Management Recommendations for Common Carp Fisheries in Turkey in Light of Their Reproductivity and Gear Selectivity

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ABSTRACT

Common carp *Cyprinus carpio* (Linnaeus, 1758) is a very important freshwater commercial species in Turkey, but landings there decreased by 73 % from 2008 to 2019. There are knowledge gaps regarding the reproductive biology of the species and the selectivity of fishing gear types in Turkish lakes. This study aims to determine appropriate management measures for common carp fisheries based on gillnet and trammel net selectivity and reproductive characteristics of the species. A study was undertaken with local commercial fishers between June 2015 and December 2016 in Demirköprü Dam Lake in Western Turkey. The spawning season peaked in March, with a secondary spawning season suggested in October/November. Their length at 50 % maturity (Lm_{50}) was 38.7 cm for females and 32 cm for males. Modal lengths for gillnets and trammel nets determined by SELECT method were larger than the minimum landing size (40 cm) and the Lm_{50} values. However, sub-minimum landing size individuals were captured at high rates by both types of nets with 65 mm mesh. Trammel nets had lower modal lengths and larger spread values than gillnets of the same mesh size. These results demonstrate that some management measures currently applied in carp fishery management are insufficient for stock sustainability.

Keywords: *Cyprinus carpio*, Fisheries management, Length at 50 % maturity, Selectivity, Spawning period

INTRODUCTION

Biodiversity is intricately linked to human livelihood; however, humans are the greatest cause of its declines (Murphy and Romanuk, 2014). The health of freshwater fish is currently facing disastrous declines (WWF, 2018), where abundances of migratory freshwater fish species have declined by 76 % from 1970-2016, and by 93 % across Europe. Common carp (*Cyprinus carpio* [Linnaeus, 1758]) is a highly important freshwater commercial species in Turkey, the bridge between Europe and Asia. Turkey ranked second highest in Europe and 16th in Asia for freshwater fish catches (FAO, 2018). However, inland fishery statistics highlight a recent decline in the last decade both for total freshwater fish catches and common carp catches in Turkey. Common carp was the second-highest caught freshwater species in 2008 at 11,600 tonnes (representing 22 % of freshwater catches), but recently declined to just 3,100 tonnes in 2019 (TUIK, 2020). This situation indicates that stocks in inland

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Received 28 October 2021 / Accepted 15 March 2022

waters have alarmingly decreased, and emphasizes the importance of improving fisheries management measures to achieve stock sustainability.

For successful fisheries management, reproductive biology studies and selectivity studies of fishing gears are of great importance. Some researchers (Gwinn *et al*., 2015) have noted the value of leaving older, larger fish to reproduce, while others (Armstrong *et al*., 1990) have argued that fishing gear types should ensure that juveniles are able to escape. Thus, it is of high importance to determine the length at 50 % maturity (Lm_{50}), which should help determine the minimum landing size. Since reproductive characteristics of fish (Lm_{50}, spawning season etc.) can vary spatially, these characteristics need to be determined in each habitat in order for a fisheries management plan to be successful (Karataş *et al*., 2010). In addition to reproductive studies, selectivity studies are needed to determine the appropriate mesh size to catch adult fish. The effects of fishing gear on stocks can be determined and controlled through selectivity studies (Hamley, 1975; Çetinkaya *et al*., 1995).

In Turkey, which has varied inland water habitats and where the climatic characteristics differ by region, the Lm_{50} values of common carp were previously determined only for southern and eastern Turkey (Yerli and Zengin, 1998; Özyurt and Avşar, 2001; Şen, 2001; Şen and Elp, 2009). Also, there is a knowledge gap regarding the reproductive biology of the species in most of these habitats. For this reason, the results of many selectivity studies on carp fisheries have been evaluated according to the standard Minimum Landing Size (MLS) prescribed for the whole country (Balık, 1999; Özyurt and Avşar, 2005; Yalçın, 2006; Aras, 2015; Cilbiz *et al*., 2015; Aydın *et al*., 2016; Dartay and Ateşşahin, 2017).

Demirköprü Dam Lake, located on the Gediz River in western Turkey, is an important carp habitat lacking prior selectivity studies and reproductive biology knowledge. Fishers in this lake use multifilament gillnets with mesh sizes of 65, 70, 75 and 80 mm in the carp fisheries (Dereli *et al*., 2018) and report that catching efficiency has decreased in recent years. Thus, this study aims to: i) calculate and compare the selectivity and catching efficiency of gillnets used by fishers (multifilament nets with 65, 70, 75, 80 mm meshes) and test experimental trammel nets for increased catching efficiency; ii) determine the reproductive characteristics (spawning season and length at 50 % maturity) of common carp in Demirköprü Dam Lake; and iii) evaluate the management measures for the carp gillnet and trammel net fisheries in light of the results of the first and second aims, and suggest appropriate management measures for the fisheries.

MATERIALS AND METHODS

To evaluate and suggest appropriate management measures for common carp, we conducted two sampling studies, one on their reproductive biology and the other on the selectivity and catching efficiency of gillnets and trammel nets.

Reproductive biology

Monthly sampling was conducted with the assistance of local commercial fishers from various sites in Demirköprü Dam Lake (Figure 1) from December 2015 to November 2016. Six types of fyke nets (ranging from 28 to 40 mm mesh size) and beach seine (9 mm mesh size) were used to collect representative samples of all size classes of common carp to determine its length at 50 % maturity and its spawning season.

Fish samples were immediately transferred to İzmir Katip Çelebi University Faculty of Fisheries Laboratory in cooler boxes. Total length (L), body weight (W) and gonad weight were measured to the nearest 0.1 cm, 1 g and 0.01 g, respectively. Sex was determined by macroscopic observation of gonads, and sex ratios were compared for equal proportions by month using the chi-square ($\chi 2$) test (Zar, 1999). Sexual maturity stages were determined applying a five-staged maturity scale developed by Holden and Raitt (1974): stage I (immature)-gonads are very small and testis is whitish; stage II (maturing and recovering spent)-gonads are small, dully transparent and pinkish-whitish; stage III (ripening)-gonads are enlarged, ovary is pinkish-yellow with granular appearance and testis is whitish to creamy; no transparent ova; stage IV (ripe)-gonads are considerably enlarged, ovaries are large and transparent, orange-pink with conspicuous superficial blood vessels; ripe ova are visible; testis is whitish-creamy, soft; and stage V (spent)-gonads are shortened, walls loose, flabby, empty, dark red with traces of sperm or ova.

