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RESEARCH PAPER

Age, Growth, Reproduction and Fecundity of Roach *Rutilus rutilus* from Volvi Lake, Northern Greece

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Abstract

The roach, *Rutilus rutilus,* is a Cyprinid which is widely distributed throughout freshwater systems in Europe. It is one of the most abundant and important commercial fish species in Greece. Age, growth, reproduction and fecundity of roach were studied in Lake Volvi from 1997-1998 females had higher growth in length (L_∞=277.18 mm, k=0.097) than adult males (L_∞=185.60 mm, k=0.148). All males older than one year and larger than 70 mm, and all females older than two years and larger than 80 mm were sexually mature. The breeding period spanned from the end of March till mid April. Fecundity ranged from 2,036 to 31,653 eggs (mean 8,102 eggs) and relative fecundity from 76.06 to 333.94 eggs/g (mean 186.78 eggs/g). Diameter of eggs were 1.3 ± 0.07 mm and weighted 0.0011 ± 0.0002 g . The weight of eggs were independent of length and age of individuals ($P>0.05$), however, there was a significant relationship between weight and egg diameter ($P<0.05$). Absolute fecundity depended on length, weight and age of the females. The relationship between absolute fecundity and length were less obvious in the case of relative fecundity and egg size. Estimated growth was at the lower end when compared with other studies conducted elsewhere.

Introduction

Roach, *Rutilus rutilus* (Linnaeus, 1758), is natural population throughout western and northern Europe (up to 69° N in Scandinavia and 56° N in Scotland), southern Europe to the north of the Pyrenees, and are found as far eastwards and southwards as the Ural Mountains, the Balkans and the catchments that drain into the Aegean, Black and Caspian seas. In Europe locally introduced in Spain, northeastern Italy and in Cyprus (Kottelat & Freyhof, 2007). In Australia was introduced from Europe in the 19th century (Stoessel, 2014). In Greece it is present from Thessalian Pinios to Evros river drainages. Also found in Kastoria, Doirani, Volvi and Vegoritis lakes. This fish inhabits a variety of habitats (nutrient-rich lakes, large- to medium-sized rivers, reservoirs and backwaters), but in Greece it is mainly found in lowland areas. (Barbieri *et al*, 2015). In the Balkan Peninsula, age and growth of roach have been studied in depth (e.g. Zivkov & Raikova-Petrova, 2001; Staras, Cernisencu, & Navodaru, 1995).

In freshwaters of Greece, roach is an abundant, commercial native species, (i.e., Economidis & Banarescu, 1991; Economou, Giakoumi, Vardakas, Barbieri, Stoumboudi, & Zogaris, 2007; Bobori, Moutopoulos, Bekri, Salvarina, & Munoz, 2010), however, few studies have accessed age and growth of individuals in populations. In Lake Volvi, only two studies for roach have been conducted in 35 years (i.e., Papageorgiou, 1979; Bobori, Kanakis, Petriki, & Tsikliras, 2017). Lake Volvi (Northern Greece, Figure 1) is the second largest natural lake in Greece, and together with the adjacent Lake Koronia belongs to the National Wetland Park. Wetland Parks have international

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Figure 1. Map of the area in which the study was conducted.

significance (Ramsar Convention) and are included in the NATURA 2000 network under the 2009/147/EEC and 92/43/EC Directives. Both lakes are also included in the Barcelona Convention for the Protection of the Mediterranean.

The aim of the present study was to investigate the life-history of the roach population in the lake Volvi by assessing the: (a) age-growth relationship, (b) annual reproductive progression, (c) fecundity (d) size of eggs, and (e) a comparison was then undertaken of parameter estimates derived from studies undertaken elsewhere. Reliable estimation of age-growth parameters can be incorporated for the development of ecosystem models for the conservation and management of lakes in a multi-species context. Fecundity and relative issues, such as the number, diameter and weight of the eggs, are a part of the estimation for the reproduction of each fish species.

Materials and Methods

Roach were collected monthly from November 1997 to November 1998 from lake Volvi using six gill nets, with stretched mesh sizes of 16, 20, 24, 28, 34 and 40 mm. In March 1999, supplementary sampling was done (i.e., 'once only') using 16 gill nets with stretched mesh sizes of 10, 12, 15, 18, 22, 24, 26, 28, 32, 34, 36, 38, 40, 45, 50 and 60 mm. In total, 3,384 fish samples were collected. From those 2,499 were collected by monthly samplings and 885 from "once only" sampling. Individuals captured were recorded per mesh size and placed in a solution of formaldehyde (10%) until later analyses. For each specimen were measured the fork length (FL) to the nearest 1 mm, total weight (TW), somatic (eviscerated) weight "net" (NW) to the nearest 0.1 g and gonad weight (GW) to the nearest 0.01 g.

