, Siliana, and Sidi Saad, reported F values lower than F_{MSY}, with F/F_{MSY} ratios falling below the critical threshold of 1.

According to the Kobe plot using CMSY++ estimations, the stocks of *L. callensis* are in an overfished state with a very high probability in Sidi Saad (69.5%), Kasseb (61.9%), Sidi Barrak (90.7%), Ghezala (71.8%), Bouheurtma (87.4%), Barbara (94.9%), and Joumine (78.9%) (Figs. 4, 5). Moreover, the stocks of *L. callensis* are recovering in Siliana, Bir Mcherga, Mellegue, and Lhma. This indicates a high probability that these stocks are recovering, as depicted in Fig. 6.

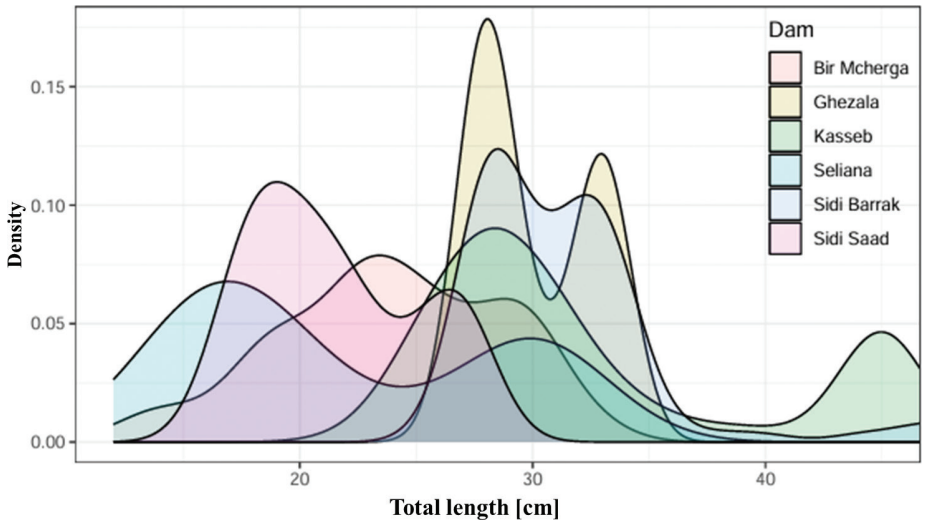

Figure 3. Length distribution of *Luciobarbus callensis* caught in Tunisian reservoirs.

Table 3. Estimated results of *Luciobarbus callensis* total length-frequency data by the Length-based Bayesian Biomass (LBB) method.

Reservoir	L_C	L_{Copt}	L_{mean}/L_{opt}	L_C/L_{Copt}	L_{95th}/L_{inf}	B/B_0	B/B_{MSY}	F/M	F/K	Z/K
Bir Mcherga	18.9	29	0.91	0.87	0.71	0.11	0.31	3.49	4.84	6.18
Ghezela	28.3	23	1.20	1.10	0.88	0.094	0.21	7.32	11.00	12.60
Kasseb 2015	27.0	34	0.99	0.96	0.95	0.068	0.17	8.46	6.22	6.99
Sidi Barrak 2013	27.5	25	1.20	1.40	1.00	0.64	1.60	0.43	0.629	2.10
Sidi Saad	17.9	14	1.00	0.93	0.89	0.89	2.30	0.0875	0.114	1.43
Siliana 2015	15.8	19	0.81	0.59	0.66	0.15	0.40	2.46	3.78	5.30

L_C, mean Total length at first capture; L_{Copt}, optimal length at first capture; L_{mean}/L_{opt}, mean length in the exploited population (L_{mean}) over the length in the unfished population (L_{opt}); L_C/L_{Copt}, length at first capture over optimum length selectivity; L_{95th}/L_{inf}, ratio of the 95th percentile length to asymptotic length; B/B_0, unfished biomass ratio; B/B_{MSY}, relative biomass to the current biomass at maximum sustainable yield; F/M, relative fishing intensity; F/K, relative fishing mortality; Z/K, relative total mortality.

