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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Reproductive Cycle, Sexual Maturity and Fecundity of *Mullus barbatus* (Linnaeus, 1758)

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Abstract: The study aims to determine the reproductive biology and 50% maturity length of red mullet (*M. barbatus*) by taking monthly samples in the Black Sea between October 2017 and September 2018. The difference in the sex ratio of the samples (female: 936, male: 454) was found to be significant. It was understood that the results of the methods used to determine the reproductive period (GSI, macroscopic analysis of gonads, microscopic analysis of gonads) were compatible with each other. The reproduction period of red mullet was between April and August in the Black Sea, but spawning occurred between May and August according to the histological method. Considering the oocyte structures and oocyte diameter distributions in the histological sections, it was observed that the red mullet in the Black Sea was a multiple spawner and had an indeterminate fecundity. Mean and standard deviation of batch fecundity (F_B) and mean relative fecundity (F_R) of red mullet during the spawning period were calculated as 4813.0±5324.0 and 124.6±124.1 g^{-1}, respectively. The maturity sizes of females and males were 12.40 cm and 11.29 cm, respectively. To ensure the sustainability of red mullet stocks in the Black Sea, a new management plan should be established that takes into account spawning periods, reproductive strategies, and sizes at maturity.

Keywords: Black Sea, maturity length (L_{m50}), *Mullus barbatus*, reproductive biology.

Mullus barbatus (Linnaeus, 1758)'un Üreme biyolojisi, Eşeysel Olgunluk Boyu ve Fekonditesi

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Öz: Bu çalışmada, Ekim 2017-Eylül 2018 döneminde Karadeniz'de aylık olarak örneklenen barbunya balığının (*M. barbatus*) üreme biyolojisi ve %50 olgunluk boyunun belirlenmesi amaçlanmıştır. Örneklerin eşeyleri arasındaki farkın (dişi: 936, erkek: 454) anlamlı olduğu belirlenmiştir. Üreme periyodunun belirlenmesinde kullanılan yöntemlerin (GSI, gonadların makroskopik analizi, gonadların mikroskopik analizi) birbirleri ile eşleştiği anlaşılmıştır. Güney Karadeniz'de barbunyanın üreme dönemi Nisan-Ağustos ayları arasında olup, histolojik yönteme göre yumurtlama Mayıs-Ağustos ayları arasında gerçekleşmiştir. Barbunyanın yumurtlama dönemindeki ortalama F_B ve ortalama F_R sayısı ve standart sapmaları sırasıyla 4813,0±5324.0 ve 124,6±124.1 g-1 olarak hesaplanmıştır. Dişilerin ve erkeklerin olgunluk boyları sırasıyla 12,40 cm ve 11,29 cm'dir. Sonuç olarak, Karadeniz'deki barbunya stoklarının sürdürülebilirliği için yumurtlama dönemleri, üreme stratejisi ve olgunluk boyları dikkate alınarak yeni bir yönetim planının oluşturulması gerekmektedir.

Anahtar kelimeler: Karadeniz, *Mullus barbatus*, olgunluk boyu (L_{m50}), üreme biyolojisi.

INTRODUCTION

Red mullet (*Mullus barbatus* Linnaeus, 1758) is one of the important target species of commercial importance in the bottom fisheries of the Mediterranean, Aegean Sea, and Black Sea (Genç, 2000; Sieli, et. al., 2011; Kokokiris, et. al., 2014 Yıldız & Karakulak, 2016). It is the main target species of bottom trawl and small-scale trammel net fishery on the Black Sea coast of Türkiye. (Aydın & Karadurmuş, 2013; Arslan & İşmen, 2014). 34% of red mullet produced through fishing in Türkiye is provided from

the Black Sea (TUİK, 2023). Red mullet is the most caught demersal fish in the Black Sea after whiting (Genç, 2000).

Studies on the bio-ecology, population dynamics, and fishing of red mullet, which are under continuous exploitation, have been carried out in the Black Sea (Genç, 2000; Kalaycı et al., 2007; Dinçer & Bahar 2008; Aksu et al., 2011; Kalaycı & Yeşilçiçek, 2012; Aydın & Karadurmuş 2013; Yıldız & Karakulak, 2016; Erdem, 2018; Çiloğlu & Akgümüş, 2019; Yılmaz et al., 2019; Melnikova & Kuzminova, 2020; Milkeladze et al., 2022; Kutsyn, 2022; Onay et al., 2023a; Onay et al.,2023b), Aegean Sea and Mediterranean (Çelik & Torcu, 2000; Özbilgin, et al., 2004; Metin, 2005; Özbilgin et al., 2011; Sieli et al., 2011; Kokokiris et al., 2014 Arslan & İşmen, 2014; Ferrer-Maza et al., 2015; Carbonara et al., 2015; Yeşilçiçek et al., 2015; Tüzün, 2019; Balcı & Aktop, 2019).

There are very few detailed studies on the reproduction of the species in the Black Sea where the study was conducted. To exploit a fish stock sustainably, knowing the reproductive strategies of that species will contribute to the management models to be conducted.