Scales from 885 individuals were used for age and growth studies. For age determination, scales were taken between the lateral line and dorsal fin (Bagenal & Tesch, 1978), placed in a plate with hot water where a drop of NaOH (8%), dried and mounted between microscope slides. Each scale was read by two different readers. There was no significant difference between readers based on t-test ($t < 0.05$). The readers using a special projector (Projecting 4002-H), featured a magnified screen and a graduated scale. Age of the roach was determined from the number of scale annuli (Bagenal & Tesch, 1978). The annulus is interpreted according to Bagenal and Tesch (1978).

The relation between the fork length (FL) and scale radius was estimated for males and females by sex and for both sexes combined. Analysis of covariance (ANCOVA) was used for comparison of the above relations derived for male and female roach.

The annual back calculation length growth relationship was estimated using the modified relation proposed by Monastyrsky (Bagenal & Tesch, 1978) using data derived from specimens captured during the "once only" sampling event: $\log l_n = \log l + b (\log S_n - \log S)$ where, l_n, is the 'back calculated' length in the age n, l, is the fork length of the fish at capture, S_n, radius of the scale from the center till the ring n, S, radius of the scale.

Von Bertalanffy equation was used for estimating growth parameters: $L_t = L_\infty [1- e^{(- k (t-t_0))}]$. Von Bertalanffy parameters L_∞, k and t_0 were estimated using the Ford –Walford graph.

The annual back growth per weight was estimated by using the modified equation of Von Bertalanffy (Hilborn & Walters, 1992): $W(t)=W_\infty(1-e^{(-k(t-t_o))b})$, where $W_\infty=a \cdot L_\infty^b$. Data were derived from previous results/estimations. The spawning period and the gonadosomatic index (GSI) were determined from monthly samples estimated. GSI determined as per Wootton (1992).

From the 'once only' sampling 481 female specimens were identified as "mature" (stage V-VI), according to the Kesteven scale which has been described by Holden and Raitt (1974) and Lagler (1978).

Absolute fecundity has been considered as the number of ripening eggs in the female prior to spawning (Bagenal & Braum, 1978). It was estimated from 153 specimens identified as being at stage V. Gilson's fluid was used for the preservation of the ovaries, and the gravimetric sub-sampling method (Bagenal, 1978) was used to estimate the absolute fecundity. The relation of absolute fecundity "F" with length, weight (total and net weights) and age was estimated as per the formula given by Bagenal equation (1978) $F= a \cdot x^b$, where, a and b are constants, x was length, (total – net) weight and age. The theoretical value of the absolute fecundity was estimated from the previous equation, where x is the length estimated from the Von Bertalanffy equation.

Diameters of eggs were measured under a stereomicroscope with an ocular micrometer. Two samples of 400 eggs were taken from each gonad. The average of these diameters was considered to be the mean egg size. The relationship between the egg diameter and egg weight with fork length, weight (total-net) and age was examined. Relative fecundity was obtained by dividing absolute fecundity with total weight (TW) of fish.

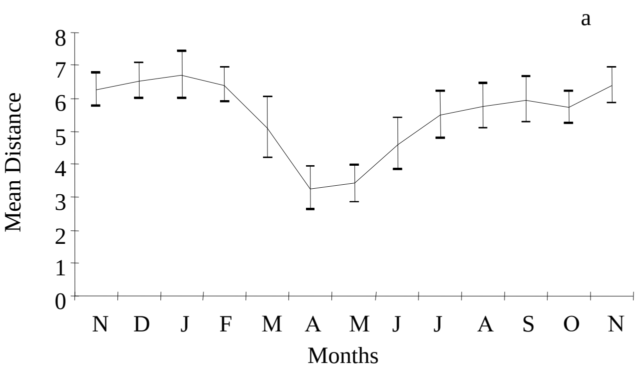
Results

Growth

In total, 3,384 fish samples were collected from which 2,499 were collected monthly and 885 "once only". Figure 2a demonstrates the average distance between the last annuli and the outer scale. As we can notice the distance was found to be lower at late April. Figure 2b shows that this distance was formed between February and July with the ring to be present in 85% of the samples between April and May. The relation between length and scale radius was significantly correlated with sex (P<0.05, Table 1, Table 2). Males were on average larger (74mm) than females (69mm) in the first year, however, the growth of females was higher in all years following (Figure 3a, b). Equivalent von Bertalanffy growth parameters were L_∞=185.6 mm, k=0.148 and t_o =-2.33 for males (n=404), L_∞ =277.2 mm, k=0.097 and t_o =-1.85 for females (n=481) roach (Figure 4a). A significant difference existed between the mean lengths-at age of the sexes, with females on average being larger than males (ANCOVA, P<0.05). Similarly, growth weight parameters were W_∞ = 120.1 g for males (n=404), W_∞ = 508.6 g for females (n=481) roach (Figure 4b). The most rapid growth and growth weight of female compared to male individuals occurred up to the age of 2+ years.