Table 4. Estimated parameters of *Luciobarbus callensis* in Tunisian reservoirs based on the CMSY++ model.

Reservoir	Parameters	r_{max} [year^{-1}]	K	F_{MSY} [year^{-1}]	MSY	B_{MSY}	Previous-year biomass	Previous-year B/B_{MSY}	Previous-year fishing mortality	Exploitation F/F_{MSY}
Barbara	Value	0.0841	0.116	0.042	0.00245	0.0582	0.0311	0.467	0.0659	1.99
	95% CL	0.0456–0.122	0.0832–0.206	0.0228–0.0609	0.00164–0.0036	0.0416–0.103	0.0175–0.0522	0.275–0.728	0.0358–0.126	0.894–6.5
Bir Mcherga	Value	0.0716	0.17	0.0358	0.00305	0.0851	0.0589	0.571	0.00368	0.126
	95% CL	0.0388–0.101	0.123–0.324	0.0194–0.0505	0.00209–0.0046	0.0615–0.162	0.0264–0.104	0.323–0.808	0.00194–0.00848	0.066–0.389
Bouheurtma	Value	0.0792	0.0786	0.0396	0.00156	0.0393	0.032	0.708	0.0513	1.54
	95% CL	0.0424–0.117	0.056–0.14	0.0212–0.0586	0.000986–0.00236	0.028–0.07	0.0181–0.054	0.493–0.998	0.0287–0.0972	0.762 –3.17
Ghezala	Value	0.0795	0.0502	0.0397	0.000997	0.0251	0.00766	0.269	0.0273	1.51
	95% CL	0.0422–0.117	0.0347–0.0915	0.0211–0.0585	0.000634–0.00154	0.0173–0.0458	0.00402–0.0136	0.146–0.488	0.0142–0.0569	0.418–5.77
Joumine	Value	0.0778	0.0872	0.0389	0.00169	0.0436	0.028	0.566	0.0446	1.33
	95% CL	0.0429–0.112	0.0615–0.153	0.0214–0.056	0.00112–0.00258	0.0307–0.0766	0.0161–0.045	0.37–0.805	0.0257–0.0823	0.678–3.34
Kasseb	Value	0.0881	0.466	0.0441	0.0103	0.233	0.15	0.563	0.0416	1.12
	95% CL	0.0479–0.128	0.331–0.835	0.024–0.0641	0.00675–0.0155	0.166–0.417	0.0861–0.249	0.351–0.808	0.0232–0.0785	0.554–2.94
Lhma	Value	0.0869	0.0552	0.0435	0.0012	0.0276	0.0129	0.408	0.0209	0.689
	95% CL	0.0468–0.128	0.0384–0.1	0.0234–0.0641	0.000786–0.00185	0.0192–0.0501	0.00635–0.023	0.221–0.654	0.0105–0.0445	0.261–2.62
Mellegue	Value	0.0792	0.147	0.0336	0.00247	0.0735	0.0413	0.487	0.00947	0.354
	95% CL	0.0379–0.096	0.104–0.263	0.019–0.048	0.00167–0.0037	0.052–0.131	0.0202–0.0728	0.284–0.75	0.00498–0.0205	0.163–1.11
Sidi Barrak	Value	0.101	1.33	0.0506	0.0337	0.665	0.361	0.484	0.0737	1.81
	95% CL	0.0536–0.152	0.921–2.37	0.0268–0.0758	0.0208–0.0524	0.461–1.18	0.197–0.614	0.278–0.783	0.0402–0.145	0.783–6.53
Sidi Saad	Value	0.0836	2.06	0.0418	0.043	35.1	0.343	0.291	0.0307	1.47
	95% CL	0.0449–0.125	1.41–3.74	0.0225–0.0626	0.0268–0.0672	27.3–61.1	0.151–0.645	0.145–0.555	0.0152–0.073	0.382–6.89
Siliana	Value	0.127	0.262	0.0633	0.00828	35.1	0.169	0.604	0.0223	0.678
	95% CL	0.043–0.117	0.341–0.869	0.0215–0.0584	0.00616–0.0144	27.3–61.1	0.0747–0.304	0.336–0.888	0.0114–0.0527	0.348–1.99

r_{max}, resilience or intrinsic growth rate; K, maximum stock size or carrying capacity; F_{MSY}, fishing mortality at MSY level; MSY, Maximum Sustainable Yield; B_{MSY}, biomass at MSY level; B/B_{MSY} previous-year, biomass relative to previous-year B_{MSY}; Exploitation F/F_{MSY}, fishing mortality relative to F_{MSY}; CL, confidence limits.

