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NEW DATA ON THE REPRODUCTIVE ACTIVITY OF *MUGIL CEPHALUS* L. FROM ALGERIAN COAST

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Abstract. The aim of this study was to provide additional insight into the reproductive activity of *Mugil cephalus* L. along the Algerian coast. All specimens were sampled from local commercial fisheries from January 2017 to January 2018. The reproductive period and the size at first sexual maturity were determined. Our results show that the males reach sexual maturity at smaller lengths (28.8 cm) than females (34.5 cm) and that sex ratio is female-skewed (63% *vs* 37%). The peak of reproductive activity took place from August to October, and spawning took place in November. Sexual rest occurred during subsequent months with a tendency of fattening from December to April. The seasonal evolution of the gonadosomatic index suggests that *M. cephalus* breeds from August to October. The analysis of the evolution of hepatosomatic index and Fulton's K apparently reveal no contribution of liver and muscle tissues to the reproduction activity of this species. The high fecundity estimated could be considered a reproductive strategy to maximise the survival of juveniles.

INTRODUCTION

The reproductive activity of fish in a given environment is very important for their survival and their maintenance in nature (Poncin 1996). A study of this physiological activity in fish needs to determine many biological indicators such as the size at first sexual maturity, relationship between size (or age) and fertility, the season or period of reproduction (Paugy and Lévêque 1999).

Mugilidae are heterosexual fish where sexual dimorphism is non-existent (Albaret and Legendre 1985; El Housni 1988; Ameur et al. 2003). *Mugil cephalus* is frequently found in coasts, estuaries and freshwater environments. The adults of this fish species tolerate salinity ranging from 0 to 75‰, while juveniles can tolerate such salinity variations only after reaching the lengths of 4–7 cm. Adult fish prefer sandy or muddy bottoms and dense vegetation and migrate in groups to the open sea for spawning. The larvae move to the coast in extremely shallow water, which provides food as well as protection from predators. After reaching 5 cm in length, young fish move towards slightly deeper waters (Farrugio 1975; Villani 1988; Brusle and Cambrony 1992).

Mugil cephalus is fished all year round, particularly in summer. Many studies were conducted on its reproductive biology in several regions (Ezzat 1965; Brusle and Brusle 1977; Albaret and Legendre 1985; Villani 1988; Brusle and Cambrony 1992; Ibañez 1994; Bartulović et al. 2011). Its reproductive biology is important for the managers of this fish resource (Albaret and Legendre 1985). *M. cephalus* presents a high commercial value and plays an important ecological role in coastal ecosystems (removes organic debris from sandy bottoms). In Algeria, little information on its reproductive biology and ecology is available. The aim of the present study is to characterize the reproductive biology of *M. cephalus* from the Algerian coast and to determine some useful biological parameters, such as fecundity and relative fecundity, for the stock management of this highly commercialized fish.

MATERIALS AND METHODS

Study area and sampling method

The specimens of *Mugil cephalus* (n = 1000) were sampled in the Algiers Bay and in the Gulf of Bejaia located on the eastern coasts of Algeria (Figure 1). Specimens of different sizes (15 cm – 64 cm both sexes combined) were monthly and randomly sampled from January 2017 to January 2018 in the studied area.

Gonad maturity and size at first sexual maturity

For each fish, the total length (Lt), the total weight (Pp), the weight of eviscerated fish (Pe), and the weight of gonads (Pg) were measured. The gonads maturation stage was determined by macroscopic observation (Figure 2) using several maturation scales established on mullets (Brusle 1981; Albaret and Legendre 1985; El Housni 1988; Brown-Peterson et al. 2011).

Figure 1. Sampling sites (black stars) modified (Wikimedia: orangesmile.com).

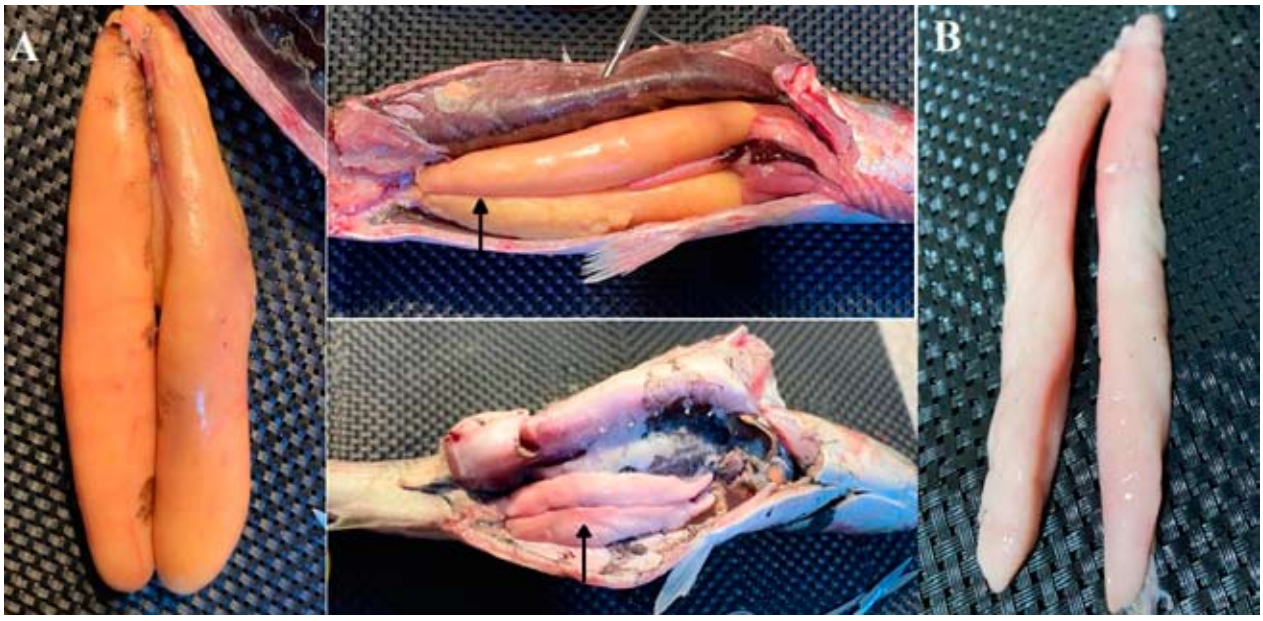

Figure 2. Macroscopic observation of the mature gonads of *Mugil cephalus* after dissection: (see dark arrow). A: female gonad (pinkish yellow and orange with oval section); B: male gonad (white with flattened section).