Reproduction

Assessment of the main spawning period of roach in Lake Volvi was based on the GSI. In both sexes the annual values of the GSI index were higher toward the end of winter and early spring (Figure 5), which declined rapidly in April. Over summer, GSI reached its lowest value; male 0.33 (SD=0.15) female 1.09 (SD=1.83). During December and January GSI of males increased in weight to 76% of the final weight. In females, GSI attained its highest value in November (23.8% of final weight) and just prior to the suspected spawning period in March (represented 21% of the final weight).



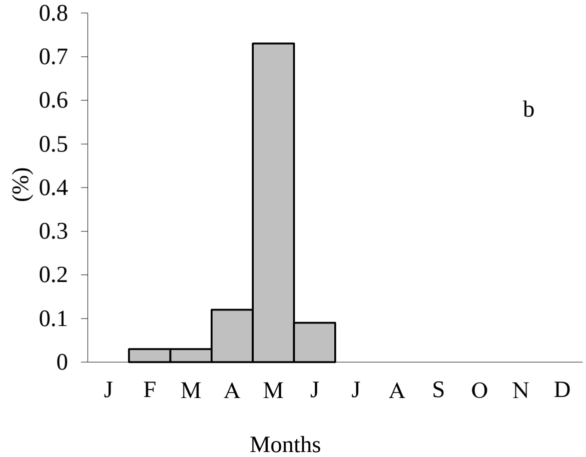


Figure 2. a) Mean monthly distance after the last check of annual ring on the scales of roach in lake Volvi (95% confidence intervals), **b)** Monthly % of roach that they have just formatted new annual ring (N=2,499).

Table 1. Relation between fork length (L,mm) and radius (R) of roach (*Rutilus rutilus*) in Lake Volvi

Sex	Linear Equation	R^2	N
Male & Female	L= 32.817 + 1.53 R	0.863	885
Male	L= 37.306 + 1.44 R	0.815	404
Female	L= 30.847 + 1.57 R	0.884	481

Table 2. "Back calculated" lengths (mm) of roach in Lake Volvi (male & female) Where, Lt= is the 'back calculated' length in the age t (t=1,2..8)

MALE

Number of specimen	Average length	Age	Estimated fork lengths					
			L1	L2	L3	L4	L5	L6
3	89.00	1	74					
53	105.61	2	75	94				
214	113.83	3	74	91	104			
114	117.18	4	70	86	99	109		
13	133.33	5	71	88	100	113	124	
7	143.60	6	71	88	99	112	124	132
Average length			73	89	100	111	124	132
Total of specimen			404	401	348	134	20	7
Standard deviation			4.84	5.84	6.44	6.60	7.97	14.83
Annual growth			72.60	16.80	11.00	10.90	12.70	7.80

FEMALE

Number of specimen	Average length	Age	Estimated fork lengths							
			L1	L2	L3	L4	L5	L6	L7	L8
4	92.33	1	69							
28	109.70	2	72	95						
138	118.88	3	70	90	108					
149	128.07	4	68	88	103	118				
98	144.54	5	67	88	105	121	134			
45	157.00	6	67	88	103	119	134	148		
18	173.85	7	66	89	104	121	138	154	165	
1	182.00	8	73	89	102	118	132	145	157	172
Average length			69	90	105	120	134	150	165	172
Total of specimen			481	477	449	311	162	64	19	1
Standard deviation			5.21	7.53	9.32	9.87	9.12	10.62	13.48	
Annual growth			69.00	20.60	15.00	14.90	14.90	14.80	14.70	6.70