Discussion

This comprehensive study provides a clear evaluation of the critical state of *L. callensis* populations in Tunisian reservoirs. Although the species is classified as Least Concern globally (Freyhof and Ford 2022) , our data clearly indicate that it meets the criteria for threatened status in Tunisia, reflecting the global decline in freshwater biodiversity.

The absence of *L. callensis* from almost half of the surveyed reservoirs indicates its precarious state. This finding signifies the local extinction of the species in these habitats, where it was recorded during earlier surveys (Mili et al. 2017, 2026; Kraiem unpublished[1]). This pattern of extirpation is similar to the documented decline of the species in the Ichkeul Lagoon following the construction of a dam (Sellami et al. 2010; Sahbani et al. 2022). This alarming population status is further quantified by the generally low and spatially variable CPUE. Additionally, a high-density population is indicated by the exceptional CPUE at the Bir Mcherga reservoir, which is significantly higher than at all other sites. However, the length-frequency analysis reveals that this population is predominantly composed of small, immature individuals (mean length = 22.5 cm, below L_{m50}). This suggests the environment may be highly favorable for recruitment and juvenile survival, but not necessarily for adult growth and longevity. This could be due to a combination of factors not measured in this study, such as lower fishing pressure on juveniles (above the legal size = 15cm), the absence of piscivorous predators (Djait et al. 2019; CTA 2023), or optimal trophic conditions for early life stages (Jeppesen et al. 2024; Park et al. 2024). In contrast, the significant