Measurements and morphometric method

Overall sex ratio

The proportions of each sex in the catches are useful data to better understand the demographic structure of a population (Camarenà 1986). The sex ratio (SR) indicates the male or female rates in a stock, so:

$SRm = (nM/nM + nF) \times 100$

$SRf = (nF/nM + nF) \times 100$

(SRm – part of males in sex ratio, SRf – part of females in sex ratio, nM – number of males, nF – number of females).

Males and females were distinguished after dissection and observation of gonads (particularly the form and the colour).

Gonadosomatic index

To define the breeding season, we followed monthly changes in the gonadosomatic ratio. The gonadosomatic index (GSI) is the ratio of fish gonad weight to body weight. The GSI is particularly helpful in identifying days and seasons of spawning, as the ovaries of gravid females swiftly increase in size just prior to the spawning seasons. Spawning times are shown when GSI values increase and peak.

The GSI was calculated according to the method of Render et al. (1995) where GSI was expressed as a percentage of gonad weight (GW) divided by body weight (BW): $GSI = [GW/ (BW – GW)] \times 100$.

The size at first maturity was determined from specimens whose gonads were at maturity stage ≥ 3.

Hepatosomatic index

In fish, the liver plays an important role in processes related to the development of gametes (Nunez 1985). The hepatosomatic index (HSI) is equal to one hundred times the liver weight to the eviscerated weight of the

fish (Bougis 1952):

HSI = (Wl/Wev) × 100

Wl – liver weight (g)

Wev – eviscerated weight of the individual (g).

Its seasonal development makes it possible to quantify the weight variations of the liver during the reproductive cycle. Bertin (1958) distinguishes two types of fish according to the method of storage and the mobilization of reserve substances in this organ:

- lean fish – accumulates lipids in the liver, thus the maximum values of the HSI precede those of the GSI.

- oily fish – accumulates lipids in the muscles, the liver only intervening in the transformation of these lipid reserves. In this case, the HSI evolves in parallel with the GSI.

Mugil cephalus is a semi-fat fish. It stores energy reserves mainly in the muscles, in the perivisceral mesenteries and under the skin. These reserves are then transferred to the liver and gonads to meet energy requirements during the breeding season (Djadji et al. 2013).

Condition index K

The energy reserve of the muscles is rather associated with proteins, while the energy contained in the liver is derived mainly from lipids. The condition factor (K) and the hepatosomatic index (HSI) can provide an estimate of seasonal variations in energy reserves (Lambert and Dutil 1997). Seasonal variations of HSI, K, GSI, and the monthly proportion of macroscopic maturity stages can help determine the moment and the duration of maturation of gonads considering the energy transfers towards gonads are considerable (Htun-Han 1978).

The condition factor is an indicator of the "fitness" of the population (Bolger and Connolly 1989). The condition factor of Fulton (1904) is as follows:

K = (W / L3) * 100

K – condition factor

W – weight of eviscerated fish (g)

L – total length (g).

Hureau (1970) specifies that many factors act on the condition coefficient, such as the state of sexual maturity, season, environment, sex, age, etc.

Microscopic (histological) study

The collected ovaries and testes were analysed histologically in the laboratory. The gonads (n = 250 females, n = 250 males) had been previously fixed in Bouin's solution. A section in the middle part of a gonadal lobe was selected and dehydrated by successive baths of alcohols of increasing concentration, subsequently embedded in paraffin, sectioned at 5 µm using a microtome and stained with haematoxylin and eosin according to McDonough et al. (2005).

Gonadal maturity profiles

The microscopic criteria applied in the classification of ovarian development are based on oocyte characteristics such as the formation of cortical alveoli, degree of yolk accumulation and nuclear migration. For males, the criteria such as the presence/absence and relative proportion of spermatogonia, spermatocytes and spermatozoa were applied.

For females, histological slides were observed at 4× magnification for the calculation of areas occupied by different cell stages. However, for the determination of certain cell stages, magnifications of 10× and 100× were used (Stenger 1959; Kuo et al. 1974; McDonough et al. 2003; Brown-Peterson et al. 2011).

For males, three fields of observation with an area of 18 500-µm2 spread of the tunic of testicle to the efferent channel were examined (100×). The distribution of areas occupied by each cell type, the nuclear diameter of germ cells and their staff within a cyst were determined. The distribution of surfaces in each field helps evaluate testicular development (Stenger 1959; Kuo et al. 1974; McDonough et al. 2003; Brown-Peterson et al. 2011). The size at first sexual maturity is by convention the size for which 50% of individuals are mature during the period of sexual maturity.

Fecundity and relative fecundity

Fecundity (F) and relative fecundity (Fr) were assessed in *M. cephalus* females using the gravimetric method (the weight of 50 specimens of mature females, phase 4). To estimate F, two subsamples of 0.1 g of ovary tissue were obtained of each individual and put in modified Gilson fluid for preservation (Simpson 1951). The diameters of oocytes were measured with a binocular magnifying glass with a micrometer.

Fecundity (F): F = n * Gi/gi (Holden and Raitt 1975):

n – number of oocytes in the subsample,

Gi – weight of the gonad (g),

gi – weight of the subsample (g),

Relative fecundity (Fr): relationship between fecundity and total length and weight:

Fr = a* xb (Holden and Raitt 1975):

x – individual weight or length,

a – intercept or initial number of oocytes,

b – slope or oocyte number changing rate.