This study aimed to reveal the reproductive characteristics such as reproductive period, fecundity, and maturity size (L_{50}) by investing the changes (macroscopic, microscopic) in the gonads and oocyte structures of red mullet throughout the year.

MATERIAL AND METHOD

In this study conducted in the Black Sea, a total of 1410 *M. barbatus* individuals were randomly sampled monthly between October 2017 and September 2018. The samples were taken from the bottom trawl operations of the Karadeniz Araştırma research vessel belonging to Recep Tayyip Erdoğan University and gill nets operations by a fisherman in the Black Sea.

The total lengths of all samples were measured with an accuracy of 1 mm and weighed with a precision of 0.01 g. After the sex determination was made by removing the gonads, the gonads and liver were weighed with a precision of 0.01gr.

Condition factor was calculated using the following equation;

$$CF = \left(\frac{BW}{L^b}\right) * 100$$

(BW: body weight, L: total length, b: exponential coefficient of length-weight relationship, (Ricker, 1973)).

Gonadosomatic index;

GSI= $\left(\frac{GW}{(BW-GW)}\right) * 100$ (GW, gonad weight) and

Hepatosomatic index;

HSI=$\left(\frac{LW}{BW}\right) * 100$

(LW, liver weight) were calculated throughout the year to determine the reproduction period, energy, and feeding change. (Craing et al., 2000; Nunes et al.,2011).

Changes in the ovaries and oocytes were investigated in two steps. A total of 936 female ovaries were staged with the macroscopic (visual) method, while 415 of these ovaries were staged by microscopic examination, taking into account the changes in the ovaries and oocyte.

Development of the ovaries macroscopically and microscopically is classified into five stages (immature I; developing II; spawning III; regressing IV; and regenerating (V) (Brown-Peterson et al., 2011). Female ovaries were kept in 10% neutral buffer formalin (Nbf) for 1 day and stored in 70% alcohol. For histological sections, the gonads were rinsed overnight under running water, then dehydrated at increasing alcohol concentrations, and clarified in xylene. After each gonad was embedded in paraffin wax, 5-10 µm thick sections were cut and stained with hematoxylin-eosin (Hunter, 1985; Murua & Motos, 2006). The preparations were examined under the microscope and the gonads were phased according to their oocyte structures.

In the study, batch fecundity was determined by using the ovaries of 45 red mullets during the spawning period. Batch fecundity and relative batch fecundity (FR) were calculated when the first post-ovulate follicles were detected in May following June and July. The gravimetric method was used to determine batch fecundity. In the estimation of batch fecundity, only hydrated oocytes in the ovary were taken into account, and post-ovulate follicles were excluded (Hunter et al., 1985; Hunter et al., 1992). After removing 0.1 g from the center of the left lobe of the ovaries, hydrated oocytes were counted under a binocular microscope. Batch fecundity (F_B) was estimated using the following relation (Hunter, et Al., 1985; Macchi et al., 2005; Murua et al., 2003).

$F_B = \sum_{i=1}^{m} \left(\frac{ni*Gi}{gi}\right) * \left(\frac{1}{m}\right)$, Where, G_i; the gonad weight of i th female, g_i; the subsample weight i th taken from of the ovaries, n_i; the number of the hydrated oocyte in the subsample taken from the i th female and m; the number of samples used to estimate batch fecundity.

Relative fecundity (F_R) was determined by dividing the number of hydrated oocytes by body weight (Hunter et al., 1992; Murua et al., 2003; Murua & Saborido-Rey, 2003). The relationship between body weight-batch fecundity and total length-batch fecundity was determined by were calculated by fitting power functions. Since the number of individuals in the spawning (III) phase decreased, regression of July samples was not used. The diameters of oocytes taken from mature gonads were measured under a binocular microscope to determine the oocyte frequency distribution throughout the reproductive period. To determine the change in oocyte diameters, oocyte diameters were measured between March before the spawning period and August,

when the spawning period ends. The diameters of oocytes smaller than 50 µm were not measured.

The %50 length of the sexual maturity (Lm50) was determined by proportioning the mature individuals in each length class to the total individuals after the macroscopic observation of the gonads taken before reproduction began. While calculating the first maturity length, the data was linearized and calculated using the following function. (King, 1995; Saborido-Rey & Junquera, 1998; Flores et al., 2015).

$$P = 1/(1 + \exp(a + b * L)$$

$$Lm_{50} = -(a/b)$$

Where; P: proportion of mature fish in the length class, L: total length, a: intercept, b: slope)

To determine the statistical significance levels, the chi-square test between the genders. Differences between all data were determined with ANOVA, all Pairwise Multiple Comparison Procedures (Dunn's Method) were used to compare Monthly CF, GSI, HIS. The One-way ANOVA applied between monthly batch fecundities and monthly relative batch fecundities during the spawning period. The TUKEY test applied between monthly measured oocyte diameters. All statistical analyzes were performed in SigmaPilot 12 software.

