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ARAŞTIRMA MAKALESİ **RESEARCH PAPER**

Spatio-temporal Distribution and Population Dynamics of the Red Mullet *Mullus barbatus* Linnaeus, 1758 from the South-east Black Sea

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Abstract: A total of 2930 *Mullus barbatus* individuals collected from the southeastern Black Sea coast between March 2017 and April 2018 were studied for growth, mortality rates and distribution according to depth and season. *M. barbatus* is abundant along of 30-45 *m* depth in winter. Von Bertalanffy growth parameters for all individuals were calculated as L_∞=28.19 *cm*, K=0.16 years^{-1}, t_0=-0.144 years. The maximum age was detected 5 years. Natural mortality, total mortality and fishing mortality exponent coefficients were calculated as 0.33 year^{-1}, 1.001 year^{-1} and 0.67 year^{-1}, respectively. The exploitation rate of the population was determined as 0.66 year^{-1}. Due to the exploitation rate is above 0.5, it can be said that there is a high fishing pressure on the stock.

Keywords: Black sea, exploitation rate, fish population, mortality, mullidae.

Güneydoğu Karadeniz' de Barbun (*Mullus barbatus* Linnaeus, 1758) Balığının Mekansal-Zamansal Dağılımı ve Popülasyon Dinamiği

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Öz: Mart 2017 ile Nisan 2018 arasında Karadeniz'in Güneydoğu sahilinden toplamda 2930 *Mullus barbatus* bireyi büyüme, ölüm oranları ve derinlik ile mevsime göre belirlenen dağılımları açısından incelenmiştir. *M. barbatus* kış aylarında 30-45 m derinliklerinde daha bol miktarda bulunduğu belirlenmiştir. Tüm bireyler için Von Bertalanffy büyüme parametreleri L_∞=28,19 cm, K=0,16 yıl^{-1}, t_0= -0,144 yıl olarak hesaplanmıştır. Maksimum yaş 5 olarak tespit edilmiştir. Doğal ölüm, toplam ölüm ve avcılık ölüm oranları üssi katsayıları sırasıyla 0,33 yıl^{-1}, 1.001 yıl^{-1} ve 0,67 yıl^{-1} olarak hesaplanmıştır. Popülasyonun sömürülme oranı 0,66 yıl^{-1} olarak belirlenmiştir. Sömürülme oranı 0,5'in üzerinde olduğu için, stok üzerinde yüksek bir av baskısı olduğunu söylenebilir.

Anahtar kelimeler: Balık popülasyonu, karadeniz, mullidae, ölüm oranı, sömürülme oranı.

INTRODUCTION

The red mullet, which belongs to the Mullidae family, is a benthic species that lives mostlly on the sandy and muddy bottom of the continental shelf and is widespread throughout the Mediterranean Sea. (Hureau, 1986; Özbilgin et al., 2014). In the Black Sea in the last four decades, the environmental pollution observed and the climate change (Bat et al., 2018), fishing pressure and the presence of alien species have caused important changes in fish stocks and biodiversity (Mee, 1992). These changes in the Black Sea ecosystem have also negatively affected Turkish overall fisheries. The production of red mullet in 1989 in Turkey rise to 8833 tonnes, while it was determined to be 1569 tonnes in 2018 (TUİK, 2019). Red mullet is one of the most important target species in fishing with active (bottom trawl) and passive (trammel, gill nets) fishing gears along the Black Sea coastline. Information about fish age, development and growth is a cornerstone for fishery research and management (Magnifico, 2007). A more comprehensive evaluation is required in order to assess food preferences, migratory behaviour, habitats for larvae, juveniles and adults,

reproduction patterns, the age structure of stock, age at maturity, sex ratio, natural mortality rate, fishing mortality rates, as well as estimate the total number or weight of individuals in the stock. (Wallace & Fletcher, 2001). Several aspects of red mullet biology including reproduction, age and growth (Samsun, 1990; Samsun & Özdamar, 1995; Şahin & Akbulut, 1997; Genç et al., 1998; Genç, 2000; Genç et al., 2002; Özbilgin et al., 2014; Arslan and İşmen, 2014; Süer, 2008; Aksu et al., 2011; Reşat, 2013; Süer, 2016; Yıldız & Karakulak, 2016; Carbonara, 2017) and distribution (Tserpes et al., 2002; Gönener & Bilgin, 2006; Gönener & Bilgin 2010; Yalçın & Gurbet, 2012; Yıldız & Karakulak, 2016; Gönener & Özdemir, 2013) have been studied but information on its bathymetric distribution and movements according to depth ranges is limited.

