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Growth, Mortality, Recruitment and Yield of Rainbow Trout, *Oncorhynchus mykiss* Walbaum, 1792 in Karacaören-I Dam Lake, Turkey

Mehmet Cilbiz[1]* and F. Banu Yalim[2]
[1]*Fisheries Research Institute, Eğirdir, Isparta-32500, Turkey*
[2]*Mediterranean Fisheries Research, Production and Training Institute, Kepez Unit, 07192, Antaya, Turkey*

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Authors' Contributions
Both authors conceived and designed the study. MC collected and analyzed data and wrote the article.

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Oncorhynchus mykiss, Rainbow trout, Length-weight relationship, Condition factor, Recruit analysis, Van Bertalanffy growth curve.

ABSTRACT

In this study, growth parameters (*i.e.* condition factor, length-weight relationship, K, L_∞, t_0), mortality rate (*Z, M, and F*), recruitment pattern and yield were investigated for *Oncorhynchus mykiss* in Karacaören I Dam Lake. Fish were collected on monthly basis between July, 2013 and June, 2014. Growth parameters were analyzed by ELEFAN with monthly length–frequency data. The *b* values of the length-weight relationship, mean condition factor, K (growth coefficient), L_∞ (asymptotic length) and t_o were estimated as 3.207, 1.13, 0.33 year^{-1}, 36.50 cm and -0.476 years, respectively. Total mortality (Z) by length-converted catch curve was estimated at 0.83 year^{-1}, fishing mortality (F) 0.14 $^{\text{year-1}}$, natural mortality (M) 0.69 $^{\text{year-1}}$ and exploitation rate (E) 0.17. According to the result of Relative Yield/Recruit analysis estimated E_{max}->E, so in this context stock of *O. mykiss* was not overexploited in Karacaören I Dam Lake.

INTRODUCTION

Native range of *Oncorhynchus mykiss* is the Eastern Pacific Ocean and the freshwaters, mainly west of the Rocky Mountains, from northwest Mexico (including extreme northern Baja, California) to the Kuskokwim River, Alaska. It is probably native in the drainages of the Peace and Athabasca rivers east of the Rocky Mountains (MacCrimmon, 1971; NOBANIS, 2015). Nowadays except for certain parts of tropical areas it has reached a global distribution area throughout the world. This distribution is based on human activity such as amateur fishing and aquaculture. *O. mykiss* was brought from Germany at first in 1970. Then its aquaculture started in Turkey (Çetinkaya, 2006). This fish is now distributed over large areas of Turkey's inland waters due to the proliferation of aquaculture locations. This fish is included in IUCN's (International Union for Conservation of Nature) list of 100 World's Worst Invasive Alien Species, though Çetinkaya (2006) has reported that there is no invasive risk of *O. mykiss* because of its inability to create fertile population in Turkey. On the contrary, Küçük and İkiz (2004) have reported that this species has ability to reproduce in some natural waters of South-West Mediterranean region of Turkey. Similarly, Candiotto *et al.* (2011) have reported that in some cases, *O. mykiss* can constitute self-sustaining stable populations. Davis (2012) has likewise reported that hatchery raised rainbow trout have the ability to reproduce and become naturalized to reservoir systems and also wild rainbow trout are recruiting to the adult population in Deerfield Reservoir.

The population of *O. mykiss* is increasing year by year. The total production was 277 t in 2000, which increased to 438 t in 2013. This production contributed around 980,000 US$ in national economy (TUIK, 2015).

In the previous studies, Leiner (1995) studied growth, mortality and production of brown and rainbow trout in 32 sites on 15 streams of New Mexico. Candiotto *et al.* (2011) studied biology of one of the rare European spawning populations of *O. mykiss* in Italian stream. Korman *et al.* (2012) studied recruitment dynamics and movement of rainbow trout in the Colorado River in Grand Canyon using an integrated assessment model.

For evaluation of commercial fish stock we have studied here the growth, mortality, recruitment and yield of *O. mykiss*. It is hoped that the results of this study will improve our understanding of population dynamics of *O. mykiss* in Karacaören-I Dam Lake.