RESULTS

Morphometry and sex ratio

The frequency distribution of the mean length indicated that the size of most fish specimens (60%) varied from 40 to 51 cm.

The smallest male had a size of 21.0 cm while the smallest female had a size of 19.5 cm. Our results of sex ratio reveal the dominance of females over males (SRf = 63% against SRm = 37%, or 1M : 1.5F).

Gonad maturation and size at first sexual maturity

During the juvenile stages, the males of *M. cephalus* showed very thin and transparent testicles. From a fork length (FL) equal to 20.3 cm male gonads became whitish, while female gonads became pinkish yellow and orange. Gonad size increased until it occupied a large part of the visceral cavity (Figure 2). During spawning, the ovaries became very soft and empty.

Figure 3 shows that the size of female *M. cephalus* at first sexual maturity was 34.5 cm and the smallest mature female observed was 32.2 cm.

For males, the size at first sexual maturity was not estimated due to a low number of observed mature males. However, the size of the smallest mature male observed was equal to 28.8 cm. This possibly indicates that in our study males mature earlier than females.

Variations in salinity lead to various effects on the biological characteristics of the species (growth, reproduction) (Figure 4). Salinity appears to play an important role in the induction of gonadal maturation in *M. cephalus*. Indeed, salinity starts to increase in the northeast of Algeria from the month of May (Figure 4), which coincides with the gonad maturation phase.

The monthly variations in the gonadosomatic index (GSI) values make it possible to specify the spawning period and thus confirm the macroscopic observations. The mean GSI values of female *M. cephalus* calculated for each sample are reported in Table 1 and shown in Figure 5.

During the sexual cycle, the weight changes of male and female gonads were synchronous. Female GSI levels were higher than of males due to a large size of ovaries. The seasonal fluctuations of GSI revealed the period of reproduction of *M. cephalus*. The GSI of females reached its maximum (12) in September and October, then decreased to low values in December (2). Female gonad maturation took place from August to October, so spawning probably occurred from October to November. In males, the progression of the GSI (Figure 5) showed that gonadal maturation reached its maximum

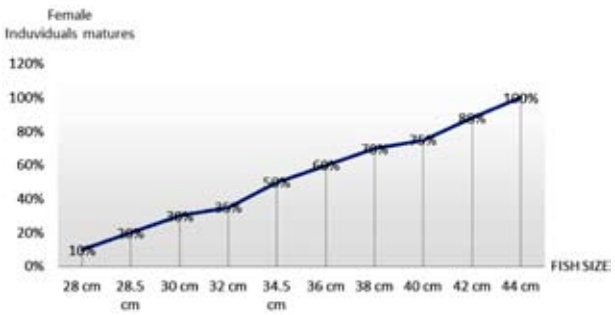

Figure 3. Mature individuals rate according to the length of *Mugil cephalus* females from Algeria (logistic model).

Figure 4. Variation of salinity in the northeast of Algeria during the study period.

Table 1. Fork length, body weight and gonadosomatic (RGS) of the sampled *Mugil cephalus*. GSI: gonadosomatic index, GW: gonad weight.

Date	Sample size		Fork length (FL) (mm)		Body weight (BW) (g)		Male (M)		Female (F)	
	M	F	M	F	M	F	GW	GSI	GW	GSI
January 2017	20	10	421.2 ± 12.2	423.3 ± 22.9	991.3 ± 12.2	991.4 ± 14.2	7	1	9	1
February 2017	17	22	335.3 ± 18.2	300.4 ± 35.1	682.4 ± 11.4	740.2 ± 21.5	5.8	1.75	15	2
March 2017	18	11	481.2 ± 25.1	482.0 ± 18.3	1212.6 ± 28.7	1281.1 ± 33.4	20	0.8	31	2
April 2017	12	10	455.6 ± 14.6	511.2 ± 14.4	1010.5 ± 12.2	1127.2 ± 45.2	18.5	3	34	4
May 2017	15	21	420.3 ± 21.1	462.3 ± 18.6	875 ± 47.6	965.5 ± 22.1	8.6	4	20	4.80
June 2017	14	17	523.3 ± 45.2	549.4 ± 25.3	1672 ± 23.5	1826.7 ± 23.6	33	7.70	52	6.55
July 2017	33	36	611.2 ± 26.8	665.2 ± 41.2	3412.6 ± 44.7	4109.4 ± 44.5	180	7.66	220	8.03
August 2017	15	18	646.5 ± 29.3	662.5 ± 26.7	3814.9 ± 22.4	4214.8 ± 23.8	200	9	220	10
September 2017	23	20	603.5 ± 25.8	611.1 ± 26.8	3550 ± 25.1	3641.2 ± 12.3	210	10.60	220	11.8
October 2017	19	16	424.3 ± 32.1	405.2 ± 34.2	961.5 ± 22.9	991.7 ± 33.2	10.4	11	22	12
November 2017	15	24	533.2 ± 13.9	517.3 ± 33.1	1512.3 ± 66.2	1224 ± 22.1	26.5	5.8	42	7.05
December 2017	18	23	514.5 ± 14.2	499.8 ± 34.6	1252.5 ± 12.2	1152.7 ± 24.8	16.3	2.8	29	2
January 2018	31	22	467.2 ± 16.9	463.5 ± 32.1	1002.2 ± 24.1	886.5 ± 14.5	15	2	22	1.71

Figure 5. Monthly variation in gonadosomatic index in females and males of the studied *Mugil cephalus*. GSIF: female gonadosomatic index, GSIM: male gonadosomatic index, GSI: gonadosomatic index.