Depth and sediment types are the dominant factors in demersal fish forming community in certain regions. It was examined the seasonal changes in the distribution pattern of red mullet in the Southeast Black Sea in this study. In order to determine factors such as maturation and seasonal timing and direction of fish movement, the research survey data on red mullet distribution, maturity, sex, age,size, biomass and abundance were compared with depth and temperature.

MATERIAL AND METHOD

Samples were collected monthly between March 2017 and April 2018 at Rize coast in the south-eastern Black Sea onboard the *R/V* Karadeniz Araştırma by using a bottom trawl with a cod-end mesh size of 12 mm. Depth range of the fishing ground was 0-30 *m* - 30-45 *m* and 45-60+ *m*. Towing speed varied between 2.5 and 3.5 knots, and towing duration was limited to 30 *min* for all hauls. Fishing took place within an area defined by the following coordinates: 40º59′29″N/40º19′52″E;40º59′57″N/40º18′50″E;41º01′32″ N/40º22′53″E;41º02′10″N/40º22′04″E (Fig 1). A total of 38 hauls were taken.

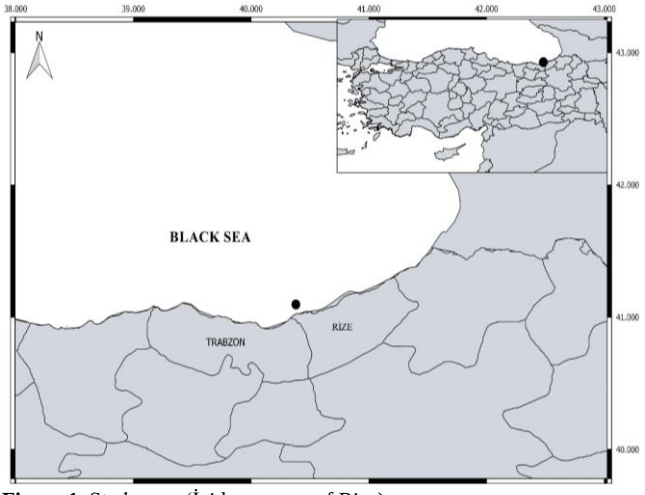

Figure 1. Study area (İyidere coasts of Rize).

