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Comparative analysis of reproductive and growth parameters in *Mugil cephalus* and *Chelon ramada* (Actinopterygii, Mugiliformes, Mugilidae) from a Tunisian reservoir

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Abstract

Mugil cephalus Linnaeus, 1758 and *Chelon ramada* (Risso, 1810) are the most commonly caught species of the family Mugilidae in Tunisian dam reservoirs. Efforts are underway to boost production to meet domestic demand. We investigated the biological and growth parameters of *Mugil cephalus* and *Chelon ramada* based on catches in the Sidi Saad Reservoir. Our results showed that the lengths at first maturity were 34.13 ± 0.12 cm for females *M. cephalus* and 33.29 ± 0.15 cm for males. For *C. ramada*, the corresponding sizes at first maturity were 30.5 ± 0.22 cm for females and 29.4 ± 0.17 cm for males. The gonadosomatic index indicated that the spawning season for *M. cephalus* extends from August to October, while that of *C. ramada* occurs from October to December. Notably, *M. cephalus* reaches sexual maturity at a larger size compared to *C. ramada*. We also assessed the von Bertalanffy growth parameters for both species: L_∞ = 77.87 cm, K = 0.1147 a^{-1}, t_0 = –2.41 for *M. cephalus*, and L_∞ = 52.01 cm, K = 0.1782 a^{-1}, t_0 = –1.41 for *C. ramada*. Our findings provide essential insights into the reproductive biology and growth parameters of these two Mugilidae species. However, more detailed surveys are necessary to manage fish resources sustainably in Tunisian dams.

Keywords

age, growth, Mugilidae, reproduction, reservoir, Tunisia

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Introduction

In Tunisia, fishing in reservoirs has been practiced since the 1960s (Losse et al. 1991; Mili et al. 2021), beginning with the introduction of Mugilidae fry (Rhouma unpublished*). Today, there are 38 reservoirs where extensive inland fish farming allows fishermen to cultivate different fish species. Between 2000 and 2017, fish production in Tunisian dam reservoirs grew from 843.5 tonnes to about 1360 tonnes (DGPA 2017).

Commonly fished species from Tunisian freshwater are *Anguilla anguilla* (Linnaeus, 1758), *Chelon ramada* (Risso, 1826), *Cyprinus carpio* Linnaeus, 1758, *Luciobarbus callensis* (Valenciennes, 1842), *Mugil cephalus* Linnaeus, 1758, *Sander lucioperca* (Linnaeus, 1758), *Sarmarutilus rubilio* (Bonaparte, 1837), *Scardinius erythrophthalmus* (Linnaeus, 1758), and *Silurus glanis* Linnaeus, 1758 (see Losse et al. 1991; Mili et al. 2021). When the catches are significant, they are sent to the capital, Tunis. Otherwise, they are sold in the towns and villages near the reservoirs or consumed directly by the fishermen.

Mugilidae are euryhaline fish that play a crucial ecological role in Tunisian freshwater and estuarine ecosystems. Although typically associated with marine and brackish habitats, several Mugilid species regularly migrate into freshwater environments (Bae and Kim 2020). Mugilids exhibit plasticity in salinity tolerance (Hotos and Vlahos 1998), making them good bioindicators of environmental changes and anthropogenic pressures (Ortiz-Zarragoitia et al. 2014).

The good growth observed in the species introduced into the reservoirs, especially mullets, associated with the productions obtained, clearly shows that the dam lakes represent a significant potential that must be further exploited (Djemali 2005). Past experiments on several fisheries showed that this resource is fragile and particularly sensitive to overexploitation. Therefore, knowledge of the biology of these species is crucial for effective fisheries management. In Tunisia, the Mugilidae is represented by six species: *Chelon auratus* (Risso, 1810), *Chelon labrosus* (Risso, 1827), *Chelon ramada*, *Chelon saliens* (Risso, 1810), *Mugil cephalus*, and *Oedalechilus labeo* (Cuvier, 1829) (see Fehri-Bedoui and Gharbi 2005). These species are gregarious. They undergo trophic migrations from the sea to the lagoons. However, gonad maturation and spawning occur exclusively at sea (Chauvet and Mkaouar 1977; Chauvet 1979). Among them, *M. cephalus* is the most commercially exploited, while *C. ramada* is notable for its high tolerance to salinity and temperature fluctuations (Gautier and Hussenot 2005). The family Mugilidae constitutes the most fished group in dam reservoirs in Tunisia, representing 34% of the total catch (DGPA 2017).

The first scientific studies on the growth of Mugilidae, in Tunisian marine and brackish waters, were carried out by Heldt (1948). They were followed by subsequent reports on growth and reproduction as well as on fishing and migration (Farrugio 1975; Chauvet and Mkaouar 1977; Kraïem et al. 2001; Fehri-Bedoui and Gharbi 2005; Mili and al. 2015; Hajlaoui unpublished**). While Mugilidae are well studied in coastal and estuarine systems (Romdhane et al. 2019), data on their biology in Tunisian freshwater reservoirs remain limited (Mili and al. 2015).

This study aims to investigate and compare the reproductive biology and growth parameters of two fish species, *Mugil cephalus* and *Chelon ramada*, that coexist in a Tunisian reservoir. By comparing these species, we can evaluate their specific adaptations and potential niche differentiation under the same environmental conditions. Understanding these differences is crucial for improving species selection in polyculture systems, designing sustainable fisheries management plans, and enhancing productivity in inland aquaculture. The broader implications of this research include contributing to the development of more efficient and ecologically informed fisheries and aquaculture strategies in Mediterranean freshwater environments.

Materials and methods

Study area. Sidi Saad Reservoir (35°22.00′N, 009°40.00′E) (Fig. 1), located in the center of Tunisia, was filled in 1981. It provides irrigation water and protects the Kairouan Plain against flooding. The reservoir has an area of 1700 ha, a volume of 209 million m^3, and a maximum depth of 30 m. It is situated in an upper arid bioclimatic zone with a Mediterranean climate, characterized by hot summers (with an average maximum temperature of 38°C) and mild winters (with an average minimum temperature of 4°C), as well as low annual rainfall of approximately 300 mm (Mabrouk et al. 2021). The rainy seasons occur in autumn and spring, while summer is dry, leading to high evaporation rates.

Since 2011, Sidi Saad has been recognized as a Ramsar site, underscoring its ecological significance. However, it is subjected to considerable human pressures, including industrial and agricultural pollution, which have caused nutrient enrichment and water quality problems (Gafrej unpublished***). The reservoir is classified as mesotrophic

* Rhouma A (1975) Étude biologique et élevage du Mulet en Tunisie. Comparaison avec une espèce d'eau douce (la Carpe). Mémoire de fin d'études 3e cycle de l'INAT, Tunis, 131 pp.