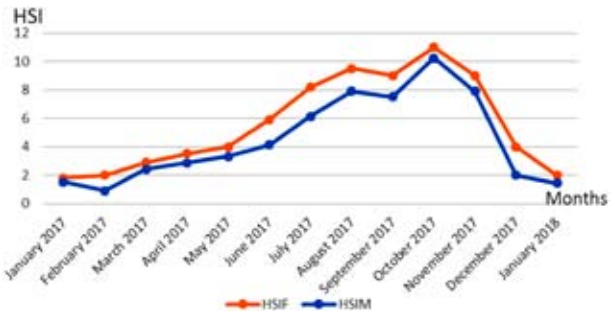

Figure 6. Monthly variation in hepatosomatic index in females and males of *Mugil cephalus*. HSIF: female hepatosomatic index, HSIM: male hepatosomatic index. HSI: hepatosomatic index.

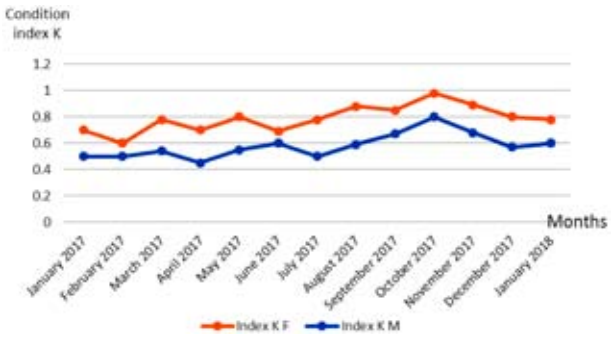

Figure 7. Monthly variation of the condition index K in females and males of *Mugil cephalus*. Index KF: index K in females, Index KM: index K in males.

in October (11). Emissions occurred in November. In this study, mature individuals were collected in October, but as the fish migrate offshore to spawn, it was difficult to collect mature male fish from the coast in October, during the presumed spawning period.

The evolution of two indexes, HSI and GSI, was similar. In females of *M. cephalus,* the maximum values of HSI were recorded during the reproduction period (August–November): 9.5, 9, 11 and 9, respectively, and the minimum values during the period of sexual rest (December–April): 2, 1.8, 2, 2.9 and 3.5, respectively (Figure 6). The HSI shows evolution comparable to that of the GSI and indicates that reproduction practically occurred in August–November. Figure 6 also describes the progression of HSI in males. The monitoring of this hepatic index during the year 2017–2018 also shows the same evolution as the GSI with peaks in October (10.24), August (7.9) and September (7.5), which explains that hepatic reserves were not devoted to the reproductive activity of this species.

The Fulton's K (condition index) was roughly stable throughout the year 2017–2018 (Figure 7) for both sexes. This morphometric index was stationary throughout the year and especially during the spawning period. Increases coinciding with the spawning period in autumn 2017 equalled 0.98 in females and 0.68 in males. This factor did not take long to decrease beyond this period when the fish regained normal weight in winter and spring.

Developmental reproductive stages

Histological observations in *M. cephalus* revealed that ovaries go through five successive developmental stages (Figure 8):

1) Immature: specimens in the early growing stage were first observed in April. The number of oocytes in the peri-nucleolus stage of 100 µm in diameter and the ovaries increased gradually, and oocytes in the oil droplet stage ranging from 100 to 150 µm in diameter showed in the ovarian lamellae (Fig. 8A).

2) Developing: the ovary-accumulated oocytes in the yolk globule phase with a granular yolk globule ranging from 150 to 300 µm in diameter happened during the beginning of September, including those in the oil-droplet stage (Fig. 8B).

3) Mature stage: the GSI peaked in October. Individuals had mature oocytes stages ranging from 300 to 480 µm in diameter with a big oil-droplet (Fig. 8C).

4) Spawning capable: there was individual variation during migration time, and fish migrated offshore in November to spawn, so no colonies were found during the spawning stage.

5) Regressing (cessation of spawning): there was a rapid decrease in GSI in November. The ovaries contained primarily immature oocytes and a few ovulatory follicles. Individuals in this stage showed up from December to March (Fig. 8D).

Concerning the evolution of sexual maturity of male gonad, there was a growing trend with peaks during the months of maturities from August to October, which coincided with the spawning period of the same. Figure 9 clearly shows the dominance of the spermatid stage.

Fecundity and relative fecundity

Fecundity was determined in females at stage 4 and ranged from 240,138 to 2,844,900 oocytes in females between 25.3 and 41.2 cm (FL). As for relative fecun-