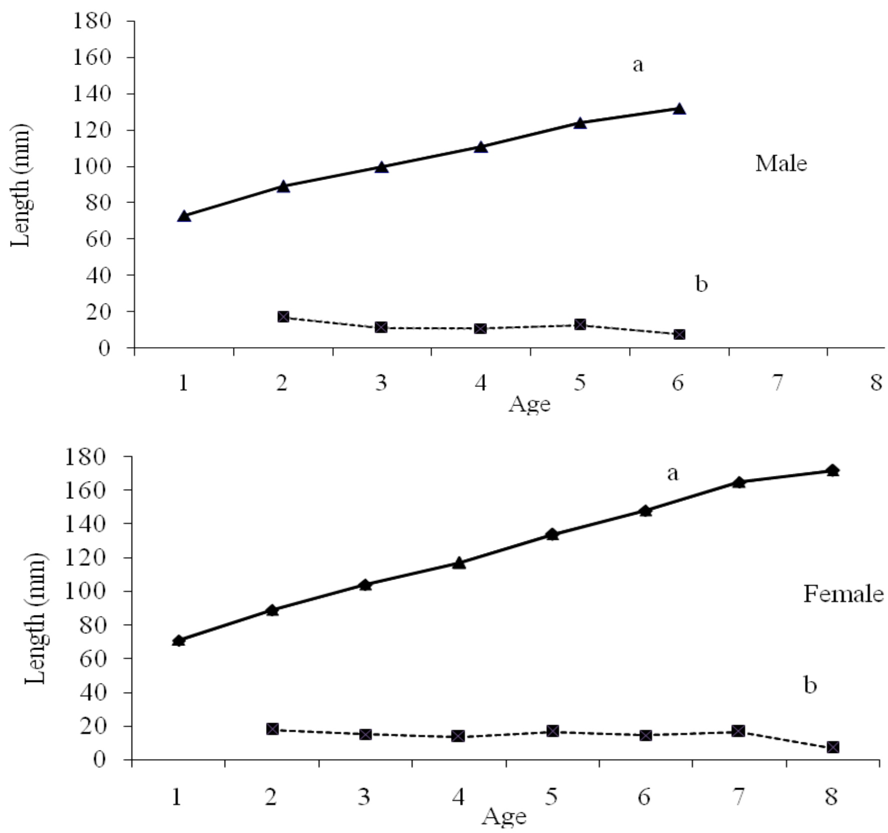


Figure 3. The mean 'back calculated' lengths **(a)** of males (N=404) and females (N=481) roach in Lake Volvi at each age group and **(b)** the annual rate of growth.

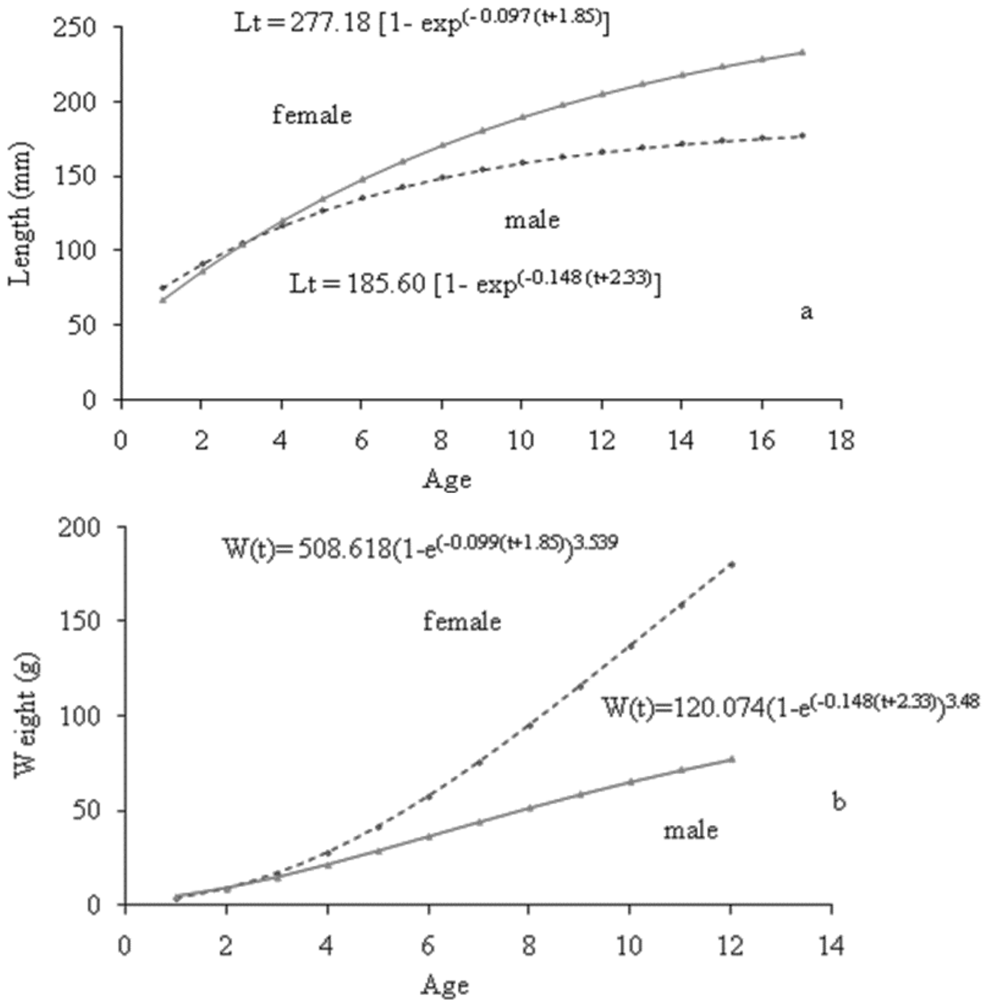


Figure 4 a) Growth of male and female roach with Von Bertalanffy method**. b)** Back calculated growth weight curve roach with age.