** Hajlaoui W (2017) Etude écobiologique et dynamique des populations de la carpe commune *Cyprinus carpio communis* et le mulet *Liza ramada* dans la retenue du barrage Sidi Saâd (Centre de la Tunisie). Thèse de Doctorat, Institut National Agronomique de Tunisie (INAT), Tunis, Tunisia, 213 pp.

*** Gafrej H (2017) Gestion intégrée des ressources en eau dans le bassin versant de l'oued Zeroud (Tunisie centrale) : Impacts des changements climatiques et des activités anthropiques. Thèse de Doctorat, Institut National Agronomique de Tunisie (INAT), Université de Carthage, Tunisie, 258 pp.

Figure 1. Satellite image of Sidi Saad Reservoir, Tunisia (Map data 2025 (C) Google.)

(with Carlson's trophic state index around 41), but it frequently experiences eutrophication events due to this nutrient overload.

Despite its ecological importance, Sidi Saad Reservoir continues to face significant challenges related to eutrophication, toxic cyanobacterial blooms, and pollution from industrial and agricultural activities. These challenges highlight the urgent need for improved water quality monitoring and effective management strategies to preserve both the health of the ecosystem and the socio-economic functions of the reservoir.

The fish community in this reservoir consists of the carp (*C. carpio*), mullet (*M. cephalus* and *C. ramada*), catfish (*S. glanis*), barbel (*L. callensis*), and eel (*A. anguilla*) with an annual yield of 511.14 tonnes (DGPA 2017).

Sampling and processing. The biological analyses were conducted using fresh specimens. Mature males and females *Mugil cephalus* (202 individuals) and *Chelon ramada* (530 individuals) were collected using gillnets from Sidi Saad dam in winter (January–February 2016); spring (March–May 2016), summer (June–August 2016), and autumn (September–November 2016). The fishes were obtained directly from local fishermen using gillnets. Due to the reliance on artisanal fisheries, a standardized protocol could not be applied. Samples were immediately transported to the Higher Institute of Marine Biology Laboratory. The total length (TL) was measured to the nearest millimeter, and weights (total weight TW and gonad weight W_G) were recorded using a top-loading digital scale (precision of 0.01 g). Sexing was performed by direct gonadal inspection through dissection. Gonads were carefully examined macroscopically to determine sex and maturity stage.

Water parameters. The environmental data, including temperature, salinity, dissolved oxygen, and pH, were measured in situ using a WTW's portable multi-parameter probe (model WTW LF.325). Additionally, nitrite, nitrate, and orthophosphate levels were analyzed in the laboratory using the Rodier (1996) method. Water transparency was measured using a Secchi disk, and values are expressed in meters. The mean and range of all measurements are recorded in Table 1.

Gonadosomatic index (GSI). GSI was calculated monthly to determine spawning periods according to the following equation (Bougis 1952; Lahaye 1980):

$$\mathrm{GSI} = (W_G \times W_E^{-1}) \times 100$$

where, W_G is the gonad weight and W_E is the eviscerated body weight, both in grams.

Table 1. Seasonal variation of water parameters recorded in Sidi Saad Reservoir, Tunisia.

Season	Temperature [°C]	Salinity [‰]	pH	Transparency [m]	Dissolved oxygen [mg·L^{-1}]	Nitrite [mg·L^{-1}]	Nitrate [mg·L^{-1}]	Orthophosphate [mg·L^{-1}]
Winter	10.53 ± 1.76	1.75 ± 0.05	8.21 ± 0.06	1.08 ± 0.19	8.70 ± 0.82	0.06 ± 0.03	0.65 ± 0.22	0.04 ± 0.02
Spring	18.03 ± 2.94	1.93 ± 0.06	8.02 ± 0.20	1.97 ± 0.15	6.97 ± 0.68	0.09 ± 0.04	0.31 ± 0.08	0.03 ± 0.00
Summer	26.93 ± 2.12	2.30 ± 0.10	7.97 ± 0.06	2.53 ± 0.25	5.43 ± 0.81	0.02 ± 0.01	0.16 ± 0.08	0.02 ± 0.01
Autumn	19.92 ± 4.46	2.00 ± 0.10	8.30 ± 0.09	1.93 ± 0.21	7.03 ± 0.50	0.09 ± 0.01	0.77 ± 0.15	0.05 ± 0.02
F	15.1	23.67	5.09	25.85	10.42	4.11	11.12	2.95
P	0.001	0.0002	0.0293	0.0001	0.003	0.0488	0.0031	0.0985

Values are presented as mean ± SD. $n = 9$ replicates per season. Statistical significance testing a significant difference was assumed when $P < 0.05$. $F = F$ statistics.

Sex ratio. The sex ratio was determined monthly as males: females (M: F), estimated using the formula:

$$\mathrm{SR} = (F \times 100) \times (F + M)^{-1}$$

where, F and M are female and male numbers, respectively.

The chi-square (χ^2) test was used to identify significant differences in the sex ratio between males and females (Vazzoler 1996).

Length at maturity. Lengths at maturity (L_{M50}), the size at which 50% of individuals are mature, were estimated from the logistic curve parameters (King 1995):

$$P_{\mathrm{M}} = 1 \times \left[1 + \exp^{[-b(L - L_{\mathrm{M50}})]}\right]^{-1}$$

where P_{M} is the proportion of mature individuals at a given length (TL), b is the slope of the maturity curve and L_{M50} is the total length at which 50% of the fish are mature.

Length–weight relationship. The relationship between total length and weight was determined using the equation of Huxley (1924):

$$W = aL^b$$

where W is the total weight in grams, TL is the total length of the fish in cm, and parameters a and b are estimated, defining b as the coefficient of allometry. The degree of association between the variables was assessed using the coefficient of determination r^2. Student's t-test was used to determine if the coefficient b differed significantly from 3 (Teissier 1948).

Age estimation. For age estimation, scales were collected from just behind the pectoral fin along the lateral line. The scales were rinsed with water and examined under a stereomicroscope. The von Bertalanffy growth curve was fitted to the data of the resulting age–length of Marquardt's algorithm for nonlinear least squares parameter estimation (Saila et al. 1988). The FSAS program (Stamatopoulos and Caddy 1989) was used to estimate the parameters of the von Bertalanffy growth equation (von Bertalanffy 1938):

$$L_t = L_\infty \left(1 - e^{-K(t - t_0)}\right)$$

$$W_t = W_\infty \left[1 - e^{-K(t - t_0)}\right]^b$$

where L_t is the predicted fork length at age t, L_∞ is the mean asymptotic total length, K is the growth constant [year^{-1}], and t_0: the theoretical age at which the fish would have been zero length, W_t is the weight of the fish at age t and W_∞ is the asymptotic weight (Le Cren 1951). The growth performance index (Sparre and Venema 1989):

$$\Phi' = 2 \log L_\infty + \log K$$

was employed to compare the growth of mullet parameters to various studies.