At the end of the operation the catch was taken to the deck and classified. First, the species with a small number of individuals were separated from the general catch, and then the sub-sampling was made from the target species, red mullet, by random sampling method. The sampled research material was transported to the laboratory in plastic containers to examine other biological data. A total of 2930 samples (1514 females, 1416 males) were taken to the laboratory and were measured (total length (*TL*)), weighed and sexed. The *TL* of each red mullet was measured with to the nearest of 1 *mm*. Specimens were weighed (wet weight) on a balance with to the nearest of 0.001 *g*. In addition, sea water temperature and depth parameters were measured using STAR ODDI device connected to the trawl net with steel wire. For age determination, otoliths of 2930 (1514 females, 1416 males) fish were removed and cleaned from blood and tissues, and then stored in containing 70% of ethanol in eppendorf tubes. The number of transparent and opaque zones of sagittal otoliths was counted using a Nikon SMZ1000 mark stereomicroscope at a magnification between ×0.8 and ×8.0 interfaced with a Nikon DSFI1 digital camera connected to a computer using reflected light. Monthly size–frequency distributions for both sexes were calculated according to 1 *cm* length-class intervals. Size–frequency distribution analysis for females and males was conducted the Mann-Whitney U test by using with the SIGMA plot 12.0 program. Comparison of the mean *TL* between females and males was performed using t-test. Statistical analyses were considered significantly different at the level of $p<0.05$. The sex-ratio of the red mullet was analysed using a x^2 test. Least squares regression analysis with MS Excel software was used to calculate the *L/W* relationship parameters (Huxley 1924). The *L/W* relationship was estimated as: $W=a\,TL^b$, where *W* is the body weight (g), *TL* is the total length (*cm*), a is the intercept, and b is the slope of the regression line. For comparison of the difference of slope value from $b=3$ both females and males, Pauly's t-test was performed (Pauly, 1984). Von Bertalanffy growth equations are used to calculate the growth in length and weight (King, 1995; Sparre & Venema, 1998). Calculation of Von Bertalanffy Growth Equation (VBGE) parameters is made by the following formula of age-length relation $L_t = L_\infty(1 - e^{-k(t-t0)})$ which was explained in Ford-Walford method of (Sparre & Venema, 1998). In the formula t is time (age), L_t is length at age t (*cm*), L_∞ is t asymptotic *TL* to the red mullet growth (*cm*), *K* is the growth rate parameter (year^{-1}), t0 is the theoretical age when fish would have been at zero *TL*. Growth performance comparisons were made using the growth performance index ($\emptyset$) which is preferred rather than using L_∞ and *K* individually (Pauly& Munro, 1984) and was computed as: $\emptyset=log(K)+2log(L_\infty)$. In the study, the total mortality rate (*Z*) was calculated according to the formula below, which was created by

making use of the mean size of the fish (Beverton and Holt, 1957): $Z=K*(L_\infty-L)/(L-L')$ where Z=Total mortality rate, K=Growth factor (year^{-1}) L_∞=Asymptotic length of fish (*cm*), L=mean length of fish used in growth constants, L'= the smallest length of fish that are fully represented in catch samples. The natural mortality factor (M) was calculated according to by (Pauly 1980), using growth parameters calculated from age data. In this equation, the average temperature of the habitat in which red mullet lives is taken as 15.2 ^oC. The following formula was used: $M=0.8\ exp(-0.0152-0.279\ Ln(L_\infty)+0.6543Ln(k)+0.463\ Ln\ (T))$, where M= natural mortality factor (year^{-1}) L_∞=Asymptotic length of fish (*cm*) K=Growth factor (year^{-1}) T=Annual average temperature of habitat (°*C*). The exploitation rate (E) is calculated by the ratio of the fishing mortality rate (F) to the total mortality factor (Z). Fishing mortality factor (F) was calculated by $F=Z-M$; $E=F/Z$, Z=Total mortality rate (year^{-1}), M=Natural mortality rate (year^{-1}), F=Fishing mortality rate (year^{-1}), E=exploitation rate. If the E value is greater than 0.5, which means that the fishing pressure on the population is high and that it is equal to 0.5 means that fishing is at the optimum level (Pauly, 1983).

Seasonal and Bathymetric Distribution-Catch per Unit Effort (CPUE): The data obtained from the shootings were standardized as catch per unit time (CPUE-kg/hour). The following equation was used when calculating the amount of CPUE (Pauly, 1980); Cw/t (*kg*/h) where is

Cw=the weight of the catch in a haul (*kg*), t=haul time of trawl net (hour). With the SIGMA plot 12.0 program, *CPUE* values of according to depth and seasons (Two Way Analaysis of Variance) were tested with Twoway ANOVA. All pairwise multiple comparison produres (Tukey test) were made.

RESULTS

Population Structure: A total of 2930 red mullet (1514 females, 1416 males) were captured between March 2017 and April 2018. TL of females varied between 5.6 and 23.6 *cm* (average 12.76±0.077 *cm*) and TL of males varied between 5.2 and 20.1 *cm* (average 11.05±0.061 cm). There was no statistically significant difference between average *TL* of the females and males (*t* test: $P>0.05$). In addition, the difference between length frequency distributions of female and male individuals was found to be statistically insignificant (Mann-Whitney test U= 154.0, $P<0.05$) Overall length frequency distribution is presented in Figure 2.

