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Short communication

The growth of pike (*Esox lucius* Linnaeus, 1798) in Lake Trasimeno (Umbria, Italy)

Massimo Lorenzoni*, Massimiliano Corboli, A.J. Martin Dörr, Mario Mearelli, Giancarlo Giovinazzo

Dipartimento di Biologia Animale ed Ecologia, Università degli Studi di Perugia, Via Elce di Sotto, 06100 Perugia, Italy

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Abstract

The growth of the pike (*Esox lucius* L.) population of Lake Trasimeno was studied. A total of 166 specimens was captured in two monthly sampling series, from May 1993 to 1994 and from February to April 1998. There were 45 females and 79 males; nine age classes were present. Regression analysis between total length (TL) and weight (*W*) was $W = 0.0001 \times TL^{3.0366}$; no significant differences between sexes were recorded. The parameter values for the von Bertalanffy growth curve for length were $L_\infty = 162.76$ cm, $K = 0.089$ yr^{-1} and $t_0 = 0.29$ yr. An inverse Lee phenomenon exists for the 2-, 3- and 4-year-old age classes in the Lake Trasimeno population, indicating a differential mortality which favoured the survival of the larger individuals. One-year-old specimens were excluded from this phenomenon. Competition between pike and the exotic species largemouth bass (*Micropterus salmoides* Lac.), recently introduced in Lake Trasimeno, could explain the differential mortality in pike, especially in the smaller specimens during winter.

Keywords: Growth; Pike; *Esox lucius*; Lake Trasimeno; Fish fauna

1. Introduction

Pike (*Esox lucius* L., 1758) is widely distributed throughout Europe, Asia and North America (Lelek, 1987). Its native area of distribution in Italy is debated. According to some authors it extends as far as the Tiber basin which would include Lake Trasimeno (Lelek, 1987; Gandolfi et al., 1991), while others contend that the native area is limited to the Padano-Veneto district (Bianco, 1993; Avian et al., 1998). In any case, Lake Trasimeno is an optimal environment for pike and, until recently the population was one of the largest in Italy (Natali and Gennari, 1989). The number of pike in Lake Trasimeno has been declining recently, caused by the reduced spawning areas, general environmental degradation and over-fishing.

Largemouth bass (*Micropterus salmoides* Lacépède, 1802), native to the south-eastern United States, was introduced into Lake Trasimeno in the late 1980s (Natali, 1993). Studies have clearly shown that the largemouth bass has acclimated well to the lake (Lorenzoni et al., 1998). The length/weight regression was $W = 0.00988 \times TL^{3.1512\pm0.027}$ (males) and $W = 0.00888 \times TL^{3.184\pm0.032}$ (females). The parameters of the von Bertalanffy growth curve for length were $L_\infty = 46.88$ cm, $K = 0.33$ yr^{-1} and $t_0 = 0.056$ yr for the females and $L_\infty = 39.4$ cm, $K = 0.42$ yr^{-1} and $t_0 = 0.019$ yr for the males (Lorenzoni et al., 2001).

* Corresponding author. Tel.: +39-755-855-716; fax: +39-755-855-733.
E-mail address: lorenzon@unipg.it (M. Lorenzoni).

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The Fulton's condition factor indicates that the Lake Trasimeno population is in excellent condition, in fact largemouth bass are collocated at the highest condition level in the scale proposed by Bennet (Heidinger, 1976).

Non-indigenous piscivorous species can directly or indirectly modify the pre-existing fish community depending on its prey and/or by competing with other predators (Mack et al., 2000). In Lake Trasimeno competition with largemouth bass may further deplete in the pike stock (Lorenzoni et al., 1998).

