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Life History Pattern of an Eurasian Cyprinid, *Rhodeus amarus*, in a Large Drinking-Water System (Ömerli Dam Lake-Istanbul, Turkey)

Büyük İçme Suyu Havzası (Ömerli Baraj Gölü-İstanbul)' nda Cyprinid, *Rhodeus amarus*' un Hayat Süreci Özellikleri

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Abstract

The life history pattern (age, growth and reproduction) of bitterling, *Rhodeus amarus* (Bloch, 1782), was studied in the Ömerli Dam Lake a large drinking water system located in Istanbul (Turkey) between April 2003 to August 2004. Age determination based on opercula readings and validated by scale readings and length frequency analysis shows that population has a 5-year life cycle. The von Bertalanffy growth function was fitted to length-at-age data and displayed variation in growth rates between sexes. Total length-weight relationship was estimated as $W = 0.0077TL^{3.29}$ for males and $W = 0.022TL^{2.73}$ for females. Spawning season was from April to August. The ratio of males to females was 1:2.32. Condition of male increased from August until April while condition of females fluctuated throughout the year.

Key words: *Rhodeus amarus*, age, growth, life history, Ömerli Dam Lake

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Introduction

The bitterling *Rhodeus amarus* (Bloch, 1782) is a small, short lived fish occurring in central and eastern Europe and northern Asia (Kottelat, 1997). Although a limnophilic species (Schiemer and Waidbacher, 1992) with a preference for stagnant water bodies (Copp *et al.,* 1994; Holčík, 1999), it may also be found in lotic habitats (Copp, 1989; Przybylski and Zieba, 2000).

Bitterling is a species with an unusual mode of reproduction and early development as it spawns into the gills of freshwater mussels (ostracophilous species according to Balon 1975). Due to its interaction with mussels, bitterling is a valuable model species in behavioral and evolutionary ecology (Mills and Reynolds, 2003).

There have been many studies on bitterling especially about its behavioural aspects of reproduction and large body of literature concerning them has recently been reviewed by Smith et al. (2004). Scientific interest in this species is also concentrated on feeding (Przybylski, 1996), systematics and morphology (Holčík, 1959; Holčík and Jedlicka, 1994; Reichard, 1998; Reichard and Jurajda, 1999). Studies on population dynamics have been conducted only for Czech and Slovak (Holčík, 1960) and recently Greek (Koutrakis *et al.,* 2003) and Polish (Przybylski and Garcia-Berthou, 2004) populations. However, many aspects of its environmental biology in general are still unknown as suggested by Holčík (1999).

The aim of the present study was to describe the life history pattern (age, growth and reproduction) of the bitterling in a large drinking water system. This study attempts to contribute to an understanding of the environmental and geographical variation on its life history characteristics and fill the gaps in management of this species.

Study area

Ömerli Dam Lake is the biggest reservoir in Istanbul and is located in northeast (approximately 30 km) of the city. The reservoir provides approximately 48% of the city's drinking water and average of 872000 m^3 per day water is discharged from the reservoir. Morphometrically, the reservoir has a surface area of 23.5 km^2 and a

volume of 2.2 x 10^6 m^3 (Albay and Akçaalan, 2003). Its maximum depth is 62 m as reported by Istanbul Water Authority (ISKI). It was established after a high dam wall was built on Riva Stream in 1972 by General Directorate of State Hydraulic Works (DSI) to provide drinking water for the city. The Riva Stream was then located between the reservoir and Black Sea as a discharge water system for the reservoir. There are four main streams which are feeding the reservoir at present, namely; the Ozan, the Göçbeyli, the Ballıca and the Kömürlük. The fifth stream named Paşaköy which was feeding the reservoir until 2004 has been connected to the Riva Stream via a tunnel (3m diameter and 6 km length) by ISKI in order to prevent domestic and industrial wastewater inputs into the reservoir (Figure 1). Due to input of domestic and industrial wastewater, coming mainly via small streams, the whole water system is mesotrophic (Albay *et al.,* 2003).

