AGE, GROWTH, MORTALITY, REPRODUCTION, AND EXPLOITATION RATES FOR FISHERY MANAGEMENT OF GREY MULLET SPECIES IN THE KÖYCEĞIZ 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). 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: $L_t = 58.78(1 – e^{–0.163(t + 0.0195)})$ for *C. auratus*, $L_t = 59.99(11 – e^{–0.169(t + 0.0132)})$ for *M. cephalus*, $L_t = 49.77(111 – e^{–0.193(t + 0.0293)})$ for *C. labrosus*, and $L_t = 46.41(111 – e^{–0.232(t + 0.0283)})$ for *C. saliens*. The growth performance index ($Ø'$) 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 thorough 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, *Chelon labrosus* (Risso, 1827), flathead grey mullet, *Mugil cephalus* Linnaeus, 1758, and thinlip grey mullet, *Chelon ramada* (Risso, 1827) (see Buhan 1998, Yerli unpublished**).

The Mugilidae is a family widely distributed in tropical, subtropical, and temperate waters. Grey mullets 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 (χ^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

$$L_t = L_\infty(1 - e^{-K(t - t0)})$$

$$W_t = W_\infty(1 - e^{-K(t - t0)})$$

where L_t is the length at age t, W_t is the weight at age t, L_∞ is asymptotic length, W_∞ 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 ($Ø'$), 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)