The monthly length frequency distribution is presented in Figure 3. For fishing, the minimum permitted fish length is 13 *cm* for red mullet in Turkey. The 68.5% of fish caught for this study were found to be below 13 *cm*. Especially in the autumn period (after September), much more fish which are under 13 *cm* were sampled.

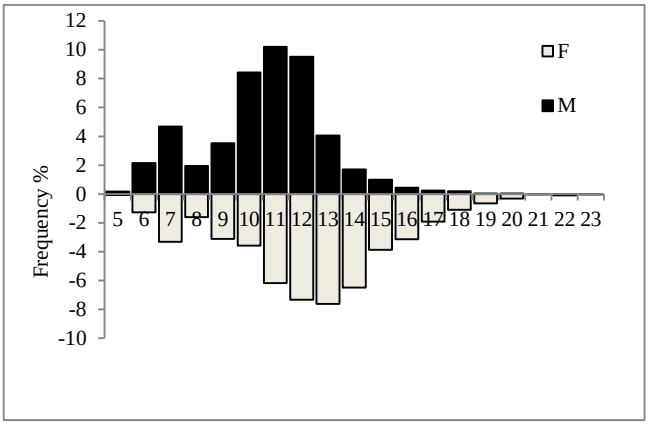

Figure 2. Overall length frequency of red mullet individuals.

According to growth models, L_∞ value was calculated to be higher in females than males. This value was determined to be 28.08 *cm* in females and 23.49 *cm* in males. The growth factor (K) value calculated for male individuals was found higher than females. K value was calculated between 0.160 years^{-1} in females and 0.225 years^{-1} in males. The growth performance index (Ø) value calculated using the parameters calculated by growth models (L_∞ and K) was determined to be 2.103 for females and 2.095 for males (Table 1).

Table 1. Growth model parameters of *M. barbatus* individuals, L_∞= asymptotic length, K= growth factor, to= age when fish length is theoretically zero, W_∞= asymptotic weight, parameter, Φ'= growth performance index.

Parameter	L_∞	k	t_o	W_∞	Fi (Φ')
Total	28,19	0,161	-0,144	245,01	2,109
Female	28,08	0,160	-0,247	247,76	2,103
Male	23,49	0,225	-0,750	127,92	2,095

The female/male ratio (1.06: 1) was in favour of females so, sex ratio difference was statistically insignificant in analysed samples ($\chi^2=3.278$ $P<0.005$). The oldest individual was found to be 5 years old for both females and males. The dominant age group was found to be 2 years old (31.24%) in females and 1 year old (52.68%) in males (Fig. 4). Otoliths of a total of 2930 red mullet (1514 females and 1416 males) were removed and aged successfully from sagittal otoliths. The oldest individual was found to be 5 years old for both females and males.

The results from otolith readings are given in table 2. The relationship between the total length-weight values obtained from red mullet individuals was calculated as follows; Female: $W=0.0048L^{3.2535}$ ($r^2=0.9838$), Male: $W=0.0055L^{3.1851}$ ($r^2=0.9722$). According to the t-test applied, it was observed that this species showed a positive allometric growth in the research area ($P<0.05$). The total mortality rate (Z year^{-1} 1.001) and natural mortality rate (M year^{-1} 0.33) were determined through the initial catch length of the red mullet population then fishery mortality rate (F year^{-1} 0.67) and exploitation rate (E year^{-1} 0.66) were calculated from those data obtained.