Statistical analysis. The data structure was first tested for normality of distribution (Shapiro–Wilk test) and equality of variance (Levene test). One-way analysis of variance (ANOVA or Kruskal–Wallis's test) was used to test for overall differences between the seasonal water parameters. Tukey's Honestly Significant Difference (HSD) or the Dunn test was used in pairwise comparisons between seasons. Statistical significance of a difference was assumed when $P < 0.05$, and the statistical software SPSS Version 25.0 was used. The PCA was used to elucidate the differential effects of seasonality on the global parameters for males and females of the two Mugilidae species (*M. cephalus* and *C. ramada*). Component plots were generated with R version 4.2.2 (R Core Team 2021).

Results

Water parameters. Results on the seasonal variations of the water parameters of Sidi Saad Dam Reservoir (Table 1) showed that in summer, it exhibited high levels of temperature (°C), salinity [‰], and transparency ($P < 0.001$). In contrast, lower dissolved oxygen, nitrate, and nitrite levels were recorded during the warm season ($P < 0.001$).

Length-frequency distribution. Length distribution of *Mugil cephalus* samples ranged between 20 and 67 mm; 69.3% of the samples had a length of 32–52 cm (Fig. 2). For *Chelon ramada*, individual lengths ranged between 12 and 45 cm. The majority of both fish species length values were between 22 and 39 cm (91.52%).

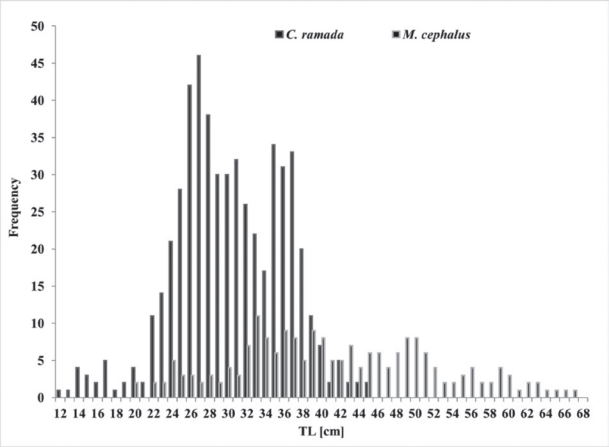

Figure 2. Total length frequency distribution of *Mugil cephalus* and *Chelon ramada* collected from Sidi Saad Reservoir, Tunisia.

Sex ratio. Of the 204 *M. cephalus* specimens captured, 110 were females and 94 were males. The females of *M. cephalus* samples predominated in all months (Fig. 3). The overall sex-ratio value estimated was 1.17, biased towards females. The Chi-square test showed no significant difference ($\chi^2 = 1.25$; df = 1; $P > 0.05$). Of 530 *C. ramada* specimens captured, 275 were females and 255 were males. Females predominated in all months, except March and April (Fig. 3). The overall sex-ratio value estimated was 1.06, biased towards females. The Chi-square test showed no significant difference ($\chi^2 = 0.42$; df = 1; $P > 0.05$). For the two species, females were dominant in high-length classes (Fig. 4).

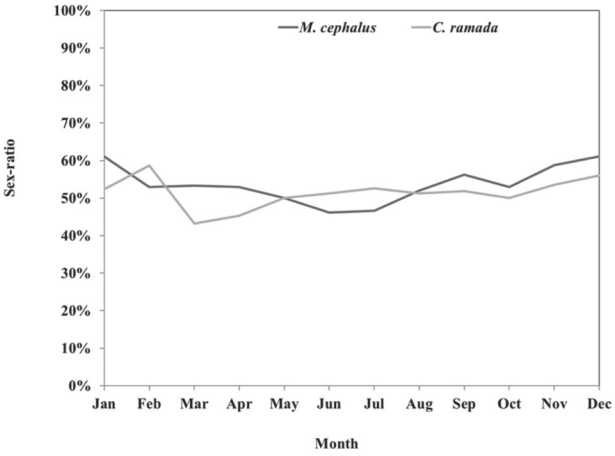

Figure 3. Sex ratio monthly evolution for *Mugil cephalus* and *Chelon ramada* in Sidi Saad Reservoir, Tunisia.

Size at sexual maturity. The estimated mean size at which 50% of females of *M. cephalus* were mature was 34.13 ± 0.12 cm. In contrast, the estimated mean size at which 50% of males were mature was 33.29 ± 0.15 cm (Fig. 5). Both females and males attained sexual maturity during the second year of their life. For the sample of *C. ramada*, 50% of the females and males attained first maturity at 30.5 ± 0.22 cm and 29.4 ± 0.17 cm, respectively (Fig. 5), indicating that females and males attained sexual maturity during the second year of their life. For both species, the males generally mature at relatively smaller sizes than the females.

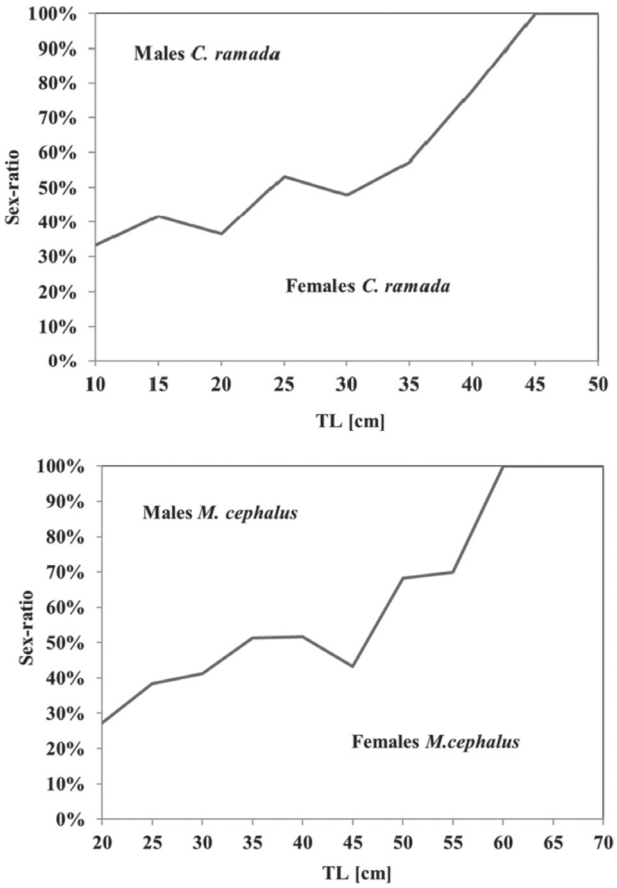

Figure 4. Sex ratio evolution by size class for *Mugil cephalus* and *Chelon ramada* in Sidi Saad Reservoir, Tunisia.