MATERIALS AND METHODS

Study area

The Karacaören-I Dam Lake is located in limits of the cities Isparta and Burdur province (West South Anatolia)

* Corresponding author: mehmetcilbiz@hotmail.com
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(Fig. 1). Surface of the lake is 45.5 km^2, maximum depth is 65 m and altitude is 85 m (Ozvarol and Ikiz, 2009). Fish sampling was carried out on monthly basis, at two different stations with a total of 24 trials, during July 2013 and June 2014. Sampling station depths were between 6-9 m. Gillnets were made of monofilament material with 3.2, 4, 5, 6, 7, 8 and 9 cm stretched mesh sizes with 0.20 mm rope thickness and hanging ratio of 0.50. Depths of all nets were 50 meshes which were 100 m long for each panel. All nets were set in the afternoon and retrieved the following morning. The fork length (*FL*) of the fish was measured to the nearest 0.1 cm with a measuring board and weight recorded with 1g precision digital scale.

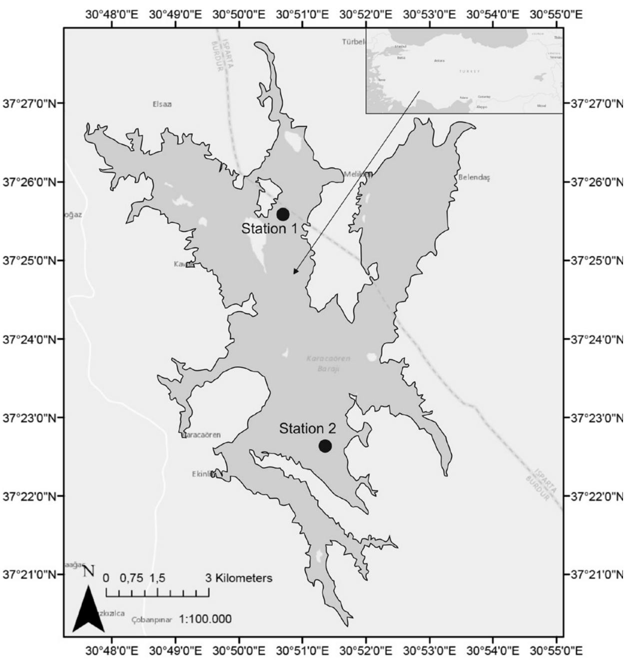

Fig. 1. Karacaören-I Dam Lake and sampling station.

Length-weight relationship and condition factor

Fishes had nonlinear relationship between length and weight that can be expressed as $W= aL^b$ (Froese et al., 2011), where W= weight of the samples in g, L= length of the samples in cm, a and b are constant parameters of the regression equation. In the calculation of condition factor (C) the formula of Fulton's coefficient of condition factors $C = (W*100)/L^3$ (Ricker, 1975) was used.

Growth analysis

The FISAT II software (Gayanilo *et al*., 2005) was used to analyze the monthly length-frequency data. Estimates of the growth parameters, L_∞ (asymptotic length), and K (growth coefficient) for the von Bertalanffy growth function (*VBGF*), were derived from the length frequency data using the *ELEFAN I* routine incorporated in the FISAT II. Algorithms of the routine require that the L_∞ parameter is known, at least within a biologically acceptable range. Initial values of L_∞ were obtained using the Powell–Wetherall method as modified by Pauly and Soriano (1986).

The ELEFAN program uses a nonparametric method to fit the von Bertalanffy growth curve through modes. The best curve will pass through the maximum possible number of modes, and the goodness of fit index (*Rn*) is defined by $Rn = 10^{ESP/ASP}/10$ (*ESP*: Explained Sum of Peaks, *ASP*: Available Sum of Peaks) (Ye *et al*., 2014).

The value of t_o was obtained from the equation Log $(-t_o) = -(0.3922)-0.2752 \log(L_\infty)-1.038 \log(K)$ (Pauly, 1983). The standard growth index (ϕ) was used as a measure of overall growth performance (Moreau *et al*., 1986). The index is defined as $\phi' = \log K + 2 \log L_\infty$.