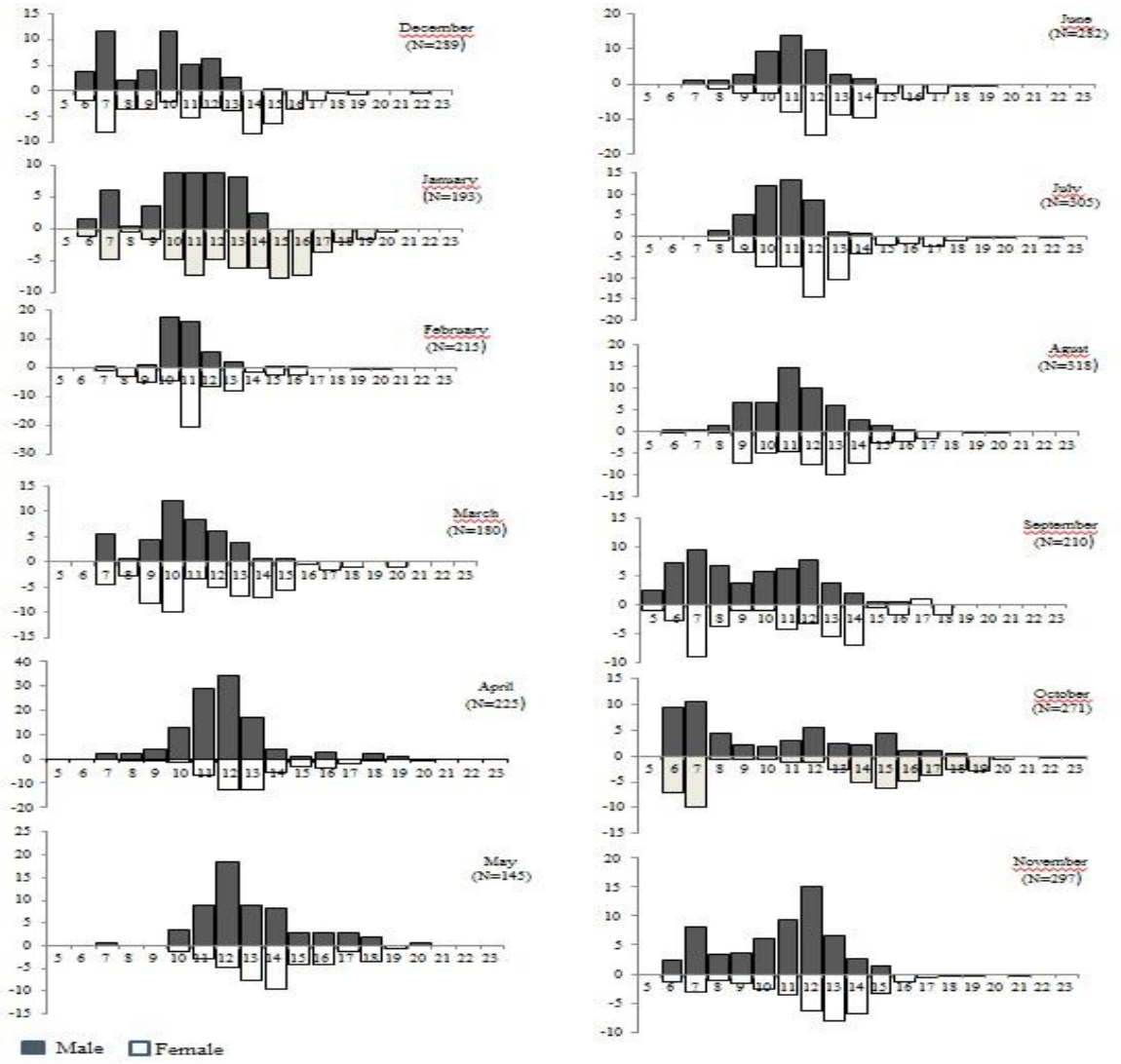

Figure 3. Monthly length frequency distribution of red mullet individuals according to sex.

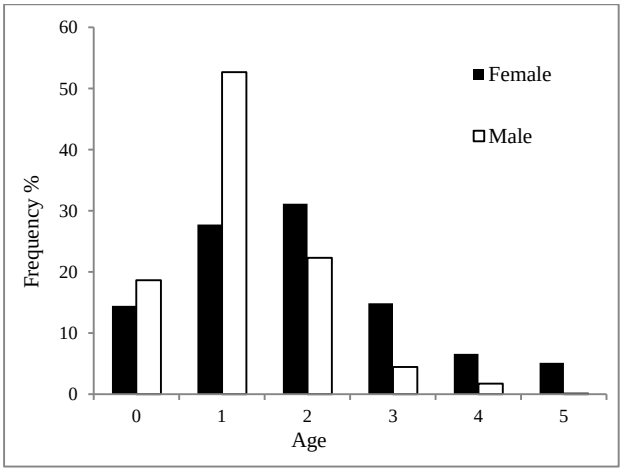

Figure 4. Age composition of male and female red mullet individuals.