Few studies have been conducted on pike biology in Italy and most of them concern populations of the Padano-Veneto district basin (Alessio, 1975a,b; Bertolo et al., 1994; Zanetti et al., 1994; Avian et al., 1998). The aim of this study was to compare the growth and the reproductive biology of the pike in the Lake Trasimeno with the recorded data in the past (Calderoni, 1965; Calderoni et al., 1980; Natali and Gennari, 1989) and to verify the possible impact on pike of the introduction of largemouth bass.

2. Materials and methods

Lake Trasimeno (latitude: 43°9′11″N and longitude: 12°5′E) is the largest laminar lake on the Italian peninsula (surface area $= 126$ km^2, average depth $=$ 4.72 m, maximum depth $= 6.3$ m). Currently, the fish fauna consists of 19 species, predominantly cyprinids. Profound changes have occurred in the composition of the fish community due to the introduction of exotic species. The new species have adapted well while the indigenous species have declined in abundance. Between 1956 and 1980 the annual average pike harvest was 84.29 t yr^{-1} (6.69 kg ha^{-1} yr^{-1}) (Mearelli et al., 1990). By 1999 the harvest had decreased to 3.41 t yr^{-1} (0.27 kg ha^{-1} yr^{-1}), quantitative even inferior to that of largemouth bass, equal to 4.25 t yr^{-1} (0.34 kg ha^{-1} yr^{-1}) (M. Lorenzoni, unpublished data).

Sampling was conducted in the south-eastern part of the lake. Samples were collected from a boat using an electric shocker (continual pulsed current, 4 kW). Two monthly sampling series were carried out, from May 1993 to 1994 and from February to April 1998. One hundred and thirty one fish were captured in the first series and 35 in the second. All specimens were measured for total length (TL) and standard length (SL), with an accuracy of 1 mm, and weighted (W) with an accuracy of 1 g. Sex was determined by macroscopic examination of the gonads. The age of the fish was determined using the microscopic scalimetric method (Bagenal, 1978). The scales were removed from the left side of the fish, above the lateral line, near the fist dorsal fin and stored in ethanol (10%) for reuse in the back-calculation. Back-calculated lengths were estimated for all specimens with readable scales. The scale radius (R_s), from the centre of ossification to the edge of the scale, and the radius of the age rings (S_t) were measured on each scale (± 0.01) (Bagenal, 1978).

The relationship between the length of the specimen at the time of capture, TL, and R_s was described using the regression $\mathrm{TL} = a + bR_s$. The fitted regression was $\mathrm{TL} = 0.175 + 0.011R_s + 0.005$ ($R^2 = 91.3\%$). The equation is linear and does not pass through the origin, this justifies using the Fraser–Lee method for the back-calculation (DeVries and Frie, 1996). Back-calculated lengths were estimated using the following formula: $L_t - a = S_t/R_s(L - a)$ (Bagenal, 1978), in which a is the intercept with the axis of the abscissa of the previous regression and L_t the TL of the fish at age t. The comparisons between the sexes of the sizes at the various ages were compared with a Mann-Whitney u-test.

The length/weight relationship, $W = a\mathrm{TL}^b$, were calculated separately for the two sexes using the least squares method (Ricker, 1975) with length expressed in millimetre and weight in grams. The relationships between the two sexes were compared using analysis of covariance (ANCOVA).

The length by age in the first three age classes was calculated using the average TL obtained from the age classes of the captured specimens grouped according to season. The average values obtained for each age class in the spring and winter were compared with the t-test.

To determine if there was a Lee phenomenon, a comparison was made using the Mann-Whitney u-test between the back-calculated lengths reached at the various ages of the specimens at age n with respect to the samples of the older fish $(n + i)$.

The von Bertalanffy (1938) equation was fitted to the mean back-calculated lengths: $L_t = L_\infty(1 - e^{-K(t-t_0)})$, where L_t is the theoretical total length (TL in cm) at age t; L_∞ the asymptotic length; K the coefficient of growth; t_0 the theoretical age (in yr) at length 0

(Bagenal, 1978). The program Statistica for Windows (Version 5.1) was used to estimate growth parameters. Only the TL values back-calculated from the last *annulus* were used in the analysis. Back-calculated lengths for all *annulus* are commonly used in growth studies but in cases where a Lee phenomenon occurs (direct or indirect), the values of the equation parameters may be over- or under-estimated (Vaughan and Burton, 1994).