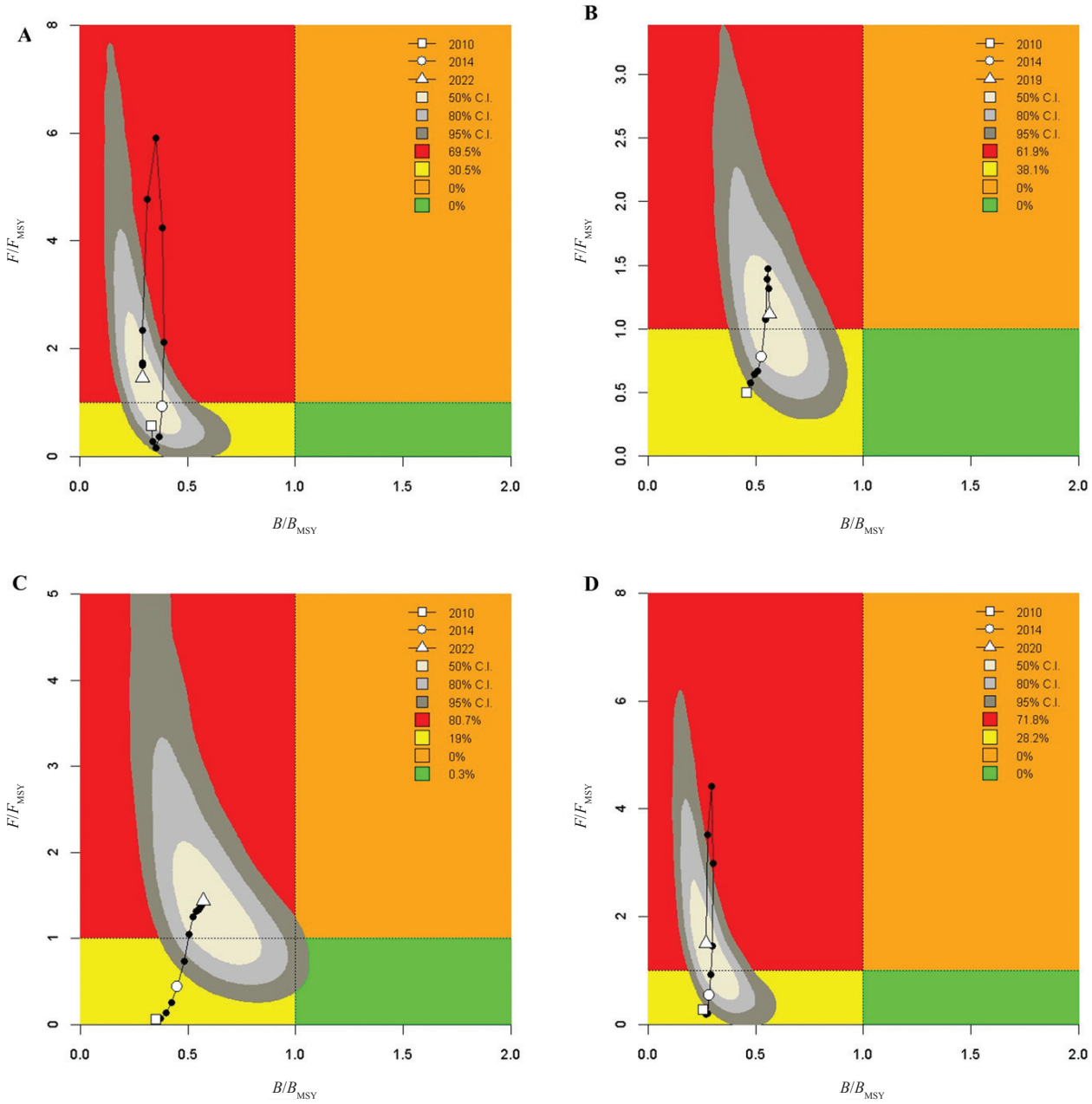

Figure 4. CMSY++ results for *Luciobarbus callensis* in Tunisian reservoirs, presented in a Kobe plot showing the synchronized changes in exploitation rate (F/F_{MSY}) and relative biomass (B/B_{MSY}). Stocks overfished and overexploited: (**A**) Sidi Saad; (**B**) Kasseb; (**C**) Sidi Barrak; (**D**) Ghezela. The plot is divided into four quadrants based on the relative biomass of the stock and the fishing mortality rate relative to B_{MSY} and F_{MSY}, respectively. These quadrants are defined as follows: red: stocks that are both overfished (low relative biomass) and overexploited (high exploitation rate); orange: relative biomass relatively high but exploitation rate high; yellow: recovering stocks; green: stocks with a sustainable exploitation rate and healthy stock biomass capable of producing high yields close to MSY. Shaded areas indicate confidence intervals at 50% (light), 80% (grey) and 95% (dark) of previous year's reference points.

decline to zero within a decade at the Sidi Barrak and Siliana reservoirs is a clear signal of population collapse.

The vulnerability of *L. callensis* is deeply rooted in its life-history strategy, which determines its response to threats. It is a slow-growing species characterized by late sexual maturity and relatively low fecundity, a classic K-selected strategy, as documented by Kraiem (unpublished[1]) and Chaouachi and Ben Hassine (1998). While this strategy is evolutionarily successful in stable environments, it becomes a severe liability in the face of rapid environmental change and heightened mortality. This is because the population lacks the intrinsic rate of increase required to recover quickly from such perturbations (Hutchings and Reynolds 2004). The composition of the exploitable fraction varied significantly between reservoirs, reflecting their distinct exploitation states. In Sidi Barrak (2013) and Ghezala, the catch predominantly consisted of adult fish ($>L_{m50}$ = 26.5 cm), as evidenced by their high mean lengths (35 cm and 30.5 cm, respectively). In contrast, the populations from