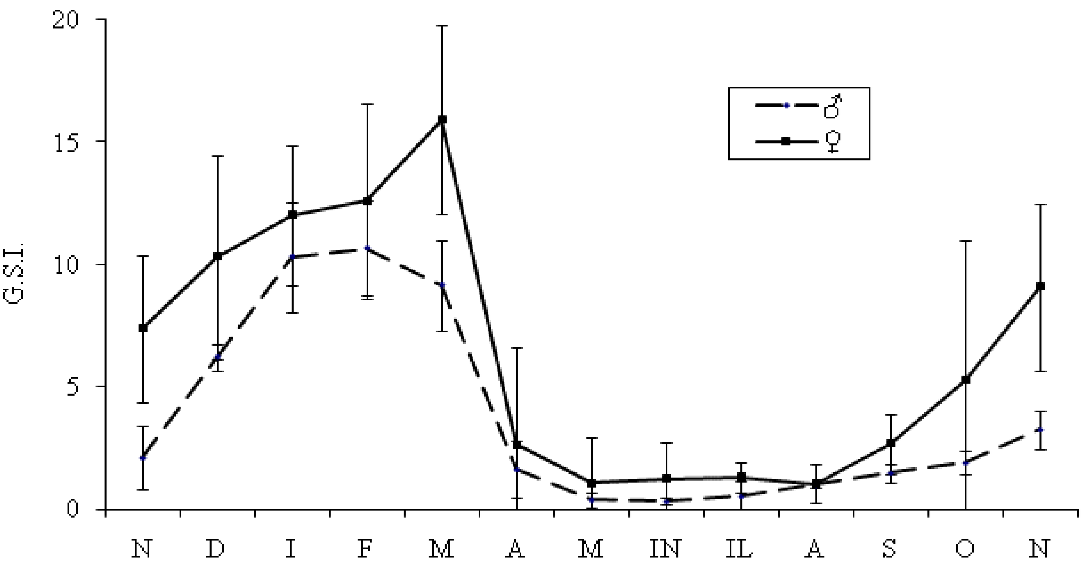


Figure 5. Mean values of the gonadosomatic index with 95% significance level per sex (N=2,499)

In 'once only' sampling we noticed that males greater than 70 mm and females greater than 80mm had achieved stage V-VI. Some of males attained the first maturity at the age of 1+ year, with all the males presented to be mature at the age of 2+. In contrary, some females started to be mature at the age of 2+ and all them older were matured at the age of 3+ years.

Fecundity and Egg Size

Fecundity of roach in Lake Volvi ranged from 2,036 to 31,653 with a mean value of 8,102. Absolute fecundity increased significantly (P<0.05) with increasing length, weight (total and "net") and age. Table 3 shows the average number of eggs of roach in lake Volvi per age class of the spawners. The number of absolute fecundity per length and "net weight" of the female roach in Lake Volvi in each age class is presented in Table 4.

The relation between absolute fecundity and fork length, total weight, "net weight" and age is presented in Table 5. Also Figure 6a shows the absolute fecundity and its theoretical value. Mean fecundity exhibited a declining trend from the theoretical value, which up to the age of 5+ approached the lowest limit of the confidence intervals of fecundity. The relation of absolute fecundity with the relative fecundity and body length of the spawners are shown in Table 6. Average relative fecundity (RF) was 186.78 eggs/g (range: 76.06 to 333.94) with RF values exhibiting no significant (P>0.05) trend with length, weight (total- net) and age.

Eggs were 1.3±0.07mm in diameter (range: 1.1mm to 1.4mm) and weighted 0.0011±0.0002 g (range: 0.0007g to 0.0015g). The weight of eggs were independent of length and age of individuals (P>0.05), however, there was a significant relationship between weight and egg diameter (P<0.05) (Table 7).

Table 3. Average number of eggs of roach (*Rutilus rutilus*) in Lake Volvi per age class of the spawners

Age	Average value	SD	SE	N	Confidence intervals 95%	
3	4,284.94	1.565	368.94	18	3,916.00	8,200.94
4	5,033.09	2.372	361.74	43	4,671.36	9,704.45
5	8,077.58	2.504	317.99	62	7,759.59	15,837.17
6	12,996.40	4.167	817.27	26	12,179.13	25,175.53
7	21,231.39	6.453	3,226.26	4	18,005.12	39,236.51

Table 4. Number of absolute fecundity per length and net weight of the female roach (*Rutilus rutilus*) in Lake Volvi in each age class.