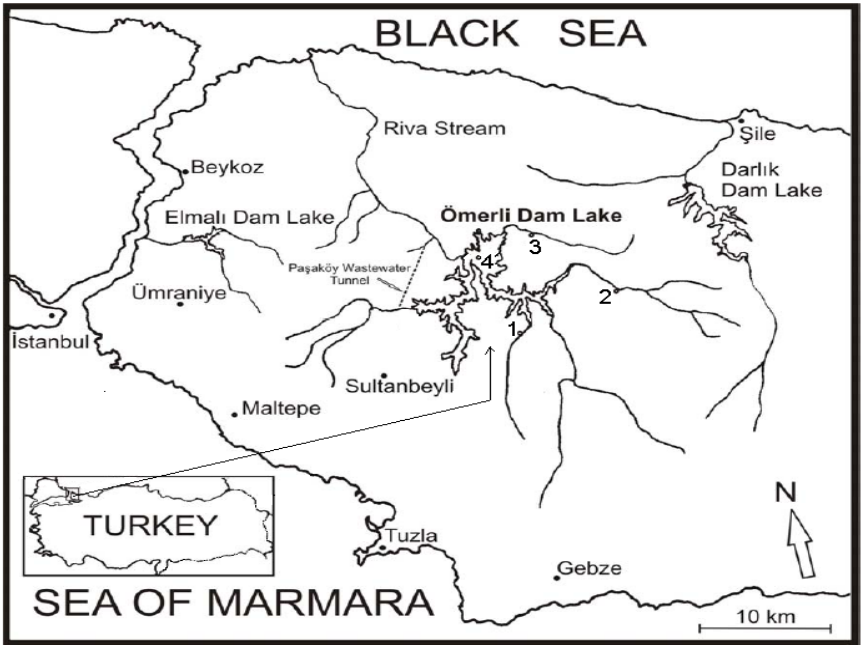

Figure 1. Sampling stations at Ömerli Dam Lake Basin. 1. Ballıca Stream (41°00′02′′N, 29°25′07′′E), 2. Ozan Stream (41°03′05′′N, 29°28′09′′E), 3. Kömürlük Stream (41°05′05′′N, 29°25′19′′E), 4. Ömerli Dam Lake

Material and Methods

During twelve sampling periods from April 2003 to August 2004, a total 538 specimens of bitterling were collected using gill-net (10 mm mesh size, 2.5 m height, and 50 m length), cast-net and electrofishing (Elektracatch, WFC911). Samples obtained in different years were handled together to get enough information about life history, seasonal variations of the population.

Fish were preserved in 4% formalin solution immediately after their capture. In the laboratory fish were sexed. It was recognized by external features, e.g. the ovipositor in females or by macroscopic examinations of gonads (young fish or uncertain specimens). The overall ratio of males to females was tested with chi-square (χ^2) goodness-of-fit test (Zar, 1999).

The length-weight relationship was described by the equation: $W = aTL^b$, where W is body weight in g, and TL is total length in mm, and a and b are constants (Le Cren, 1951). Regressions on log-transformed data were tested for differences in slopes and intercepts between sexes using ANCOVA (Zar, 1999).

Age was determined from operculum bone and scales. Operculum bones were examined under a stereomicroscope. For several randomly selected specimens, age was validated from the scales. Scales were removed from the preferred area between the left lateral line and dorsal fin approximately five to ten. Six scales from each specimen were placed on a 1 mm thick polycarbon plastic plate and pressed at a roller press. After the scales were removed, their prints were left on the plate. The prepared plates bearing the prints of scales were read using a Microfish Reader (Lagler, 1956). Age validation was also attempted using length frequency analysis.

As the scale shape was not suitable for back-calculation, the previous growth of bitterling was determined by back-calculation from the operculum bone measurements. In operculum bones, annual increments were measured from the origin to the posterior edge. The relationship between total length (TL) and operculum radius (R) was best described by a linear equation ($TL = (a + b)R$). TL-R regressions were tested for differences in slopes and intercepts between sexes

using ANCOVA (Zar, 1999). $TL_n = (TL x R_n)/R$ (where TL_n = length of fish when annulus 'n' was formed. TL = total length of the fish when the scale sample was obtained, R_n = radius of annulus 'n', R = total operculum bone radius) (Bagenal and Tesch, 1978).

