Bulletin
Marine and Freshwater Sciences

Vol. 49, 2024, 157–166

Research Article

Reproductive characteristics of common carp *Cyprinus carpio carpio* Linnaeus, 1758 after 21 years of its introduction

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Received: 23/12/2023; **Accepted:** 06/12/2024; **Published:** 30/12/2024

Abstract: The common carp, *Cyprinus carpio carpio* is economically and ecologically an important freshwater fish. However, the reproductive knowledge of this species in Tunisian freshwaters, is scarce. The reproductive aspect of common carp (*C. carpio carpio* L, 1758) in the greatest reservoir “Sidi Salem” in Tunisia was studied monthly between May 2011 and August 2013. A total sample of 588 specimens, composed of 208 males, 256 females and 124 undetermined, were collected for this study.

The sex ratio between females and males did not differ significantly from 1:1. The size at first sexual maturity (L_{50}) for males was 35.31 cm (TL) while the females reached L_{50} at 40.00 cm TL. *Cyprinus carpio* in this dam is characterized by a single fractional spawning, for both sexes. It begins, when water temperature reaches 20.2 °C and photoperiod at 10.29 hours. The HSI (hepato somatic index), the RI (repletion index) and K (condition factor) were calculated.

The examination of the sexual cycle of *C. carpio carpio* explains more their reproductive biology. This holds significant implications for biodiversity conservation, fisheries management and aquaculture practices, and contributes to a more comprehensive understanding of ecological systems.

Keywords: Introduced species; freshwater fish; *Cyprinus carpio carpio*; reproduction; Sidi Salem dam; Tunisia.

1. Introduction

Cyprinus carpio carpio is globally one of the most widely introduced and established freshwater fish species (Casl, 2006). This is primarily due to its high tolerance to temperature, turbidity and prolific pond breeding habit, it was established promptly in most of natural inland waters, including rivers, lakes, streams, canals, wetlands and even village ponds of the country (Khan *et al*., 2016).

Notably, it was the first freshwater fish species introduced in Europe (Copp *et al*., 2005). However, *C. carpio carpio* is also recognized as one of the eight most invasive freshwater fish species (Lowe *et al.,* 2000). It is considered as a significant pest in some regions of Australia (Koehn *et al*., 2004), and it has been linked to wetland degradation and the decline of native fish populations throughout Australia (Koehn *et al*., 2000). Its reproductive strategy is believed to be a key factor in its success as an invasive species. Therefore, the sexual maturity investigation of the common carp is fundamental for fishery assessment.

In Tunisia, the common carp has been well acclimated since 1964. Nevertheless, there is a paucity of biological studies on this species in Tunisian freshwaters. The only relevant biological studies concerning this species in Tunisia were conducted quite some time ago, with Kraiem, in Losse *et al.* (1991) focusing on the Sidi Salem reservoir and Hajlaoui (2006) on the Sidi Saad reservoir.

The first objective of this study was to assess the adaptability and reproductive patterns of *C. carpio carpio* in a North African temperate reservoir. This included determining its size at sexual maturation and identifying its spawning period. The ultimate goal would be to enable sustainable fisheries exploitation.

2. Materials and Methods

2.1. Study area

Sidi Salem reservoir (fig 1) (36°, 33'N; 9°, 3' E; 48.24 Km above sea level.) is located in the middle valley of the Mejerdah River, Northern Tunisia. The impoundment has a surface area of 4208 ha (losse *et al*.,1991), a mean depth of 4 m (Mouelhi.,2000). The region's climate is Mediterranean. The mean annual rainfall is between 400 and 600 mm. The Sidi Salem Lake is meso-eutrophic; Its water temperature, in the period study, ranges between 10,6°C and 30°C (data from DGBGTH).

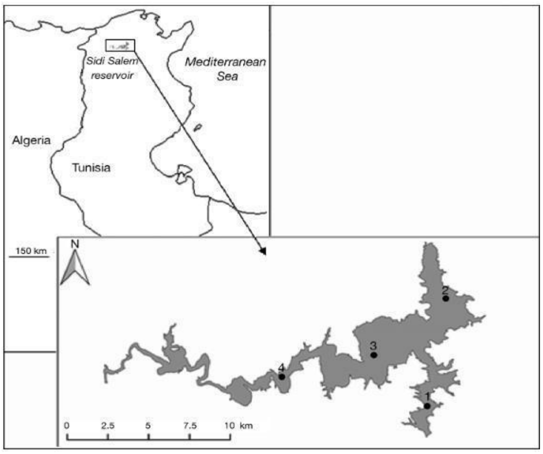

Figure 1: Geographic locations of four sites in Sidi Salem reservoir. S1: Downstream. S2: Oued Zargha. S3: Central station. S4: Upstream (Djait *et al*., 2019)

2.2. Samples collection

To analyze life history aspects of *C. carpio carpio*, samples were collected bimonthly from May 2011 to July 2013, using gillnets (mesh size: 30, 35, 40, 60, 70 mm). In the field, the captured fish were sorted by species, measured (total, fork and standard lengths: TL, FL and SL nearest 1mm) and weighed (total and gutted weight: TW, EW nearest 0.1g). In the laboratory, the fish were dissected to identify the sex and gonads; liver and stomach were collected and weighed.