RESULTS

The length distributions of a total of 1410 red mullet (*Mullus barbatus*) individuals obtained in the study were found to be between 9-21 cm, females 10-21 cm, and males 9-17 cm. As a result of the sex determination, 66.4% (n=936) of the samples were female, 32.2% (n=454) were male, and 1.4% (n=20) were sex-unidentified individuals. The number of females and males were significantly different each other ($\chi 2_{(df=1)}$) = 362.57; p<0.05). Monthly GSI, HSI, and CF were calculated according to sexes (Fig. 1, Fig. 2). It was determined that while HSI peaked in November (1.885±0.404) and June (1.980±0.284) in females, it peaked in November (1.532±0.227) and April (1.546±0.407) in males. Considering the monthly GSI values, it was observed that it peaked in June (female: 6.931±3.218, male: 4.323±1.865) in both sexes. Monthly CF values in females and males showed similar fluctuations, with the highest values in December (female: 1.100±0.078, male: 1.070±0.119) and the lowest values in May (female: 0.900±0.087, male: 0.830±0.113) (Figure 1, Figure. 2).

As a result of statistical analysis performed on monthly GSI values for both females and males, April, May, June, and July showed significant differences from other months (p<0.05).

It was determined that the difference was significant in both females and males (November, March, April, May, June, and July) (p<0.05). CF values showed similar monthly trends in both genders. Statistically, November and December differed from other months (p<0.05).

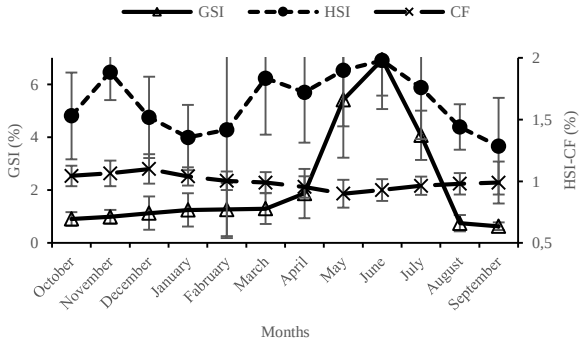

Figure 1. Monthly GSI, HSI, and CF distributions in females.

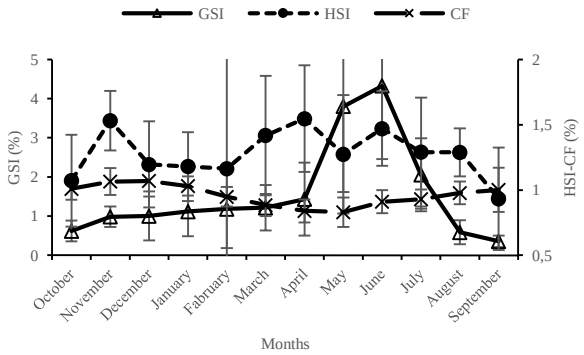

Figure 2. Monthly GSI, HSI, and CF distributions in males.

When the gonads were examined, it was seen that April, May, June, and July were intensely represented by the spawning (III) and regressing (IV) phases, while the other months completely consisted of the immature (I), developing (II) and regenerating (V) phases (Fig. 3).

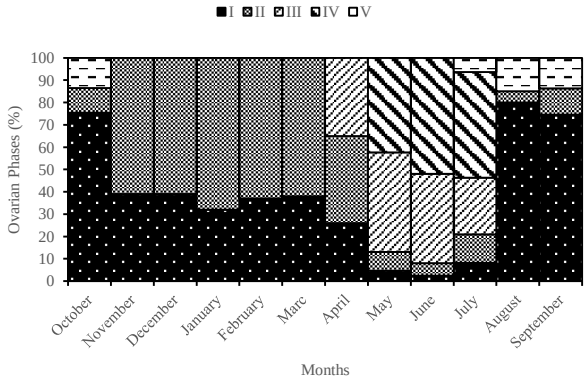

Figure 3. Monthly macroscopically ovaries maturation phases of *M. barbatus.*

To determine the maturity stages of the ovaries from histological sections microscopically, sections were taken from the ovaries of 10 females every month throughout

the year. These sections were examined under the microscope, taking into account the oocyte structures in the ovaries, and the ovaries were evaluated in five stages (Figure 4).

In the sections taken from female ovaries between September and March, some oocytes were found to be in oogonium (polygonal, cytoplasm basophilic, and nucleus quite large) and primary growth (Pg) structures (Figure 4A). It was determined that the ovaries of female individuals in these months were in the immature (I) stage.

Although most of the female ovaries in April were represented in the structure of primary growth and cortical alveolar (Ca) (enlargement of the cytoplasm in some oocytes, reduction of the nucleus diameters, formation of nucleolus, etc.) it was observed that some oocytes were in vitellogenic (Vtg1) structure. Some female individuals in this month were immature (I) and some were in the development (II) stage (Figure 4A, 4B).