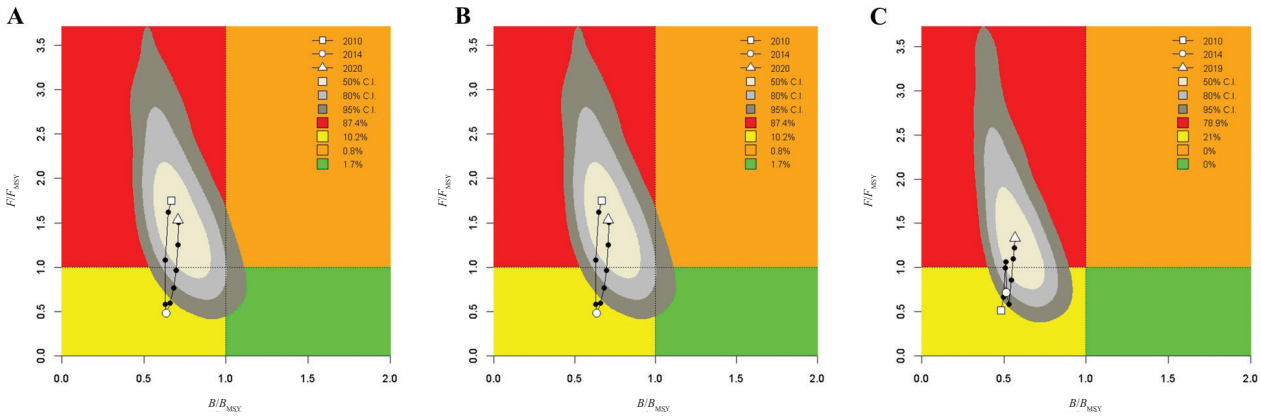

Figure 5. CMSY++ results for *Luciobarbus callensis* in Tunisian reservoirs, presented in a Kobe plot showing the synchronized changes in exploitation rate (F/F_{MSY}) and relative biomass (B/B_{MSY}). Stocks overfished and overexploited: (**A**) Bouhertma; (**B**) Barbara; (**C**) Joumine.

Bir Mcherga, Siliana, and Mellegue consisted mainly of immature fish (mean lengths of 22.5 cm, 23 cm, and 19.5 cm, respectively). From a biological perspective, these fish are classified as undersized, even though they exceed the legal catch size (15 cm). The LBB analysis quantitatively supports this, showing a low length at first capture (L_C) compared to the optimal value (L_{Copt}) in these reservoirs. This confirms a truncated population structure due to the harvest of juveniles. The presence of a wide size range alone (12–46 cm in Kasseb) does not indicate a healthy stock; the key indicator is the predominance of larger mature individuals. The LBB results for Kasseb (2015) show high exploitation ($F/M > 1$) and low biomass ($B/B_0 < 0.5$). Despite the historical presence of large fish, this indicates that the stock was under severe stress, which is consistent with its subsequent collapse in 2021.

A comparative analysis of the stock status before the collapse of *L. callensis* in different reservoirs reveals distinct trajectories. In Sidi Barrak in 2013, LBB indicators suggested a relatively healthy stock, with moderate fishing pressure ($F/M = 0.43$), high relative biomass ($B/B_0 = 0.64$) and mean capture size close to the optimum ($L_C/L_{Copt} = 1.4$). Despite this initially favorable state, the species had disappeared from the reservoir by 2022. By contrast, in Kasseb (2015), the stock was in a pronounced state of overexploitation before its collapse, characterized by intense fishing pressure ($F/M = 8.46$), low biomass ($B/B_0 = 0.068$) and a truncated population structure ($L_C/L_{Copt} = 0.96$). These divergent outcomes suggest that, while overexploitation is a significant contributing factor, populations with initially robust indicators can also decline due to other cumulative factors, such as habitat degradation, fishing mortality, and predation. The CMSY++ results corroborate the diagnosis of overexploitation in both reservoirs, with a high probability that stocks were overfished (Sidi Barrak: 90.7%; Kasseb: 61.9%). This highlights the complexity of the species' decline and the need for management strategies tailored to each reservoir that address both fishing mortality and the full range of environmental pressures.

While dam construction has transformed river ecosystems into reservoirs unsuitable for *L. callensis* (Mimeche et al. 2013; Mimeche unpublished[3]), we found that dam age had no significant effect on populations.