Estimation of mortality rates

Mortality was estimated for the total sampling period. Length-converted catch curve was used to estimate total annual instantaneous mortality rates (Z) (Memon *et al*., 2016). The right descending arm of this curve was fitted with a regression line. The regression equation has the form $\ln(N) = a + bt'$, where N is the number of fish in pseudo-cohorts 'sliced' by means of successive growth curves, t' is the relative age of the fish in that pseudo-cohort, and b with the sign changed provides an estimate of Z. To obtain an independent estimate of natural mortality rate (M), the equation of Pauly (1980) $\log(M) = -0.0066-0.279 \log(L_\infty) + 0.6543 \log(K) + 0.4634 \log(T)$ was employed. Here, T means annual habitat temperature (19.5 °C).

Estimation of recruitment pattern

Recruitment patterns were determined from the routine implemented in FISAT II, which involved backward projection of the length frequency data onto the time axis based on the estimated growth parameters (Moreau and Cuende, 1991; Ye *et al*., 2014).

Estimation of relative yield per recruit

The model of Beverton and Holt (1956) as modified by Pauly and Soriano (1986) was used to estimate relative yield-per-recruit (Y'/R) and relative biomass per-recruit (B'/R) for *O. mykiss*. Both the ogive selection method and the knife-edge selection method were used. From these, the values of exploitation rate giving maximum relative yield-per-recruit (E_{max}) was estimated. E_{max} (exploitation rate producing maximum yield), $E_{0.1}$ (exploitation rate at which the marginal increase of Y'/R is 10% of its virgin stock) and $E_{0.5}$ (the exploitation rate under which the stock is reduced to half its virgin biomass) were computed through the first derivative of the function (Uneke et al., 2010).

RESULTS

In the fishing trial we caught 166 *O. mykiss* species fork lengths of which were between 13.6-34.5 cm. Generally, more samples were collected during winter months than in other seasons. *O. mykiss* could not be obtained in June, July and August. Monthly catch composition is given in Table I and length-frequency distribution is shown in Figure 2.

Figure 3 shows a nonlinear relationship between length and weight of *O. mykiss* population. Regression model parameters calculated as a= 0.006; b=3.207 [3.162-3.252], R^2= 0.968 and p<0.001. Using these parameters in the equation ($W=a*L^b$) (Froese et al., 2011) and ultimately length-weight relationship equation gave the estimate as $W=0.006*L^{3.207}$. In this study *O. mykiss* showed positive allometric growth pattern (b>3).

Mean condition factor of *O. mykiss* population in Karacaören-I Dam Lake was calculated as 1.13 (min.= 0.85, max.= 1.61 and SE= 0.01).

Powell-Wetherall plot of *O. mykiss* is shown in Figure 4. Black points in Figure 4A were used for the regression analysis (Y= 7.29+ (-0.220)*X, r^2= 0.977, L_∞=33.08 cm and Z/K= 3.538).

Table I.- Monthly catch composition of *O. mykiss*.

Sampling period	N	Fork length Mean ± SEM (Min - Max)	Total weight Mean ± SEM (Min - Max)
Oct 2012	1	19.5 ± 0.00 (19.5-19.5)	94.0± 0.00 (94.0-94.0)
Nov 2012	6	25.8 ± 0.3 (25.0-27.0)	194.5 ± 2.4 (189.0-205.0)
Dec 2012	61	18.6 ± 0.5 (13.6-29.5)	83.2 ± 8.6 (33.0-321.0)
Jan 2013	25	17.6 ± 0.3 (14.5-22.4)	56.3 ± 3.0 (35.0-101.0)
Feb 2013	40	19.6 ± 0.4 (15.3-29.5)	89.1 ± 8.9 (40.0-315.0)
Mar 2013	7	21.0 ± 1.6 (15.5-28.8)	141.3 ± 34.7 (75.0-337.0)
Apr 2013	19	25.6 ± 0.7 (18.0-31.8)	210.9 ± 16.5 (76.0-383.0)
May 2013	7	28.5 ± 1.2 (25.8-34.5)	330.3 ± 43.0 (236.0-554.0)