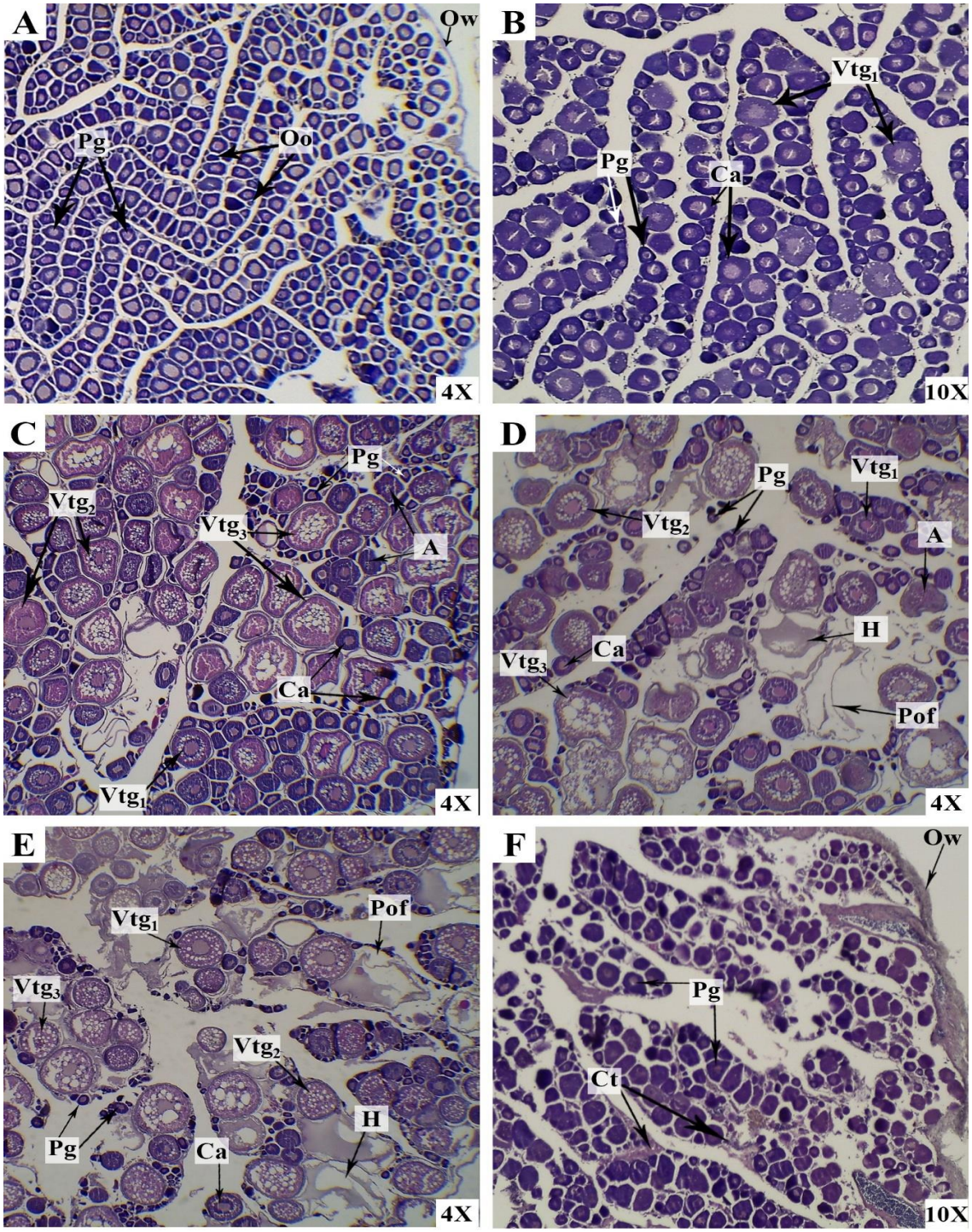

Figure 4. Histological images of ovarian phase: A, immature I; B, developing II; C, spawning III; D, regressing IV; E, regenerating V (Pg: primary growth, Ca: cortical alveolar, Vtg: vitellogenic, A: oocyte atresia, Pof: postovulatory follicles, H: hydrated oocytes, Ct: connective tissue).

The oocytes were found to be quite heterogeneous in the ovary in Pg, Vtg1, vitellogenic (Vtg2), and tertiary vitellogenic (Vtg3) structures in May. Hydrated oocytes (H), oocyte atresia (A), and postovulatory follicles (Pof) were first encountered in May (Figure 4C, 4D). According to the oocyte structures in the ovary, it was detected that the ovaries of female individuals in this month was in the stages of developing (II), spawning (III), and regressing (IV).

Although oocytes were heterogeneous in June, many postovulatory follicles were detected as well as Vtg2, Vtg3, and hydrated oocytes (Figure 4D, 4E). It was revealed that the ovaries of some female individuals were in the spawning (III) and regressing (IV) phases in this month.

Although the oocytes in the ovaries of the shrunken female individuals in July were heterogeneous, most of them were Pof and a few were Pg, the ovarian stages of the female individuals in this month were determined as regression (IV) and regeneration (V) (Figure 4E, 4F).

It was revealed that the ovaries of female individuals completely shrunk in August. The presence of degenerate follicles in the ovaries in this month, the formation of connective tissue (Ct) between the follicles, and the fact that almost all of the oocytes are Pg in some ovaries showed that the ovaries were in the regenerating (V) and immature (I) stages (Figure 4F, 4A).