Using the above results, we estimated the relation of the total length $L(t)$ to age t. Here, we adopted the von Bertalanffy growth equation (Bertalanffy, 1938), $L(t) = L_\infty\{1 - e^{-k(t-to)}\}$, where L_∞, k and t_0 are the asymptotic total length (mm), growth coefficient ($year^{-1}$) and age at which the back-calculated total length is 0, respectively. Since, bitterling larvae are 3 mm in total length (Aldridge, 1999), we assumed that $L(0)$ was equal to 3 mm. The non-linear least squares method with a constraint was applied for the estimation of the three parameters. That is, we estimated where L_∞, k and t_0 to minimize the weighted sum of least squares

$$SS\ (L_\infty, k \text{ and } t_0), \qquad SS\ (L_\infty, k, t_0) = \sum_{t=0}^{T} = n_t\ [L(t) - L_\infty\ \{1 - e^{-k(t-\ to)}\}]^{\ 2},$$

subject to $L(0) = L_\infty(1 - e^{kto})$, where n_t and T are the number of specimens at t years old and the maximum age of each sex, respectively. Instantaneous rate of increase (Ricker, 1975) was calculated as;

$$IGR = ln\ L_{t+1} - ln\ L_t.$$

Condition (K) of fish was calculated as $K = 100 \times W \times TL^{-3}$, where W is body weight in g, and TL is total length in mm. Student's t – test (Zar, 1999) was used to determine possible significant differences between condition coefficient by sex and season for both species. Water temperature was measured to determine the relationship between temperature and gonad growth. Spawning time was determined by direct observation of the gonads.

Results

Age and growth

The population of bitterling in the Ömerli Dam Lake was represented by five age groups. The scale reading was difficult due to irregular shape of scales which cause insufficient annulus formation and

unclear appearance of the annulus ring. However, the yearling bands of bitterling were clearly visible in all parts of the bone. Hence, age determination of bitterling was accomplished by examining operculum bones. The number of bands seen on operculum bones corresponded to the number of annuli that could be detected in the scale. Although the relative age frequency distribution of the population was affected by the gear selectivity, which captured specimens larger than 50 mm, length frequency analysis also validated the age distribution of the population (Figure 2).

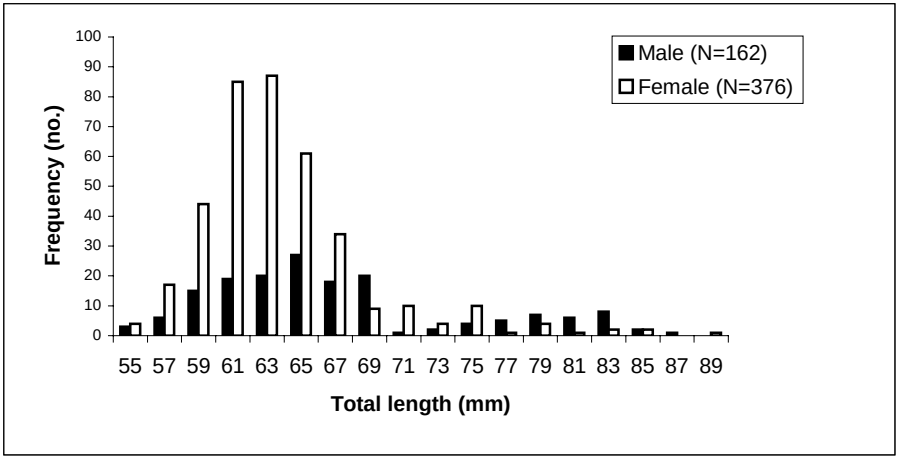

Figure 2. Total length frequency distribution of bitterling caugth from the Ömerli Dam Lake Basin

The total length of individuals ranged from 50 mm to 87 mm the weight was from 2 to 8.9 g. The relationship between weight and length of the fish calculated were; $W = 0.0077\ TL^{3.29}$; $W = 0.022\ TL^{2.73}$ and $W = 0.0132\ TL^{3.01}$ for males, females and sexes combined, respectively (Figure 3). The slopes of the logarithmic equations indicated the positive, negative allometric and isometric nature of growth for males, females and sex combined, respectively and differed significantly between sexes ($P<0.001$).