Seasonal and Bathymetric Distribution-Catch per Unit Effort: In 38 experimental operations carried out during the study, was swept and a total catch of 875.04 *kg* of red mullet were caught. The highest *CPUE* value was observed in the winter season when the temperature is low (Fig. 5).

Table 2. Red mullet age-length key for all individuals.

Total Lenght (cm)	Age groups												
	Female						Male						
	0	1	2	3	4	5	0	1	2	3	4	5	Total
5	2						5						7
6	37						63						100
7	97						137						234
8	47						57						104
9	36	55					2	101					194
10		105						247					352
11		181						299					480
12		79	136					99	180				494
13			223						114	5			342
14			113	77					22	28			240
15				113						25	4		142
16				35	57					5	8		105
17					43	13					7		63
18						32					6		38
19						19						1	20
20						9						1	10
21						1							1
22						3							3
23						1							1
Total	219	420	472	225	100	78	264	746	316	63	25	2	2930

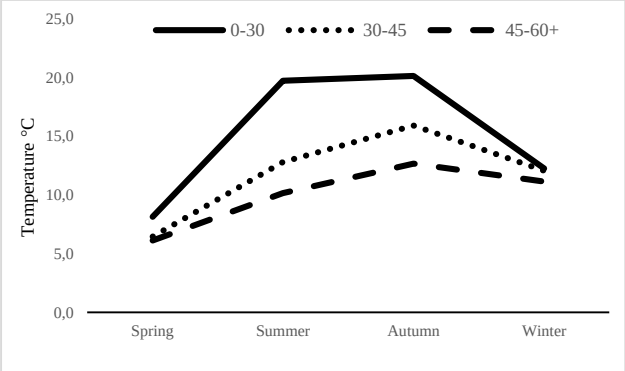

Figure 5. Seasonal temperature change during the sampling period.

The amount of catch caught per unit time (*CPUE-kg*/hour) from the catch data was 28.95 *kg*/hour in spring, 27.58 *kg*/hour in summer, 59.76 *kg*/hour in autumn, and 68.59 kg/hour in winter (Fig. 6). According to the calculations, for all over the experimental period it was found as 49.04 *kg/h* at 0-30 *m* depth, 65.36 kg/h at 30-45 *m* depth and 32.42 *kg/h* at 45-60^{+} *m* depth. The lowest *CPUE* value of red mullet individuals were determined in spring (April), and the highest *CPUE* value was determined in winter (January). (Fig. 6).

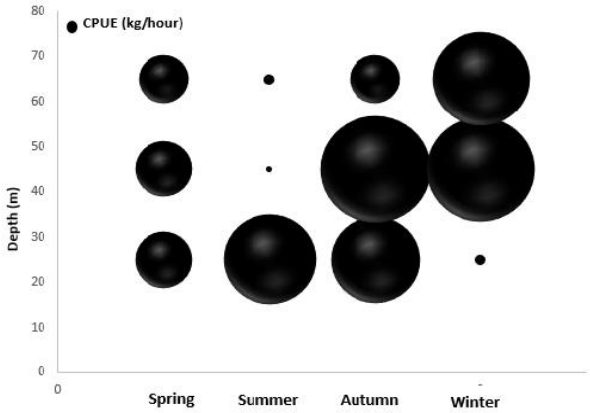

Figure 6. CPUE values of red mullet individuals according to depth and seasons.