Sexual cycle and spawning period. The mean monthly GSI values for *M. cephalus* were low from January to May. After June, the gonads began their development, and GSI started increasing again. The maximum GSI value was 4.2 ± 0.32 for females and 2.8 ± 0.4 for males in August. In October, the GSI value decreased (Fig. 6). Our findings suggest that the reproductive period of this species occurs regularly between August and October.

The mean monthly GSI values for *C. ramada* were low from January to June. After July, the gonads started their development, and the values of GSI gradually increased. The maximum GSI value was 3.4 ± 0.30 for females and 1.8 ± 0.14 for males in October. In December, the GSI value decreased (Fig. 6). Our results indicate that the reproductive period of this species occurs regularly between October and December.

Length–weight relationships. Length–weight relationships were calculated separately for females, males, and both sexes. For *M. cephalus*, the equation for females was $W = 0.0077 \times TL^{3.09}$, for males $W = 0.0106 \times TL^{2.99}$, and the combined sexes $W = 0.0081 \times TL^{3.07}$ (Fig. 7). The *b* value was not significantly different from the theoretical value of 3 for males ($t = 0.17$; $P > 0.05$), females ($t = 1.7$; $P > 0.05$) indicating an isometric growth. For the combined sexes, the *b* value was significantly greater than 3, indicating a positive allometric growth pattern. ($t = 2.35$; $P < 0.05$) (Table 2).

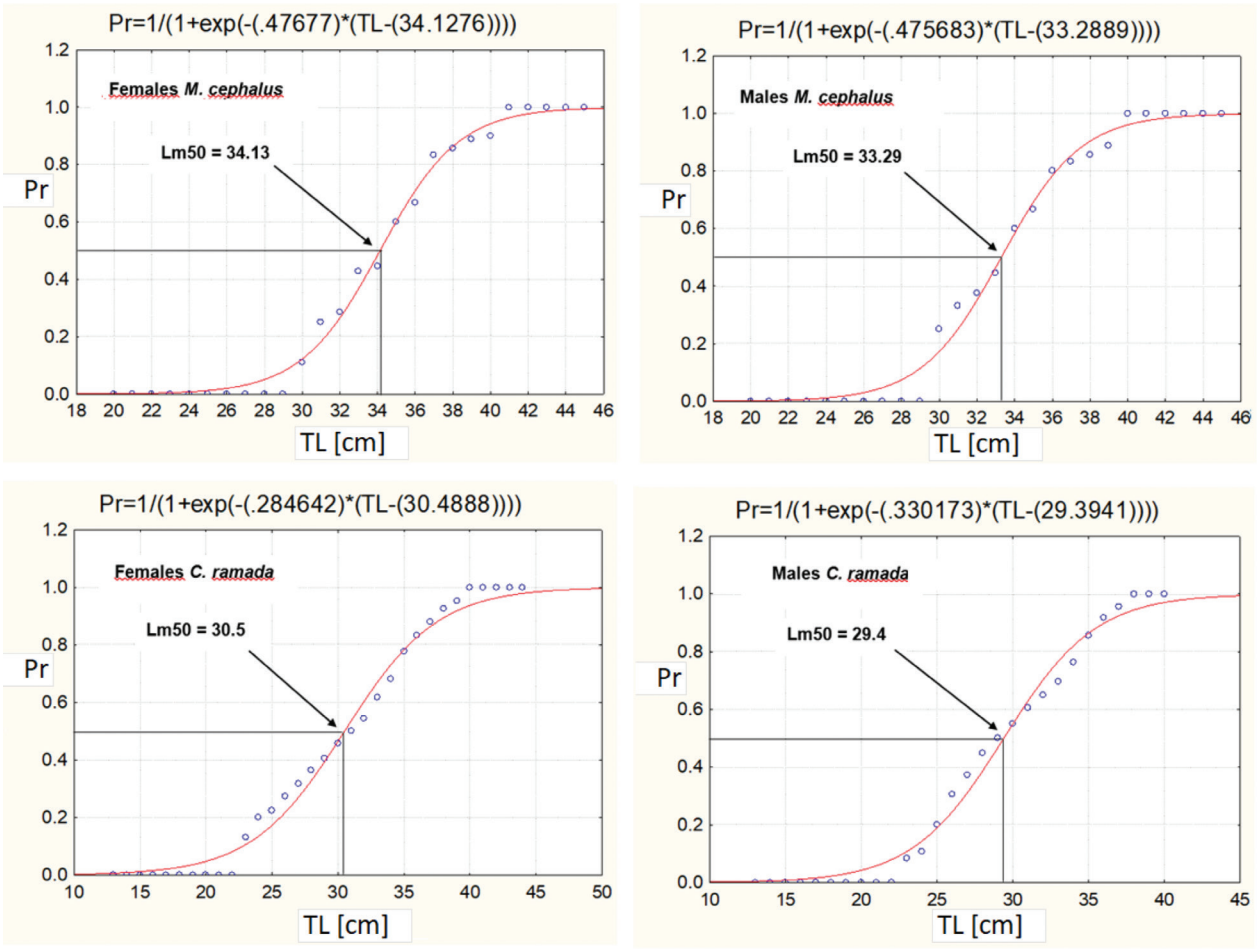

Figure 5. Sexual maturity size for *Mugil cephalus* and *Chelon ramada* in Sidi Saad Reservoir, Tunisia.

Table 2. Regression parameters of the length–weight relationships of *Mugil cephalus* and *Chelon ramada* in in Sidi Saad Reservoir, Tunisia.

Fish and equation	Sex	*a*	*b*	R^2	*t*	Significance	Allometry
Mugil cephalus	**F**	0.0077	3.09	0.9789	1.7	–	Isometric
$W_t = aL_t^b$	**M**	0.0106	2.9921	0.9786	0.17	–	Isometric
	F + M	0.008	3.068	0.982	2.35	+	Positive
Chelon ramada	**F**	0.0108	2.9538	0.9634	1.4	–	Isometric
$W_t = aL_t^b$	**M**	0.01	2.9803	0,9597	1.1	–	Isometric
	F + M	0.0105	2.9644	0.9624	0.51	–	Isometric

F = females, M = males, *a* = the proportionality constant, *b* = the allometry coefficient value, L_t = total length, W_t = total weight, R^2 = coefficient of determination, *t* = correlation test (Student's *t*-test).

