AGE, GROWTH, MORTALITY, REPRODUCTION, AND EXPLOITATION RATES FOR FISHERY MANAGEMENT OF GREY MULLET SPECIES IN THE KÖYÇEĞİZ LAGOON–ESTUARY (MEDITERRANEAN COAST)

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Background. The Mugilidae is a widely distributed family in the tropical, subtropical, and temperate waters. These fish species have a global economic value because of the high quality of their flesh and caviar. This study provides new data on the age, growth, and reproduction parameters of commercially exploited grey mullets from the Köyceğiz Lagoon, Turkey, namely golden grey mullet, Chelon auratus (Risso, 1810), leaping mullet, Chelon saliens (Risso, 1810), thicklip grey mullet, Chelon labrosus (Risso, 1827), and flathead grey mullet, and Mugil cephalus Linnaeus, 1758. The obtained results are intended for fisheries management of golden mullets in the area.

Materials and methods. A total of 1195 fish specimens were collected from the Köyceğiz Lagoon (south-western Anatolia, Turkey). The mullets were caught monthly, between January 2017 and December 2017, using fish barrier, trammel net, beach seine, and cast-net. The fish age was determined from sagittal otoliths. Growth parameters were determined by applying the von Bertalanffy growth function. Reproduction period, mortality and exploitation, relative yield per recruit (Y′/R), and biomass per recruit (B′/R) were determined.

Results. The most frequent mullet age groups were 3– and 4– (for M. cephalus and C. labrosus) and 4+ (for C. auratus and C. saliens). The following von Bertalanffy’s growth models were calculated: \( L_t = 58.78(1 - e^{-0.143(t+0.105)}) \) for C. auratus, \( L_t = 64.41(1-e^{-0.223(t+0.023)}) \) for C. labrosus, and \( L_t = 46.41(111 - e^{-0.198(t+0.609)}) \) for C. saliens. The growth performance index (\( \Phi \)) for C. auratus, M. cephalus, C. labrosus, and C. saliens was calculated as 2.750, 2.772, 2.679, and 2.698, respectively. The reproduction periods of C. auratus, M. cephalus, C. labrosus, and C. saliens were found as October–January, June–September, December–March, and April–July, respectively. The exploitation rate \( E \) was determined for C. auratus, M. cephalus, C. labrosus, and C. saliens as 0.68, 0.80, 0.66, and 0.62 year–1, respectively.

Conclusions. Fisheries management policies need to be established and implemented immediately in the Köyceğiz Lagoon considering the intense fishing pressure, environmental pollution, and tourism.

Keywords: Köyceğiz Lagoon, exploitation, grey mullet, population parameters, fishery management

INTRODUCTION

The Köyceğiz Lagoon (south-western Anatolia) is one of the most important active lagoon fishing areas in Turkey. It covers 5400 ha of open water and 1150 ha of marsh delta and is connected to the sea through a 14-km long canal. The width of the canal varies between 5 and 70 m and its depth between 1 and 6 m (Buhan 1998). Grey mullets (Mugilidae) are the most important commercial fish species in the Köyceğiz Lagoon. There are five grey mullet species in the Köyceğiz Lagoon, namely: golden grey mullet, Chelon auratus (Risso, 1810), leaping mullet, Chelon saliens (Risso, 1810), thicklip grey mullet, and Mugil cephalus Linnaeus, 1758, which are catadromous fish species, frequently found coastally in estuaries and freshwater environments (Nelson 2006). These fish species have a global economic value because of the high quality of their flesh and caviar (Hung and Shaw 2006, Turan 2016). Due to the economic importance of grey mullets, their biology has been studied in different 

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** Yerli S. 1989. Köyceğiz lagün sistemi ekonomik balık populasyonları üzerine incelemeler. [Investigations on economic fish species in the Koycegiz Lagoon System.] PhD thesis, Hacettepe University, Ankara, Turkey. [In Turkish.]
water bodies (Arruda et al. 1991, Hotos et al. 2000, Hoşsucu 2001a, Fazli et al. 2008a, Kraljević et al. 2011, Saoudi and Aoun 2014, Tulkani 2017, Panda et al. 2018).

For the sustainable management of fish stocks, information is needed on their age and growth, mortality, and exploitation rates. This study provides new data on selected biological parameters of commercially caught grey mullets in the Köyceğiz Lagoon required for proposing some targeted reference points for its management.

MATERIAL AND METHODS
The fish samples were collected monthly using a fish barrier, trammel net, beach seine, and cast-net in the Köyceğiz Lagoon, Turkey between January 2017 and December 2017 (Reis and Ateş 2019) (Fig. 1). The fish samples were brought to the laboratory and were taxonomically identified according to Thomson (1997). Total length (TL) was measured to the nearest 0.1 cm, and body weight \( W \) was determined with a precision balance (0.01 g). The sex of all specimens was recorded by macroscopic examination of the gonads as female, male, or immature. The sex ratio of the studied grey mullet species was analyzed using the Chi-square test \( (\chi^2) \).