$$Ø' = Log\ K + 2\ Log\ L_\infty$$

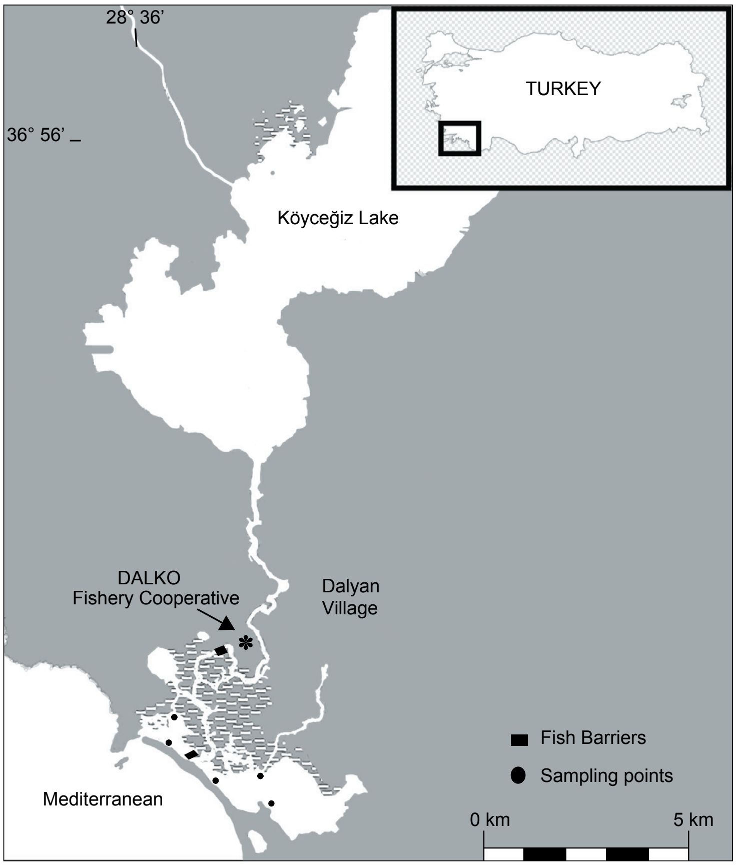

Fig. 1. Sampling points of Köyceğiz Lagoon, Muğla, Turkey

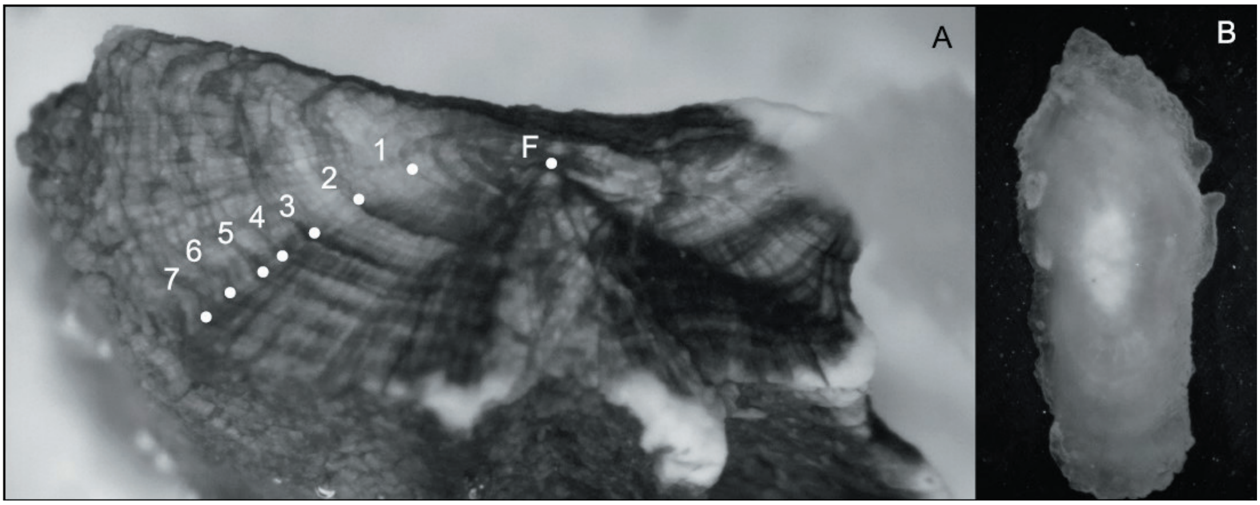

Fig. 2. Age rings of *Mugil cephalus* (TL = 40.8 cm) sampled from the Köyceğiz Lagoon, Turkey, in 2017; (**A**) After otolith is broken and burn; (**B**) Before otolith is broken and burn

Beverton and Holt's (1956) equation to obtain the total mortality coefficient Z as

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

where $\acute{L}$ 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

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

where L_∞ 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 Beverton 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)

$$\text{GSI} = 100 W_\text{G} \cdot W_\text{T}^{-1}$$

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 χ^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