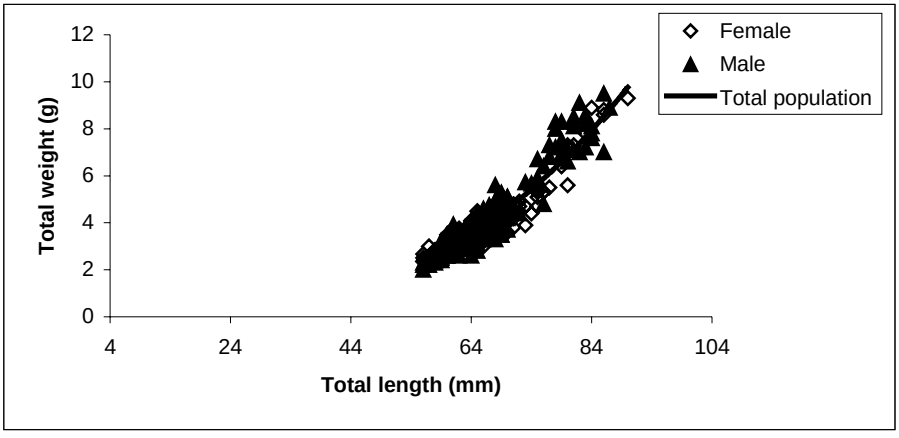

Figure 3. Length-weight relationship of bitterling by sex group.

Operculum bone radius (*R*, mm) was linearly related to TL (mm) indicating that bone growth was proportional to fish growth. The regressions of TL on *R* were estimated for males, females and for sexes combined (Table 1). The slopes of TL-*R* regressions did not differ significantly between sexes ($P>0.05$).

Table 1. Relationship parameters of total length (TL) and opercula bone radius (*R*) of bitterling from the Ömerli Dam Lake.

Sex	Equation	95% CI of *b*	R^2	*P*-value
Male	TL = 1.754 + 0.154*R*	0.133 - 0.176	0.89	> 0.05
Female	TL = 1.101 + 0.168*R*	0.132 – 0.204	0.93	> 0.05
Total	TL = 1.633 + 0.157*R*	0.139 – 0.174	0.90	> 0.05

The mean back-calculated TLs of each age group were smaller than the observed length of the same age group at the time of capture and greater than the observed TL at the time of capture of the previous age group. The comparison of observed and back-calculated length showed a good agreement. Mean annual increments of bitterling length varied but the highest increments were noted between the first and second year for both sexes. Nevertheless, the instantaneous growth rate decreased as the age increased (Table 2).

The parameters of the von Bertalanffy growth equation computed by using back-calculated TLs to the most recent annuli, to reduce bias in asymptotic length and growth coefficient *k* due to the presence of Lee's phenomenon (Table 3). The theoretical asymptotoic TL, 92.7 mm for sexes combined, is realistic as the largest specimen caught during this study had an 87 mm TL.

Table 2. Mean observed and back-calculated total lengths (mm) obtained from measurement of operculum bones.

Age group	Observed length (cm) average (SD)	No of fish	Length-at-age- (years)				
			1	2	3	4	5
			Female				
1	-	-	29.5				
2	54.0 (0.53)	185	30.3	51.0			
3	68.1 (0.76)	166	31.3	52.0	64.6		
4	77.7 (0.76)	16	32.7	52.3	64.7	75.2	
5	79.2 (0.30)	9	32.6	52.8	66.2	76.3	78.6
Mean (SD)			31.3 (0.14)	52.0 (0.08)	65.2 (0.09)	75.8 (0.08)	
Annual increment				20.7	13.1	10.6	2.9
Instantaneous rate of increase IGR				0.51	0.23	0.15	0.04
			Male				
1	-	-	29.8				
2	51.0 (0.61)	51	30.6	47.9			
3	65.3 (0.69)	76	31.2	48.5	63.5		
4	73.8 (0.76)	15	32.1	49.1	64.0	72.0	
5	80.3 (0.42)	20	32.4	50.1	64.5	72.8	80.2
Mean (SD)			32.4 (0.11)	48.9 (0.09)	64.0 (0.05)	72.4 (0.06)	
Annual increment				17.7	15.1	8.4	7.8
Instantaneous rate of increase IGR				0.45	0.27	0.12	0.10

Table 3. Estimates of L_∞, k and t_0 of female and male bitterling in the Ömerli Dam Lake.

Parameter	Males	Females	Total
L_∞ (mm)	92.8	89.1	92.7
k (year^{-1})	0.400	0.512	0.420
t_0 (year)	-0.018	0.172	0.040

Reproduction

The direct macroscopically observation of gonad showed that bitterling in the Ömerli Dam Lake is a multiple spawner. The reproduction effort profile of the ovaries indicated that bitterling reproduction is extended and lasts from April to August, peaking in mid April. Our observations claimed that bitterling deposited its eggs in species of the genus Anadonta in spawning period at water temperatures 11.7 - 26.2 °C.