Among the samples taken, the smallest individual was 11.4 cm (15.79 g) and the largest individual was 19.6 cm (83.50 g). Batch fecundity (F_B) was calculated from hydrated oocytes only as determined in the method. Among the samples taken, batch fecundity of 11,4 cm (15,79 g) of the smallest individual was 1693 hydrated oocytes and 19.6 cm (83.50 g) of the largest individual was 12318 hydrated oocytes (Table 1). In the samples examined, batch fecundity varied between 890 and 12318 hydrated oocytes, and the number of average hydrated oocytes and standard deviation was estimated as 4813.0±5324.0. While the relative batch fecundity ranged from 11 to 501 hydrated oocytes g^{-1}, it was found as an average of 124.6±124.1 hydrated oocytes g^{-1} (Table 1).

Table 1. Monthly mean batch fecundity (F_B), mean relative batch fecundity (F_R) and standard deviation (±).

Months	N	Average (F_B)	Average (F_R)
May	15	5064.8±4145.6	92.9±75.5
June	17	5585.2±7306.3	162.1±154.8
July	13	3512.7±3154.3	112.2±120.1
Average	45	4813.0±5324.0	124.6±124.1

As a result of the statistical analysis (One-way ANOVA) applied between monthly batch fecundities and monthly relative batch fecundities during the spawning period, it was determined that the difference was not significant ($p>0.05$).

It was determined that the relationship between length-batch fecundity and weight-batch fecundity of individuals whose gonads were in the third stage (III) and whose fecundity was determined in May and June during the spawning period were positive and statistically significant (Fig. 5A-B). According to the results of the regression analysis, the relationships between length-batch fecundity (R=0.818, F=64.77) and weight-batch fecundity (R=0.816, F=63,76) were found to be significant ($p<0.001$).

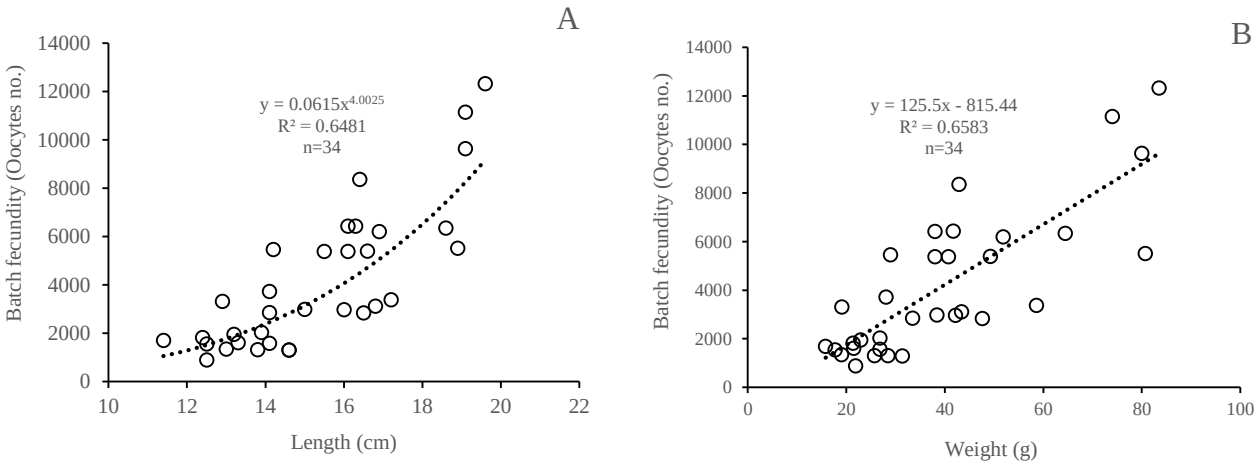

Figure 5. The relationship between total length-batch fecundity (A) and total weight-batch fecundity (B).

The first hydrated oocytes were detected in May and were found in the ovaries until the end of June and July. The mean of total measured hydrated oocytes was 774.8±131.8 µm, the mean of hydrated+unhydrated oocytes was 456.8±272.7 µm, and the maximum measured oocyte diameter was 1187 µm (Table 2, Figure 6).

The difference between monthly measured oocyte diameters (hydrated+anhydrous), was found to be

significant between all months (df:5, F=458.190, p=<0.001). Performing the same test analysis among monthly hydrated oocytes, it was revealed that May differed from June and July. (df:2, F=77.750, p=<0.05).

The first maturity length lengths (L_{m50}) values in male and female individuals were found to be 11.29 cm and 12.40 cm respectively (Figure 6).

Table 2. Monthly hydrated mean oocyte diameters, mean hydrated+unhydrated oocyte diameters and standard deviations.