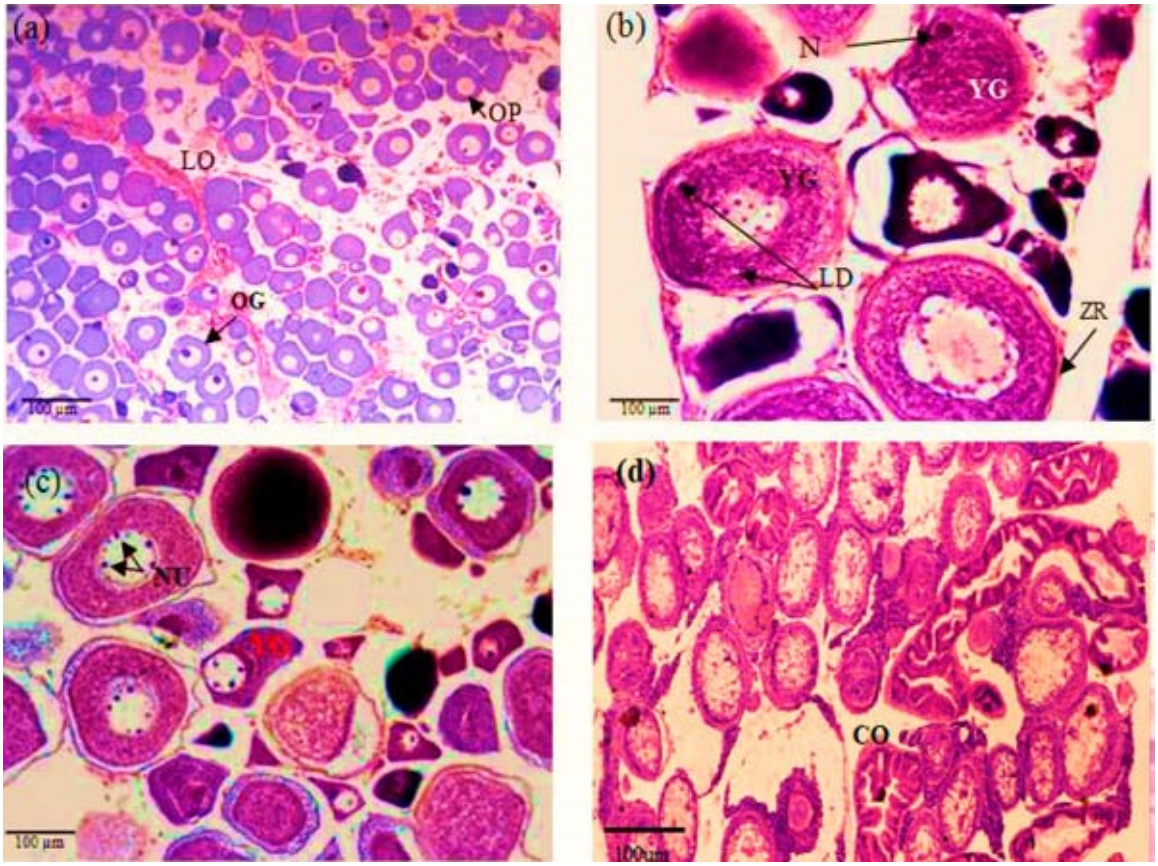

Figure 8. Different stages of developmental ovaries of *Mugil cephalus*. **(a)** Premature in the pre-vitellogenic yolk stage**, (b, c)** mature in the late vitellogenic yolk stage, **(d)** after spawning. CO: ovarian cavity, OG: oogonia (G × 100), Lo: ovarian lumen, OP: pre-vitellogenic oocytes (G × 10), N: nucleus, ZR: Zona Radiata, NU: nucleolus.

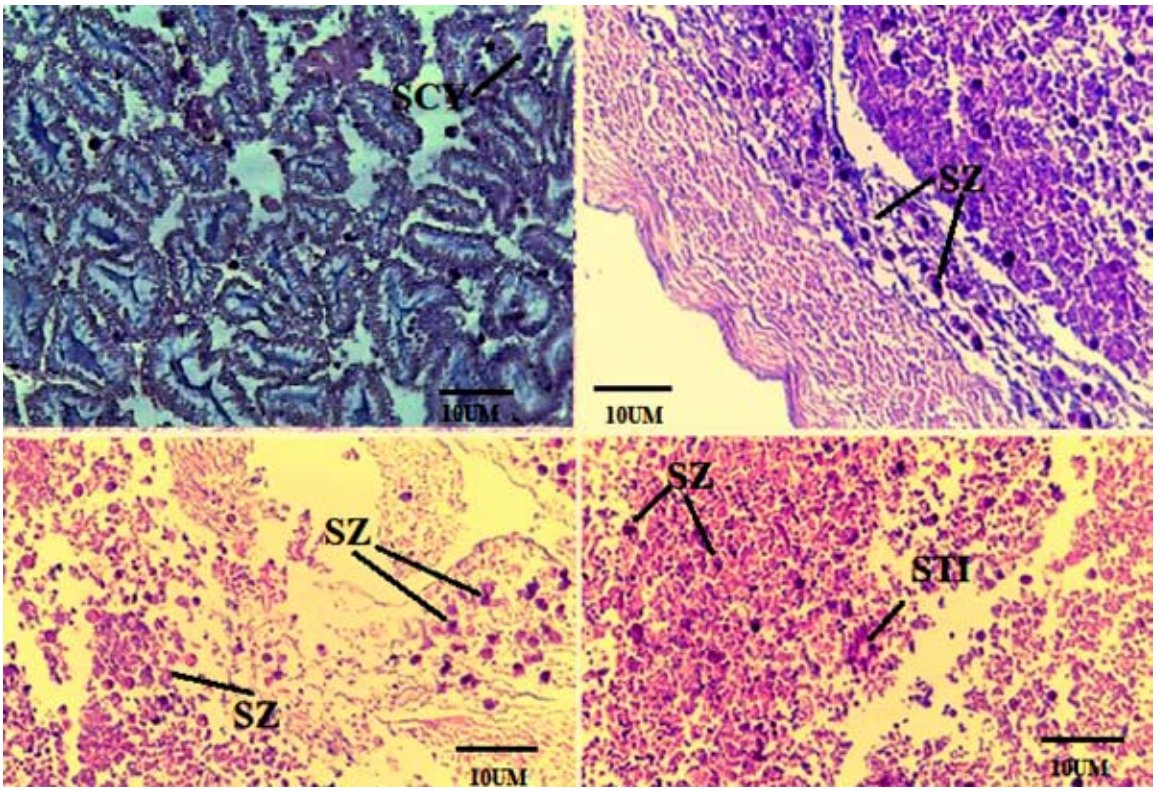

Figure 9. Maturation of testes of *Mugil cephalus* from northeast of Algeria. SCY: spermatocyte, STI: spermatid, SZ: spermatozoa.