The lowest temperatures detected throughout the year were measured in winter and spring seasons. Accordingly of CPUE there was a statistically significant interaction between seasons and depth ($p<0.05$). It was found the differences on *CPUE* value between 0-30 *m* and 45-60^{+} *m* depths in autumn. Also, there were differences on *CPUE* value between 30-45 and 45-60^{+} *m* depths in autumn. In winter, the differences were observed only between 0-30 *m* and 45-60^{+} *m*. Considering all seasons, there were differences when the depth was changed. Between spring and autumn, *CPUE* value was different at 0-30 *m* depth. Between winter and autumn, *CPUE* value was different at 0-30 *m* depth. Between summer and autumn, *CPUE* value was different at 30-45 *m* depth. The red mullet was found at all depths in the spring, however the red mullet got close to the shore in summer. Then, it was observed that the red mullet started to move deeper in autumn. In the winter, it was seen that red mullet completely moved away from the shore and gone deeper side (Fig. 6).

DISCUSSION AND CONCLUSION

Population Structure: Considering the studies (Aksu et al., 2011; Aydın & Karadurmuş, 2013; Genç, 2000; Reşat, 2013; Samsun, 1990; Süer, 2008; Süer, 2016; Yıldız & Karakulak, 2016; Zengin et al., 2011) which are conducted in Black Sea, it is seen that the length range and mean length values are compatible with this study. A study (Süer, 2016) reported that the length range was between 4.2 and 18.5 cm and also mean length was 8.42 cm. Another study (Reşat, 2013), reported that length range was between 4.8 and 23.3 cm and mean length 9.78 cm. However, when looking at the smallest lengths and mean lengths recorded, it can be said that stock of red mullet is extremely vulnerable in terms of sustainability. It is believed that the reason that creates the differences between the length data is due to the different fishing gear used in the studies. Length-weight relationship parameters were calculated separately for males, females and all individuals. In current studies, all individuals display different length-weight relationships and also display positive allometric growth. The results obtained in our study are similar to other studies (Ak, 2009; Ak et al., 2009; Genç, 2000; Genç et al., 2002; Samsun & Erkoyuncu1992; Samsun & Özdamar, 1995; Samsun, 1990; Süer, 2008; Süer, 2016; Yıldız & Karakulak, 2016). However, some studies (Aksu et al., 2011; Samsun & Erkoyuncu, 1992) reported negative allometric growth. Sex ratio was in favor of the female. Female individuals seem to be dominant throughout the year. The previous studies in the Black Sea generally showed a situation in favor of females (Samsun, 1990; Samsun & Özdamar, 1995; Genç, 2000; Genç et al., 2002; Ak, 2009; Reşat, 2013; Süer, 2016; Yıldız & Karakulak, 2016), this situation is similar with our study. However, other studies had different situation (Süer, 2008; Şahin & Akbulut, 1997) which indicated sex ratio was in favor of the male. The reason for this situation may be that the size distribution range in males is narrower than that of females. In other words, there are only female individuals in a certain length range and this explains that females are dominant in all sampling. The dominant ages were determined as 1, 2 and 0 in the age-frequency distribution, respectively. Studies have reported that the dominant age groups were 1, 2, 3 (Samsun, 1990; Şahin & Akbulut, 1997; Süer, 2008; Süer, 2009; Aydın & Karadurmuş, 2013; Yıldız & Karakulak, 2016; Samsun, 2017; Yılmaz et al., 2019). The highest maximum age was reported as 9 only by (Genç, 2000). After this study, in some studies