The maturity cycle and the spawning period of the common carp, were studied by the monitoring of the monthly variations of the gonad somatic index (**GSI = [Wg / We] x 100**), where Wg: gonad weight and We: fish gutted weight. Accumulation and depletion of reserves in the liver and the muscles were studied by analyzing the hepatosomatic index (HSI) and the condition index (K). These indexes were calculated as follows

HSI= [LW / We] x 100 and **K = [EW / TL³] x 100**

Where LW is the weight of liver and EW is the eviscerated weight

The amount of food in the stomach content was evaluated using the repletion index (RI) calculated as follows:

$$\mathbf{RI} = \left(\frac{FW}{TW}\right) * 100$$ (Figueiredo *et al.*, 2005)

where FW is the fresh weight of the digestive tract and its contents in grams The size at the first sexual maturity, was determined by macroscopic exam of gonads. Females are considered mature when gonads: occupy the totality of their abdominal cavity, ovocytes are visible to the naked eye with yellow orange colour.

Mature males have white compact gonads which occupy 2/3 of the abdominal cavity.

The proportions of males, females and both sexes grouped are calculated, according to a logistic function: **Pr: 1/1 + e-r (Lt - L50)**

Pr: proportion of mature fish size L; r: slope of the maturity curve; L50: size at which 50% of fish were mature. The sex ratio (SR) was determined using the formula:

$$\mathbf{SR} = \frac{\text{Number of females}}{\text{Number of males}}$$

3.1. Statistical Analyses

The fit of the distributions to data sets was assessed by a dithered Kolmogorov-Smirnov goodness fit test. Statistical significance was tested by using Kruskal-Wallis one-way ANOVA on ranks followed by Mann-Whitney U test. The significance of changes in the sex ratio based on month and size is verified by the chi- square test (χ2) the calculated value of χ2 gives an indication of the realism of the null hypothesis H0. Spearman and Pearson Linear regression were used for correlation analyzes.

Comparison of LT_{50} values for males and females was performed using a specific treatment toxicological data REGTOX program (version EV7.0.5) (Vindimian *et al.*, 1999) based on linear and not linear regression models.

3. Results

3.1. Structure of population

Total of 588 individuals were examined: 208 males, 256 females and 124 undetermined, because of their gonad not developed yet. In order to get a monthly larger sample, we combined the two-year samples. The size (TL) range of fish was from 16.8 to 58.6 cm in males and from 13.8 to 70 cm in females (Table. 1; fig. 2). Male and female mean lengths were not significantly different (Mann-Whitney test: z=-1.056, p<0.291).

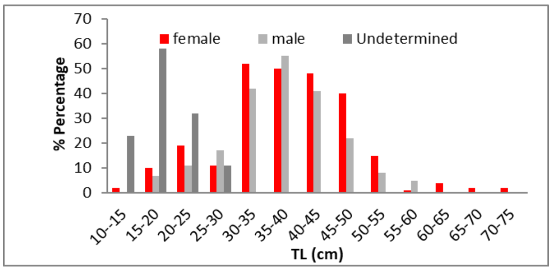

Figure 2. Length-frequency distribution of males, females and undetermined of *C. carpio* collected in Sidi Salem reservoir.

Table 1. Biometric data of *C. carpio* collected in Sidi Salem reservoir during the years 2011 to 2013. N, number; TL, total length; FL, Fork length; SL, Standard length; We, gutted weight.