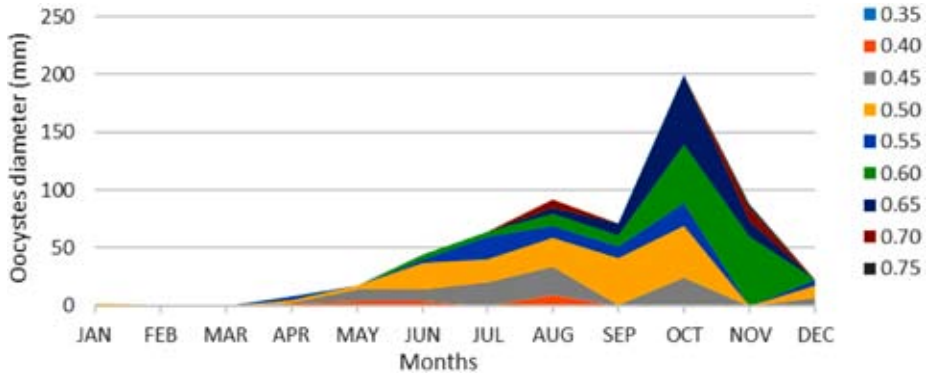

Figure 10. Distribution of oocytes diameters of gonads females at macroscopic stage 4 in *Mugil cephalus* from northeast of Algeria.

dity, the average is 815 ± 400 oocytes*g^{-1} of body mass. The unimodal distribution of oocyte diameters suggests a synchronous development of oocytes with a single oocyte laying (Figure 10).

DISCUSSION

Our study of the reproductive biology of *M. cephalus* from the Algerian east coast show a sex ratio in favour of females (63%) over males (37%). These results corroborate with those recorded by Bouhadiba (2018) in the Algerian west coast, where the total percentage of females was 62.79%; females were significantly more numerous than males with a percentage of 37.21% (sex ratio was 1:1.68 in favour of females). The overall sex ratio compared to a balanced sex ratio shows a significant difference in favour of females. Our results are in agreement with different works done on *M. cephalus*. An unbalanced sex ratio in favour of males has been observed by several authors. Some have shown the dominance of females over males, as in the case of the Merja Zerga population (Le Dantec 1955; Ezzat 1965; Landret 1974; Brulhet 1975; Brusle and Brusle 1977; Brusle 1981).

Whatever the period of the year and whatever the size of the individuals caught, several authors (Le Dantec 1955; Ezzat 1965; Landret 1974; Brulhet 1975; Brusle and Brusle 1977; Brusle 1981; Ameur et al. 2003) have also observed this imbalance in *M. cephalus*. This predominance of one sex is a relatively frequent phenomenon in many fish species. In teleosts in general, males are predominant during the breeding period, whereas females are predominant during the sexual resting season (Santos et al. 2007; Sylla et al. 2009). This hypothesis is not confirmed by our results.

Fryer and Iles (1972) explain that sex ratio is in favour of males because they grow faster than females. For these authors, seasonal variation in sex ratio could be due to the fact that once egg fertilisation is complete, males probably migrate from the spawning grounds to less protected feeding areas where they are more easily caught. In contrast, females migrate to rocky areas to avoid predators. To explain the disproportion of sex ratio in this species, several hypotheses were suggested by Brusle and Brusle (1977): (1) segregation of sexes according to seasons, (2) distribution varies according to size and age, (3) natural selective mortality, (4) different migratory activity, (5) selectivity of fishing gear, which would capture one sex more than the other.

Our results regarding size at sexual maturity (34.5 and 28.8 cm in females and males, respectively) are different from those recorded by Silva and Silva (1981), particularly in male specimens. These authors reported that the size at the first sexual maturity was 31.5 and 34 cm in females and males, respectively. The first sexual maturity shows a small difference between two sexes. Indeed, females reach their first sexual maturity size later than males. Our results are very similar to those of Arnold and Thompson (1958), Oren (1981), and Ibañez and Gallardo-Cabello (2004). Other works on the size of the first sexual maturity in populations of *M. cephalus* from different regions are summarised in Table 2.

From all these results it appears that the sexual maturity of *M. cephalus* is almost similar in both sexes. However, it is evident that the size of the first sexual maturity of the Mediterranean population is different from those found in other regions of the world. The size at first sexual maturity depends on the region, but its value remains homogeneous within each geographical unit (Table 2). For *M. cephalus* from the eastern coasts of Algeria, the size at first sexual maturity is greater than in specimens sampled in the Gulf of Annaba (Saoudi and Aoun 2014) and lower than in individuals examined by Farrugio (1975) and Brusle and Brusle (1977) off the Tunisian coasts. In the Marmara Sea, maturation is delayed, while it is very early in the Atlantic regions. In the Mediterranean, North Atlantic and West Africa, maturation occurs at intermediate sizes. In the western Mediterranean Sea, this size is smaller than in the Atlantic (Senegal–Mauritania).

Salinity starts to increase in the northeast of Algeria from May (Figure 4), which coincides with the gonad maturation phase. Ameur et al. (2003) explain that salinity plays a major role in the reproduction process of *M. cephalus*. It would be an important factor in the sea migration because its increase would promote physiological adaptation linked to the osmoregulation that takes place during the change of environment (Ameur et al. 2003; Mohamed 2004; Cardona 2006). Moreover, Ameur et al. (2003) have shown that other factors such as temperature and photoperiod (although not directly involved in the beginning of the spawning period) could be stimulating factors of the reproductive activity.

The metabolic activity required for the maturation of gametes increases with temperature (Ameur 1994; Djadji et al. 2013). Low water temperature causes immature *M. cephalus* to migrate offshore to pass winter, while salinity causes mature fish to migrate offshore in the spawning season (Tamaru et al. 1994; Cardona 2000).

The progression of the gonadosomatic index (GSI) in our study shows that the spawning period is spread over a single period of the year with marked peaks in October and November in females and in November in males. Female GSI levels are higher than those of males due to a large size of the ovaries. GSI increase coincides with gametogenesis while its decrease indicates active oviposition (Lahaye 1979). For this reason, *M. cephalus* gonads begin to develop in September when water temperature starts to drop, and the GSI rapidly increases to 11.8 in October. GSI is variable depending on the species of the same family of fish (Bartulović et al. 2011). According to Hsu et al (2007), the gonadosomatic index of *M. cephalus* in north-eastern (NE) waters (coastline of Taiwan) increased significantly from 0.5 at the beginning of the spawning season to more than 21 for females and 19 for males at the peak of the spawning season, which begins in winter from mid-December to mid-January. In this study, mature individuals were collected in October and November, but because fish migrate offshore to spawn, it was difficult to collect mature fish on the coast in November, during the presumed spawning period.