For aging, the gill cavity of the fish was opened and the otoliths were removed with forceps and cleaned from waste materials in Petri dishes containing 90% ethyl alcohol. The otoliths were then stored in numbered Eppendorf tubes for age determination. After marking the centers of otoliths under the microscope, they were broken from the marked places using thumb and index fingers (Skurdal et al. 1985). Broken otoliths were burned in a spirit stove until they were brown (Aprahamian 1988). For the age determination, the burned otoliths were placed on the tack it with their broken surfaces facing up and glycerin was dropped to reveal the age rings (Fig. 2) and examined under a stereomicroscope (Christensen 1964). Otoliths of each fish were read 3 times by the researchers, and reading for a given fish otolith was accepted only when 2 readings agreed.

Growth parameters were investigated by applying the von Bertalanffy (1938) growth function as follows

\[
L_t = L_\infty (1 - e^{-K(t-t_0)})
\]

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

where \( L_t \) is the length at age \( t \), \( W_t \) is the weight at age \( t \), \( L_\infty \) is asymptotic length, \( W_\infty \) is asymptotic weight, \( K \) is the growth coefficient, and \( t_0 \) is the hypothetical age at which length is equal to zero.

The growth performance index \( \bar{\Omega} \), to compare the growth parameters obtained in the presently reported study with those reported by other authors for the same species, was calculated by the equation of Pauly and Munro (1984)

\[
\bar{\Omega} = \log K + 2 \log L_\infty
\]

Fig. 1. Sampling points of Köyceğiz Lagoon, Muğla, Turkey
Beverton and Holt’s (1956) equation to obtain the total mortality coefficient $Z$ as

$$Z = K(L_\infty - \bar{L})(L_\infty - L)^{-1}$$

where $\bar{L}$ is the mean length of fish of length $L$ and longer, while $L$ is the lower limit of the length class of highest frequency.

The natural mortality coefficient ($M$) was calculated using the formula of Djabali et al. (1993) as

$$M = 1.0661L_\infty - 0.1172K^{0.5092}$$

where $L_\infty$ is the asymptotic length and $K$ is the growth coefficient.

The fishing mortality coefficient ($F$) was computed as

$$F = Z - M$$

while the exploitation rate $E$ was computed from the formula of Gulland (1971)

$$E = FZ^{-1}$$

In this study the relative yield per recruit ($Y'/R$) and relative biomass per recruit ($B'/R$) models, developed by Bevorton and Holt (1966) and incorporated in FISAT II software (Gayanilo et al. 2005), were used to evaluate the stock of grey mullets.

The gonadosomatic index (GSI) was calculated monthly following the formula of Avşar (1998)

$$\text{GSI} = 100 \frac{W_G}{W_T}$$

where $W_G$ is the gonad weight, and $W_T$ is the total fish weight.

**RESULTS**

As of 2003, the amount of fishing has changed between 169–633 tons per year in the last fifteen years and has been determined as mean 348 tons per year in Köyceğiz lagoon. Based on the fishing amounts of the Köyceğiz Lagoon in the last 15 years, mullet fishing has the highest ratio with 85.9%. This is followed by eel fishing with a rate of 1.2% and sea bass fishing with a rate of 0.9%. However, eel fishing has decreased considerably in recent years and it is determined as 0.06% in 2017.

**Sex ratio.** During the sampling period, 1195 individuals were collected, in this number 476 (39.8%) representing *Chelon auratus*, 291 (24.3%) *M. cephalus*, 279 (23.3%) *Chelon labrosus*, and 149 (12.5%) *Chelon saliens*. Female:male ratios of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* were 1:0.60, 1:0.47, 1:0.58, and 1:0.52, respectively. The $\chi^2$ test revealed that there were significant differences between the female and male for sex ratio of all studied species ($\chi^2 = 28.38$, df = 1, for *C. auratus*; $\chi^2 = 28.38$, df = 1, for *M. cephalus*; $\chi^2 = 28.38$, df = 1, for *C. labrosus*; $\chi^2 = 28.38$, df = 1, for *C. saliens*; $P < 0.05$).

**Age and length composition.** It was determined that the age composition of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* individuals ranged within $0^+–5^+$, $0^+–7^+$, $0^+–6^+$, and $0^+–5^+$, respectively. The most frequent age groups were 4’ (for *C. auratus* and *C. saliens*) and 3’ and 4’ (for *M. cephalus* and *C. labrosus*). The mean total length of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* was determined as 27.9, 30.2, 25.1, and 24.0 cm, respectively. The mean length, mean weight, number of fish, and the standard deviations corresponding to the age groups of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* are given in Table 1.