	TL (cm)				EW (g)		
Sex	N	Mean	SD	(Min-Max)	Mean	SD	(Min-Max)
Mâle	208	37.94	8.39	(16.8-58.6)	793.07	561.24	4890-60.81
Femelle	256	37.98	10.13	(13.8-70)	934.23	891.67	37.95-9293
Immature	124	20.29	6.62	(12.1-44)	151.42	187.03	27.59-1226

3.2. Length at first maturity

Size at first maturity was reached respectively for males and females at 35.31 cm (TL) (FL. = 29.38 cm) (fig. 3) and 40.05 cm (TL) (FL= 31.48 cm) (fig. 4). Size at 50% maturity was attained, for both sexes grouped, at 36.49 cm (TL) (FL= 31.08 cm). The smallest mature male and female recorded were respectively 28.9 cm et 29.5 cm TL

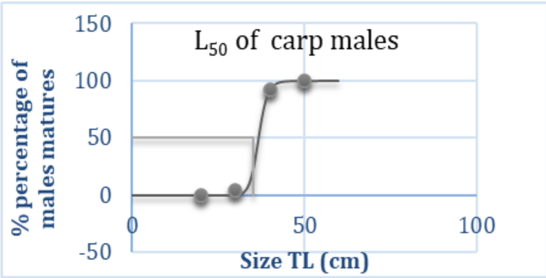

Figure 3. Size at first maturity of male in Sidi Salem Reservoir

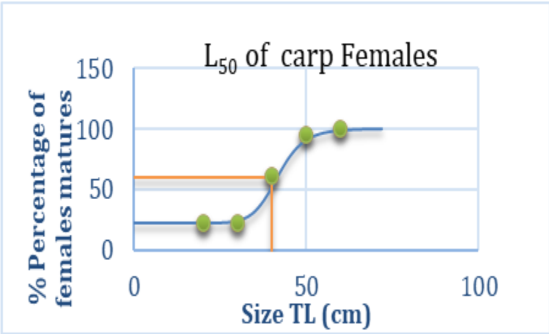

Figure 4. Size at first maturity of females in Sidi Salem Reservoir

Table 2. Monthly variation of the sex proportion (%) of *C. carpio* in Sidi Salem reservoir. N, number; *= *P* <0.05; **= *P*<0.01; *** = *P* <0.001

	Female		Male		χ^2 test	
Months	N	F%	N	M%	χ^2	*P*
Januray	25	9.77	16	7.69	1.97	0.16
Februray	30	11.72	22	10.58	1.23	0.26
March	15	5.86	17	8.17	0.12	0.72
April	15	5.86	15	7.21	0	1
May	19	7.42	29	13.94	2.08	0.14
June	27	10.55	7	3.37	11.76	0.001
July	8	3.13	9	4.33	0.05	0.8
August	28	10.94	23	11.06	0.49	0.48
September	13	5.08	17	8.17	0.53	0.46
October	46	17.97	27	12.98	4.94	0.02
November	12	4.69	14	6.73	0.15	0.69
December	18	7.03	12	5.77	1.2	0.27

3.3. Sex ratio

The number of females was greater than that of males in total carp samples. The estimated sex-ratio (males/females) for all samples is 0.80 which is not significantly different from unity (χ^2 = 18.66; P = 0.5). Tables 2 and 3 show the number of males according to the months and seasons.

Table 3. Evolution of sex proportion according to the size (Total length, TL) in *C. carpio* N, Number; *= *P* <0.05

	Female		Male		χ^2test	
Size classes TL (cm)	N	%	N	%	χ^2	*P*
15-25	31	12.11	18	8.65	3.44	0.06
25-35	67	26.17	62	29.81	0.19	0.66
35-45	99	38.67	96	46.15	0.46	0.83
45-55	50	19.53	27	12.98	6.87	0.009
55-65	5	1.95	5	2.4	0	1
65-75	4	1.56	0	0	-	-

3.4. Sexual cycle

3.4.1. Gonadosomatique index (GSI)

Cyprinus carpio carpio in Sidi Salem reservoir has more than one peak spawning season starting from August to June. The highest peak spawning season for both sexes were in November (%GSI_{female}=23; %GSI_{male}=20). Two additional peaks were observed for female; in September (%GSI= 8.13) and March (%GSI= 12.91) (fig. 5A) and three for males, in March (9.14%), September (10.32%) and December (12.75%). Mann-Whitney U test doesn't show difference between GSI of male and female (P=0.77)

3.4.2. Hepatosomatic Index (HSI)

The monthly mean hepatosomatic index (HSI) ranged from 0.77 to 3.57 % (1.90± 0.79) for females and 0.73 to 2.83 % (1.81± 0. 73) for males. Pearson correlation shows no signifying correlation between mean GSI and mean HSI for female (Pearson correlation, r=0.36; P=0.24) and male (Pearson correlation, r=0.53; P=0.71)

3.4.3. Condition index

The monthly mean condition factor fluctuated from 1.29±0.11 in October to 1.56±0.94 in August for female and from 1.18±0.40 (November) to 1.51 ±0.14 (April) for male. The condition k and the Gonado-somatique index are correlated significantly and negatively only for males (Pearson correlation, r=-0.58; P=0.014) (fig. 5B)

3.4.4. Repletion index

The lowest value of the repletion index was recorded in November for both sexes, while the highest values were observed in June for females (3.08) and in April for males (3.01). The GSI and The RI are correlated negatively and significantly only for female (r=-0,76; P<0.01) (fig.5A).