The most significant impact of dam construction is the hydrological fragmentation of river systems (Larinier 2001; Marmulla 2001), which blocks essential migratory pathways that species rely on to access optimal spawning grounds (Magalhães et al. 2007). According to Kraiem unpublished[1], densities of *L. callensis* increase in specific areas of streams that provide favourable reproductive conditions. Beyond fragmentation, the transformation of lotic environments into lentic reservoirs creates a habitat that is intrinsically alien to *L. callensis*.

Our finding that the species exhibits a strong preference for the top three metres of the water column aligns with the results of previous studies conducted in Tunisian (Mili et al. 2021, 2026; Kraiem unpublished[1]; Laouar unpublished[2]), Algerian and Moroccan (Mimeche et al. 2013; Mimeche unpublished[3]; Benabid unpublished[4]) reservoirs. This vertical distribution is probably a behavioral adaptation that mitigates stressors in the lentic environment. By occupying the upper water column, *L. callensis* can avoid deoxygenated, warmer and saltier conditions that can develop in the deeper, stratified layers of reservoirs, thereby accessing a habitat that better meets its ecological requirements.

The escalating impacts of climate change are powerfully amplifying the detrimental effects of hydrological alteration (Jonsson and Jonsson 2009; Park et al. 2024), which acts as a pervasive stressor in various ways (Harrod 2015). The temperature increase recorded in recent years (INM 2023) has likely disrupted the finely tuned reproductive

[3] Mimeche F (2014) Écologie du barbeau de l'Algérie, *Luciobarbus callensis* (Valenciennes, 1842) (Pisces: Cyprinidae) dans le barrage d'EL K'sob (M'Sila). PhD Thesis, National Higher School of Agronomy, EL-Harrach Algiers, Algérie.

[4] Benabid M (1990) Bioécologie de deux espèces du barbeau (*Barbus barbuscallensis* (Gthr.) et *Barbus labeobarbus fritschi* (Val.)) d'un cours d'eau du Haut-Atlas du Maroc. PhD thesis, University of Marrakech, Morocco.