**Growth parameters.** The constants of the von Bertalanffy’s growth model were calculated (Table 2) yielding the following equations for growth in length and weight:

- *C. auratus*
  
  $$L_t = 58.78(1 - e^{-0.163(t + 0.0095)})$$

- *M. cephalus*
  
  $$W_t = 1501.20(1 - e^{-0.163(t + 0.0095)})$$
Table 1

The principal biometric characters of grey mullet species collected in 2017 in the Köyceğiz Lagoon, Turkey

| Species        | Sex | Age | $n$ | Total length [cm] | Weight [g] |
|----------------|-----|-----|-----|-------------------|------------|
| **Chelon auratus** | Females | 1 | 22 | 14.3 ± 1.30 | 24.22 ± 5.10 |
|                |      | 2 | 23 | 20.4 ± 2.18 | 65.63 ± 27.14 |
|                |      | 3 | 34 | 26.3 ± 1.59 | 141.79 ± 22.18 |
|                |      | 4 | 145 | 31.8 ± 2.31 | 247.49 ± 60.22 |
|                |      | 5 | 53 | 36.0 ± 1.55 | 373.30 ± 68.00 |
|                |      | 6 | 17 | 39.5 ± 2.69 | 589.13 ± 131.67 |
|                |      | 7 | 9  | 43.5 ± 1.82 | 787.90 ± 108.53 |
| **Mugil cephalus** | Females | 1 | 6  | 13.8 ± 1.73 | 20.53 ± 7.23 |
|                |      | 2 | 9  | 21.1 ± 2.13 | 78.12 ± 30.89 |
|                |      | 3 | 23 | 26.1 ± 1.57 | 138.04 ± 22.35 |
|                |      | 4 | 105 | 30.1 ± 2.00 | 201.23 ± 46.32 |
|                |      | 5 | 22 | 34.2 ± 2.00 | 342.96 ± 87.35 |
|                |      | 7 | 9  | 43.5 ± 1.82 | 787.90 ± 108.53 |
| **Chelon labrosus** | Females | 1 | 5  | 14.7 ± 1.42 | 23.06 ± 5.46  |
|                |      | 2 | 19 | 20.3 ± 1.77 | 82.93 ± 30.84  |
|                |      | 3 | 41 | 25.8 ± 1.19 | 161.31 ± 23.30  |
|                |      | 4 | 56 | 29.2 ± 1.47 | 227.87 ± 46.20  |
|                |      | 5 | 15 | 33.0 ± 1.30 | 345.95 ± 46.78  |
|                |      | 6 | 14 | 36.2 ± 0.96 | 416.07 ± 48.42  |
| **Chelon saliens** | Females | 1 | 6  | 14.5 ± 1.30 | 23.31 ± 5.84 |
|                |      | 2 | 17 | 19.9 ± 1.63 | 59.67 ± 19.07 |
|                |      | 3 | 13 | 26.1 ± 2.10 | 140.93 ± 45.78 |
|                |      | 4 | 38 | 30.6 ± 1.83 | 234.59 ± 46.77 |
|                |      | 5 | 7  | 33.6 ± 1.22 | 335.27 ± 76.49 |
| **Pooled sample** | Females | 0 | 22 | 8.2 ± 1.16 | 4.58 ± 1.78 |
|                |      | 1 | 40 | 13.5 ± 1.91 | 20.28 ± 7.10 |
|                |      | 2 | 32 | 20.9 ± 2.20 | 68.93 ± 28.33 |
|                |      | 3 | 57 | 26.2 ± 1.57 | 140.28 ± 22.12 |
|                |      | 4 | 250 | 31.3 ± 2.34 | 228.06 ± 59.30 |
|                |      | 5 | 75 | 35.4 ± 1.86 | 364.40 ± 74.88 |
|                |      | 6 | 19 | 39.8 ± 2.76 | 594.82 ± 135.76 |
|                |      | 7 | 13 | 43.2 ± 2.02 | 778.29 ± 117.71 |

The total length and weight values are mean ± standard deviation; $n$ = the number of fish sampled.
Selected vital characteristics of mullets from Köyceğiz Lagoon

$L_t = 59.99(1 - e^{-0.169(t + 0.0132)})$

$W_t = 1865.59(1 - e^{-0.169(t + 0.0132)})$

**C. labrosus**

$L_t = 49.77(1 - e^{-0.193(t + 0.0293)})$

$W_t = 1160.64(1 - e^{-0.193(t + 0.0293)})$

**C. saliens**

$L_t = 46.41(1 - e^{-0.232(t + 0.0283)})$

$W_t = 795.68(1 - e^{-0.232(t + 0.0283)})$

The growth performance index ($\theta'$) for *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* was calculated as 2.750, 2.772, 2.679, and 2.698, respectively.