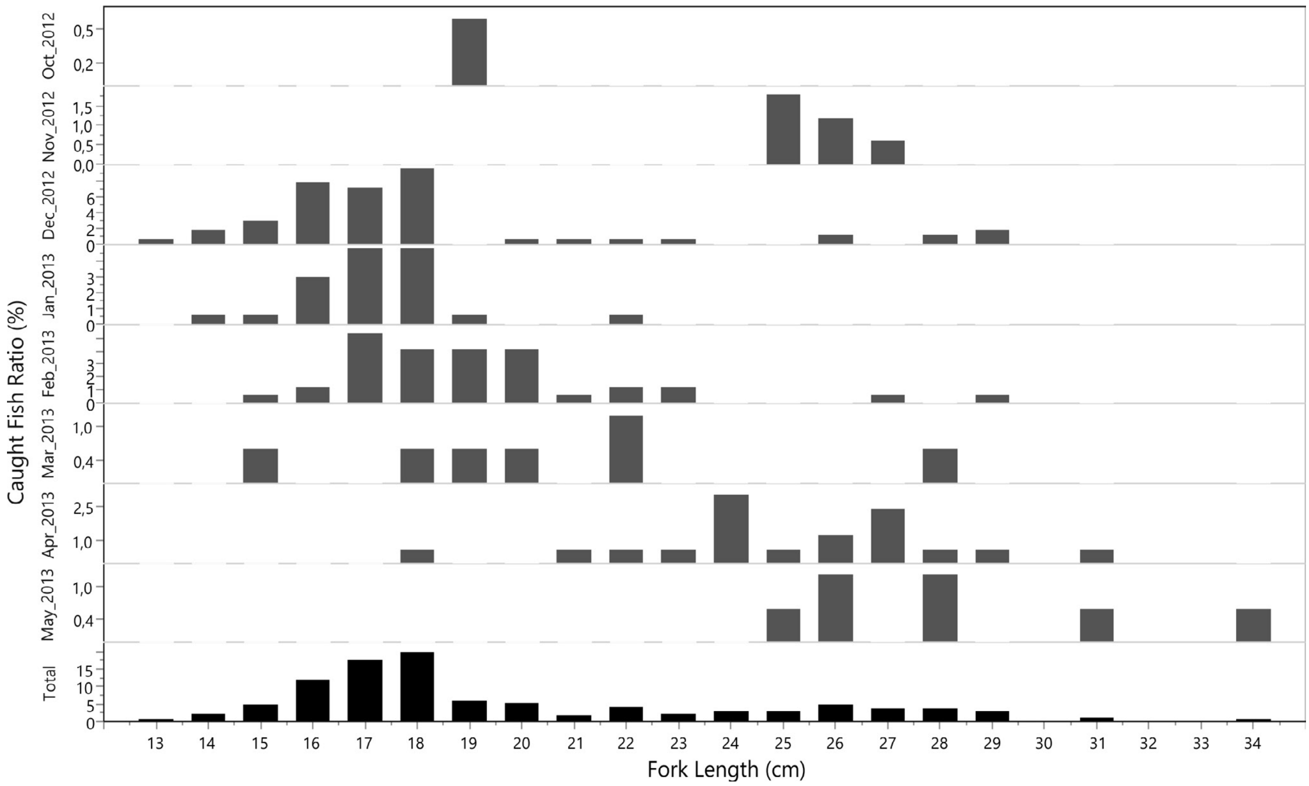

Fig. 2. Monthly length-frequency distribution of *O. mykiss*.

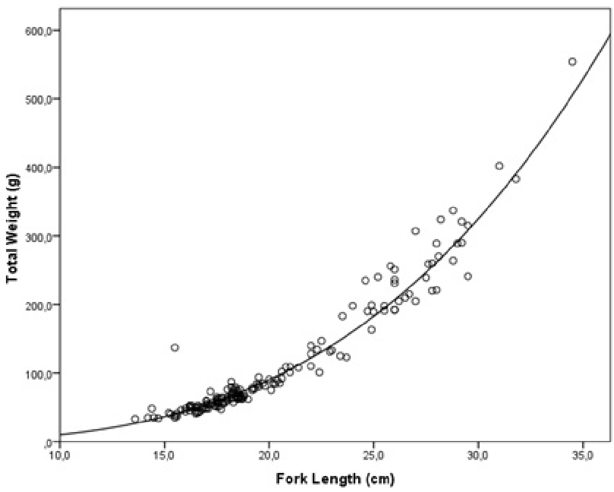

Fig. 3. Length and weight relationship of *O. mykiss*.