$L_t = 58.78(1 - e^{-0.163(t + 0.0195)})$

$W_t = 1501.20(1 - e^{-0.163(t + 0.0195)})$

M. cephalus

Table 1

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

Sex	Age	*Chelon auratus*			*Mugil cephalus*			*Chelon labrosus*			*Chelon saliens*		
		n	Total length [cm]	Weight [g]	*n*	Total length [cm]	Weight [g]	*n*	Total length [cm]	Weight [g]	*n*	Total length [cm]	Weight [g]
Females	1	22	14.3 ± 1.30	24.22 ± 5.10	5	14.8 ± 1.79	30.60 ± 10.90	14	14.7 ± 1.42	23.06 ± 5.46	14	14.5 ± 1.30	23.31 ± 5.84
	2	23	20.4 ± 2.18	65.63 ± 27.14	12	21.6 ± 2.26	93.18 ± 32.81	19	20.3 ± 1.77	82.93 ± 30.84	17	19.9 ± 1.63	59.67 ± 19.07
	3	34	26.3 ± 1.59	141.79 ± 22.18	56	27.4 ± 2.22	182.67 ± 48.87	41	25.8 ± 1.19	161.31 ± 23.30	13	26.1 ± 2.10	140.93 ± 45.78
	4	145	31.8 ± 2.31	247.49 ± 60.22	53	31.7 ± 3.13	289.00 ± 91.25	56	29.2 ± 1.47	227.87 ± 46.20	38	30.6 ± 1.83	234.59 ± 46.77
	5	53	36.0 ± 1.55	373.30 ± 68.00	36	36.2 ± 3.15	440.73 ± 132.70	15	33.0 ± 1.30	345.95 ± 46.78	7	33.6 ± 1.22	335.27 ± 76.49
	6				17	39.5 ± 2.69	589.13 ± 131.67	14	36.2 ± 0.96	416.07 ± 48.42			
	7				9	43.5 ± 1.82	787.90 ± 108.53						
Males	1	6	13.8 ± 1.73	20.53 ± 7.23	4	13.6 ± 1.38	25.35 ± 7.50	10	14.5 ± 1.25	22.85 ± 5.30	6	15.3 ± 2.06	27.66 ± 9.00
	2	9	21.1 ± 2.13	78.12 ± 30.89	6	20.1 ± 1.96	72.57 ± 23.19	9	20.1 ± 2.27	79.95 ± 33.67	8	21.5 ± 1.04	74.84 ± 14.92
	3	23	26.1 ± 1.57	138.04 ± 22.35	23	26.6 ± 2.07	171.30 ± 48.11	17	25.7 ± 1.25	153.20 ± 18.57	17	26.7 ± 1.75	142.52 ± 47.67
	4	105	30.1 ± 2.00	201.23 ± 46.32	33	32.3 ± 2.51	304.95 ± 77.53	49	29.5 ± 1.61	241.49 ± 50.32	13	30.6 ± 1.27	214.62 ± 34.02
	5	22	34.2 ± 2.00	342.96 ± 87.35	17	35.6 ± 2.18	421.58 ± 86.35	8	32.7 ± 1.16	332.92 ± 42.12	3	33.3 ± 1.42	324.68 ± 80.71
	6				2	41.0 ± 4.17	643.15 ± 221.76						
	7				4	42.7 ± 2.61	756.67 ± 152.03						
Pooled sample	0	22	8.2 ± 1.16	4.58 ± 1.78	7	8.9 ± 1.28	12.21 ± 3.70	21	7.9 ± 1.58	4.65 ± 2.27	9	7.0 ± 2.45	3.87 ± 4.34
	1	40	13.5 ± 1.91	20.28 ± 7.10	16	13.5 ± 1.48	25.46 ± 7.63	30	13.9 ± 1.88	20.49 ± 6.96	25	14.0 ± 2.04	22.22 ± 8.13
	2	32	20.9 ± 2.20	68.93 ± 28.33	18	20.6 ± 2.19	86.31 ± 30.90	28	20.2 ± 1.91	81.97 ± 31.18	25	20.4 ± 1.62	64.53 ± 18.96
	3	57	26.2 ± 1.57	140.28 ± 22.12	79	27.2 ± 2.20	179.36 ± 48.62	58	25.8 ± 1.19	158.93 ± 22.17	30	26.4 ± 1.88	141.83 ± 46.07
	4	250	31.3 ± 2.34	228.06 ± 59.30	86	31.9 ± 2.91	295.12 ± 86.12	105	29.4 ± 1.54	234.23 ± 48.41	50	30.6 ± 1.70	229.80 ± 44.56
	5	75	35.4 ± 1.86	364.40 ± 74.88	53	36.0 ± 2.88	434.59 ± 119.28	23	32.9 ± 1.24	341.42 ± 44.69	10	33.6 ± 1.21	332.09 ± 73.31
	6				19	39.8 ± 2.76	594.82 ± 135.76	14	36.2 ± 0.96	416.07 ± 48.42			
	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.

$L_t = 59.99(1 - e^{-0.169(t + 0.0132)})$
$W_t = 1865.59(1 - e^{-0.169(t + 0.0132)})$
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 (*Ø′*) 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_∞ [cm]	58.78	59.99	49.77	46.41
W_∞ [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
$Ø'$	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_∞ = asymptotic length, W_∞ = asymptotic weight, K = growth coefficient, t_0 = hypothetical age, $Ø'$ = 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%.