**Reproduction.** In this study, the monthly mean values of the gonadosomatic index of female individuals for *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* were calculated. The highest value amounting to 13.85 was found for *C. auratus* in December (14.9°C). It was followed by 13.46 for *M. cephalus* in July (30.0°C), 7.70 for *C. labrosus* in January (13.1°C), and 10.85 for *C. saliens* in May (24.0°C). The above-mentioned values suggest that the spawning periods of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* extend from October to January, from June to September, from December to March, and from April to July, respectively (Fig. 3).

### Table 2

Population parameters of grey mullet species collected in 2017 in the Köyceğiz Lagoon, Turkey

| Population parameter | *Chelon auratus* | *Mugil cephalus* | *Chelon labrosus* | *Chelon saliens* |
|----------------------|------------------|------------------|-------------------|------------------|
| $L_\infty$ [cm]      | 58.78            | 59.99            | 49.77             | 46.41            |
| $W_\infty$ [g]       | 1501.20          | 1865.59          | 1160.64           | 795.68           |
| $K$ [year$^{-1}$]    | 0.163            | 0.169            | 0.193             | 0.232            |
| $t_0$ [year]         | -0.0195          | -0.0132          | -0.0293           | -0.0283          |
| $\theta'$            | 2.750            | 2.772            | 2.679             | 2.698            |
| $Z$ [year$^{-1}$]    | 0.82             | 0.94             | 0.86              | 0.84             |
| $M$ [year$^{-1}$]    | 0.26             | 0.29             | 0.29              | 0.32             |
| $F$ [year$^{-1}$]    | 0.56             | 0.65             | 0.57              | 0.52             |
| $E$ [year$^{-1}$]    | 0.68             | 0.70             | 0.66              | 0.62             |
| $L_c$ [cm]           | 28.0             | 26.86            | 23.73             | 22.44            |
| $E_{max}$            | 0.708            | 0.692            | 0.695             | 0.683            |
| $E_{0.1}$            | 0.609            | 0.604            | 0.606             | 0.557            |
| $E_{0.5}$            | 0.357            | 0.357            | 0.357             | 0.363            |

$L_\infty$ = asymptotic length, $W_\infty$ = asymptotic weight, $K$ = growth coefficient, $t_0$ = hypothetical age, $\theta'$ = growth performance index, $Z$ = total mortality, $M$ = natural mortality, $F$ = fishing mortality, $E$ = exploitation rate, $L_c$ = length at first capture, $E_{max}$ = maximum sustainable level of exploitation, $E_{0.1}$ = the level of exploitation at which the marginal increase in yield per recruit reaches 10%, $E_{0.5}$ = the exploitation level that will result in a reduction of the unexploited biomass by 50%.

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![Fig. 3](image_url) **Fig. 3.** Monthly variation of the GSI values for females of *Chelon auratus* (A), *Mugil cephalus* (B), *Chelon labrosus* (C), *Chelon saliens* (D) and the water temperatures in the Köyceğiz Lagoon, Turkey in 2017.
Mortality and exploitation rates. The total mortality coefficients $Z$ for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$ were estimated as 0.82, 0.94, 0.86, and 0.84 year$^{-1}$, respectively. The natural mortality coefficients $M$ for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$ were found as 0.26, 0.29, 0.29, and 0.32 year$^{-1}$, respectively. The fishing mortality coefficients $F$ for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$ were calculated as 0.56, 0.65, 0.57, and 0.52 year$^{-1}$, respectively. The exploitation rates $E$ for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$ were determined as 0.68, 0.80, 0.66, and 0.62 year$^{-1}$, respectively (Table 2).

Length at first capture. The length at first capture $L_c$ was calculated as a component of the length converted catch curve analysis (FISAT). The length at first capture ($L_c$) values for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$ were obtained 28.0, 26.86, 23.73, and 22.44, respectively.

Relative Yield per Recruit and Biomass per Recruit. The relative yield per recruit ($Y'\over R$) and the relative biomass per recruit ($B'\over R$) were shown in Fig. 4 for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$. Also, the exploitation rates, $E_{0.1}$, $E_{0.5}$, and $E_{\text{max}}$ were estimated for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$. The obtained values of $E_{0.1}$ for $C. auratus$, $M. cephalus$, $C. labrosus$, and $C. saliens$ were 0.609, 0.604, 0.606, and 0.557, respectively. The $E_{0.5}$ values were 0.357 for $C. auratus$, $M. cephalus$, $C. labrosus$ and 0.363 for $C. saliens$.

**DISCUSSION**

The annual total catch efficiency of the Köyceğiz Lagoon was between 26–97 kg per ha per year and its mean value for the last fifteen years was 53 kg per ha per year (based on face to face interview). In a study carried out by Buhan (1998) in the Köyceğiz Lagoon, the reported catch efficiency values were between 27–80 kg per ha per year. The mean catch efficiency of the Homa Lagoon was found as 20.83 kg per ha per year by Acarlı (unpublished). In a different study, carried out in the Muni Lagoon, the catch efficiency was reported as 125–250 kg per ha per year by Koranteng et al. (2000). The total of the lagoons of Turkey has been reported as 20–50 kg per ha per year, while in other Mediterranean countries it reached 56 kg per ha per year (Crivelli 1992). It is therefore evident that the catch efficiency of the Köyceğiz Lagoon is quite high among lagoons of Turkey and is average among Mediterranean countries.