A comparative analysis of the breeding populations of *M. cephalus* from different regions of the world shows differences from one population to another (Table 3). Our results regarding the breeding period recorded from the Gulf of Bejaia are similar to those recorded by Saoudi and Aoun (2014) in the Gulf of Annaba (Algerian coasts). Both studies found that the breeding period of *M. cephalus* occurs from August to November. In the Mediterranean Sea, Caspian Sea and the Sea of Marmara, *M. cephalus* populations breed from June to October (Faouzi 1938; Erman 1959; Morovic 1963; Farrugio 1975; Brusle and Brusle 1977; Brusle 1981). However, in the Atlantic Ocean, its reproduction took place in winter from October to January (Landret 1974; Greely et al. 1987; Ibañez 1994). Therefore, it is clear that the breeding period of this fish species varies according to seasons, environmental factors, and the considered region.

A comparison of the monthly variation curves of the GSI and the HSI shows that the two indices evolve in a synchronous manner. The maximum GSI coincides with the maximum HSI. The increase in liver weight appears to be related to the increase in genital activity. This result may be explained by the fact that *M. cephalus* is a semi-fat fish. It stores energy reserves mainly in the muscles, in the perivisceral mesenteries and under the skin. These reserves are then transferred to the liver and gonads to meet energy requirements during the breeding season, hence the low value of the condition factor during the breeding season (Djadji et al. 2013). The monthly variation curves of the condition factor have a similar evolution in both sexes. The maximum values of K for females and males were observed in the month of October while the minimum values were recorded in February and March. Djadji et al. (2013) reported that the maximum values of K for females and males were observed in March and January and the minimum values were recorded in February and November, respectfully.

Table 2. Size at first sexual maturity of *Mugil cephalus* from different geographical regions (populations).

Areas	Size at first sexual maturity (cm)	Authors
U.S. Atlantic coast (Florida)	♂ 23.0 – 23.9; ♀ 24 – 31	Broadhead (1953)
U.S. Atlantic coast (Florida)	♂ 23; ♀ 27	Greely et al. (1987)
African Atlantic coast (Mauritania)	♂ SL = 28; ♀ SL = 27	Brulhet (1975)
Mediterranean Sea (Tunisia)	♂ SL = 28; ♀ SL = 27	Farrugio (1975)
Mediterranean Sea (Tunisia)	♂SL = 38; ♀ SL = 40	Brusle and Brusle (1977)
Mediterranean – Sea of Marmara (Turkey)	TL = 47 for both sexes	Deniczi (1958)
Mediterranean – Sea of Marmara (Turkey)	♂ FL = 40; ♀ FL = 41	Erman (1959)
Atlantic coast (Morocco)	♀ FL = 37.1	Ameur et al. (2003)
Algeria (Annaba)	♂ FL = 30; ♀ FL = 34	Saoudi and Aoun (2014)
Algeria (present study)	♂ FL = 28.8; ♀ FL = 34.5	Present study (2017–2018)

♀: female, ♂: male, FL: fork length, TL: total length, SL: standard length.

Table 3. Reproduction period of *Mugil cephalus* in different region of the world.

Areas	Reproduction period (month)												Authors
	JN	JUL	AUG	SEP	OCT	NOV	DEC	JAN	FEV	MAR	AP	MY	
Mediterranean – Sea of Marmara (Turkey)													Erman (1959)
Caspian sea													Avanesov (1972)
Atlantic coast (Morocco)													Ameur et al. (2003)
Mediterranean (Egypt)													Faouzi (1938)
Adriatique Sea													Morovic (1963)
Mediterranean Sea (Tunisia)													Brusle and Brusle (1977)
Mediterranean Sea (Tunisia)													Brusle (1981)
Mediterranean Sea (Tunisia)													Farrugio (1975)
Gulf of Mexico													Ibañez (1994)
U.S. Atlantic coast													Greely et al. (1987)
Northwest of the Gulf of Mexico													Ibañez and Gallardo-Cabello 2004
Coastal lagoon Sri Lanka													Silva and Silva (1981)
Algeria (Gulf of Annaba)													Saoudi and Aoun (2014)
Algeria (present study)													Present study 2017–2018

JN: June, JUL: July, AUG: August, SEP: September, OCT: October, NOV: November, DEC: December, JAN: January, FEV: February, MAR: March, AP: April, MY: May.

Saoudi and Aoun (2014) point out that the monitoring of the sexual maturity of *M. cephalus* caught in 2014 in the Annaba region of Algeria allowed them to observe the presence of females and males laying eggs in the same season as we found in our study. In the Gulf of Annaba, the reproduction of *M. cephalus* is quite short. Gonad maturation in females occurs from September to October. At the end of this period, spawning takes place and ends in November and December (Saoudi and Aoun 2014). Gonad maturation in males starts one month before that in females. The same phenomenon observed in *M. cephalus* in our study was also observed in another species of Mugilidae (*Chelon labrosus*) (Besbes et al. 2002) and in *Liza aurata* from the east and south of Tunisia (Fehri-Bedoul et al. 2002). In the Mediterranean Sea, where climate is temperate, reproduction moves towards winter and the longest period of laying occurs during summer. It is therefore very likely that the breeding of different populations is influenced by water temperature or photoperiod, although these two factors are not directly involved in the onset of the laying period. The results suggest an effect of temperature (Ameur 1994), leading to increase in the metabolic activity required for the maturation of gonadal products and physiological changes that accompany this event.

Histological observations in *M. cephalus* reveal that ovaries go through five successive stages. The ovary developmental stages are indicated in Figure 8. *M. cephalus* is a group-synchronous spawner, and two groups of oocytes are seen in the ovary near the spawning period. It is thought to spawn once a year; the developmental stage of mature oocytes is not separated during a short time after activities begin within the ovary, but oocytes pass through each stage consecutively.