The condition factor (CF) and the gonadosomatic index (GSI) were estimated for both sexes using the formulae: $CF = W \times 100/L^3$ (Ricker, 1975) and $GSI = (Gw/W) \times 100$, where Gw and W are the gonad and body weight, respectively (Bagenal and Tesch, 1978).

Lm_{50} was calculated for females using samples from spring (March, April and May) and from November, when GSI values and the proportion of mature individuals (stages III, IV and V) increased. The parameter was calculated for males using samples from spring and October. The mature (stages III, IV and V) and the immature individuals (stages I and II) were proportioned for each size group with 1 cm intervals. Lm_{50} was estimated by modeling the proportion of mature individuals to their respective length classes based on the following logistic function: $P = 1/1+e^{-a\,(L-b)}$, where P = percentage of mature fish by length class, L = total length class, a and b are model coefficients. This analysis allows the estimation of the 95 % confidence intervals for Lm_{50}. The Lm_{50} was estimated using the equation: $Lm_{50} = -a/b$. Data were analysed using "Solver" in Microsoft's Excel program (Tokai, 1997).

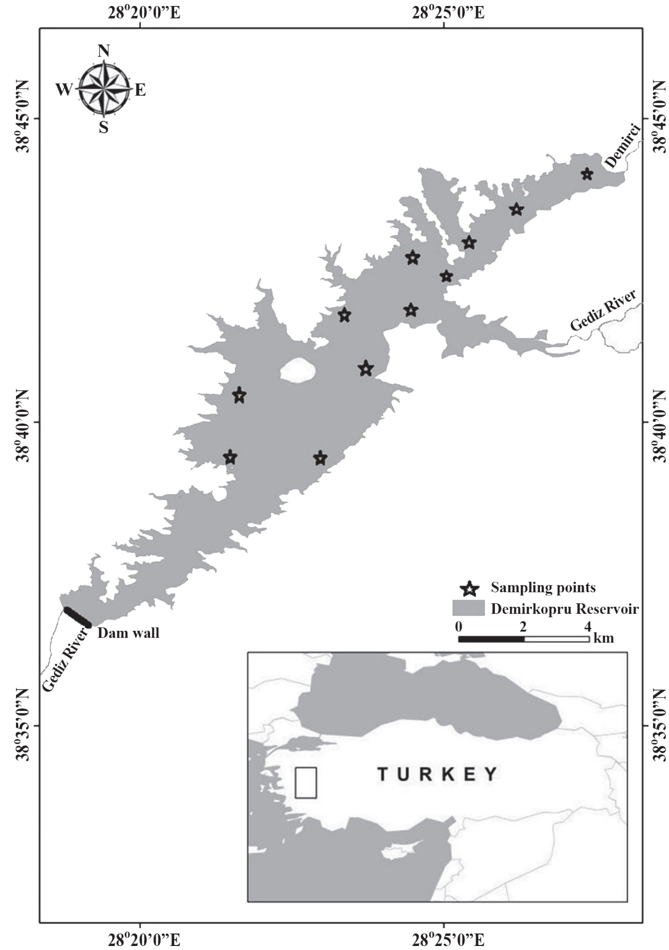

Figure 1. Study area (Demirköprü Dam Lake), showing sampling sites with stars.

Selectivity and catching efficiency of gillnets and trammel nets

Field experiments examined the selectivity and catching efficiency of gillnets and trammel nets three times per month between June 2015 and December 2016, excluding the March-May period when fishing was prohibited for commercial fishers. In each operation, multifilament gillnets with the same characteristics as the commercial fisheries provided by Dereli *et al*. (2018) and multifilament trammel nets with 65, 70, 75, 80 mm (outer panel with 200 mm) nominal mesh size (bar length) were used (Figure 2).

As in the commercial fisheries, a passive fixed method was used to set the nets in the afternoon and retrieve them the following morning. The soak