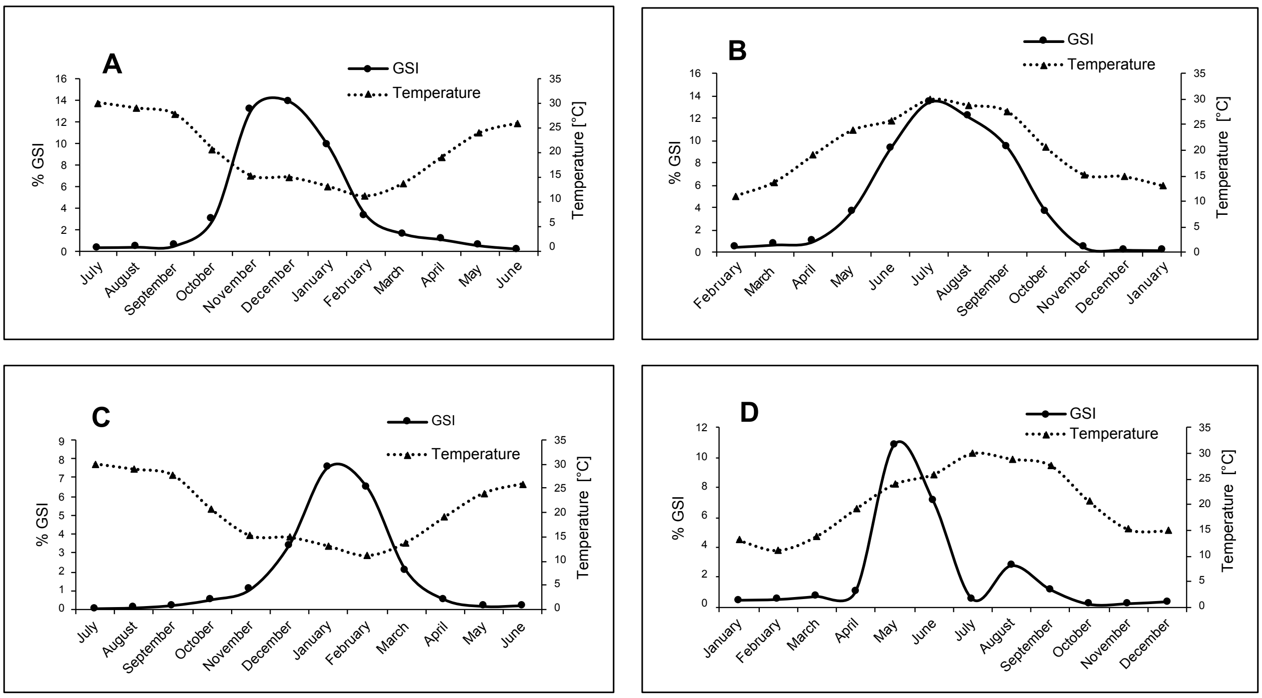

Fig. 3. Monthly variation of the GSI values for females of *Chelon auratus* (**A**), *Mugil cephalus* (**B**), *Chelon labrosus* (**C**), *Chelon saliens* (**D**) and the water temperatures in the Köyceğiz Lagoon, Turkey in 2017

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'/R) and the relative biomass per recruit (B'/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_{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.