Months	N	Hydrated oocytes (µm)	N	Hydrated+unhydrated oocytes (µm)
March			410	125.6±39.3
April			425	333.5±137.5
May	739	721.1±127.6	1659	474.5±253.5
June	878	793.4±130.5	1813	540.1±268.2
July	639	799.4±126.1	1254	576.5±253.8
August			526	182.1±82.3
Total/average	2256	774.8±131.8	6087	456.8±272.7

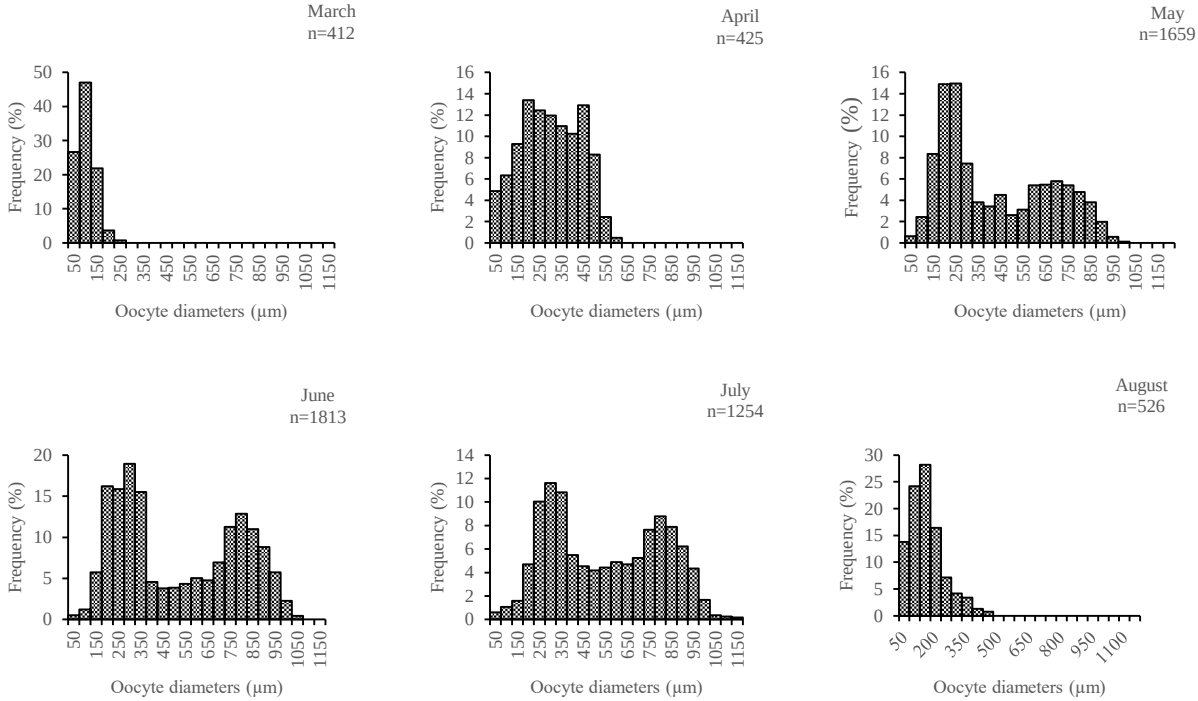

Figure 6. Monthly oocyte diameter frequency distributions.

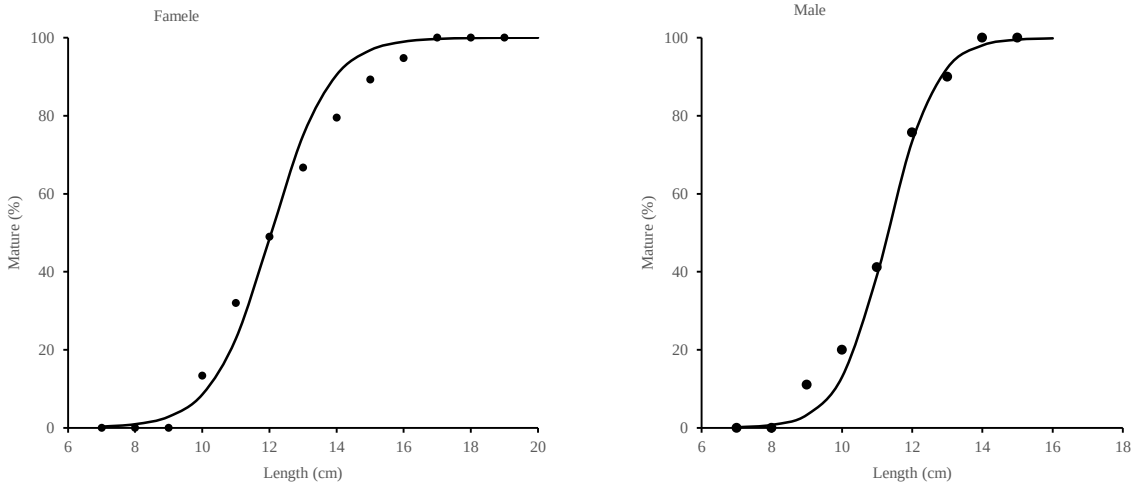

Figure 7. Maturity length (L_{m50}) of *M. barbatus.*

DISCUSSION

Considering the biometric measurements of the lengths, it was observed that females were larger than males, and even length classes greater than 17 cm were completely represented by females. Similar results were obtained in some studies on *M. barbatus*. (Genç, 2000; Sieli et al., 2011; Aydın & Karadurmuş 2013; Yıldız & Karakulak, 2016). In the study, it was found that females were at a higher rate than males and the statistical analysis

($\chi 2$) between the ratios (Female/Male) showed a significant difference ($p<0,05$). Similar results have been reported in some studies on this species (Genç, 2000; Sieli, 2011; Aydın & Karadurmuş 2013; Çiloğlu, 2019). This shows that from past to present, *M. barbatus* stocks have a similar structure in terms of sex ratios.