Our smallest individuals caught were 50 mm (2 ages) and 51.8 mm (2 ages) for males and females, respectively. They had already attained the sexual maturity. As the all individuals bigger than these lengths was mature, it can be suggested that bitterling in the Ömerli Dam Lake was all mature in their second year of life. Due to lack of smaller individuals in the present study, whether bitterling attained sexually mature in their first year is not clear.

Sex ratio

Overall sex ratio for bitterling collected in this study was 162 males : 376 females, or 1:2.32. A chi-square test of the sex ratio indicated statistically significant deviations from 1:1 (P<0.001) (Table 4).

Table 4. Sex ratios of bitterling population in the Ömerli Dam Lake by sampling dates. Differences of the observed sex ratios from 1:1 were tested by χ^2 (n.s. = not significant).

Date	Number collected		Sex ratio	*P*
	Male	Female	Male:Female	
12 April 2003	6	0	-	-
3 May 2003	14	9	1.6:1	n.s.
24 May 2003	12	2	6.0:1	<0.01
7 June 2003	2	0	-	-
16 August 2003	7	6	1.2:1	n.s.
20 September 2003	3	9	1:3.0	n.s.
12 October 2003	0	4	-	-
8 November 2003	4	2	2.0:1	n.s.
24 April 2004	33	31	1.1:1	n.s.
22 May 2004	46	56	1:1.2	n.s.
12 June 2004	10	222	1:22.2	<0.001
19 August 2004	25	35	1:1.40	n.s.
All	162	376	1:2.32	<0.001

Condition

Condition of fish decreased after May until August regardless of sex. After August, condition of male increased rapidly until April while condition of females fluctuated during rest of the growing season (Figure 4).