For *C. ramada*, the weight–length relationships were $W = 0.0108 \times TL^{2.95}$ for females, $W = 0.01 \times TL^{2.98}$ for males, and $W = 0.0105 \times TL^{2.96}$ when both sexes were combined indicating an isometric growth for this species (Fig. 7). The *b* value was not significantly different from the theoretical value of 3 for males ($t = 1.1$; $P > 0.05$), females ($t = 1.4$; $P > 0.05$), and combined sexes ($t = 0.51$; $P > 0.05$) (Table 2).

von Bertalanffy growth parameters. For *M. cephalus*, the respective von Bertalanffy growth equations fitted to fish length and age data using the observed methods for females, males, and combined sexes (Table 3) were:

Table 3. Estimates von Bertalanffy growth parameters for males, females, and combined sexes for *Mugil cephalus* and *Chelon ramada* in Sidi Saad Reservoir, Tunisia.

Species	Sex	L_∞ [cm]	K [yr^{-1}]	t_0 [yr]
Mugil cephalus	Females	84.03	0.1012	–2.64
	Males	72.64	0.1291	–2.18
	Females + males	77.87	0.1147	–2.41
Chelon ramada	Females	53.13	0.1733	–1.42
	Males	50.93	0.1830	–1.40
	Females + males	52.01	0.1782	–1.41

L_∞ = asymptotic length, K = growth coefficient, t_0 = theoretical age.

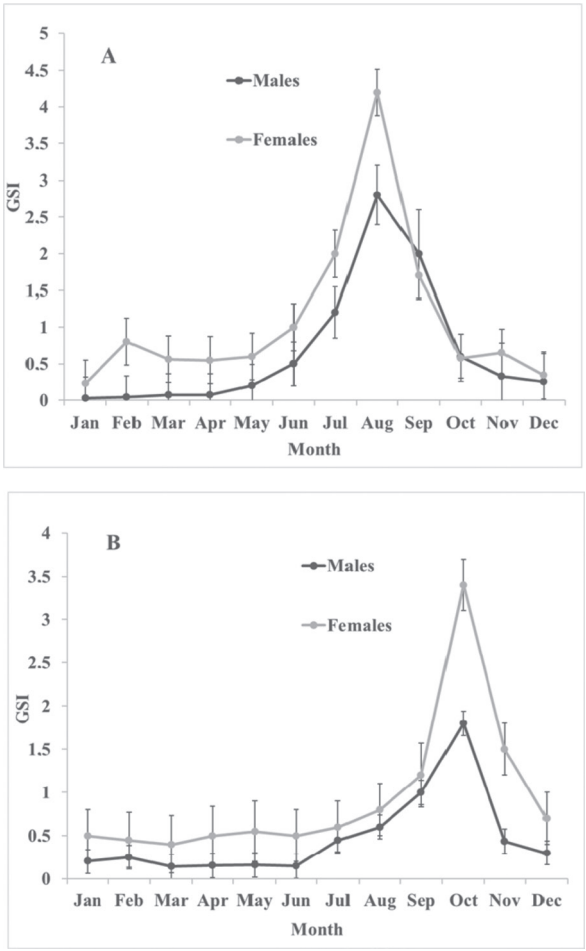

Figure 6. Variation of the gonadosomatic index (GSI) for males and females of *Mugil cephalus* (**A**) and *Chelon ramada* (**B**) in Sidi Saad Reservoir, Tunisia.

$TL = 84.03(1 - e^{-0.1012(t + 2.64)})$
$TL = 72.64(1 - e^{-0.1291(t + 2.18)})$
$TL = 77.87(1 - e^{-0.1147(t + 2.41)})$

The respective growth-in-weight for females, males, and combined sexes of *M. cephalus* were:

$W = 6685.02(1 - e^{-0.1012(t + 2.64)})^{3.09}$
$W = 3927.63(1 - e^{-0.1291(t + 2.18)})^{2.99}$
$W = 5142.91(1 - e^{-0.1147(t + 2.41)})^{3.07}$

For *C. ramada*, the respective von Bertalanffy growth equations fitted to fish length and age data using the observed methods for females, males, and combined sexes were:

$TL = 53.13\ (1 - e^{-0.1733(t + 1.42)})$
$TL = 50.93\ (1 - e^{-0.1830(t + 1.4)})$
$TL = 52.01\ (1 - e^{-0.1782\ (t + 1.41)})$

The respective growth-in-weight described by the von Bertalanffy equation for females, males and combined sexes of *C. ramada* were:

$W = 1348.13\ (1 - e^{-0.1733(t + 1.42)})^{2.95}$
$W = 1222.63\ (1 - e^{-0.1830(t + 1.4)})^{2.98}$
$W = 1283.39\ (1 - e^{-0.1782\ (t + 1.41)})^{2.96}$

The annual growth-in-weight rate was slightly higher for females, with a more pronounced difference with the ageing. The growth rate reached its maximum during the first year of life of both fish species.

PCA for *M. cephalus*. The PCA was used to reveal the effects of the abiotic factor's seasonal fluctuations on the biological parameters for male and female *M. cephalus* (Fig. 7). The first two principal components of the PCA explained 64.1% of the total variance, with Dim 1 (Eigenvalue = 6.13) accounting for 41% and Dim 2 (Eigenvalue = 3.47) accounting for 23%. Fig. 7 illustrates, in Dim 1, positive loadings of S (0.90), T (0.87), Transparency (0.88), and GSI (0.72) and negative loadings of O_2 (–0.89), nitrate (–0.72), pH (–0.66), nitrite (–0.63), and orthophosphate (–0.54). Dim 2, a unipolar axis, is defined by W_E (0.83), TL (0.83), TW (0.82), TL_∞ (0.57), HSI (0.57), and CI (0.53). Principal Component Plots show that summer stood out from all the other seasons. These findings confirm that temperature (r = 0.71, ddl = 13, $P < 0.01$), salinity (r = 0.69, ddl = 13, $P < 0.01$), and transparency (r = 0.66, ddl = 13, $P < 0.01$) are key factors in determining the gonadosomatic index (GSI) of *M. cephalus*. In this line, a clear separation was observed between males and females, collected during winter, spring, and autumn, where the dissolved oxygen, nitrate, and nitrite contents are higher compared to those in summer.

PCA for *C. ramada*. The first two principal components of the PCA explained 59.2% of the total variance, with Dim 1 (Eigenvalue = 5.45) accounting for 36.3% and Dim 2 (Eigenvalue = 3.42) accounting for 22.8%. Fig. 8 illustrates, in Dim 1, positive loadings of O_2 (0.91), nitrate (0.76), nitrite (0.67), and orthophosphate 0.59) and negative loadings of S (–0.91), T (–0.89), and transparency (0.88). Dim 2, a unipolar axis, is defined by TW (0.93), Wev (0.92), TL (0.88), and GI (–0.65). As observed for *M. cephalus*, the summer water physicochemical parameters, mainly temperature, salinity, and transparency, determine the biological parameters of males and females of *C. ramada*. However, for males and females, plots of spring, autumn, and winter seasons overlapped and matched with the determined parameters (Fig. 8).