The growth pattern, which was von Bertalanffy growth curves of *O. mykiss* is shown in Figure 5. Parameters of the von Bertalanffy growth equation were indicated by *ELEFAN* as L_t=36.50[1-exp$^{-0.33(t+0.4760)}$] and W_t=583.87[1-exp$^{-0.33(t+0.4760)}$]$^{3.207}$ (L_∞=36.50 cm FL, W_∞=583.87 g, K=0.33 year^{-1}, t_o=-0.4760 years, SS=8, SL=31.50, Rn=0.597 and ϕ=2.64).

In the population of *O. mykiss,* there was one recruitment peak in a year (Fig. 6). This peak was in June with 18.38% recruitment. Most of the recruitments occurred in spring (*i.e.* March 15.92%, April 15.63%, May 16.67%).

The computed length-at-first-capture L_{25}, L_{50} (or L_c), and L_{75} were 13.84, 14.11 and 14.37 cm, respectively (Fig. 7). Total mortalities (Z) calculated by non-seasonalized length-converted catch curves were 0.83 year^{-1}. Catch curve is shown in Figure 8. Natural mortality was estimated as M= 0.69 year^{-1} (annual mean water temperature was evaluated

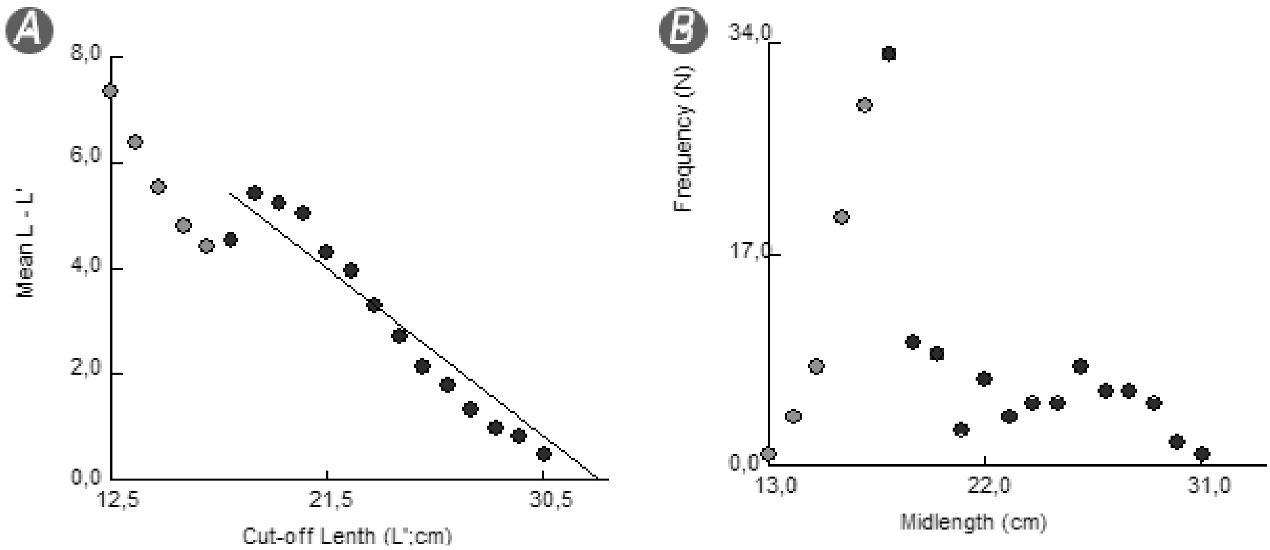

Fig. 4. Powell-Wetherall plot for (A) and Pseudo-Catch Curve (B) *O. mykiss*.