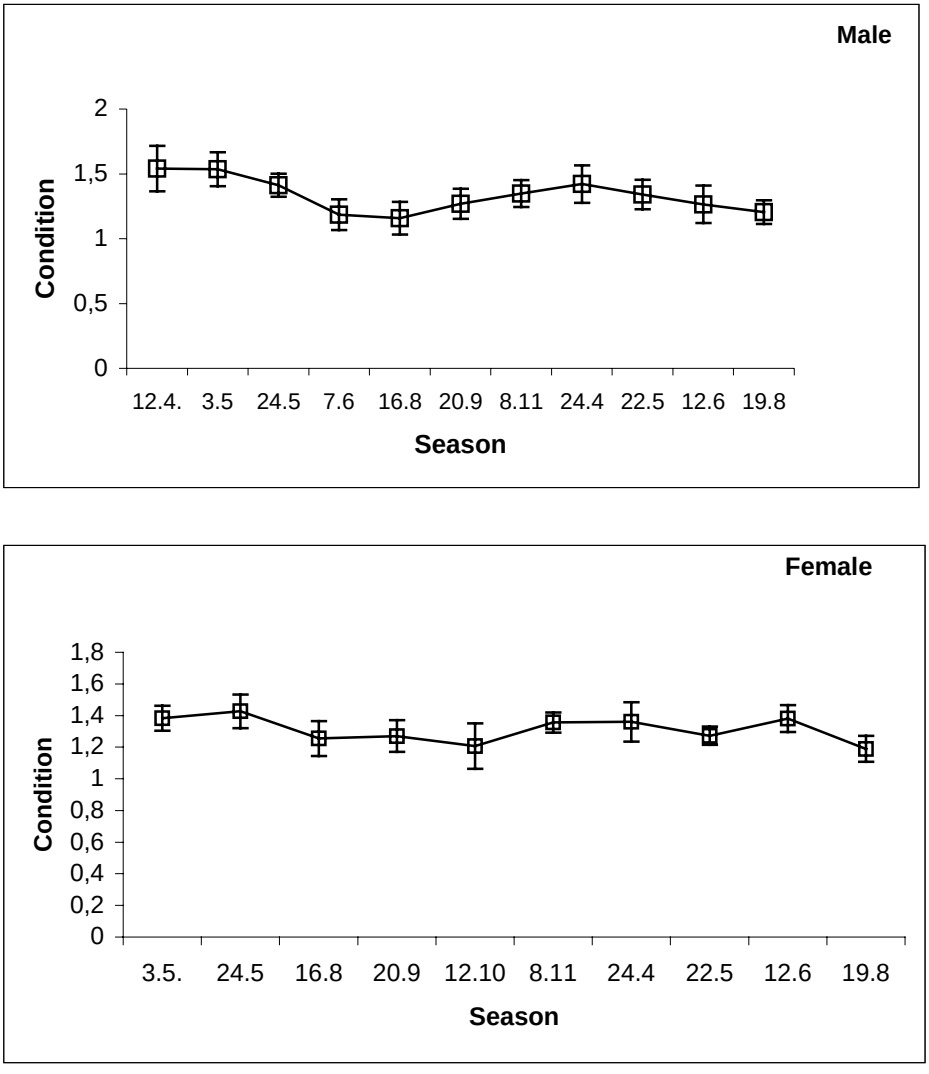

Figure 4. Seasonal changes in condition (mean ± s.d.) for males and females of bitterling. Data points that do not share any latter in their markings are statistically different according to the *t*-test ($P < 0.05$).

Discussion

Although bitterling age determination has been the subject of some studies (Holčík, 1999), only Przybylski and Garcia-Berthou (2004) validated the age determination and they suggested that age determined from scales was the same as from the opercular bones. In this study, even though age determination from operculum bones was easier than scale, both structures had the same age estimates. Moreover, the age population structure is the same as was revealed by length frequency analysis.

The life span of the bitterling population in the Ömerli Dam Lake was short, with only five age groups being evident (maximum age class: 4+). This is agreement with general pattern observed in most other bitterling populations previously studied throughout their distribution range (Holčík, 1960; Koutrakis *et al.,* 2003; Przybylski and Garcia-Berthou, 2004). On the other hand, the results differ greatly from the Tym' River and the Elbe River populations where the oldest fish was reported 6+ and 8+, respectively (Zhul'kov and Nikiforov, 1987; Wagler, 1949 cited by Holčík, 1999). This fact suggests that the ages of those populations might have been miscounted, but the ageing has to remain in doubt in absence of validation.

Holčík, (1960) discussed the suitability of several methods for back-calculation and found that a non-linear body-scale relationship gave best satisfactory result. However, in this study linear regressions of fish length on operculum radius were best fit. Przybylski and Garcia-Berthou (2004) also reported that linear regressions of fish length on scale radius were good fit in bitterling population of the Wieprz-Krzna Canal (Poland).

The values of *b* in the equation relating total length and somatic weight for males and females differ from three while both sexes combined did not. These values indicate that male bitterling had a better weight gain in relation to growth in length but female bitterling showed opposite growth pattern in the Ömerli Dam Lake. It may indicate a poor feeding of females which was also demonstrated by variation in condition of females in the growing season. Positive allometric growth was noted for several bitterling populations and

only the Severka River bitterling seemed to grow isometrically (Holčík, 1999). This variation in the exponents could be attributed to different stages of ontogenetic development, as well as to the differences in age, maturity, sex and species. Geographic location and associated environmental conditions, such as seasonality (date and time of capture), stomach fullness, disease and parasite loads, can also affect the value of *b* (Le Cren, 1951; Bagenal and Tesch, 1978).

Back-calculated length-at-age for bitterling was consistently less than observed lengths-at-age for all age groups, which may be attributed to Lee's phenomenon (Ricker, 1975). As bitterlings are not harvested commercially or recreationally in the Ömerli Dam Lake, the presence of Lee's phenomenon in the back-calculation estimates may be due to higher mortality of larger individuals within an age class.

Bitterling is a slow-growing species and individuals reached 40 % of their growth during the first year of their life in the Ömerli Dam Lake. Other studies (reviewed by Holčík 1999) relative to the growth of the bitterling proposed growth more than 50 % for the first year of the life. Von Bertalanffy growth curves fitted the data very well. Values for asymptotic lengths for both sexes agreed well with observed lengths. In the Ömerli Dam Lake bitterling population, asymptotic lengths calculated for each sex separately as well as for combined sex were higher than those reported for other populations (Holčík, 1999). However, the highest bitterling asymptote length was noted in a Greek bitterling population (Koutrakis *et al.,* 2003), which is relatively close to our study area.

Variation in von Bertalanffy parameters reveals plasticity of fish growth (Wootton, 1990). Thus the differences noted in length might result from variation in temperature (Ricker, 1975) and, possibly, differences in productivity (Mann et al, 1984). The von Bertalanffy function can be a result of resource allocation between growth and reproduction (Kozlowski, 1996). Therefore, intersex or inter-population differences in L_∞ could also reflect differences in reproductive effort of the fish.