![Fig. 4. Relative Yield per Recruit ($Y'\over R$) and Biomass per Recruit ($B'\over R$) for Chelon auratus (A), Mugil cephalus (B), Chelon labrosus (C), and Chelon saliens (D) collected from the Köyceğiz Lagoon, Turkey, in 2017](image-url)
Sex ratio. The female: male ratios of the presently reported study agree with the results reported in the Gulf of Gabes for *C. auratus* (see Abdallah et al. 2013); in the Homa Lagoon for *M. cephalus* (Acarlı unpublished), while the ratio of females was lower in the Sinop–Samsun coast of the Black Sea for *C. auratus* (see Bilgin et al. 2006); in the Homa Lagoon for *C. saliens* (see Acarlı unpublished) and in the Homa Lagoon for *C. labrosus* (see Akyol 1999). El-Zarka and El-Sedfy (1970) reported that the sex difference was due to the age and size of maturity. Also, Brusle (1981) reported that conditions such as heat and cold resistance and breeding migrations affect the female: male ratio in a population.

Age and length composition. Bilgin et al. (2006) reported the following mean length values for individual age groups of *C. auratus* from the Sinop–Samsun coast of the Black Sea as follows: age 1 (16.4 cm), age 2 (20.3 cm), age 3 (24.1 cm), age 4 (32.2 cm), age 5 (36.9 cm), and age 6 (39.0 cm). Hoşsucu (2001a) presented individual age categories of *M. cephalus* from the Güllük Lagoon as follows: age 1 (19.3 cm), age 2 (24.6 cm), age 3 (30.7 cm), age 4 (39.0 cm), and age 5 (43.0 cm). Moura and Gordo (2000) determined individual age categories of *C. labrosus* from the Güllük Lagoon as follows: age 0 (9.01 cm), age 1 (16.13 cm), age 2 (20.71 cm), age 3 (23.18 cm), age 4 (25.45 cm), age 5 (27.43 cm), and age 6 (31.50 cm). Balık et al. (2011) also presented individual age categories of *C. saliens* from the Beymelek Lagoon as follows: age 0 (19.9 cm), age 1 (23.5 cm), age 2 (27.2 cm), age 3 (30.6 cm), age 4 (32.6 cm) and age 5 (33.0 cm). Age composition determined by different researchers for *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* is given in Table 3. Some differences were observed in age groups of the species under study when compared to previous researches. These differences may be due to the sampling method, fishing activity, feeding habitats, population density, and the ecological conditions of water bodies.

Growth parameters. The value of $L_\infty$ for *C. auratus*, determined in presently reported study, was smaller than that from the Caspian Sea (Fazli et al. 2008a) and higher than that from the Mirma estuary (Kraljević et al. 2011). The $L_\infty$ value of *M. cephalus* obtained in this study was smaller than that from the Bardawil Lagoon (El-Ganainy et al. 2002) than that from the Mirna estuary (Kraljević et al. 2011). The $L_\infty$ value for *C. labrosus*, whilst Richter (1995) reported higher $L_\infty$ value compared to the presently reported study. Balık et al. (2011) reported a smaller $L_\infty$ value for *C. saliens* in the Beymelek Lagoon compared to this research. The value of $W_c$ was found 292.26 g for *C. auratus* in the Bitter Lakes (Mehanna, 2004), in contrast the value of $W_c$ was found 1501.20 g in this study. Ibáñez Aguirre et al. (1999) reported a higher $W_c$ value for *M. cephalus* compared to the present study. Koutrakis and Sinis (1994) reported a smaller $W_c$ value for *C. labrosus* and *C. saliens* compared to the presently reported study. The growth coefficient values ($K$) of studied species were generally lower than compared to the results of different authors (Table 4). The mean growth performance index ($\Omega$) value of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* was reported as 2.693, 2.996, 2.799, and 2.540, respectively (Ibañez 2016). The growth parameters ($L_\infty, K, t_0$) and growth performance index ($\Omega$) obtained in this study are also compared by different researches in the other water bodies (Table 4). Ma et al. (2010) reported that different age compositions may be causes of differences of the estimated parameters in different study areas. Kennedy and Fitzmaurice (1969) reported that the different growth coefficients found in different regions were due to differences in water temperature and this is because grey mullets spend most of their lifespan in shallow inshore waters, where the temperature is influenced more by local conditions than by temperature of the open sea, which is more stable.