Discussion

This study presented detailed data on the reproductive and growth characteristics of *Mugil cephalus* and *Chelon ramada* in a Tunisian freshwater reservoir. Both species showed a slight female dominance in their sex ratios, particularly in the larger size classes, with males maturing at smaller sizes. The spawning period occurred from late summer to

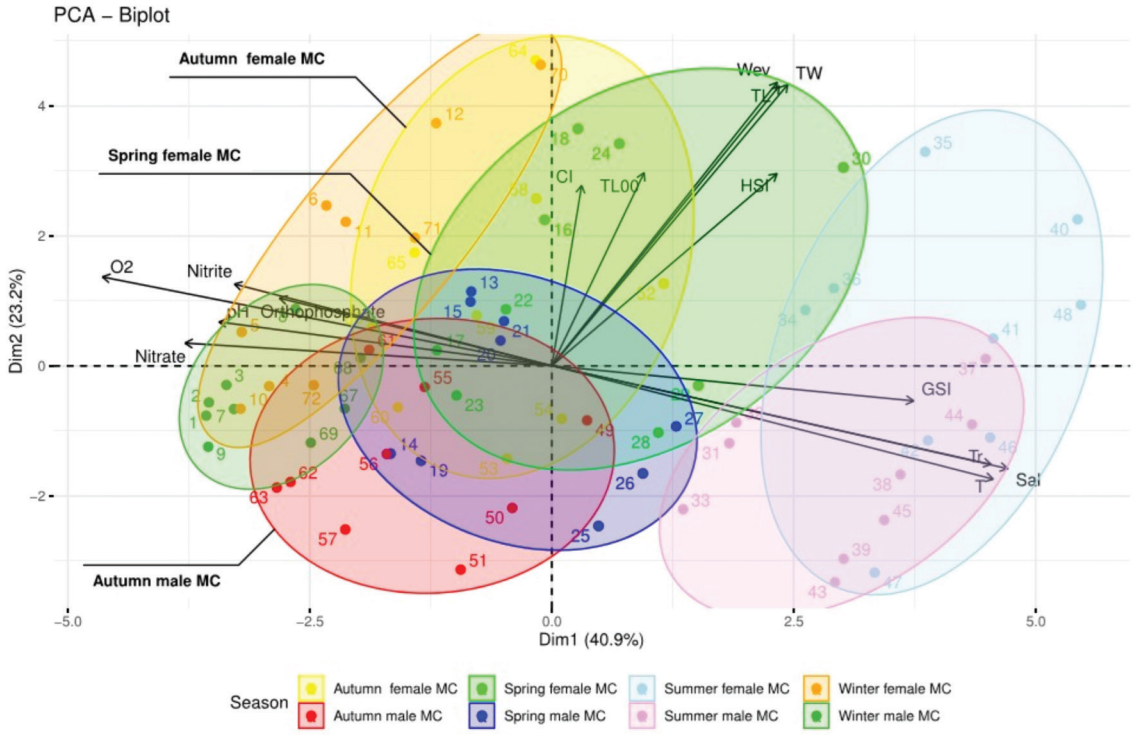

Figure 7. Biplot of the first two principal components (Dim 1 and Dim 2, explaining 40.9% and 23.2% of the total variance, respectively) extracted by the correlation matrix generated by computing the correlations between the biological parameters of *Mugil cephalus* male and female, and the environmental variables measured in Sidi Saad Reservoir, Tunisia.

early winter, with slight variations between the two species. Growth patterns were primarily isometric. However, female *M. cephalus* exhibited greater growth potential and larger asymptotic lengths. Principal Component Analysis (PCA) emphasized the significant impact of seasonal environmental variables, particularly temperature, salinity, and transparency, on reproductive activity and physiological patterns. These findings reflect the adaptive strategies of Mugilid species in response to the fluctuating environmental conditions typical of Mediterranean reservoirs.

The findings of the present study indicated that *M. cephalus* and *C. ramada* showed no significant differences in the proportions of males and females throughout the months, except for the combined sex ratio of *M. cephalus*. Similar sex ratio values for *C. ramada* were reported in various lagoons in Turkey (Yerli 1991; Ergene 2000), while for *M. cephalus*, comparable results were noted in Greece (Katselis et al. 2005), Sri Lanka (Silva and Silva 1981), and Mexico (Ibanez and Gallardo-Cabello 2004). In contrast, studies have reported a significant female dominance in *C. ramada* populations in the lagoons of Egypt (El-Maghraby et al. 1974) and Portugal (Oliveira and Ferreira 1997).

In general, the sex ratio, especially in high length classes, favors females (Brusle 1981). This agrees with the results of this study, where the females of *M. cephalus* and *C. ramada* dominated the populations. Female domination is relatively common for members of the family Mugilidae (see Koutrakis 2011). Several theories have been put forward to explain female domination: segregation of the sexes through different periods of the year, various natural and fishing mortality of the two sexes, environmental conditions favoring one sex over the other, differences between the two sexes in length and age, reproductive migrations (El Zarka and El Sedfy 1970; Brusle 1981). The domination of females in the larger length classes could be attributed to differential growth in favor of the females along with increased natural mortality of the males in smaller sizes/ages (Albaret and Legendre 1985).

As far as length at first sexual maturity is concerned, *M. cephalus* sexually matures in greater size than *C. ramada* (Fig. 5). It seems that there is also a differentiation in maturity between the two sexes. Most males reach maturity smaller and younger age than females. This explains that females are mature later than males (Nikolsky 1969; Albaret and Legendre 1985). These results are rather similar in areas with similar environmental conditions. Koutrakis (2011) reports an average total length of 26.76–27.97 cm and an age of 3 years for the first sexual maturity of *C. ramada*. Espino-Barr et al. (2016) reported an average total length of 34–35 cm and an age of 4 years for the first sexual maturity of *M. cephalus*. Brusle (1981) observed a correlation between the first sexual maturity and temperature in every region. Hence, younger ages and smaller sizes at maturity are observed in warm waters, while in cooler waters, both age and size at maturity are higher.