Age	Length (mm)											N
	100-109	110-119	120-129	130-139	140-149	150-159	160-169	170-179	180-189	190-199	200-209	
3^+	2789	4829										18
4^+	4039	3783	5380	8755	9714							43
5^+		3892	5058	7180	9402	10185	12625					62
6^+				8449	10370	11079	16419		22057			26
7^+								13962	23450	26282	31653	4
N	6	39	19	23	28	23	10	1	2	1	1	153
Age	Net weight (g)											N
	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-100			
3^+	4285											18
4^+	4083	5295	9564	10574								43
5^+	4967	6341	8608	10410	10043							62
6^+		8053	9197	11564	15644	17939		22057				26
7^+							23450	26282				4
N	59	31	25	21	10	1	2	4				153

Table 5. Relation between Absolute Fecundity (F) and Relative Fecundity (R.F) with Fork length, Total weight, Net weight and age of roach (*Rutilus rutilus*) in Lake Volvi

Fork length (mm)	$F= 2.9753 \cdot 10^{-4} L^{3.47}$	$R^2 = 0.870$	N=153
Total weight (g)	$F= 164.68 \cdot TW^{1.0310}$	$R^2 = 0.955$	N=153
"Net" weight (g)	$F= 169.86 \cdot NW^{1.1001}$	$R^2 = 0.910$	N=153
Age	$\ln F = 6{,}99 + 0{,}4149 \ln (t)$	$R^2 = 0.980$	N=153
Fork length (mm)	$R.F.= 0.155 \cdot l + 165.8$	$R^2 = 0.007$	N=153
Total weight (g)	$R.F.= 0.097 \cdot TW + 182.5$	$R^2 = 0.004$	N=153
"Net" weight (g)	$R.F.= 0.172 \cdot NW + 181.3$	$R^2 = 0.006$	N=153
Age	$R.F.= 0.994 \cdot t + 182.0$	$R^2 = 0.000$	N=153

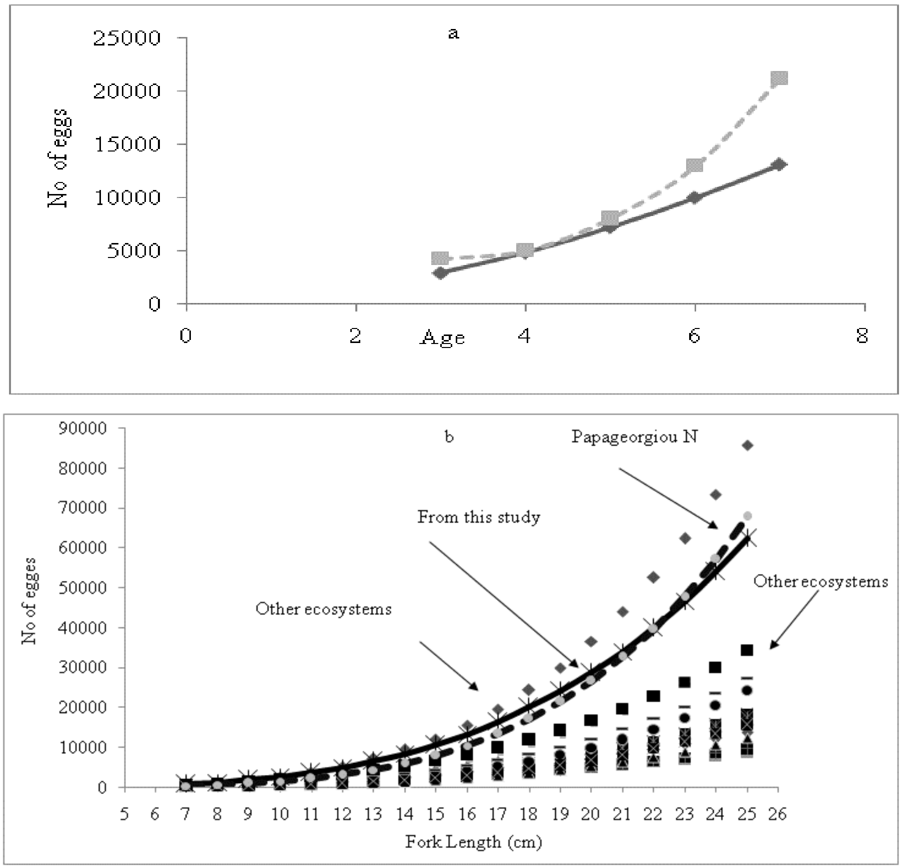


Figure 6. a) Relation between fecundity and age of roach in Lake Volvi (N=153). Continue line= theoretical curve, Interrupted line= observed curve and **b)** the fecundity of roach in lake Volvi and in other ecosystems**.**

Table 6. Average absolute and relative fecundity per length class of the spawners roach (*Rutilus rutilus*) in Lake Volvi