Reproduction. The spawning periods of studied species are in agreement with other studies on the spawning periods of these species in different areas (Hoşsucu 2001b, Patimår 2008, Abdallah et al. 2013). In this study, spawning periods of the studied species were compared to the other researchers in Table 5. We assume that the physical parameters of the water, which differ from region to region, affect the spawning periods, which are found different from the results of this study. Sagi and Abraham (1984) reported that the water temperature and salinity effect reproduction periods. Whereas, Brusle (1981) reported that grey mullets reproduction in different geographic regions at different times of the year.

Mortality and exploitation rates. Fishing mortality ($F$) and natural mortality ($M$) contribute to the total mortality ($Z$). According to Barry and Tegner (1990), the predominance of growth on mortality can be perceived by the ratio $Z/K$ being lower than 1; a ratio higher than 1 means that the stock is collapsing; if the ratio is equal to 1, the population is in a steady state and if this proportion is much higher than 2, the stock is overexploited. The ratio $Z/K$ was 5.03 for *C. auratus*, 5.56 for *M. cephalus*, 4.46 for *C. labrosus*, and 3.62 for *C. saliens* and these results show overexploited of the studied species in the Köyceğiz Lagoon. The exploitation rates calculated in the presently reported study agree with the previous studies (Buhan 1998, Mehanna 2004, Hotos et al. 2019). Gulland (1971) reported that the rate of exploitation for the fish stock should be 0.5 ($F = M$). According to this result, it is inevitable that the fish stocks have a fishing pressure in the Köyceğiz Lagoon and that stocks will reach the level that will be exhausted. For the sustainable management of the grey mullet stocks in the Köyceğiz Lagoon, some of the mature grey mullets that enter the fish barriers should be left to the sea.

Length at first capture. The length at first capture of the fish individuals of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* was 28.00, 26.86, 23.73, and 22.44 cm, respectively. In the presently reported study, the length at first capture for *C. saliens* ($L_c = 22.44$ cm) was bigger than the length of first sexual maturation ($L_m = 21.3$ cm, Froese and Pauly 2019), but the length at first capture for

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* See footnote on page 305.
Table 3

Mean length of individual age groups of four grey mullet species studied by different researchers

| Species         | Location          | Method | \( n \) | Age group | Reference                  |
|-----------------|-------------------|--------|---------|-----------|----------------------------|
|                 |                   |        |         | 0\(^{+}\) | 1\(^{+}\) | 2\(^{+}\) | 3\(^{+}\) | 4\(^{+}\) | 5\(^{+}\) | 6\(^{+}\) | 7\(^{+}\) |
| Chelon auratus  | Aveiro Lagoon     | Scale  | 3689    | 10.5     | 16.5     | 21.9     | 26.8     |         |         |         |         |
|                 | Obidos Lagoon     | LFA    | 983     | 8.35     | 13.45    | 18.44    | 21.7     | 27.9     |         |         |         |
|                 | Black Sea (Turkey)| Scale  | 500     | 16.4     | 20.27    | 24.13    | 32.19    | 36.9     | 39.02    |         |         |
|                 | Klisova Lagoon    | Scale  | 991     | 17.8     | 24.7     | 30.2     | 34.3     | 40       | 42.4     |         |         |
|                 | Köyceğiz Lagoon   | Otolith| 476     | 8.2      | 13.5     | 20.9     | 26.2     | 31.3     | 35.4     |         |         |
| Chelon labrosus | Köyceğiz Lagoon   | Scale  | 763     | 23.0     | 30.4     | 35.3     | 41.5     | 44.8     |         |         |         |
|                 | Tamiahua, Mexico  | Otolith| 232     | 24.6     | 28.2     | 31.7     | 34.9     | 37.5     |         |         |         |
|                 | Gülük Lagoon      | Otolith| 132     | 19.3     | 24.6     | 30.7     | 39.0     | 43.0     |         |         |         |
|                 | Gulf of Gökova    | Scale  | 120     | 22.95    | 27.6     | 33.2     | 35.9     | 49.5     |         |         |         |
|                 | Köyceğiz Lagoon   | Otolith| 291     | 8.9      | 13.5     | 20.6     | 27.2     | 31.9     | 36.0     | 39.8     | 43.2     |
| Chelon saliens  | Gulf of İzmir     | Scale  | 47      | 25.7     | 27.3     | 34.2     |         |         |         |         |         |
|                 | Köyceğiz Lagoon   | Scale  | 130     | 20.9     | 23.9     | 26.5     | 30.3     | 35.0     |         |         |         |
|                 | Obidos Lagoon     | LFA    | 217     | 9.38     | 15.84    | 20.37    | 23.43    | 25.63    | 27.46    |         |         |
|                 | Gülük Lagoon      | Otolith| 45      | 22.0     | 23.9     | 26.5     | 30.3     | 35.0     |         |         |         |
|                 | Köyceğiz Lagoon   | Otolith| 279     | 7.9      | 13.9     | 20.2     | 25.8     | 29.4     | 32.9     | 36.2     |         |
|                 | Homa Lagoon       | Scale  | 430(FL) | 17.3     | 23.0     | 25.7     | 28.1     | 31.5     |         |         |         |
|                 | Gülük Lagoon      | Otolith| 38      | 19.2     | 22.2     | 25.6     | 28.0     | 39.0     |         |         |         |
|                 | Gulf of Gorgan    | LFA    | 294\(^{\dagger}\) | 11.7     | 16.3     | 19.2     | 23.0     | 24.6     | 26.0     | 28.5     |         |
|                 | Köyceğiz Lagoon   | Otolith| 149     | 7.0      | 14.0     | 20.4     | 26.4     | 30.6     | 33.6     |         |         |