Based on the presently reported study, the spawning season of *M. cephalus* is confirmed between August and October, indicating that reproduction is triggered during late summer and early autumn. In the Adriatic Sea, this period is short, and the species spans from August to

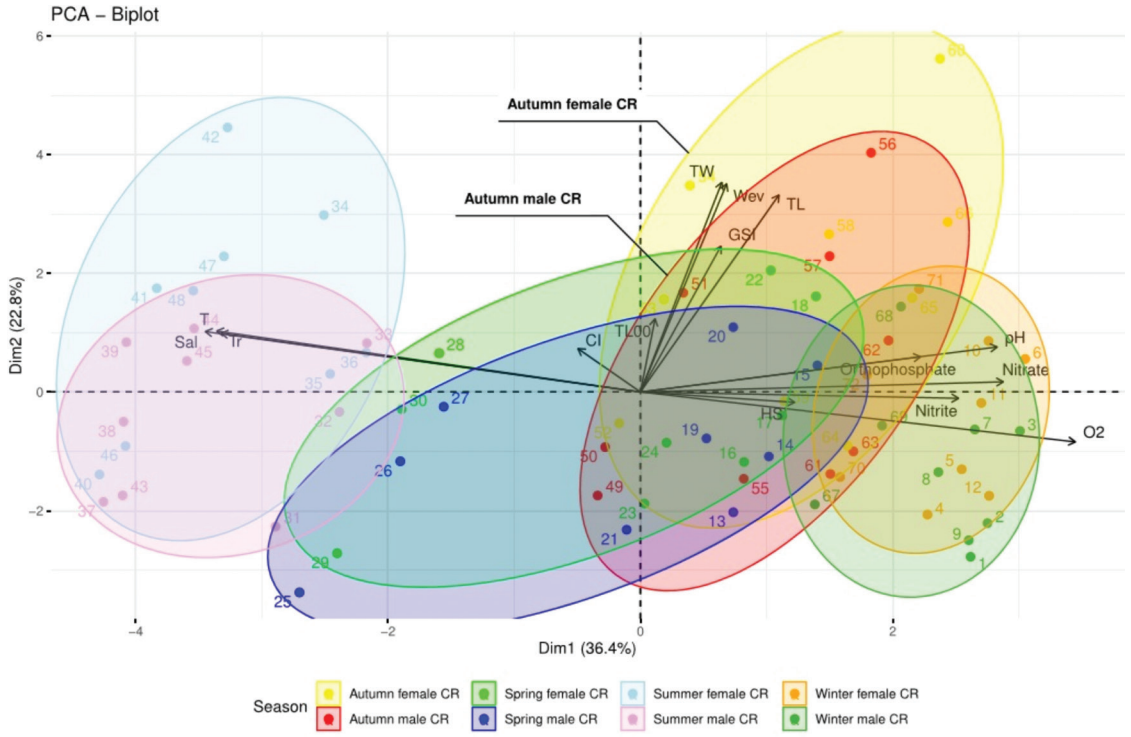

Figure 8. Biplot of the first two principal components (Dim 1 and Dim 2, explaining 36.4% and 22.8% of the total variance, respectively) extracted by the correlation matrix generated by computing the correlations between the biological parameters of *Chelon ramada* male and female, and the environmental variables measured in Sidi Saad Reservoir, Tunisia.

September (Bartulović et al. 2011). In many areas such as Hawaii, southwest of the Bay of Bengal, southwestern Taiwan, and the central Mexican Pacific coast, the massive spawning period of *M. cephalu*s starts from the end of autumn and still during winter (November to February) (Honebrink 1990; Jeyaseelane 1998; Chang et al. 2000; Espino-Bar et al. 2016). However, in other areas, *M. cephalus* spawns mainly during summer, as reported by Scotton et al. (1973) and Delaware et al. (1973), as well as in the Natal estuaries of South Africa (Marais unpublished*) and in Primorye, Russia (Novikov et al. 2002). These geographic differences highlight the influence of environmental variables, particularly water temperature and photoperiod, on reproductive timing. Warmer regions tend to delay spawning until cooler months, while temperate regions promote summer reproduction when metabolic and developmental rates are optimal.

Concerning *C. ramada*, the presently reported study confirmed that the spawning occurs from October to December. Similarly, in the Egyptian, Italian, and French Mediterranean area, *C. ramada* had a spawning period between October and January (Faouzi 1938; Ghittino 1983; Campillo 1992; El-Halfawy et al. 2007). Ergene (2000), based on the GSI temporal variation, suggests a shorter spawning period (November to December) in the Levantine Sea (Eastern Mediterranean). Whereas, in the northern Aegean Sea, the spawning period was spread out from September to January (Koutrakis 2011). These spatial differences in GSI among the same species could be caused by differences in food resources, living temperature, or the evolutionary adaptation of populations to the specific ecological properties of specific ecosystems (Bartulović et al. 2011).

A fundamental tool for studying morphological variations and life history patterns in many fish species and fish populations is finding the relationship between length and weight (Santos et al. 2002). The length–weight relationships' regression parameters (*a* and *b*) of *C. ramada* and *M. cephalus* from different localities around the world, compared to those in Sidi Saad Reservoir (Table 4) showed that the *C. ramada* exhibited isometric growth, showing a proportionally similar length increase than weight increase. For *M. cephalus*, most groups exhibited isometric growth, except for the combined sex category, where the increase in weight surpassed that of length. This frequently denotes appropriate environmental circumstances, gonadal development, or optimal feeding conditions.

Compared to previous studies, the values obtained in our study are similar to those expressed by other authors (Koutrakis and Tsikliras 2003; Laugier et al. 2011; Çiloğlu 2023), but they present differences with specific works (Table 4). The exponent *b* in the length–weight relationship may be influenced by many factors such as the

* Marais JFK (1976) The nutritional ecology of mullets in the Swartkops estuary. PhD Thesis, University of Port Elizabeth, Port Elizabeth, South Africa.

Table 4. Comparison of the length–weight parameters of *Mugil cephalus* and *Chelon ramada*.