Observing changes in GSI throughout the year is the most popular method to determine the reproductive period of fish (De Vlaming et al., 1982; Stahl & Kruse, 2008; Pham & Naguyen, 2019). Considering the monthly GSI values of males and females throughout the year in the study, it was observed that both sexes started to rise from April and reached the highest value in June (Figure 1, Figure 2). The rapid decrease in the GSI values from June to August and then the steady state indicates that the spawning of red mullet in the Black Sea occurred during a period. These months (April, May, June, July, and August) differed statistically from other months. In addition, the spawning phase (III) was observed in April in the macroscopic examination of the gonads (Figure 3). Considering the monthly GSI and the macroscopic phasing of the gonads, it can be said that the reproductive season of red mullet stocks in the Black Sea is between April and August. In some studies, conducted in the Black Sea, the reproductive period was determined by the GSI method between Genç (2000) May-August, Aydın & Karadurmuş, (2013) April-September & Yılmaz (2019) May-July. In studies conducted in other seas (Mediterranean, Aegean), Akyol (2000) April-August, Sieli et al. (2011) April-September, Kokokiris et al. (2014) April-June and Carbonara et al. (2015) April-July reproductive period was determined. In this case, it can be said that the reproduction period of red mullet is from the middle of spring to the end of summer.

CF is an important indicator that reveals monthly or seasonal nutritional oscillations (Bolger & Connolly, 1989; King, 1995).

In the study, while CF had the highest value in December and the lowest value in May in female and male individuals, it increased with a similar trend in other months (Figure 1, Figure 2). Fluctuations in condition during the year vary depending on factors such as food abundance, changes in the food supply of individuals, and gonad development (Hodgkiss et al., 1977; Serrat, 2019).

HSI, which is an important energy reserve indicator, started to increase from March before the spawning season and continued to increase throughout the reproductive cycle (Nunes et al., 2011). This is an indication of fat accumulation in the liver. Its increase during the spawning period indicates that feeding continues during this period. Lloret et al., (2007) emphasize that the energy used in the development of the gonads in red mullet is obtained from the fats stored in the liver because the energy invested in egg production is obtained directly from nutrition instead of muscle.

In the study, the ovaries were staged by taking into account the changes in the oocyte structures in the ovaries of red mullet, and the changes that occurred during the reproductive period were monitored. When the sections taken from the ovaries throughout the year were examined microscopically, it was determined that there was no reproductive activity in the ovaries of the red mullet from September to March. The oocyte structures in this period show Oo and Pg characteristics, indicating that the ovaries are in the immature (I) phase and that the red mullet has no reproductive activity during this period. The fact that five of the ovarian development stages (immature I; developing II; spawning III; regressing IV; regenerating V) were observed in the period from April to August and that all oocyte structures (Pg, Vtg1, Vtg2, Vtg3, H, Pof) were found to be heterogeneous in the ovaries indicate that the reproductive activity of the red mullet takes place in these processes (Figure 4). Vitellogenic structures, which are the initial indicator of reproductive activity in the ovaries, were first observed in April (Figure 4B). In August, the shrinkage of a large part of the ovaries of female individuals, the deterioration of the follicles, and the structuring of the connective tissue are indicators of the end of reproduction (Figures 4E, 4A). Considering these mentioned features, it can be said that the mullet fish is a partial spawner and its reproductive activity occurs between April and August in the Black Sea. When this situation is considered as a period, GSI, macroscopic, and microscopic examination results of the ovaries show that the reproductive period matches (April-August). Many studies state that the reproductive activity of red mullet starts from mid-spring and continues until the end of summer (Aydın & Karadurmuş 2013; Genç, 2000; Tsikliras et al., 2010; Sieli et al., 2011; Kokokiris et al., 2014; Carbonara et al., 2015; Balci & Aktop, 2019; Melnikova & Kuzminova, 2020). However, since hydrated eggs were first encountered in May in the ovaries examined microscopically, it can be said that the release of oocytes of red mullet stocks in the Black Sea occurs in May. In this context, it is stated that the use of microscopic methods in determining the reproductive characteristics of marine organisms provides more reliable results (Saborido-Rey & Juquera, 1998; Stalh & Kruse, 2008; Ferreri et al., 2009; Tomkiewicz, et al., 2003).