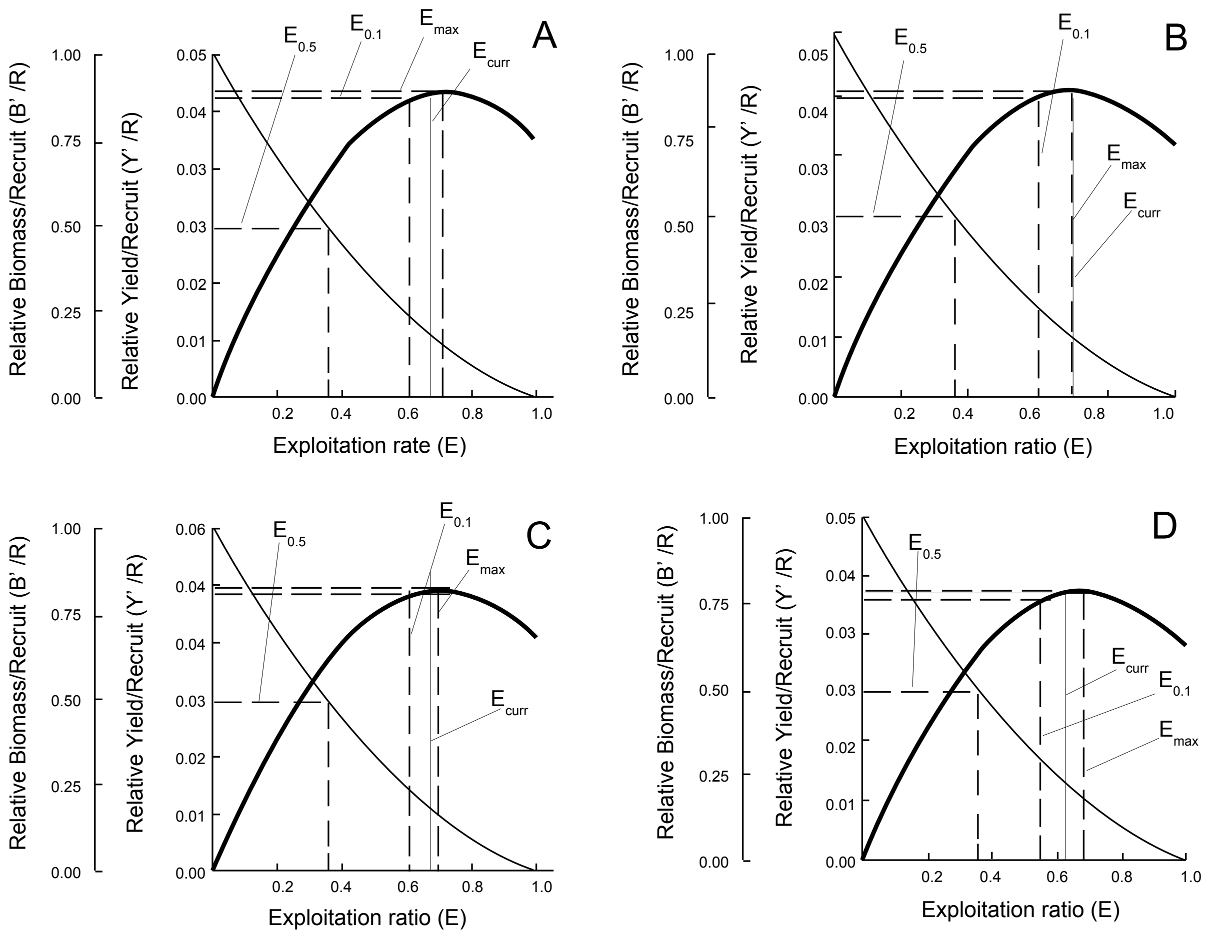

Fig. 4. Relative Yield per Recruit (Y'/R) and Biomass per Recruit (B'/R) for *Chelon auratus* (**A**), *Mugil cephalus* (**B**), *Chelon labrosus* (**C**), and *Chelon saliens* (**D**) collected from the Köyceğiz Lagoon, Turkey, in 2017

[*] Acarlı D. 2007. Homa Lagünü balıkçılığı ve geliştirilmesi üzerine araştırmalar. [Studies on fisheries and improving its fishery in Homa Lagoon.] Doktora Tezi, Ege Üniversitesi Fen Bilimleri Enstitüsü, Bornova, İzmir, Turkey. [In Turkish.]

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_∞ 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 Mirna estuary (Kraljević et al. 2011). The L_∞ value of *M. cephalus* obtained in this study was smaller than that from the Bardawil Lagoon (El-Ganainy et al. 2002) and higher than that from the Bafra fish lakes (Yılmaz and Polat 2011). Moura and Gordo (2000) reported a smaller L_∞ value for *C. labrosus*, whilst Richter (1995) reported higher L_∞ value compared to the presently reported study. Balık et al. (2011) reported a smaller L_∞ value for *C. saliens* in the Beymelek Lagoon compared to this research. The value of W_∞ was found 292.26 g for *C. auratus* in the Bitter Lakes (Mehanna, 2004), in contrast the value of W_∞ was found 1501.20 g in this study. Ibáñez Aguirre et al. (1999) reported a higher W_∞ value for *M. cephalus* compared to the present study. Koutrakis and Sinis (1994) reported a smaller W_∞ 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 ($Ø'$) value of *C. auratus*, *M. cephalus*, *C. labrosus*, and *C. saliens* was reported as 2.693, 2.996, 2.799, and 2.540, respectively (Ibáñez 2016). The growth parameters (L_∞, K, t_0) and growth performance index ($Ø'$) 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, Patimar 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