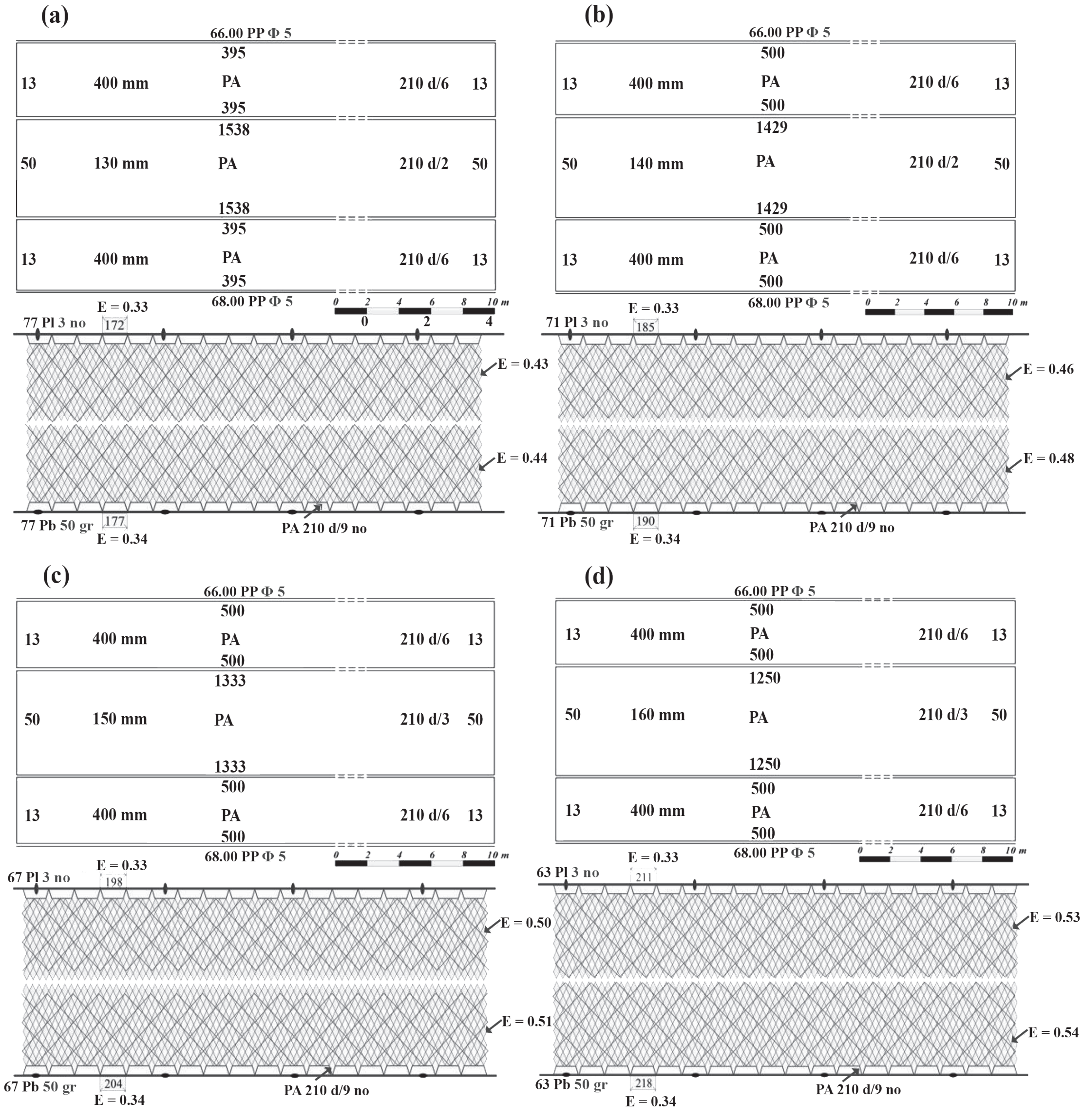

Figure 2. Scaled (top) and detailed (below) technical plans of trammel nets (a: 65 mm mesh, b: 70 mm, c: 75 mm, d: 80 mm).

time was an average of 16 h. The fish caught in the nets were classified according to net type. After being landed, species were identified according to Geldiay and Balık (2009). Total length to the nearest 1 mm and body weight to the nearest 1 g were measured by measuring tape and digital scale, respectively. The minimum, maximum and average values of carp lengths and weights were calculated for each sampled net group. The ratio of juveniles in each gear type was calculated based on the individual weights of carp below the minimum landing size (40 cm). To assess the catching efficiency, the catch per unit effort (CPUE) was calculated from the following equation: CPUE = $\Sigma(Y/L)/n$, where Y is the catch in weight (kg) of a given species in one operation, L is the length (m) of nets and n is the number of operations (Hyvärinen and Salojärvi, 1991; Balık and Çubuk, 2001).

Indirect estimation using the SELECT method was used to determine gear selectivity (Millar, 1992; 1995; Millar and Holst, 1997; Millar and Fryer, 1999). For this method, the expected catch proportions are fitted to the observed catch proportions using maximum likelihood, under the assumption that catches fall under the Poisson distribution (Feller, 1968; Millar and Fryer, 1999). The selectivity parameters of nets were estimated using GILLNET software (Constat, 1998). This program, based on the comparison of fish caught with different mesh sizes, can calculate the parameters of five different models (normal location, normal scale, log-normal, gamma and bi-modal) with the following formulas (Millar, 1992; Millar and Holst, 1997; Millar and Fryer, 1999):

Normal location: $\exp[-(l-k\times m_j)^2/2\sigma^2]$

Normal scale: $\exp[-(l-k_1\times m_j)^2/2k_2{}^2\times m_j{}^2]$

Log-normal: $m_j/(l\times m_l)\exp[\mu-\sigma^2/2-((\log(l)-\mu-\log(m_j/m_l))^2/2\sigma^2]$

Gamma: $[l/(\alpha-1)\times k\times m_j)]^{\alpha-1}\exp[\alpha-1-l/(k\times m_j)]$

Bi-modal: $\exp[-(l-k1\times m_j)^2/2k_2{}^2\times m_j{}^2] + c\times\exp[-(l-k_3\times m_j)^2/2k_4{}^2\times m_j{}^2]$

In the equations, "l" is mean total length (cm), m_1 is the smallest mesh size, "m_j" is j^{th} mesh size, μ is the average length of fish, σ is standard deviation of fish length and "k" is the constant.

The model with the lowest deviation value was chosen as the most suitable model, and the selectivity curves were plotted for different net mesh sizes (Millar and Holst, 1997; Park *et al*., 2004). From the selected model, optimum catch lengths were determined and deviance residuals were plotted using the deviation values.

The IBM SPSS (Version 22) program was used for statistical evaluations. The Kolmogorov-Smirnov (K-S) test was used to statistically compare the size-frequency distributions of the catch. To compare the mean length and CPUE, either the Student's t-test or Mann-Whitney U test was used, depending on whether the data were normally distributed or not. For each mesh size, and for each gear type, all data were pooled together before the K-S, Student's t-test and Mann-Whitney U test were applied.

Evaluation of management measures for common carp fisheries

Selectivity, catch efficiency and reproductive biology results were evaluated while considering management measures for the carp fisheries. Carp fishery management in Turkey is regulated by the Turkish Commercial Fisheries Regulations (published every four years), and management measures, specifically closed seasons and minimum landing size are applied. The closed season, which is intended to cover the spawning season of carp, is three months long, and varies according to each of four different geographical areas. However, the minimum landing size (MLS) for this species is set at 40 cm across the country. Fishers are permitted to land undersized specimens (<40 cm), provided that they do not exceed 5 % of the total catch weight. The authority responsible for fisheries management, including assigining gear specifications (such as minimum mesh size) is the Provincial Directorates of the Ministry of Agriculture and Forestry (GDFA, 2016; 2020). Also, the use of monofilament gears was prohibited in all inland waters during some periods from 2012 to 2016 (GDFA, 2012).