\( n \) = number of fish sampled, LFA = length frequency analysis, \(^{\dagger}\) = female, FL = fork length.

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\( ^{\dagger} \) See footnote on page 301.
Selected vital characteristics of mullets from Köyceğiz Lagoon

C. auratus ($L_c = 28.00$ cm), M. cephalus ($L_c = 26.86$ cm), and C. labrosus ($L_c = 23.73$ cm) was smaller than the length of first sexual maturation ($L_m = 34.0$ cm, $L_m = 35.4$ cm and $L_m = 29.5$ cm, respectively, Froese and Pauly 2019). Due to the harvesting pre-spawning fishes, a greater reduction may be in the fishing in the near future. For sustainable grey mullet fishing, it is of great importance to give each fish a chance to reproduction at least once in its lifecycle, and therefore the length at first capture ($L_c$) should be bigger than the length at first sexual maturation ($L_m$).

### Table 4

Growth parameters of four grey mullet species studied by different researchers

| Species | Location | $n$ | $L_\infty$ | $K$ | $t_0$ | $O'$ | Reference |
|---------|----------|----|------------|-----|-------|------|-----------|
| Chelon auratus | Ria de Aveiro Lagoon | 3689 | 68.5 | 0.11 | -0.51 | 2.71 | Arruda et al. 1991 |
| Köyceğiz Lagoon | 406 | 37.6 | 0.519 | -0.152 | 2.865$^c$ | Buhan 1998 |
| Caspian Sea | 3502 | 62.7 | 0.15 | -0.23 | 2.770$^c$ | Fazli et al. 2008a |
| Mirta estuary | 1103 | 40.0 | 0.214 | -1.15 | 5.817 | Kraljević et al. 2011 |
| Köyceğiz Lagoon | 476 | 58.78 | 0.163 | -0.0195 | 2.750 | Presently reported study |
| Mugil cephalus | Tamiahua, Mexico | 232 | 64.24 | 0.10 | -2.850 | 2.615$^c$ | Ibáñez Aguirre et al. 1999 |
| Bardawil Lagoon | 585 | 74.16 | 0.246 | -0.969 | 3.131$^c$ | El-Ganainy et al. 2002 |
| Bafa fish lakes | 171 | 44.41 | 0.21 | -1.39 | 2.617 | Yılmaz and Polat 2011 |
| Chilika Lake | 1078 | 70.0 | 0.700 | -0.097 | 3.5 | Panda et al. 2018 |
| Köyceğiz Lagoon | 291 | 59.99 | 0.169 | -0.0132 | 2.772 | Presently reported study |
| Chelon labrosus | Northeastern Greece | 349 | 35.8 | 0.287 | -0.406 | 2.565$^c$ | Koutrakis and Sinis 1994 |
| Strangford Lough | 199 | 60.94 | 0.119 | -0.416 | 2.645$^c$ | Richter 1995 |
| Obidos Lagoon | 65 | 39.0 | 0.523 | -0.239 | 2.900$^c$ | Buhan 1998 |
| Köyceğiz Lagoon | 227 | 30.06 | 0.391 | -0.924 | 2.548$^c$ | Moura and Gordo 2000 |
| Köyceğiz Lagoon | 279 | 49.77 | 0.193 | -0.0293 | 2.679 | Presently reported study |
| Chelon saliens | Northeastern Greece | 438 | 29.4 | 0.279 | -0.346 | 2.382$^c$ | Koutrakis and Sinis 1994 |
| Mediterranean coast | 257 | 39.60 | 0.314 | -0.433 | 2.692$^c$ | Buhan 1998 |
| Gulf of Gökova | 1401 | 32.99 | 0.258 | -4.47 | 2.448$^c$ | Katselis et al. 2002 |
| Gulf of Annaba | 1078 | 70.0 | 0.700 | -0.097 | 3.5 | Panda et al. 2018 |
| Köyceğiz Lagoon | 149 | 46.41 | 0.232 | -0.0283 | 2.698 | Presently reported study |

$n$ = number of fish sampled, $L_\infty$ = asymptotic length, $K$ = growth coefficient, $t_0$ = hypothetical age, $O'$ = growth performance index, $^c$ = calculated from the $L_\infty$ and $K$ values of the published data.