Length (mm)	Absolute fecundity (eggs)					Relative fecundity (eggs)					Number
	Average		STDEV	Range		Average		STDEV	Range		
100-109	3205	±	776.8	2370	4540	180.34	20.00	157.26	206.95	180.34	6
110-119	4135	±	1069.4	2822	8249	185.58	35.29	142.33	297.78	185.58	39
120-129	5187	±	1716.4	2036	8096	187.86	61.56	76.06	321.20	187.86	19
130-139	7464	±	1093.2	6039	9973	183.59	24.59	146.35	234.22	183.59	23
140-149	9595	±	1444.7	6834	11877	190.80	26.03	121.62	226.97	190.80	28
150-159	10514	±	1938.1	7461	14105	173.66	22.72	112.86	217.30	173.66	23
160-169	15945	±	3416.2	11460	20851	216.83	58.68	158.09	333.94	216.83	10
170-179	13962					154.50				154.50	1
180-189	22753	±	985.0	22057	23450	206.99	12.36	198.25	215.73	206.99	2
190-199	26282					225.66				225.66	1
200-209	31653					190.05				190.05	1

Table 7. Relation of egg diameter (mm) and egg weight (g) with length(mm), age and weight (Total – Net)(g) of roach (*Rutilus rutilus*) in Lake Volvi

Egg diameter = 0.0037·L+12.346	R^2=0.0188	P>0.05
Egg diameter = 0.0891·t +12.424	R^2=0.0165	P>0.05
Egg diameter = 0.0046 ·NW+12.70	R^2=0.0119	P>0.05
Egg diameter = 0.0037·TW +12.69	R^2=0.0119	P>0.05
Egg weight = 0.0011·L+0.9203	R^2=0.0188	P>0.05
Egg weight = 0.0213·t +0.966	R^2=0.0175	P>0.05
Egg weight = 0.0012·NW+1.0274	R^2=0.0161	P>0.05
Egg weight = 0.001·TW+1.0224	R^2=0.0203	P>0.05
Egg weight = 1.899·Egg diameter – 1.3723	R^2=0.6670	P<0.05

Discussion

The growth of roach in Lake Volvi can be characterized as one of the lowest worldwide, where as the onset of maturation occurs at a comparably early age, and fecundity is comparably high. In fact, roach achieves its highest length compared with the reported average (60 mm) during the first year of its life, whereas after the second year growth rate was highly reduced. The mean weight and growth of the roach is suggested to be highly dependent on lake size, suggesting that the lower abundance of the roach in large lakes is a phenomenon and not related to gear selectivity (Olin, Tiainen, Kurkilahti, Rask, & Lehtonen, 2016). Intraspecific competition appears to be one of the main factors affecting the growth rate of roach, and the mean weight and growth rate were the lowest in case that abundance was highest (Olin *et al.,* 2016).

Our findings are in agreement with those of other studies, which found that females of roach exhibited higher ultimate length (L_∞) than males, whereas L_∞ values for combined sex were lower than those estimated in other lakes (Caspian lake: Naddafi, Abdoli, Kiabi, Amiri, & Karami, 2005; and Tavropos Lake: Bobori *et al.,* 2017) (Figure 7). The differences in L_∞ values can be explained by the changes of environmental conditions and mainly from temperature. For instance, L_∞ increases when the temperature decreases (Basilone, Guisande, Patti, Mazzola, Cuttitta, Bonanno, & Kallianiotis, 2004).

The value of W_∞ for females (508.618g) was four times higher than in males (120.074 g), a fact that is related to the population density (Nikolsly, 1969). The curve of correlation of the total weight with the age for both sexes, showed a superiority of the females in weight after the age of 3+. The maturity in females compared to the males usually occurs one year later (in the age of 2+) (Mann, 1992). This, combined with the relatively higher mortality rate of males, contributes to the density of the population, thus ensuring large females who usually have higher fecundity for a given amount of food (Nikolsky, 1969).

Early maturity in males in relation to female is a common phenomenon worldwide (Hansen, 1981; Zerunian, Valentini, & Gibertini, 1986; Stoessel, 2014). The same was also true for the positive correlation between age and geographical latitude (Wootton, 1992). In hot climates many cyprinidae mature in lower age (*Rutilus rutilus*: Goldspink, 1979; cyprinidae: Mann, 1992; *Chalcalburnus chalcoides macedonicus*: Kokkinakis, 1992; *Abramis brama*: Valoukas, 1999). The range of mature for male roach is between 1-4 years and for female 2-5 years (Tarkan, 2006; Stoessel, 2014). Our findings showed that in Lake Volvi, the roach becomes mature in lower age than in other areas, which is in agreement with those referred by the study of Papageorgiou (1979).

Annual ring is formed once a year (May) simultaneously with the start of growing period that can be considered as the month for starting age of roach in Volvi, which is in agreement with Mann, 1973 and Stoessel, 2014, while in other studies annual ring is formatted in June (U.K.: Hellaweell, 1972; Linfield, 1979). This difference in growth can be attributed to temperature due to the positive correlation between k parameter and water temperature (Pauly, 1980).