Species	Parameter				Area	Reference
	a	*b*	Number	Allometry		
Mugil cephalus	0.014	2.88	246	Isometric	Bonny Estuary (Nigeria)	Aleleye-Wokoma et al. 2001
	0.0128	2.779	290	Negative	Strymon Estuary (Greece)	Koutrakis and Tsikliras 2003
	0.0095	3.178	242	Positive	Rihios Estuary (Greece)	Koutrakis and Tsikliras 2003
	0.023	2.765	840	Negative	Vellar Estuary (India)	Murugan et al. 2012
	0.0194	2.81	304	Negative	Senegal	Sarr et al. 2012
	0.01	2.940	94	Negative	Bir Mchergua Dam (Tunisia)	Mili et al. 2015
	0.0106	2.81	304	Isometric	Köyceğiz Lagoon (Turkey)	Reis and Ates 2019
	0.0126	2.9565	407	Isometric	El Mellah lagoon (Algeria)	Bensaâd-Bendjedid et al. 2022
	0.0041	3.22025	471	Positive	Köyceğiz Lagoon-Estuary (Turkey)	Çiloğlu 2023
	0.0081	3.068	204	Positive	Sidi Saad Reservoir	Presently reported study
Chelon ramada	0.0060	3.1301	74	Positive	Edku Lake (Egypt)	Kraim et al. 2001
	0.0056	3.1453	53	Positive	Merja Zargua (Morocco)	Kraim et al. 2001
	0.0184	2.821	166	Negative	Ichkeul (Tunisia)	Kraim et al. 2001
	0.0110	2.955	412	Negative	Strymon Estuary (Greece)	Koutrakis and Tsikliras 2003
	0.0107	2.948	249	Negative	Rihios Estuary (Greece)	Koutrakis and Tsikliras 2003
	0.004	3.18	362	Positive	Neretva River delta (Croatia)	Glamuzina et al. 2007
	0.0005	2.25	120	Negative	Gökova Bay, Muğla (Turkey)	Kasimoglu et al. 2011
	0.0085	3.02	320	Isometric	Thau Lagoon (France)	Laugier et al. 2011
	0.007	3.038	65	Positive	Sidi El Barrak Reservoir (Tunisia)	Mili et al. 2016
	0.0161	2.866	70	Negative	Ghzala Reservoir (Tunisia)	Mili et al. 2017
	0.010	2.94	842	Negative	Manzala Lake (Egypt)	El-Azab et al. 2020
	0.0105	2.9644	530	Isometric	Sidi Saad Reservoir	Presently reported study

a = the proportionality constant, *b* = the allometry coefficient value.

number of specimens studied, habitat, feeding rate, stage of maturity, sex, health, and overall fish conditions such as spawning period and gonad development, and environmental conditions (Abowei et al. 2009). Besides, the value of *b* varies between stocks and between areas.

Spatial differences in environmental conditions like temperature, water quality, and the structure of the food web can result in variations in growth patterns among different fish stocks. This variability highlights the importance of conducting local assessments of length–weight relationships (LWRs) to understand the adaptive responses and ecological strategies of fish populations in different ecosystems.

The values of the parameters of the von Bertalanffy growth equation for *M. cephalus* and *C. ramada* in different areas (Table 5) obtained by different authors (Okumus et al. 1997; Sahoo et al. 2012; Sarr et al. 2012) showed that *M. cephalus* has a higher growth potential than that of *C. ramada*. A similar result was obtained in this study. According to numerous studies carried out in different regions, the authors reported that the growth variability in Mugilidae could be due to the diverse environmental conditions, to a bad interpretation of the scales, or to the density of the population and to migration, which promotes mixing between migrant and local populations (Quignard and Farrugio 1981; Fehri-Bedoui and Gharbi 2005; Gautier and Hussenot 2005). By comparing our results with those of authors who have worked on Mugilidae, we can confirm that the growth of *M. cephalus* is faster in freshwater. A similar result was found by Bar-Ilan (1975), who reported that the fathead grey mullet reaches an overall weight twice that of the thinlip grey mullet in a freshwater lake. The rapid growth of *M. cephalus* and *C. ramada* has also been reported by Vidy and Franc (1992). Quignard and Farrugio (1981) indicated that grey mullets living in coastal ponds and estuaries grow faster than in the open sea.

The multivariate analysis showed that the biological parameters of both *M. cephalus* and *C. ramada* varied seasonally and that a combination of intrinsic biological and extrinsic environmental factors significantly influenced the growth of both sexes.

The presently reported study underlined the importance of studying fish populations from particular ecosystems, such as reservoirs. Our finding gives insight into the biological and growth parameters of two commercially important fish species (*M. cephalus* and *C. ramada*) harvested from a Tunisian reservoir.

However, our study presents certain limitations that future research could address. It was conducted at a single reservoir and over a one-year sampling period, which may limit the generalizability of the findings. Broader spatial and temporal coverage would strengthen the robustness of conclusions and allow for a better understanding of population dynamics.

This research establishes a foundation for future in-depth studies and supports the development of sustainable fishery management strategies in Tunisian dam ecosystems. Looking ahead, future research should incorporate multi-year monitoring to assess temporal variability and consider the integration of environmental and genetic data to gain a deeper understanding of the factors influencing reproduction and growth. Additionally, the application of histological and molecular techniques could enhance the accuracy of sex and maturity assessments, thereby contributing to more informed and adaptive fisheries management.

Table 5. Comparison of Von Bertalanffy parameters for *Mugil cephalus* and *Chelon ramada* in Sidi Saad Reservoir, Tunisia.

Species	Parameter			Number	Area	Source
	L_∞	K	t_0			
Mugil cephalus	74.0	0.39	0.38	585	Egypt	Zaky-Rafail 1968
	71.88	0.25	–0.56	174	Black Sea (Turkey)	Okumus et Basçinar 1997.
	33.2	0.55	0.15	246	Bonny Estuary (Nigeria)	Aleleye-Wokoma et al. 2001
	63.08	0.22	–0.64	66	Mexico	Vincent 2010
	60.6	0.28	–0.74	267	Chilika Lagoon (India)	Sahoo et al. 2012
	68.78	0.42	–0.012	432	Senegal	Sarr et al. 2012
	51.38	0.20	1.24	94	Bir Mcherga Dam (Tunisia)	Mili et al. 2015
	59.99	0.169	0.0132	291	Köyceğiz Lagoon (Turkey)	Reis and Ates 2020
	58.8	0.3	–0.461	407	El Mellah lagoon (Algeria)	Bensaâd-Bendjedid et al. 2022
	77.87	0.1147	–2.41	204	Sidi Saad Reservoir	Presently reported study
Chelon ramada	53.44	0.12	–1.5	419	Tagus River (Portugal)	Almeida et al. 1995
	54.6	0.22	–0.07	74	Edku Lake (Egypt)	Kraïem et al. 2001
	50.7	0.20	–0.31	53	Merja Zargua (Morocco)	Kraïem et al. 2001
	53.0	0.21	–0.18	166	Ichkeul (Tunisia)	Kraïem et al. 2001
	59.96	0.26	–0.45	362	Neretva River Delta (Croatia)	Glamuzina et al. 2007
	48.9	0.21	–1.01	120	Gökova Bay (Muğla) (Turkey)	Kasimoglu et al. 2011
	58.05	0.25	0.005	65	Sidi El Barrak Reservoir (Tunisia)	Mili et al. 2015
	30.45	0.48	–0.339	842	Manzala Lake (Egypt)	El-Azab et al. 2020
	44.62	0.2920	–0.9400	1200	Bardawil Lagoon (Egypt)	Salman et al. 2022
	52.01	0.1782	–1.41	530	Sidi Saad Reservoir	Presently reported study

L_∞ = asymptotic length, K = growth coefficient, t_0 = theoretical age.

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