In our study region, the fecundity of *M. cephalus* was determined in females at stage 4. It ranged from 240,138 to 2,844,900 oocytes (FL = 25.3–41.2 cm). As for relative fecundity, the average is 815 ± 400 oocytes*g^{-1} of body mass. Fecundity increases with the size of females. In general, fecundity is very high in Mugilidae but particularly in *M. cephalus* (McDonough et al. 2003). Bester (2004) and Hill (2004) estimated the fecundity of *M. cephalus* at 0.5 to 2.0 million eggs per female. Meseda and Samira (2006) reported fecundities varying between 213,000 and 3,010,000 oocytes for relatively large females (TL = 33.1–59.2 cm). Similarly, Matthieu and Mohamed (2002) reported fecundities of 5 to 7 million oocytes on the Mauritanian coast. High fecundity in fish which does not practice parental protection, like *M. cephalus* (Abou-Seedo and Dadzie 2004; Sylla et al. 2009), may be explained by the strategy to maximise offspring survival.

Table 4 shows the fecundity values of *M. cephalus* in different countries; the highest values correspond to the Black Sea, where it can reach values over 7 million of oocytes (Oren 1981). Also, Berg reports in the same area 7 million of oocytes in organisms of 52.00 cm of total length and 13 years of age (Oren 1981). In the Hawaiian Islands, Keith et al. found a maximum fecundity of 7 million of eggs (Keith et al. 1999); in Mauritania, Brulhet found a maximum of 6 million (Brulhet 1975); and Popescu reported 5 million in organisms from the Danubian delta (Oren 1981). Grant and Spain reported 4 million 800 thousand in Australia (Grant 1975). The values of fecundity of 3 million 790 thousand eggs were reported in SW Korea by Yang and Kim, and of 3 million in Taiwan by Tung and Hsu (Hsu et al. 2007; Yang and

Table 4. Fecundity values by different authors and countries.

Area	Fecundity (oocytes)	Organism size	Author
Australia	1,275,000–2,781,000	/	Thomson (Thomson 1963)
Australia	1,275,000–2,781,000	/	Kesteven (Kesteven 1942)
Australia	1,600,000–4,800,000	/	Grant and Spain (Grant 1975)
Australia	2,000,000–2,500,000	/	Tosh (Oren 1981)
Taiwan	700,000–3,000,000	/	Tung (Tung 1981)
Taiwan	700,000–3,000,000	/	Hsu (Hsu et al. 2007)
SW Korea	3,790,000	78.7 cm, 5 years old	Yang and Kim (Yang and Kim 1962)
France	500–2800/g	/	Keith (Keith and Allardi 2001)
Black Sea: Danubian delta	5,065,800–5,085,440	/	Popescu (Oren 1981)
Black Sea	3,089,000–7,206,000	/	Nikolskii (Oren 1981)
Black Sea	5,000,000–7,000,000	52 cm, 13 years old	Berg (Oren 1981)
Mauritania	4,000,000–6,000,000	/	Brulhet (Brulhet 1975)
Mauritania and Senegal	2,322,400	50 cm FL	Landret (Landret 1974)
Hawaii	340,000–795,000	induced spawning	Shehadeh (Oren 1981)
Hawaii	5,000,000–7,000,000	/	Keith (Keith et al 1999)
Tamaulipas, Mexico	1,341,000–2,919,000 (6510 oocytes/g)	48 and 56 cm (TL)	Solís (Solís 1966)
Veracruz, Mexico	405,767–898,512 (1680 oocytes/g 680–4776)	/	Ibáñez and Gallardo-Cabello (2004)
Central Mexican Pacific	1,422,076–1,747,736 (2830 /g; 1500 – 2900/)	28.5 cm to 48.8 cm (TL)	Espino-Barr (Espino-Barr et al. 2016)
Algeria (present study)	240,138–2,844,900 (815 ± 400 oocytes/g)	25.3 and 41.2 cm (FL)	This study

Kim 1962; Tung 1981). Solís found a maximum value of fecundity for *M. cephalus* in Tamaulipas, Mexico, in the Atlantic Ocean, i.e. 2 million 919 thousand oocytes in females of 48.00 to 56.00 cm of total length (Solís 1966). In Australia, Thomson and Kesteven reported 2,781,000 and Tosh reported 2 million and a half in females of *M. cephalus* (Oren 1981; Kesteven 1942; Thomson 1963). In Mauritania and Senegal, Landret found a value of 2,322,400 oocytes (Landret 1974). In a study of Espino-Barr et al. (2016), the values of 1,582,684 to 1,747,736 oocytes were found in organisms of 37.70 to 48.80 cm of total length and 6 to 12 years of age on the coast of the Central Mexican Pacific. The lowest values (898,512 oocytes in females of 38.00 cm total length and 6 years of age) were reported by Ibáñez and Gallardo-Cabello from the Tamiahua Lagoon, Veracruz, Mexico, although these authors mention to have found fecundity values of 1,483,056 oocytes in females older than 6 years of age (Ibáñez and Gallardo-Cabello 2004). At last, Shehadeh et al. found the lowest value of 795,000 oocytes in *M. cephalus* females from Hawaii (Oren 1981). This great variability of the values found for the fecundity of *M. cephalus* can be because of the difference in length and age of the studied organisms, as there is a positive relation between fecundity and bigger and older females, even in the same area.

Finally, we can conclude that the reproductive biology of *M. cephalus* from the northeast coast of Algeria does not differ significantly from other Mediterranean areas. This paper highlighted the likely role of salinity in triggering the maturation of gonads. Females are more numerous than males in the studied populations. The size at first maturity is not significantly different between the two sexes. The unimodal distribution of oocyte diameters suggests a synchronous development of oocytes with a single oviposition. The high absolute fecundity could be considered a reproductive strategy to maximise the survival of juveniles of this fish.

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