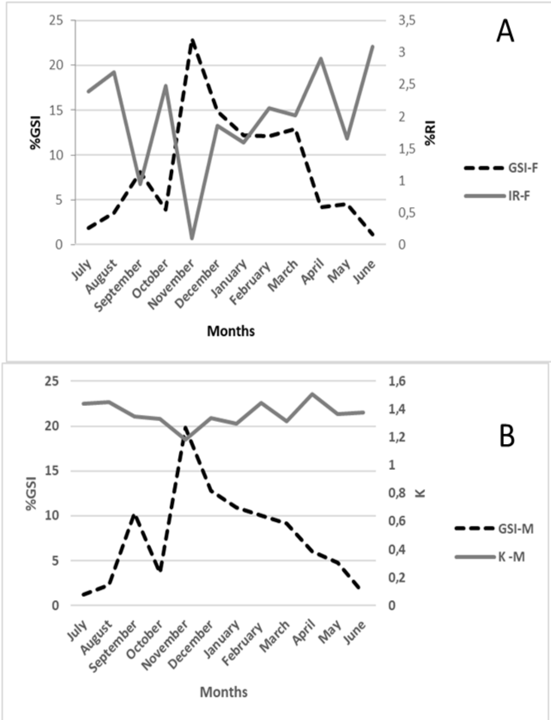

Figure 5. (A). Monthly variations in mean GSI and repletion index RI for female *C. carpio* in Sidi Salem reservoir (B) Monthly variation in mean GSI and condition factor k for male of *C. carpio*

3.4.5. Effect of temperature and photoperiod on female sexual cycle

Significant correlation was found between mean GSI female values and water surface temperatures (spearman correlation; r=-0.67; P=0.01) (fig. 6A) and between GIS male values and water temperatures surface (r=-0,60; P=0.03). The same relation is showed between photoperiod and GSI female (r= -0,39; P=0.001) (fig. 6B) and GSI male (r=-0.86; P=0.00). The spawning period occurs when water surface temperature reaches at 20.2°C and 10.29 h photoperiod.

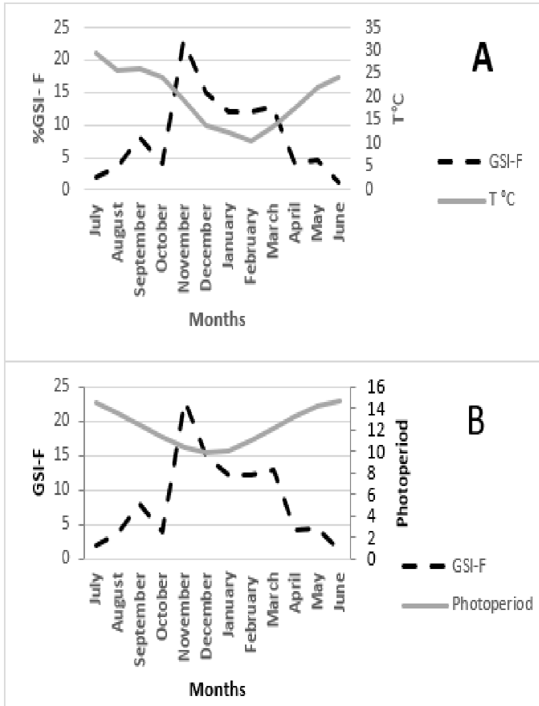

Figure 6. Monthly evolution of GSI in females of *C. carpio* and environmental parameters:

(A) temperature; (B) photoperiod

4. Discussion

This reproductive biology study of *C. carpio* in the Sidi Salem Reservoir represents the first report and provides essential baseline data. In this reservoir, the main spawning period extends from November to June, with a peak in November, when the photoperiod reaches 10.29 hours and the water temperature averages 20.2°C.

In contrast, the spawning season of *C. carpio* in Lake Hayq, Ethiopia, occurs between February and April, with water temperatures ranging from 21.1 to 25.1°C (Tessema *et al*, 2020). The Gonadosomatic Index (GSI) of female carp showed an inverse relationship with water temperature, a pattern also observed in carp populations in the lower Waikato region of New Zealand (Tempero *et al.*, 2006).