### Table 5

Reproduction period and GSI values of C. auratus, M. cephalus, C. labrosus, and C. saliens in different populations from different researchers

| Species | Location | $n$ | GSI | Reproduction period | Researches |
|---------|----------|----|-----|---------------------|------------|
| Chelon auratus | Klisova Lagoon | 297 | 5.92 | August to November | Hotos et al. 2000 |
| Caspian Sea | 462 | 17.0 | October to December | Fazli et al. 2008b |
| Neretva estuary | 359 | 13.85 | October to December | Abdallah et al. 2013 |
| Gulf of Gabes | 344 | 5.19 | October to December | Presently reported study |
| Köyceğiz Lagoon | 277 | 13.85 | October to January | Presently reported study |
| Mugil cephalus | South Carolina estuaries | 119 | 17.0 | October to April | McDonough et al. 2003 |
| Neretva estuary | 355 | 13.40 | June to September | Bartulović et al. 2011 |
| Gulf of Gökova | 55 | 3.36 | June to July | Kasımoğlu and Yılmaz 2011 |
| Gulf of Annaba | 119 | 6.43 | October to November | Saoudi and Aoun 2014 |
| Köyceğiz Lagoon | 188 | 13.46 | June to September | Presently reported study |
| Chelon labrosus | Gülük Lagoon | 45 | 2.52 | November to December | Hoşsucu 2001b |
| Mediterranean coast | 205 | 5.97 | October to December | Tulkani 2017 |
| Northwestern Wales | 205 | 7.50 | December to March | Presently reported study |
| Köyceğiz Lagoon | 159 | 10.85 | April to July | Presently reported study |
| Chelon saliens | Ionian Sea | 217 | 11.9 | June to October | Katselis 1996 |
| Gulf of Gorgan | 294 | 5.97 | May to July | Patimar 2008 |
| Beymelek Lagoon | 282 | 1.35 | May to July | Balık et al. 2011 |
| PLL and VG | 135 | 1.35 | June to October | Koutrakis 2011 |
| Köyceğiz Lagoon | 89 | 10.85 | April to July | Presently reported study |

$n$ = number of fish sampled, PLL and VG = Porto Lagos Lagoon and the Vistonicos Gulf estuarine systems, northern Aegean Sea.

C. auratus ($L_c = 28.00$ cm), M. cephalus ($L_c = 26.86$ cm), and C. labrosus ($L_c = 23.73$ cm) was smaller than the length of first sexual maturation ($L_m = 34.0$ cm, $L_m = 35.4$ cm and $L_m = 29.5$ cm, respectively, Froese and Pauly 2019). Due to the harvesting pre-spawning fishes, a greater reduction may be in the fishing in the near future. For sustainable grey mullet fishing, it is of great importance to give each fish a chance to reproduction at least once in its lifecycle, and therefore the length at first capture ($L_c$) should be bigger than the length at first sexual maturation ($L_m$).
Relative Yield per Recruit and Biomass per Recruit.
The relative yield per recruit (Y/R) analysis results for
grey mullet species in the Köyceğiz Lagoon has shown
that additional fishing effort would provide very little
additional catch, this means no economic return. Also, the
results of biomass per recruit (B'/R) analysis showed that
the increase in exploitation rate causes a sharply declined
in Biomass per recruit (B'/R). It could be concluded that the
grey mullet stocks are in a situation of overexploitation in
the Köyceğiz Lagoon. For the management implications of
the assessment, the present level of exploitation rate should
be decreased by about 47.5, 49, 45.9, and 41.45
percentage points for C. auratus, M. cephalus, C. labrosus,
and C. saliens, respectively to maintain sufficient spawning
biomass for recruitment. This can be realized by reducing
the number of fishing days and allow some of the captured
fish to be released from the barriers and migrate to the sea.

CONCLUSION
As a result, growth parameters provide some indication
of resource utilization and the effectiveness of management
strategies. When age and growth were evaluated in
combination, it can be easier to understand the relation
between population size and biomass. This understanding
is the basis of modern fisheries resource allocation and
management. Fisheries management should be designed
on biological data to understand the status and to manage
fish stocks. The Köyceğiz Lagoon is an important fishing
area in Turkey. This study provides information related to
age, growth, mortality, reproduction, and exploitation rates
of the grey mullet species from the Köyceğiz Lagoon. The
results of the study may be used for fisheries researches,
management, and conservation in the Köyceğiz Lagoon.
In addition, due to activities such as fishing pressure,
environmental pollution, and tourism intense, fisheries
management policies should be implemented to ensure
optimum and sustainable use of the Köyceğiz Lagoon
immediately.

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