conducted in different years, the maximum age of 7 was determined, but the number of individuals determined at the age of 7 is quite low (Aydın & Karadurmuş, 2013; Süer, 2008; Süer, 2016). In some recent studies, it has been reported that the maximum age is 4 (Yıldız & Karakulak, 2016; Samsun, 2017; Yılmaz et al., 2019). Thus, our findings and some study indicates that there is a decline in the maximum age. Researchers reported that a population dominated by young individuals could not be in balance because of the withdrawal of older age groups due to fishing and population fluctuations may occur due to varying growth rates (Berkeley, 2004; Anderson et al., 2008). Considering this situation, it can be said that red mullet fishery is in danger in terms of sustainability. In the comparison between the sexes, it was seen that males and females exhibit different growth characteristics. Males grow faster than females and reach their maximum length at an earlier age. A study (Jennings et al., 1999) reported that the growth rate in populations which is under prolonged fishing pressure study, the *K* values were higher and the $L\infty$ length was lower for males. However, considering all studies, it is thought that the difference of $L\infty$ value may be related to the wider or narrower length range in the studies. The reason for the change of *K* value according to years and regions may be due to the different length composition of the fish studied, age composition, biotic (prey-predator relationship, genetic variation) and abiotic (such as temperature, salinity) environmental factors. In population dynamics studies and can be used to compare growth under the influence of different environmental factors. In addition, the growth performance index is an index used to compare previous studies in the same region (Pauly, 1991). In our study, the (Ø) value calculated for females was slightly higher than males thus females grew slightly faster than males. Also, considering the studies conducted (Aksu et al., 2011; Genç, 2000; Genç et al., 2002; İşmen et al., 2000; Samsun & Erkoyuncu, 1992; Samsun & Özdamar, 1995; Süer, 2008; Süer, 2016; Şahin & Akbulut, 1997; Yıldız & Karakulak, 2016) in the Black Sea, it is similar our study (No significant difference found with T test, $p<0.05$). But (Süer, 2008) and (Aksu et al., 20011) report the differences in index values. The reason for this difference may be due to the of different fishing gear. If the exploitation rate is higher than 0.5, it means that the fishing pressure on the population is high and if it is equal to 0.5, it means that fishing is at an optimum level (Pauly, 1983). This may be due to the fact that the fishing mortality rate calculated in previous studies (Aksu et al., 2011; Genç, 2000; Genç et al., 2002; Samsun, 1990; Süer, 2016; Yıldız & Karakulak, 2016) in the Black Sea varies from year to year and this is due to different fishing pressures by years, the strength of the year class according to years, and therefore different biotic and abiotic factors that control the growth characteristics of new individuals. In addition, wide length composition positively effects on breeding success and egg production and can be more resistant to environmental damage and hence mortality rates may be affected (Karkach, 2009).

Seasonal and Bathymetric Distribution-Catch per Unit Effort (CPUE): A study (Genç, 2000) stated that the amount of biomass of red mullet in the Black Sea, depends on the season and depth. The author reported that the highest amount of catch was at a depth of 50-100 *m* in winter and 0-20 *m* in summer. Another study (Zengin et al., 2011) which contains sampling throughout the year, stated that the red mullet was detemined in every season and the most abundant seasons were winter, autumn and then spring. (Gönener & Bilgin, 2006), It was also calculated the amount of fish per unit area at two different depths (<75 and> 75 *m*) and reported that there was a higher amount of catch at a depth of <75 *m*. It was calculated the highest fishing values in October and December. Another study (Süer, 2016) calculated the quantity of red mullet per unit area and unit time according to season and depth. Author determined the highest values in autumn and then in winter. The unit determined the highest amount of biomass at a depth of 0-30 *m* depending on the depth. With the studies carried out in the Black Sea and this study, it was determined that the red mullet was abundant, and the depths were similar, but it was observed that there were differences between amounts. It is thought that the differences between these studies may be due to the fishing gear and the method used. Another study (Yalçın, 2009) in the Aegean Sea, reported the highest catch amount in winter, followed by spring, autumn, and summer. This study also stated that fish abundance at low temperatures is higher depending on the temperature. Another study (Yalçın & Gurbet, 2012) in the Aegean Sea, reported that the red mullet was found in shallow waters less than 60 *m* depth. It also reported that red mullet was the most abundant at a depth of 30-60 *m* and at a temperature of 16.5-19 *ºC.* In addition, it stated that the highest amount depending on the season, was intense in autumn (September) and winter. Another study (Tserpes et al., 2002), in the Mediterranean, reported the highest amount of fish depending on the depth is between 50-100 *m*. The result of mentioned studies are similar with our results. Conclusion, **t**his study showed that the species of red mullet distribution in coastal waters, is depending on environmental parameters.

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CONFLICTS OF INTEREST/ COMPETING INTERESTS

The authors declare that they have no conflict of interest. This article does not contain any studies involving animals or human participants performed by any of the authors.

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