Several studies suggest that female gonad development is continuous when the photoperiod exceeds 10 to 12 hours, with oocyte maturation and ovulation consistently occurring at temperatures above 16°C (Crivelli, 1981; Guha and Mukherjee, 1991; Smith and Walker, 2004; Oyugi *et al*., 2011; Winker *et al*., 2011), regardless of geographical location. The carp population in the Sidi Salem Reservoir is no exception to this pattern.

The GSI value of females in August is lower than that in November, suggesting that breeding in August may be an adaptation. A similar pattern has been observed in carp populations in West Bengal (Ghua and Mukherjee, 1991). According to Ghua and Mukherjee (1991), during the monsoon, some other environmental factors, other than temperature, are responsible for gonadal development.

Size at 50% maturity was attained, for both sexes grouped, at 36.49 cm (TL) this result is on concordance with results of English, 1951; Sigler, 1958; Rehder, 1959; Bishai *et al*., 1974 they suggest that in temperate climates, *C.carpio* typically mature at lengths between 355 and 430 mm. In this study, the highest length at first maturity for males 35.3 cm (TL) and for female 40.05 cm (TL) were recorded. In the same lake, Losse *et al.* (1991) noted that the size at first maturity ranged between 150 and 200 mm for males and between 280 and 300 mm for females. In Lake Hayq (Ethiopia), the first sexual maturity size of *C. carpio* was 17.5 cm for males and 21.5 cm for females (Tessema *et al*., 2020).

These values closely resemble those reported for *C. carpio* in the Sidi Saad Reservoir, Tunisia, where males and females measured 15.8 cm and 22.5 cm, respectively (Hajlaoui *et al*., 2016). However, they differ significantly from the sizes recorded in other regions: 27 cm for males and 28.3 cm for females in Amerti Reservoir (Hailu, 2013), 27 cm and 28.7 cm in Lake Ziway (Abera *et al*., 2015), and 34 cm and 42 cm in Lake Naivasha, Kenya (Oyugi, 2012).Those differences were likely due to differences in water temperature, as higher water temperature are associated with lower minimum lengths at maturity (Adamek *et al*., 2015).

In this study, the total length of the specimens recorded in Sidi Salem reservoir ranged between 16.8 to 58.6 cm in males and between 13.8 and 70 cm in females. The maximum size of carp collected in Sidi Salem reservoir exceeded the sizes reported in the Waikato region (686 mm FL) (Tempero *et al*., 2006), Granja River (690 mm LF) (Singh *et al*., 2010), Sidi Saad dam (560 mm TL) (Hajlaoui, 2006), and the Amerti reservoir (450 mm FL) (Hailu, 2013). However, the largest carp caught in Sidi Salem dam were smaller than those caught in Seghan Lake, Turkey (715 mm TL) (Erguden and Goksu, 2009) and in eight localities in lakes in Victoria, Australia (Sivakumaran *et al*., 2003).

These discrepancies can be explained by differences in fishing gears and methods used, as well as factors such as relative abundance, lake morphometry, water column solids, lake depth, lake surface area, and watershed (Weber *et al*., 2010).

During the reproductive period, male *C. carpio* draw energy from their muscles. In contrast, females, when not reproducing, feed and obtain energy from the ingested prey. Intense feeding during non-reproductive periods can represent a strategy for energy allocation to reproduction, when these reserves would be used (Barbieri *et al*., 1996).

Thus, the energy for reproduction differs between male and female *C. carpio.* Previous studies have proved these differences in energy utilization. In fact, .in females, the depletion of muscle protein (main source energy) is largely compensated by an increase in ovary protein, while in males, it is associated with rapid development of secondary sexual characteristics. (Radhakrishnan *et al*., 2020).

The sex ratio between females and males did not differ significantly from 1:1 in sidi

Salem reservoir. This result agrees with the report (1.15:1) female to male ratio in Amerti Reservoir (Hailu., 2013). The result of this study disagrees with Tessema *et al* (2020) that has reported significant variation (1.3:1) female to male ratio in Lake Hayq, Ethiopia.This finding differs from the findings of Losse *et al*. (1991) for the same dam, where there was a significant predominance of males. The sampling methods used, such as electrofishing and gillnets, may explain these differences. It appears that male carp avoid gillnets (a passive fishing gear) but not electric fields (an active fishing gear).

The obtained results provide insight into the fish population status and support the establishment of strategies for the sustainable management of the Sidi Salem reservoir's fisheries.

Acknowledgments:

This study is the result of a collaborative work between the Technical Centre of Aquaculture and the University of Tunis El Manar.

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