In the Ömerli Dam Lake bitterling spawns between April and August, with a peak in spawning occurring in May. This finding was in accordance with the results of several authors who studied on

bitterling in different areas (Zhul'kov and Nikiforov, 1987; Holčík, 1999; Douglas, 2003; Koutrakis et al. 2003). Even though bitterling in Turkey occurs near the limits of their distribution area, spawning period seems to be same with more northern populations. Although a number of environmental factors have been implicated as possible proximate cues including photoperiod, temperature, rainfall, food supplies and pheromones, which is the seasonally-changing pattern of daylight and probably responsible for the cueing and timing of reproduction in the majority of fish. Even the maturation and spawning of many cyprinids, which existing literature would have us believe are cued by temperature or rainfall, almost certainly rely on photoperiod as a measure of daily and possibly calendar time (Bromage *et al.,* 2001).

As suggested by Reichard & Jurajda (1999), sexual maturity is reached by both sexes in 1 year, when fish are *c*. 30-35 mm standard length. We found that all 2 years old bitterling had already sexually matured in the Dam Lake. Due to absence of smaller individuals than 2 years old, it is not known certain attainment of sexual maturity in Ömerli bitterling population.

Holčík (1958) (cited by Smith *et al.,* 2004) reported that bitterling do not necessarily require mussels for reproduction under natural conditions. However, according to our observations, female bitterling did not release eggs in the absence of mussels. This observation is consistent with the finding of Smith et al. (2004) who claimed bitterling are not able to reproduce successfully without mussels under natural conditions.

The proportion of males and females of bitterling in the population appears to depend on temporal factors, such as the reproduction period. The almost equal ratio of males to females at relatively similar sizes indicate that equal numbers of two sexes are born and enter the population, while an unequal sex ratio during the spawning season more females appeared, than males. This can be result of small scale migrations made by female individuals of the stock to increase spawning success. Contrary to the present study, Smith et al. (2000) recorded that the sex ratio of bitterling population in a series of oxbow lakes in Czech Republic was always 1:1. Koutrakis et al. (2003)

determined that male strongly dominated females in the population of bitterling in the Rihios River (Greece). The sex ratio differs from one population to another of the same species and may vary from year to year in the same population. The reasons of this variation may be different and numerous: the species differences, the body length of the fish, the seasonal aspect, the feeding and reproductive periods, different growth rates in males and females, earlier maturation of one of the sex, overall mortality and accidental (due to fishing technique) mortality difference for each sex and perhaps the environmental conditions (Peczalka, 1968).

In general, seasonal condition showed a similar pattern in both sexes. In the both years of study, seasonal conditions were highest in May, being higher in general in the feeding months and in the months just prior to spawning, but it is lower in other months. This finding suggests that variation in the condition factor of fish may be indicative of several biologic events, such as fat reserve level, adaptation to the environment, and gonadal development of bitterling in the Ömerli Dam Lake.

In conclusion, life history pattern of *R.amarus* in the population under consideration point to a low number of age groups, a high growth rate during the first years of life and a clear decrease in the growth rate with longevity, a short lifespan, a long spawning period and seasonal variation in the sex-ratio and condition. These life history tactics are common in productive and/or unstable environments (Stearns, 1976; Mann *et al.,* 1984; Mills, 1987) and do not differ much from those of the other bitterling populations.

Özet

Ömerli Baraj Gölünden yakalanan Acıbalık *Rhodeus amarus* (Bloch, 1782)'un yaşam süreci özellikleri (yaş, büyüme ve üreme) Nisan 2003 ile Ağustos 2004 tarihleri arasında çalışıldı. Operkulum kemiklerinden yapılan yaş tayini; pullardan yapılan yaş tayini ve boy frekans analizleri ile doğrulandı. Populasyonun 5 yıllık bir hayat döngüsünün olduğu görüldü. Yakalanan balıkların yaş-boy verilerine von Bertalanffy büyüme denklemleri uygulandı ve eşeyler arasındaki büyüme oranlarında farklılıklar tespit edildi. Boy-ağırlık ilişkileri erkeklerde $W=0.0077TL^{3.29}$ ve dişilerde $W = 0.022TL^{2.73}$ olarak hesaplandı. Üreme mevsimi Nisan ile Ağustos ayları arasında idi. Eşey oranları 1:2.32 olarak bulundu. Erkek

bireylerin kondisyon değerleri Nisan-Ağustos arasında artarken, dişilerin kondisyon değerleri yıl boyunca dalgalanma gösterdi.

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