The relationship between length and scale radius was found significantly linear, which is similar with other studies conducted worldwide (i.e., Hellawell, 1972; Mann, 1973; Goldspink, 1979; Cowx, 1988; Horppila, 2000).

Reproduction takes place once a year, from the end of March till April following a quick decline in accordance with the estimates provided by Papageorgiou (1979). Roach breeding occurs in a short period (from 1 to 3 months: Vøllestad & L'Abée-Lund,

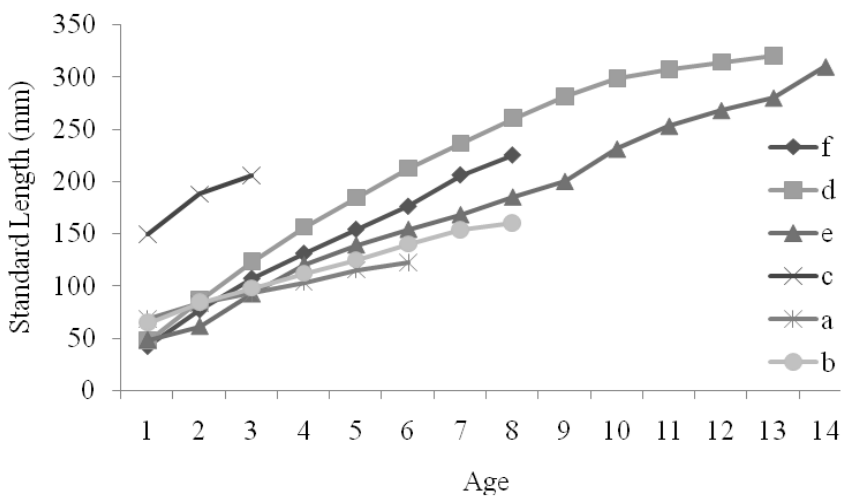


Figure 7. Growth curves of roach from other ecosystems, **a)** males from Lake Volvi, **b)** females from Lake Volvi, **c)** Puiu lake, **d)** Frome river, **e)** Rskovsk reservoir and **f)** Dniepe river

1987; Tarkan, 2006). On the contrary, when the rate of temperature gradually increases, roach breeding is lasting for a longer period of time. Sexual maturty of roach is delayed when temperature declines with distance from the equator (i.e., Vøllestad & L'Abée-Lund, 1987; Cowx, 1990; Tarkan, 2006; Stoessel, 2014).

Reproductive circle of Cyprinidae in temperate climate countries triggered from external factors such as the photo-period and the temperature (Scott, 1979; Mills, 1992). The beginning of reproduction period for roach within time is not stable. Temperature, rainfall and wind are factors that play an important role in the onset of the breeding period (Diamond, 1985; Vøllestad & L'Abée-Lund, 1987). During this period the roach move towards the coast where there are the adequate conditions to lay their eggs. However, none of the above factors have been studied herein.

The absolute fecundity of roach increased with increasing length, weight and age a result applied for the great majority of fish species as it is referred by Bagenal (1978). Relative fecundity was found not to be affected from the changes in length, weight (total-net) and age that is observed during the fish growth.

The fecundity of fish of the same length, weight or age fluctuated between relatively wide limits. The relation that connects the age and fecundity was found to be expressed better with the exponential equation also as Mackay and Mann (1969). In the present study, the estimated fecundity was among the highest when compared with that from other ecosystems worldwide (Figure 6b: Mackay & Mann, 1969; Mann, 1973; Goldspink, 1979; Papageorgiou, 1979; Libosvarsky, Saeed, & Nemcova, 1985; Vøllestad & L'Abée-Lund, 1990; Vila-Gispert & Moreno-Amich, 2000). Bagenal, (1978) showed that between many factors, such as food and density of the population, are playing an important role in fecundity.

The size of the eggs is part of the reproduction strategy of the fish. In many species, it has been observed that there is a relationship between the size of the eggs, the length of female and the temperature (Vøllestad & L'Abée-Lund, 1987; Wootton, 1992). In the present study, the diameter of the eggs (1.063-1.423 mm) was within the range founded by other studies (Naddafi *et al.,* 2005; Tarkan, 2006). Naddafi *et al*. (2005) compared two different populations of roach and they do not observe any statistical difference in the mean value of egg diameter. The diameter and the weight of eggs were independent from the size of the fish and its age (P>0.05). The only positive correlation was found between the diameter and the weight of the eggs. Vøllestad and L'Abée-Lund, (1990) showed that in 5 out of 7 studied populations there was no correlation between the weight of eggs and the length. However, the length-weight relationship of eggs was statistically different between the populations and in some of them between the year period. It seems that the weight and the diameter of the eggs have been affected by many environmental factors (Vøllestad & L'Abée-Lund, 1990)

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