RESULTS

Reproduction characteristics

As a result of the 12-month sampling in Demirköprü Dam Lake, a total of 603 common carp individuals were caught by fyke net and beach seine to examine their size and spawning season. Sample sizes by sex and month are presented in Table 1. Of the entire sample, 293 (49 %) of the carp were females, 266 (44 %) were males, and 44 (7 %) were of undetermined sex. The sex ratio (♂:♀) was calculated to be 0.91:1. There was a significant difference in the catches sex ratio by month ($\chi 2$: 21.284, $p<0.05$).

Gonadosomatic index (GSI) values peaked for females in March (8.65) and decreased afterwards, with a second smaller peak in November. Males also peaked in March (4.35), with a second higher peak in October (5.35). The condition factor (CF) values increased after March for both sexes, peaking in June (♀:1.58; ♂:1.57) before decreasing to their lowest value in November (1.21) for females, and in October (1.26) for males (Figure 3).

The proportion of ripening (stage 3) and ripe (stage 4) females also increased in March, and coincided with the peak GSI values. High percentages of ripe and spent (stage 5) individuals were observed in the April-July period and in November, and GSI declined from April to September and increased again from October to November (Figure 4). In males, the proportion of ripening and ripe individuals also increased for two seperate GSI peaks (March and October), and the proportion of spent individuals increased from April to June. In October, the male population consisted of individuals at the IV and V stages (Figure 5). The length at 50 % maturity (Lm_{50}) was 38.7 cm for females and 32 cm for males (Figure 6).

Selectivity and catch efficiency

To compare the fishing gear selectivity, from a total of 45 trammel and gillnet operations, a total of 841 fish (1344.9 kg) were caught, from six species. The target species, common carp, was the most abundant species caught in both net groups (690 individuals, 82 % of the total fish number; and 1164.4 kg, 87 % of the total weight). Their distribution by net type is presented in Table 2. While 386 individuals (621.7 kg) were caught in the gillnets, 304 individuals (542.7 kg) were caught from the trammel nets. Mean lengths and weights for 65, 70, 75 and 80 mm mesh size of the gillnets and trammel nets are presented in Table 2. Mean lengths and weights of the carp increased linearly with mesh size, both for gillnets and trammel nets.

Table 1. Sample sizes (number of fish) of common carp by sex and month for reproduction study.

Month	Female	Male	Undetermined sex	Total
December 2015	23	13	4	40
January 2016	16	16	1	33
February 2016	17	17	1	35
March 2016	33	20	5	58
April 2016	50	49	4	103
May 2016	61	49	14	124
June 2016	15	23		38
July 2016	9	22		31
August 2016	16	17	2	35
September 2016	12	18	7	37
October 2016	20	14		34
November 2016	21	8	6	35
Total	293	266	44	603

Table 2. Total length and weight values of common carp from gillnets and trammel nets (N = number of fish caught, min = minimum, max = maximum, SD = standard deviation).

	Mesh size (mm)	N	Total weight (kg)	Total length (cm)			Weight (kg)		
				min	max	mean±SD	min	max	mean±SD
Gillnets	65	180	237.4	8.0	86.2	43.4±8.55	0.008	8.5	1.32±0.90
	70	104	143.1	16.5	69.5	44.1±9.97	0.06	4.3	1.38±0.70
	75	45	89.4	35.5	82	52.7±8.13	0.5	5.9	1.97±0.90
	80	57	151.8	14.5	81	55.5±13.82	0.05	7.2	2.66±1.50
	Total	386	621.7						
Trammel nets	65	109	138.1	21.0	73	43.1±7.25	0.13	5.1	1.28±0.68
	70	90	150.2	20.0	87	47.9±10.23	0.07	7.5	1.67±1.08
	75	50	101.3	26.2	74	49.9±9.86	0.23	5.8	2.03±1.20
	80	55	153.1	23.6	74	58.0±12.01	0.02	5.7	2.78±1.28
	Total	304	542.7						

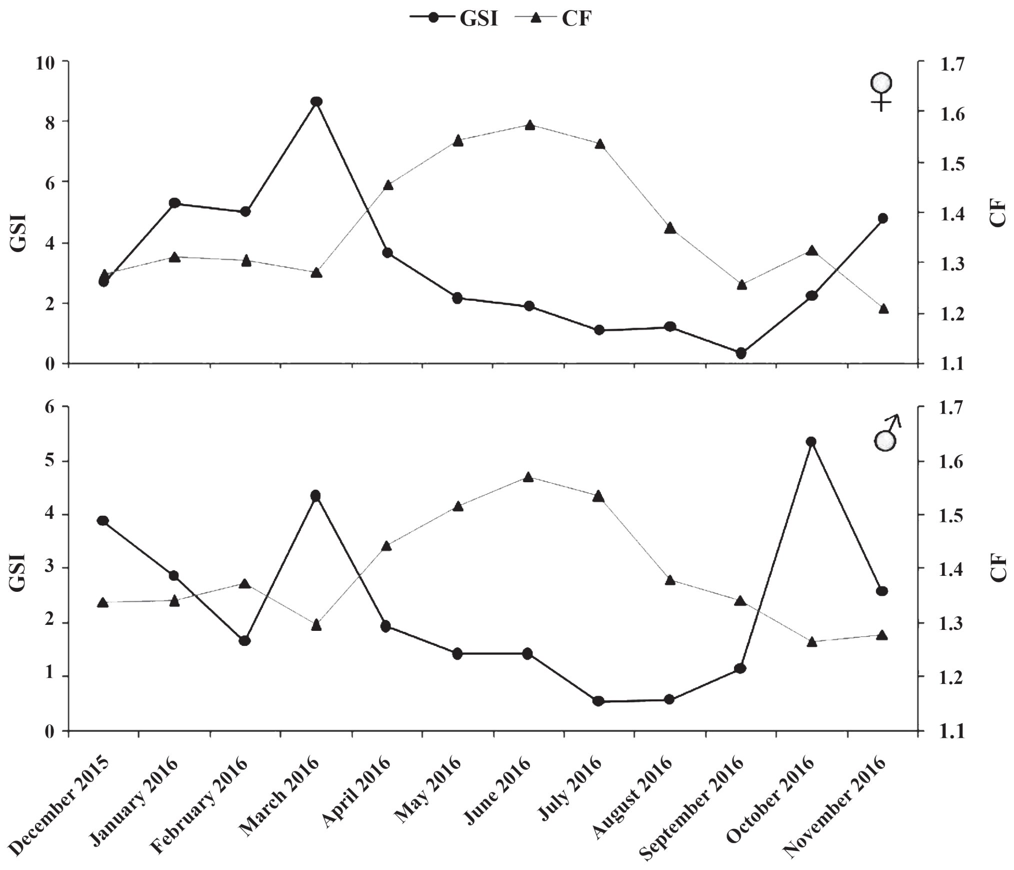

Figure 3. Gonadosomatic index (GSI) and condition factor (CF) trends for female (♀) and male (♂) common carp in Demirköprü Dam Lake over a one-year period.