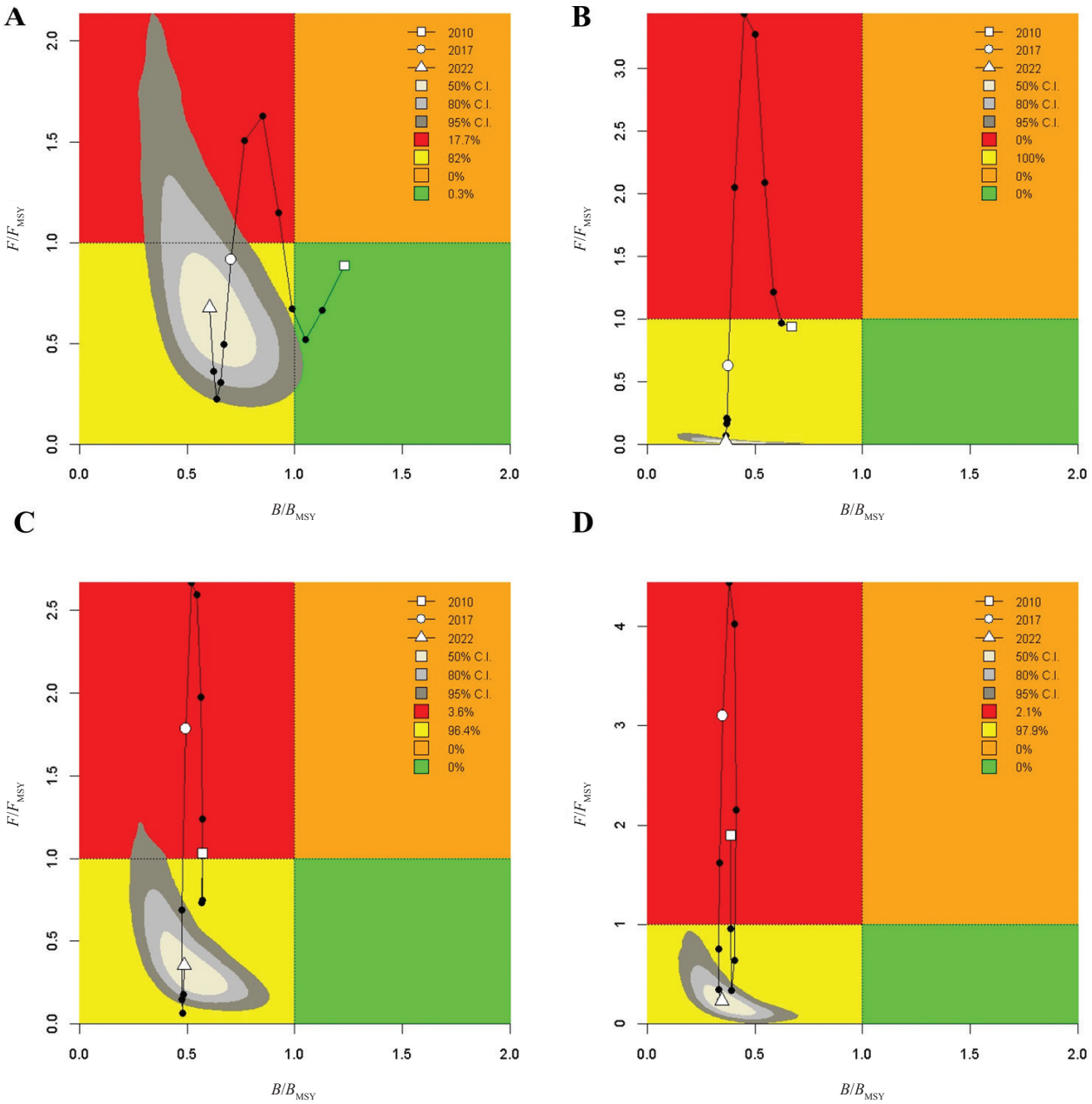

Figure 6. CMSY++ results for *Luciobarbus callensis* in Tunisian reservoirs, presented in a Kobe plot showing the synchronized changes in exploitation rate (F/F_{MSY}) and relative biomass (B/B_{MSY}). Recovering stocks: (**A**) Siliana; (**B**) Bir Mcherga; (**C**) Mellegue; (**D**) Lhma.

cycle of *L. callensis*. As established by Kraiem (1998) and observed by Mouaissia et al. (2017) and Aberkane et al. (2018) in Algerian populations, spawning is thermally mediated and initiated when water temperatures exceed 20°C. Historically, this occurred between mid-May and early July. This timing was ecologically synchronized with the Tunisian national fishing calendar, which traditionally prohibits fishing activity in March and April (JORT 1995), thereby protecting pre-spawning adults.

However, considering the documented warming trends (INM 2023), we hypothesize that this spawning window is shifting earlier, potentially beginning at the end of April (personal observations). This phenological shift creates a critical misalignment: spawning adults, which were previously protected by the spring fishing ban, are now becoming vulnerable to fishing pressure in May, before they have had the opportunity to reproduce, as indicated by Pankhurst and Munday (2011). This scenario represents a clear case of maladaptation to climate change (Jonsson and Jonsson 2009; Harrod 2015), creating a significant gap between biological and management timelines.

Furthermore, climate change is exacerbating regional droughts (Morrongiello et al. 2011; Jaeger et al. 2014; Barbarossa et al. 2021), resulting in reduced freshwater input and increased water extraction for human use. This results in significantly lowered water levels during summer, increasing salinity and leading to the fragmentation of water bodies into isolated, stagnant pools, a process described by Sumner and Belaineh (2005).

Such conditions are detrimental to *L. callensis*, as it requires clear, well-oxygenated waters for successful egg and larval development (Kraiem 1998; Ould Rouis et al. 2012; Mouaissia et al. 2017). As noted by Holt (2011) and Martínez et al. (2021), stagnation reduces oxygen levels, particularly in warmer months, and can lead to the formation of hypoxic zones that impair embryonic growth and larval survival. The combined effects of dams and climate change (Poff et al. 2007; Pankhurst and Munday 2011) create severe habitat restrictions, pushing this rheophilic species closer to local extinction thresholds.