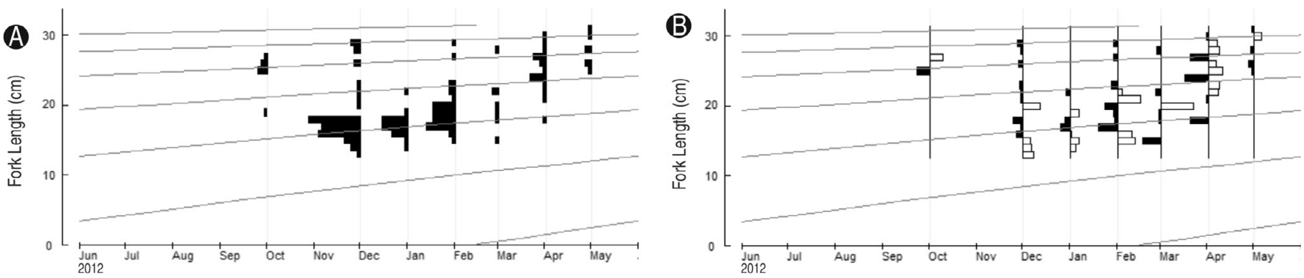

Fig. 5. von Bertalanffy growth curves of *O. mykiss* with normal length-frequency histogram (A) and restructured histogram (B).

as 19.5 ºC). Fishing mortality coefficient F was 0.14 $year^{-1}$. E (exploitation rate) was computed as 0.17. Annual survival rate was estimated as 43.60%, 9.52% and 46.88% for S (survive), C (fishing), D (natural*)*, respectively.

Using the Knife-Edge selection procedure for the analysis of relative yield and biomass per recruit of *O. mykiss* (Fig. 9) gave an E_{max}, (the value of exploitation rate E giving the maximum relative yield per recruit) of 0.618, $E_{0.1}$ (the value of E at which increase in the Y'/R is 10% of its value) of 0.520 and $E_{0.5}$ (the value of E at 50% of the unexploited relative biomass per recruit) of 0.327 (Table II). Selection ogive procedure of *O. mykiss* is shown in Figure 9. $E_{0.1}$,$E_{0.5}$ and E_{max} values estimated as 0.517, 0.316 and 0.618, respectively, based on ogive procedure.

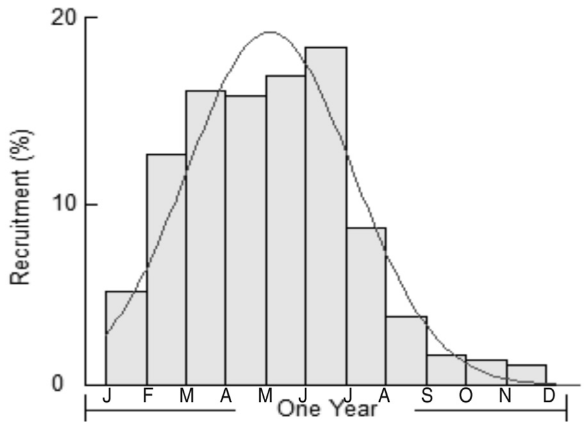

Fig. 6. The annual recruitment pattern of *O. mykiss*.

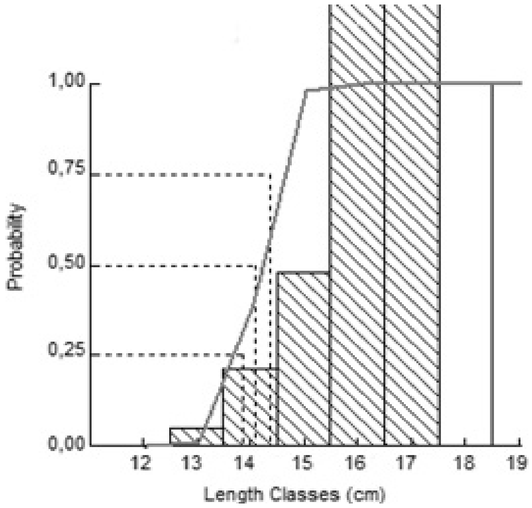

Fig. 7. Probability of capture analysis for *O. mykiss*.

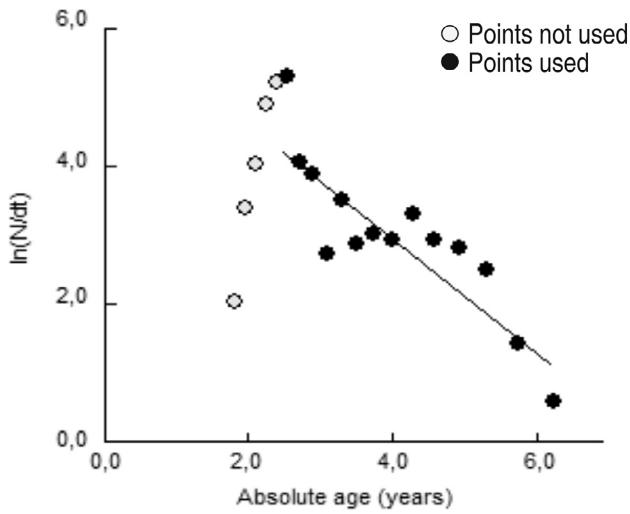

Fig. 8. Length-converted catch curve of *O. mykiss*.