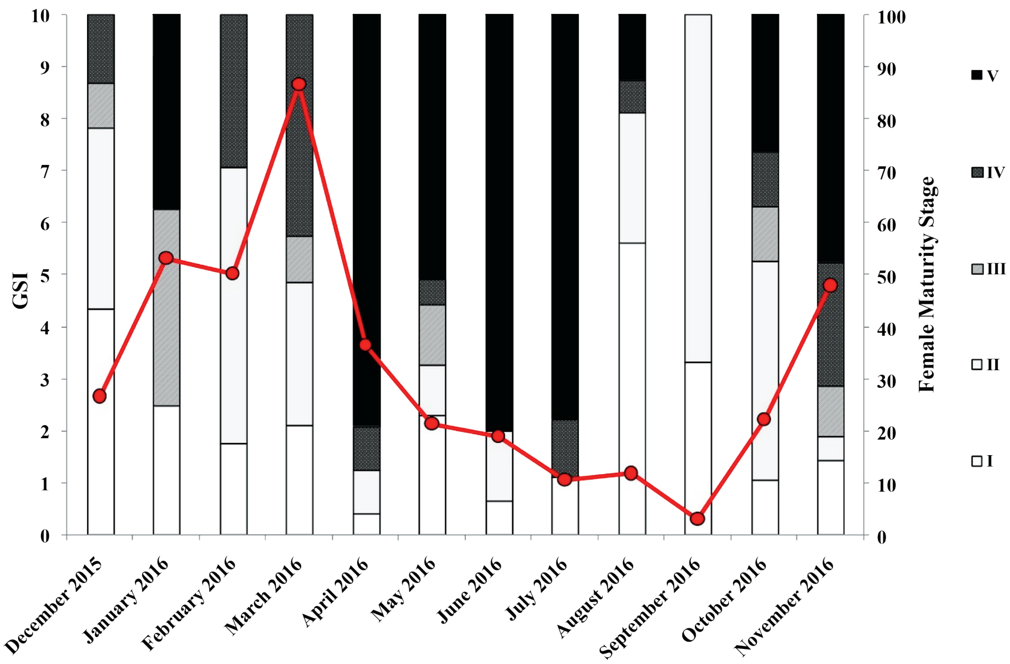

Figure 4. Monthly variations in female maturity stages (bars) and gonadosomatic index (GSI) values (red line) of common carp in Demirköprü Dam Lake.

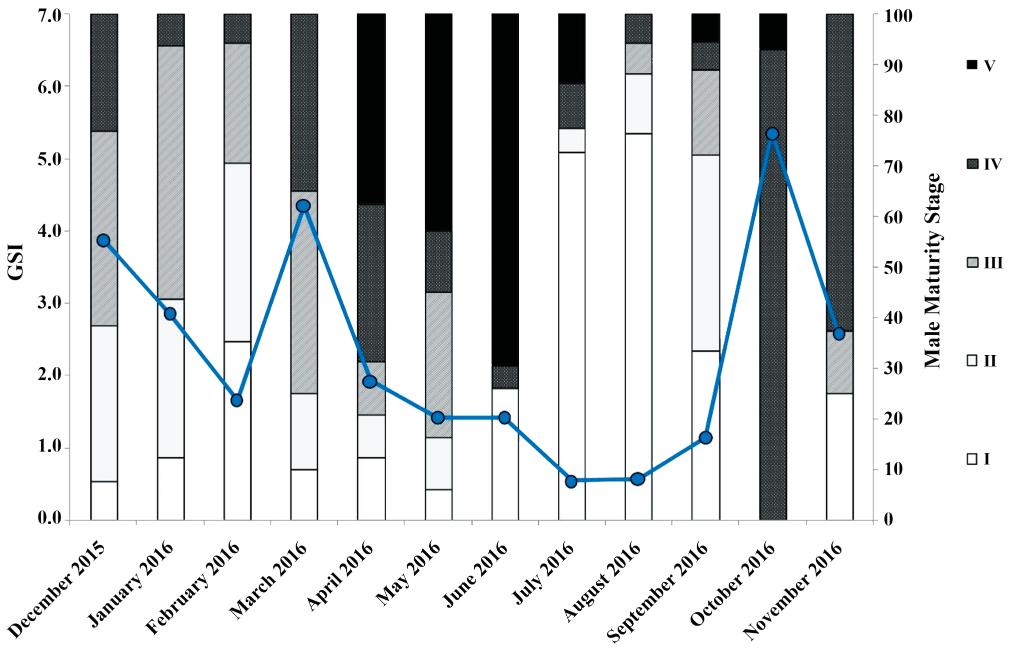

Figure 5. Monthly variations in male maturity stages (bars) and gonadosomatic index (GSI) values (blue line) of common carp in Demirköprü Dam Lake.