Fecundity is one of the reproductive parameters used to determine the reproductive capacity of individual fish, the reproductive potential of fish stock, and the biomass of the spawned stock. Since annual fecundity is indeterminate in multiple spawner fish, batch fecundity is the most useful measurement for these species. (Hunter et al., 1985; Murua et al., 2003; Sequeira et al., 2012; Rogers

et all., 2019). In this study, batch fecundity (F_B) and batch relative fecundity (F_R) of red mullet were evaluated monthly during the spawning period (Table 1). Considering the batch and batch relative fecundities it can be said that red mullet is a multiple spawner. Although there is no difference as a result of the statistical analysis (One-way ANOVA) between monthly fecundity efficiencies, it can be stated that the most productive month is June (Table 1). As a result of the fecundity calculations, the batch fecundity of the red mullet in the Black Sea is between 890 and 12318 hydrate oocytes, the average F_B=4813.0±5324.0 hydrated oocytes, and the average F_R=124.6±124.1 hydrated oocytes g^{-1} was estimated (Table 1). Although there are few studies on batch fecundity on the species, Genç (2000) reported that batch fecundity in the Black Sea ranged between 1263-14885 oocytes and the average was 5228+499.9, Metin (2005) reported that batch fecundity varies between 1923-13600 oocytes in the Aegean Sea and Tiraşin (2007) reported that the average FB = 7030±4564 oocytes and FR = 128±45 in the Aegean Sea. Ferrer-Maza, (2015) reported in the study conducted in the Western Mediterranean Sea that the F_B of mullet fish was between 2408 and 43736, with an average F_B of 18163±9778 oocytes and F_R= 234±63 g-1. The results of some of the studies about fecundity mentioned vary. It can be said that these differences arise from the size of the samples and geographical and ecological differences. In their fecundity studies, they stated that as the size of fish increases, fecundity also increases (Hunter & Macewicz, 1980; Kjesbu et al., 2011; Carbonara et al., 2015; Ferrer-Maza et al., 2015).

The length of the red mullet increases, fecundity is also increasing exponentially, and its weight increases, fecundity is also increasing linearly (Figure 5). In previous studies, similar results were obtained with length-fecundity and weight -fecundity. (Metin, 2005; Aydın & Karadurmuş 2013; Ferrer-Maza et al., 2015; Carbonara, et al., 2015).

Determinate or indeterminate fecundity can be detected by using the distribution of egg diameters. If there is a gap between immature egg reserves and mature egg reserves during the reproductive period, it is reported as determinable fecundity; if there is no gap, it is reported as indeterminate fecundity (Hunter & Macewicz, 1985; Lowerre-Barbieri et al., 1996). Considering the distribution of egg diameters measured monthly throughout the reproduction period in the study (Table 2, Figure 6), the continuity of mature and immature oocytes and the absence of a gap can be said that the reproductive model of red mullet in the Black Sea is asynchronous and has an indeterminate fecundity. These results were found to be similar to the results of studies on the species (Ferrer-Maza et al., 2015; Carbonara et al., 2015, Follesa & Carbonara, 2019). The fact that the growth in egg diameters begins in April, peaks in July, and decreases again in August indicates that the reproductive period is between April and August. However, since hydrated oocytes were found only in May, June, and July (Table 2), it can be said that the spawning period also occur between May and July.

Maturity length (L_{m50}) is a population parameter that is extremely important in the management of exploited stocks (Tisikliras & Strgios, 2014; Lappalainen, 2016). In the research, L_{m50} values of *M. barbatus* for females and male were calculated (Figure 7). In studies conducted on this species over the years (since 1952) in the study region and outside the study region, it has been reported that the L_{m50} value varies between 10.4-14.2 cm in females and 9.4-15.5 in males. The results of the research were found to be between the values determined in the literature (Genç, 2000; Tsikliras & Stergiou, 2014; Follesa & Carbonara, 2019). It is emphasized that maturity length in exploited stocks may vary depending on fishing pressure and changes in ecological conditions (especially temperature and food quality) in the habitat where the living organism (Saborido-Rey & Junquera 1998; Lowerre-Barbieri 2009, Tisikliras & Strgios, 2014). The maturity length results obtained in the study (Female L_{m50} = 12.40 cm, Male L_{m50} = 11.29 cm) are below the minimum landing size of red mullet (13 cm) in the communique regulating fishing. However, there has been a decrease in the catch amount of mullet stocks exploited with acceptable minimum landing size in recent years. This situation can be explained by the fact that more productive larger individuals are withdrawn from stocks due to fishing pressure for many years and recruitment decreases. For this reason, it negatively affects the sustainability of both red mullet stocks and fishing. To maintain the biomass of stocks, fish should be allowed to spawn at least once in their lifetime before being caught (Beverton & Holt 1957). However, having large individuals in the stock will reinforce recruitment by increasing the survival chances of the larvae as they will produce high fecundity and quality eggs (Birkeland &Dayton, 2005; Miethe et al., 2009; Tsikliras & Stergiou, 2014;). In this context, the measures taken to ensure the sustainability of red mullet stocks and fisheries in the Black Sea should be reviewed and new regulations should be made taking into account the results of the study.

In conclusion, reproductive success is the most important factor that ensures the sustainability of the species (Lowerre-Barbieri, 2009). In this context, knowing the reproductive strategies of exploited fish populations is extremely important for the management of the populations (Murua & Saborido-Rey, 2003; Morgan, 2008).

The biomass of the red mullet spawning stock in the Black Sea is unknown. Batch fecundity should be taken into account to determine the spawning stock of red mullet,

which is multi-spawner with indeterminate fecundity. As a result of the study, it was revealed that larger individuals have higher reproductive ability and will better support recruitment in the stock. Therefore, in addition to the minimum landing size, taking measures to increase the survival rate of large-sized individuals will contribute to the sustainability of both stocks and fisheries.

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