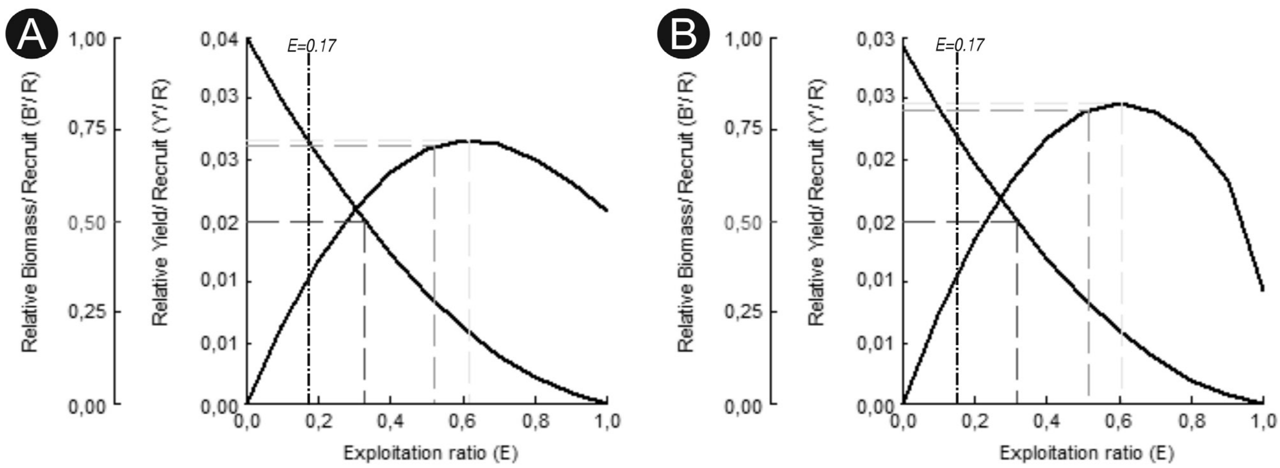

Fig. 9. Relative yield and biomass recruit of *O. mykiss* using selection Knife Edge selection procedure (A) and Ogive selection procedure (B).

DISCUSSION

The reason for low or no fish catch during June, July and August is because of high water temperature. The decrease in water depth may also be cause of sudden rise of water temperature which makes the fish to move to deeper lake area or relatively colder spring waters supporting the Dam Lake.

In this study, *O. mykiss* population of Karacaören-I Dam Lake's showed positive allometric growth proportion (b>3). This result showed parallelism with other studies which were conducted in Turkey (*i.e.* Erguden and Goksu, 2009; Çiçek and Birecikligil, 2013). But our b value was different from the one reported by Leiner (1995),

Table II.- Result of Relative Yield/Recruit Analysis for *O. mykiss* (L_c/L_∞=0.380; M/K=2.09).

Parameters	Knife edge selection	Ogive selection
$E_{0.1}$	0.520	0.517
$E_{0.5}$	0.327	0.316
E_{max}	0.618	0.618

Table III.- Summary of previous biology studies on *O. mykiss*.