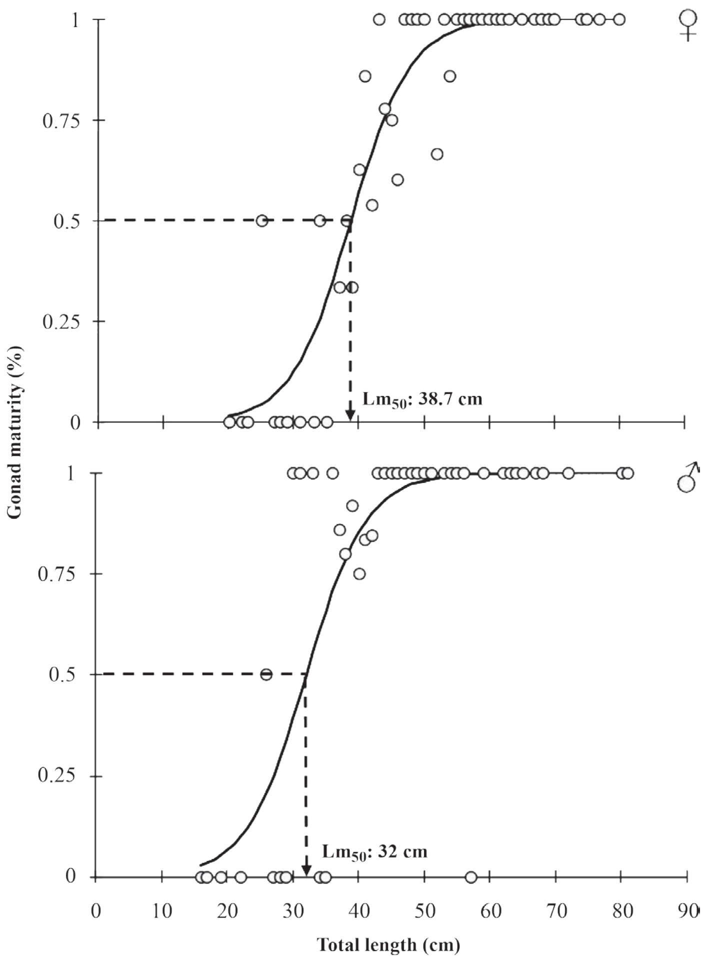

Figure 6. Length at 50 % maturity (Lm_{50}) for females (♀, N = 165) and males (♂, N = 132) for common carp in Demirköprü Dam Lake.

Length-frequency distributions of common carp are provided in Figure 7, and are combined here for gillnets and trammel nets. For both net types, the length distribution ranged from 8-87 cm and the most common length groups were between 34-72 cm (92.5 %) (Figure 7).

The percentages of common carp landed below the MLS (40 cm) for 65, 70, 75, 80 mm mesh sizes of gillnets were 9.6, 7.5, 0.6, 0.8 %, respectively, and 6 % for all mesh sizes combined. For trammel nets, the percentages under the MLS were 10.7, 4.3, 1.9, 2.4 and 4.9 %, respectively. The highest CPUE values were determined as 25.86 $g \cdot m^{-1}$ in the 65 mm mesh size for gillnets and as 16.67 $g \cdot m^{-1}$ in the 80 mm mesh size for trammel nets (Table 3).

Comparisons of mean total lengths (L), length-frequencies and CPUE values for common carp in gillnets and trammel nets are provided in Table 3. A significant difference was only found for mean lengths using 70 mm mesh size, with higher values in trammel nets (47.9 cm) than in gillnets (44.2 cm) ($p = 0.015$).

By comparing the deviances of five models in the SELECT method, the normal scale model (with the lowest deviation value) was found to be the most appropriate for both gillnets and trammel nets (Table 4).

Table 3. Comparisons of mean total lengths (L), length frequencies and catch per unit effort (CPUE) values of common carp from gillnets (G) and trammel nets (T).

Mesh size (mm)	L (mean±SE)					CPUE ($g \cdot m^{-1}$)			
	G	**T**	**Mann-Whitney U test**	**Student's t-test**	**K-S test**	**G**	**T**	**Ratio (T/G)**	**Mann-Whitney U test**
65	43.3±0.64	43.1±0.69	p = 0.833		p = 0.884	25.86	15.04	0.58	p = 0.146
70	44.2±0.98	47.9 ±1.08	**p = 0.015**		p = 0.076	15.59	16.36	1.05	p = 0.544
75	51.1±1.21	49.9±1.4		t = 0.842 df = 93 p = 0.402	p = 0.325	9.74	11.04	1.13	p = 0.367
80	55.8±1.83	58.0±1.62	p = 0.256		p = 0.420	16.53	16.67	1.01	p = 0.762

Table 4. Selectivity parameters for gillnets and trammel nets (α, k, μ, σ, k_1, k_2, k_3, k_4: selectivity constants of models) used for common carp fisheries in Demirköprü Dam Lake.

Net Group	Model	Equal fishing powers parameters	Modal Deviance	p-value	Fishing power α mesh-size (bar length) parameters	Modal Deviance	p-value	Degree of Freedom (d.f.)
Gillnets	Normal Location	(k; σ) (4.04706, 9.39949)	235.7	0.0005	(k; σ) (4.15211, 9.50959)	236.15	0.0005	169
	Normal Scale	**(k1, k2) (4.06525, 0.54359)**	**225.84**	**0.0023**	**(k1, k2) (4.13615, 0.53667)**	**225.92**	**0.0023**	**169**
	Gamma	(k; α) (0.11054, 37.98739)	235.72	0.0005	(k; α) (0.11054, 38.8739)	235.72	0.0005	169
	Log Normal	(μ; σ) (4.05885, 0.19966)	253.51	0.0000	(μ; σ) (4.19871, 0.19966)	253.51	0.0000	169
	Bi-modal		No Fit			No Fit		
Trammel nets	Normal Location	(k; σ) (3.80876, 8.88784)	203.05	0.0018	(k; σ) (3.80876, 8.88784)	203.05	0.0018	148
	Normal Scale	**(k1, k2) (3.91072, 0.56861)**	**201.73**	**0.0022**	**(k1, k2) (3.99320, 0.56124)**	**201.73**	**0**	**0**
	Gamma	(k; α) (0.10148, 38.63293)	203.64	0.0017	(k; α) (0.10148, 38.63293)	203.64	0.0017	148
	Log Normal	(μ; σ) (3.193151, 0.17715)	211.01	0.0005	(μ; σ) (3.93151, 0.17715)	211.01	0.0005	148
	Bi-modal		No Fit			No Fit		