* 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				Arruda et al. 1991
	Obidos Lagoon	LFA	983	8.35	13.45	18.44	21.7	23.79				Moura and Gordo 2000
	Black Sea (Turkey)	Scale	500		16.4	20.27	24.13	32.19	36.9	39.02		Bilgin et al. 2006
	Klisova Lagoon	Scale	991		17.8	24.7	30.2	34.3	40	42.4		Hotos and Katselis 2011
	Köyceğiz Lagoon	Otolith	476	8.2	13.5	20.9	26.2	31.3	35.4			Presently reported study
Mugil cephalus	Köyceğiz Lagoon	Scale	763		23.0	30.4	35.3	41.5	44.8			Yerli unpublished1*
	Tamiahua, Mexico	Otolith	232			24.6	28.2	31.7	34.9	37.5		Ibáñez Aguirre et al. 1999
	Güllük Lagoon	Otolith	132		19.3	24.6	30.7	39.0	43.0			Hoşsucu 2001a
	Gulf of Gökova	Scale	120		22.95	27.6	33.2	35.9	49.5			Kasımoğlu and Yılmaz 2011
	Köyceğiz Lagoon	Otolith	291	8.9	13.5	20.6	27.2	31.9	36.0	39.8	43.2	Presently reported study
Chelon labrosus	Gulf of Izmir	Scale	47		25.7	27.3	34.2					Temelli 1987
	Köyceğiz Lagoon	Scale	130		20.9	23.9	26.5	30.3	35.0			Yerli 1991
	Obidos Lagoon	LFA	217	9.38	15.84	20.37	23.43	25.63	27.46			Moura and Gordo 2000
	Güllük Lagoon	Otolith	45			22.0	23.9	26.5	30.3	35.0		Hoşsucu 2001a
	Köyceğiz Lagoon	Otolith	279	7.9	13.9	20.2	25.8	29.4	32.9	36.2		Presently reported study
Chelon saliens	Köyceğiz Lagoon	Scale	257		19.0	22.3	26.7	29.3	31.7	34.8		Buhan 1998
	Homa Lagoon	Scale	430(FL)		17.3	23.0	25.7	28.1	31.5			Akyol 1999
	Güllük Lagoon	Otolith	38			19.2	22.2	25.6	28.0	39.0		Hoşsucu 2001a
	Gulf of Gorgan	LFA	294^F		11.7	16.3	19.2	23.0	24.6	26.0	28.5	Patimar 2008
	Köyceğiz Lagoon	Otolith	149	7.0	14.0	20.4	26.4	30.6	33.6			Presently reported study

n = number of fish sampled, LFA = length frequency analysis, ^{F} = female, FL = fork length.

* See footnote on page 301.

Table 4

Growth parameters of four grey mullet species studied by different researchers

Species	Location	n	L_∞	K	t_0	$Ø'$	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
	Mirna 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
	Bafra 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
	Köyceğiz Lagoon	65	39.0	0.523	–0.239	2.900[C]	Buhan 1998
	Obidos 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
	Köyceğiz Lagoon	257	39.60	0.314	–0.433	2.692[C]	Buhan 1998
	Messolonghi Etoliko Lagoon	1401	32.99	0.258	–4.47	2.448[C]	Katselis et al. 2002
	Beymelek Lagoon	1248	39.9	0.271	–2.233	6.067	Balık et al. 2011
	Köyceğiz Lagoon	149	46.41	0.232	–0.0283	2.698	Presently reported study

n = number of fish sampled, , L_∞ = asymptotic length, K = growth coefficient, t_0 = hypothetical age, $Ø'$ = growth performance index, [C] = calculated from the L_∞ 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		October to December	Fazli et al. 2008b
	Neretva estuary	359		July to November	Bartulović et al. 2011
	Gulf of Gabes	344	5.19	October to December	Abdallah et al. 2013
	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		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	Güllük Lagoon	45	2.52	November to December	Hoşsucu 2001b
	Mediterranean coast			February to April	Kottelat and Freyhof 2007
	Northwestern Wales	205		October to December	Tulkani 2017
	Köyceğiz Lagoon	159	7.50	December to March	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		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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