In addition to overfishing and habitat degradation, the decline of *L. callensis* may be further exacerbated by the introduction of non-native piscivorous fish such as pikeperch, *Sander lucioperca*, and wels catfish, *Silurus glanis* Linnaeus, 1758. These species have been documented to impact native fish communities (Losse et al. 1991; Kopp et al. 2009; Yerli et al. 2013; Djait et al. 2019; Mili et al. 2021; Encina et al. 2024; Djemali unpublished[5]). This introduces compounded mortality risk across life stages. While fishing pressure likely contributes significantly to adult mortality, as evidenced by the capture of mature individuals below the optimal size (low L_C/ L_{Copt} ratios), introduced piscivores can cause severe mortality among juveniles. This creates a synergistic threat scenario in which predation on young-of-the-year suppresses recruitment, while fishing simultaneously depletes the spawning stock.

The cumulative impact of fishing on *L. callensis* is exacerbated by a critical misalignment between its life history, current climate trends and outdated management practices. Firstly, the Tunisian legal minimum catch size of 15 cm (JORT 1995) is set far below the size at which the species matures (L_{m50} = 26.5 cm; Kraiem unpublished[1]). This promotes overfishing by removing juveniles before they can reproduce (Hountcheme and Ahouansou 2024). Secondly, this regulatory failure is exacerbated by a behavioral vulnerability: the nocturnal feeding rhythm of *L. callensis* (see Berrouk et al. 2020; Kraiem unpublished[1]) coincides with the operational timing of gillnets (Mili et al. 2021), significantly increasing its susceptibility to capture. Thirdly, climate warming is likely causing a phenological shift, advancing spawning activity into spring earlier than before (Mili et al. 2025; Kraiem unpublished[1]). This shift potentially exposes migrating, pre-spawning adults to fishing pressure in May, a period during which they were historically protected by the traditional fishing calendar. Thus, the population faces a synergistic trap: juveniles are legally harvested before they mature, adults are behaviorally vulnerable to capture year-round, and the spawning stock is increasingly at risk due to climate-induced timing mismatches. The combination of harvesting immature stocks and elevated mortality at all life stages exceeds the species' compensatory resilience (Jeppesen et al. 2024). Our stock assessment models (CMSY++ and LBB) strongly support this conclusion, indicating widespread overfishing.

To conserve *L. callensis*, an integrated, multifaceted strategy is required. This must address the synergistic threats through immediate targeted actions, such as revising fishing regulations to align with the species' biology, coupled with long-term initiatives. The latter should include targeted breeding programs and restocking efforts to recover critically depleted populations. The most urgent issue is the immediate revision of fishing regulations. The legal-size limit should be increased to at least 26.5 cm to protect immature females and ensure that every individual can spawn at least once, a fundamental prerequisite for sustainable exploitation (Jeppesen et al. 2024). Secondly, it is crucial to proactively manage populations of invasive pikeperch, especially in identified reservoir refuges, which are vital for the species' survival. Thirdly, habitat restoration efforts should be explored and implemented where feasible, including measures to improve hydrological connectivity (Poff et al. 2007; Hanfouri et al. 2024), to ensure environmental flows that can mimic the natural regimes necessary for successful spawning and recruitment. Finally, a robust, long-term monitoring program must be established to track population responses to these interventions and adapt management strategies accordingly. The loss of *L. callensis* is not inevitable, but avoiding it requires moving beyond merely documenting its decline and implementing the bold, science-based conservation actions that our findings, and those of many others, clearly dictate.

Conclusion

The majority of Tunisian reservoirs exhibit low levels of fish diversity and productivity. These reservoirs require strong management support to enhance productivity and address overfishing issues. Our results confirm that this important indigenous cyprinid species is in serious decline. *L. callensis* deserves the urgent attention of biologists and the authorities responsible for the protection of native species before it becomes completely and irreversibly extinct. Conservation strategies, including targeted breeding programs and restocking efforts, should be seriously considered to safeguard the future of this native species.

Acknowledgments

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