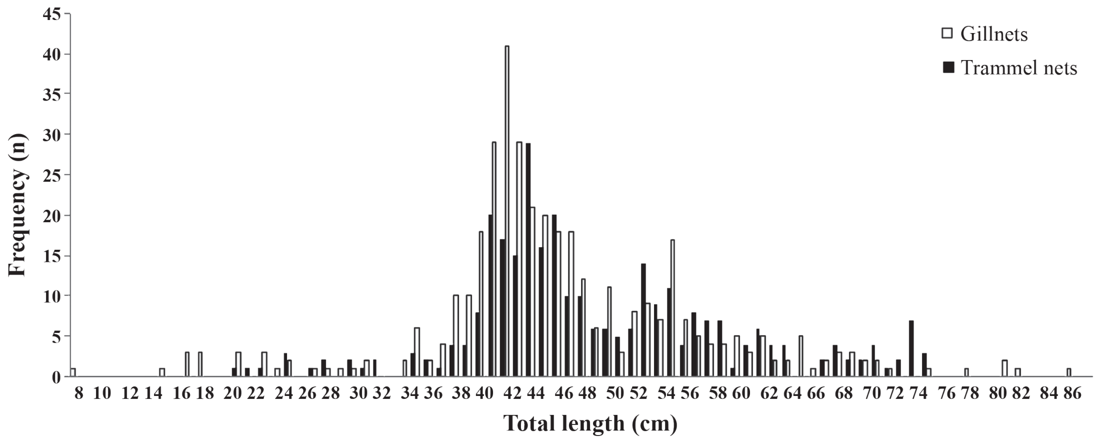

Figure 7. Comparison of total length-frequency distributions of common carp caught in gillnets (white bars) and trammel nets (black bars).

The modal length and spread values were calculated according to the normal scale model for 65, 70, 75, 80 mm mesh size gillnets as 52.85±7.07 cm, 56.91±7.61 cm, 60.98±8.15 cm and 65.04 ±8.70 cm, respectively. For trammel nets, modal lengths and spread values were determined as 50.84 ±7.39 cm, 54.75±7.96 cm, 58.66±8.53 cm and 62.57 ±9.10 cm, respectively. The fitted selectivity curves with the corresponding deviance residual plots are provided in Figure 8. The modal lengths and spread values increase with mesh size. Gillnets have higher values in modal lengths than trammel nets of the same mesh size, whereas trammel nets have higher spread values.

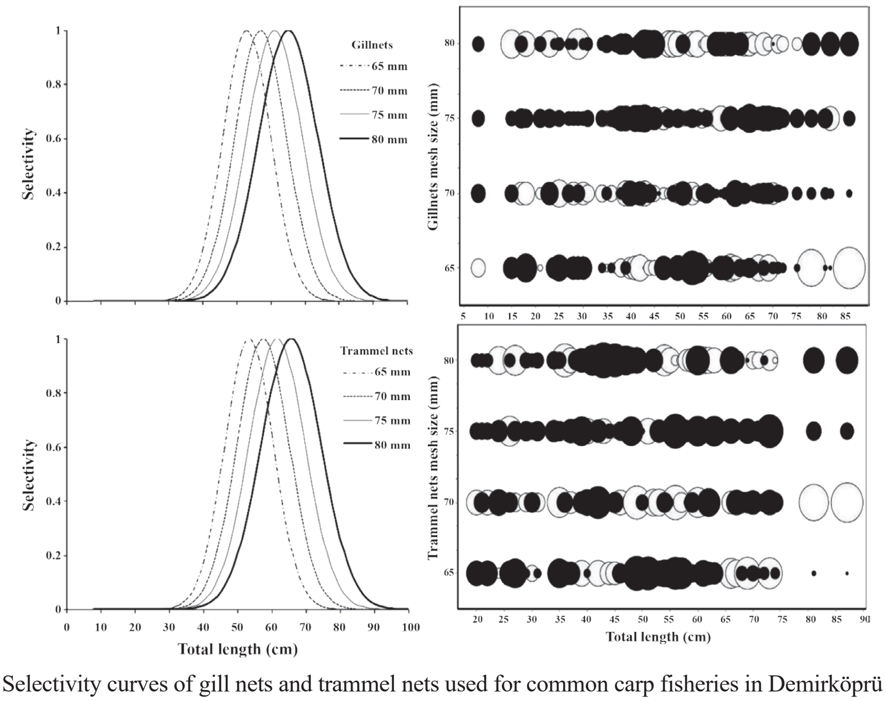

Figure 8. Selectivity curves of gill nets and trammel nets used for common carp fisheries in Demirköprü Dam Lake, and deviance residual plots (● positive residual, ○ negative residual).

DISCUSSION

The reproductive characteristics, selectivity and catching efficiency of gillnets and trammel nets were examined for the first time together in this study for common carp in Demirköprü Dam Lake. Then, the suitability of national management measures for carp was evaluated.

The spawning period for common carp according to their GSI and gonadal development stages shows two distinct annual spawning events, one in March and the other in October-November, with a heavy majority of spent individuals found between these peaks. It could be that carp are triggered to spawn via temperature cues. Türk Çulha and Erdoğuş (2018) found mean surface water temperatures in Demirköprü Dam Lake to be 26.3 ºC in summer (June, July, August), 22.2 ºC in autumn (September, October, November), 10.4 ºC in winter (December, January, February), and 16.7 ºC in spring, with significant changes in mean temperature found by season ($p<0.05$). To determine the exact duration of the spawning season, weekly gonad samples need to be collected, with the eggs examined under histological slides to locate the presence of post-ovulatory follicles.

Carp utilize some energy reserves for gonadal development during the spawning seasons, reflected by the inverse GSI relationship with condition factor (Avşar, 2005). The spring peak detected in this study was found to coincide with the spawning period stated by Vilizzi *et al*. (2014), who reviewed 30 studies on the reproduction of common carp across 26 waterbodies in Anatolia (Turkey). They emphasized that the reproductive features of common carp are largely homogeneous across Anatolia, with the spawning season beginning between March and June, and lasting for 2-7 months. The potential of this species for protracted spawning was also noted by Smith and Walker (2004). This study revealed a second spawning season based on GSI values and high ratio of mature individuals (stage III-V) in October and November, which was previously unknown.