	Parameters				Location	Author
	N	a	b	r^2		
Length-weight relationship	157	-4.698*	2.88	0.96	Rio Gr.,Str, New Mexico	Leiner (1995)
	16	-4.377*	2.73	0.94	Red Stream, New Mexico	
	8	-5.687*	3.30	0.98	Pecoz Stream,New Mexico	
	39	0.004	3.29	0.92	Seyhan Dam Lake, Turkey	Erguden and Goksu (2009)
	794	0.00005	2.69	0.98	Lemme Creek, Italy	Candiotto *et al.* (2011)
	359	-4.921*	2.96	0.99	Dachigam Stream, India	Shah *et al.* (2011)
	87	0.0066	3.19	0.99	Ecemiş Stream, Turkey	Çiçek and Birecikligil (2013)
	70	0.902	3.39	0.86	Kashmir Valley, India	Sharma and Bhat (2015)
	166	0.006	3.20	0.96	Karacaören-I D.L. Turkey	Present Study
Condition factor	K_Mean	K_Min	K_Max			
	-	0.76	1.08		Flaming Gorge, USA	Budy *et al.* (2003)
	1.15	-	-		Dachigam Stream, India	Shah *et al.* (2011)
	1.83	-	-		Kashmir Valley, India	Sharma and Bhat (2015)
	1.13	0.85	1.61		Karacaören-I D.L. Turkey	Present Study
Age	Class	Min.	Max.			
	6	2	7		Mimbres Str., New Mexico	Leiner (1995)
	5	0	4		Red Stream, New Mexico	
	6	0+	5+		Sacramento River, USA	Glowacki (2003)
	2	3	4		Kadıncık Stream, Turkey	Korkmaz (2004)
	5	0+	4+		Lemme Creek, Italy	Candiotto *et al.* (2011)
	2	2+	3+		Karakaya D.L. Turkey	Ateşşahin *et al.* (2011)
	6	0+	5+		Karacaören-I D.L. Turkey	Present Study
Growth parameters	L_∞	K	t_0			
	37.63	0.080	-1.630		Mimbres Str., New Mexico	Leiner (1995)
	29.13	0.390	-0.360		Red Stream, New Mexico	
	36.50	0.330	-0.476		Karacaören-I D.L. Turkey	Present Study
Mortality rate	Z	M	F	E		
	0.42	-	-	-	Mimbres Str., New Mexico	Leiner (1995)
	0.46	-	-	-	Red Stream, New Mexico	
	0.83	0.69	0.14	0.17	Karacaören-I D.L. Turkey	Present Study

*Log(a).

Candiotto et al. (2011) and Shah et al. (2011) (Table III). The mean condition factor estimated as 1.13 is similar to that reported by Shah et al. (2011) but very low compared to 1.83 reported by Sharma and Bhat (2015). It is thought that this differences may be due to sex ratio distributions, feeding status, age distributions, number of samples and sampling period.

While estimated *K* value (0.33) is similar to (0.39) that reported by Leiner (1995) for Red stream *O. mykiss* population, it is different from that of Mimbers stream population (0.08) reported by same author. It is assumed that this difference is because of different number of samples, sampling methods (*i.e.* gillnet vs electro shockers) and origin of rainbow trout. Davis (2012) reported that wild fish exhibited faster growth than the rainbow trout raised in a hatchery and he developed a non-lethal method to differentiate between hatchery-raised and naturally reproduced rainbow trout based on growth characteristics of scales.

It could not be explicitly determined that whether recruitment of *O. mykiss* in Karacaören I Dam Lake was based on self-sustaining individuals or due to escape from the nearby aquaculture facility every year. Davis (2012) reported that managers should focus on continuing to monitor genetic contribution to natural reproduction by hatchery-reared rainbow trout and also fisheries biologists should focus on continuing to improve non-lethal technique to continue to monitor recruitment.

In the light of relative yield and biomass recruit information, it can be concluded that there are no serious fishing pressures on stock, since the estimated E_{max} with knife-edge selection (0.618) and ogive selection (0.618) greater than current exploitation rate (E = 0.17). The main target of fishermen are common carp (*Cyprinus carpio*) and Prussian carp (*Carassius gibelio*) in Dam Lake, so fishermen use gillnet and trammel nets with 100-110 mm stretched mesh size intended for this species. These nets are very inefficient in *O. mykiss* fishing due to very large size of this species. Estimated fishing mortality (F=0.14) may originate from pikeperch's (*Sander lucioperca*) nets or tangling with teeth on carps nets. The anglers probably cause least fish mortality.

CONCLUSION

It shows that *O. mykiss* stock is not use within economic ratability scope due to most of the deaths based on natural. Because of gillnets are inefficient in *O. mykiss* fishing (Cilbiz *et al*., 2015), angling may be encourage in Karacaören I Dam Lake for better exploiting of the *O.mykiss* stock.

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Conflict of interest statement

We declare that we have no conflict of interest.

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