The seasonal fishing ban for the province of Manisa, where Demirköprü Dam Lake is located, was from 15 March to 15 June in the previous regulation, active from 2016-2020 (GDFA, 2016), and was amended to 1 March to 1 June in the latest regulation for 2020-2024 (GDFA, 2020). The current seasonal closure does protect the March spawning peak, but does not capture the secondary spawning peak in October-November. Thus, we hereby recommend management to extend the closure to also include October and November for Demirköprü Dam Lake in the upcoming update of regulations forecasted for late 2024.

Here, the length at 50 % maturity (Lm_{50}) for males (32 cm) was much lower than females (38.7 cm). Other studies also support that males mature at smaller sizes than females (Avşar, 2005; Karataş *et al*., 2010). The female Lm_{50} value is just 1.3 cm under the MLS of 40 cm, and shows that the prescribed MLS size is adequate. Length of maturity values are usually set at the minimum length of maturity for females, which allows the stock to at least reproduce once before being caught (Yildiz and Ulman, 2020). Sexual maturity for common carp was calculated to occur between two to four years in age from other studies in Turkey (Vilizzi *et al*., 2014).

It was found here that both gillnets and trammel nets were efficient in catching carp by the high ratios of carp (82 % by total number, 87 % by body weight) in the catch compositions. Allowing juvenile fish the chance to escape is a very important mechanism in ensuring sustainability (Sarı, 2015), hence optimum mesh sizes should exclude juvenile classes. The modal lengths from the gillnet mesh sizes are larger than both the MLS and the Lm_{50} value determined in this study; however, they still catch juveniles up to 8 cm, as seen from Figure 7 and Table 3. Moreover, the proportions of juveniles below MLS in two of these gillnets (65 and 70 mm mesh size) and combined gillnets were higher than the 5 % legal limit. Due to this, we reccomend the use of these mesh sizes to be discouraged to improve the sustainability of carp.

By improving gear selectivity, the reduced fishing mortality on juveniles improves their chances to replenish the stocks (Pope *et al*., 1975). When gillnets were compared to trammel nets here, lower modal lengths and higher spread values were found in trammel nets. For trammel nets, the modal lengths were higher than MLS and Lm_{50} values. Trammel nets caught individuals as small as 20 cm (Figure 7 and Table 3), and the proportion of juveniles below MLS (at 10.7 %) was higher than the 5 % legal limit for only the 65 mm mesh size. A significantly larger mean length value for carp was observed in trammel nets compared to gillnets at the 70 mm mesh size.

There was no significant difference found between gillnet and trammel nets in terms of CPUE. Variation in CPUE is affected by two factors: fish availability (i.e., distribution over time and space) and gear vulnerability (i.e., catchability) (Engås and Løkkeborg, 1994; Arreguin-Sanchez, 1996). Due to the widespread use of CPUE data for fisheries management, understanding the factors affecting catchability, particularly density-dependent relationships, is important for interpreting CPUE data in fish populations (Pierce *et al*., 2010).

Although not significant, trammel nets produced higher CPUE values than gillnets in all mesh sizes, except for 65 mm. This result is supported by other research for common carp fisheries. Balık (1996) reported that multifilament trammel nets were 3.08 times more efficient than multifilament gillnets in the common carp fisheries in Beyşehir Lake. Aydın *et al*. (2016) reported that trammel nets caught 97 % more individuals than gillnets in Marmara Lake, located on the same river (Gediz River) as our study area. Also, it has been reported that trammel nets are more efficient than gillnets (Acosta and Appeldoorn, 1995). The use of monofilament gillnets in the lake and sea was prohibited in Turkey for the 2012-2016 period (GDFA, 2012); hence, commercial fishers in the Demirköprü Dam Lake switched to multifilament gillnets, but their high visibility resulted in low catch efficiencies (ZDA, 2014). The use of monofilament nets was only permitted for inland waters from 2016 onwards, including the current regulation (GDFA, 2016; 2020). If monofilament nets become prohibited again in lakes, the use of trammel nets as a substitute would result in improved catches, as demonstrated here.

CONCLUSION

Two complementary studies-a biological study and a fishing gear selectivity study were performed to assess the efficacy of current management procedures for common carp in a lake in western Turkey. From the biological study, carp had two reproductive peaks, one in March followed by a slightly smaller peak in October/November. The length at 50 % maturity (Lm_{50}) was 38.7 cm for females and 32 cm for males. Modal lengths of gillnets and trammel nets were larger than the MLS and Lm_{50} values. Trammel nets of the same mesh size had lower modal lengths and larger spread values than gillnets but both produced similar CPUE values. Two mesh sizes (65 and 70 mm) in gillnets and one mesh size (65 mm) in trammel nets captured juveniles over the 5 % legal limit.

From this evaluation, two management measures in particular applied for carp fishery management were found to be insufficient for its sustainability: the seasonal ban time and the minimum mesh sizes. The seasonal ban, applied in the spring, fails to incorporate the second reproductive season in the October-November period. Even though the modal lengths were above MLS and Lm_{50}, the 65 mm mesh size nets (both for gillnet and trammel net) pose a disadvantage for the sustainability of the stock due to the high ratios of juveniles caught. Manisa Provincial Directorate of Agriculture and Forestry (MPDAF) in 2007 established that in Demirköprü Dam Lake, the minimum mesh size that can be used for common carp is 65 mm. Also, gillnets of 70 mm mesh size and combined nets still caught a high proportion of juveniles. Therefore, we suggest that trammel nets larger than 70 mm mesh sizes (which produce higher average weights and CPUE values) should be used instead of gillnets for sustainable carp fishing in the lake. The 40 cm MLS is sufficient based on the length of maturity of the females and males. We also suggest that fisheries management measures for carp fisheries should be developed specifically according to basin by collecting the necessary fisheries and biological data with research, rather than being standardized for the whole country due to biological variabilities in the stocks.

ACKNOWLEDGEMENTS

The study was sponsored by TUBITAK (214O632 Numbered Project) and Izmir Katip Çelebi University Scientific Research Projects (2015-ÖDL-SUÜF-0003 Numbered Project). We thank Saniye Türk Çulha, Fikret Öndes and Fatma Rabia Karaduman for their help with the laboratory studies. The authors also thank the journal editor and anonymous referees for their valuable comments and suggestions.

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