The Φ parameter was calculated according to the equation (Pauly and Munro, 1984): $\Phi = \log(K) + 2\log(L_\infty)$, it allows comparison of the growth of different populations.

The relative weight (W_r) was calculated on the basis of the following (Wege and Anderson, 1978): $W_r = 100(W/W_s)$, where W is always the individual weight and W_s is a typical standard weight of the species, predicted from the following (Anderson and Neumann, 1996): $\log(W_s) = -5.437 + 3.096\log(\mathrm{TL})$. The independence of size from the relative weight was confirmed by linear regression. The relationship between W_r and TL was $W_r = 101.85 - 0.137 \times \mathrm{TL}$ ($R^2 = 0.0347$). The comparison between the average W_r values for each age class were carried out by analysis of variance (ANOVA), while the LSD test was used to compare seasons.

3. Results

The sample was made up of 166 specimens, 131 captured in 1994 and 35 in 1998. There are nine age classes with most of specimens in the 2+ age class; the number of individuals captured decreases progressively in the older age classes (Table 1).

The average parameter values (±S.D.) for the total sample are TL = 35.66 (±14.50) cm, SL = 31.66-(±13.22) cm, W = 426.16 (±657.46) g and age = 3.04 (±2.02) yr. It was impossible to determine the age of 18 specimens because the scales were damaged or illegible (regenerate scales).

The whole sample was composed of 45 females and 79 males. The average values ± S.D. were TL = 33.09 ± 11.32 cm, W = 322.83 ± 375.81 g for females and TL = 31.54 ± 9.82 cm, W = 261.93 ± 305.91 g for males. Females were slightly larger and a little older than males.

The average parameter values for the specimens captured in 1994 (TL = 31.91 ± 10.16 cm, W = 277.21 ± 325.32 g) were markedly lower compared to those captured in 1998 (TL = 49.68 ± 19.21 cm, W = 1206.67 ± 1209.41 g), with highly significant difference (TL: $t = 7.42$, $p = 0.0001$) (W: $t = 7.56$; $p = 0.0001$). These differences can be attributed to the older average age of the 1998 sample (1994 = 3.455 yr; 1998 = 4.021 yr; $t = 6.10$; $p = 0.0001$).

The TL and weight regression of the whole sample was $W = 0.001 \times \mathrm{TL}^{3.0366}$ ($R^2 = 99.1\%$, standard error of $b = 0.046$); for females $W = 0.001 \times \mathrm{TL}^{3.003}$ ($R^2 = 99.1\%$, standard error of $b = 0.074$) and for males $W = 0.001 \times \mathrm{TL}^{3.055}$ ($R^2 = 99.0\%$, standard error of $b = 0.067$). No significant differences were shown between the two sexes ($F = 0.37$, $p = 0.546$).

Table 1
E. lucius: back-calculated lengths for the whole sample in Lake Trasimeno

Age	No.	I	II	III	IV	V	VI	VII	VIII	IX
1	33	19.163								
2	47	21.885	29.710							
3	27	18.229	30.434	38.418						
4	10	18.585	32.953	42.447	49.797					
5	5	18.497	33.519	46.914	56.480	52.738				
6	7	20.875	33.746	45.745	56.607	64.057	71.533			
7	4	18.773	40.906	50.066	59.064	64.422	73.780	79.000		
8	2	16.566	25.828	39.788	49.365	63.890	71.207	77.352	83.231	
9	1	26.747	38.643	49.161	58.711	69.428	75.677	82.135	87.481	91.000
Mean		19.944	30.704	41.069	53.032	64.328	72.353	78.960	84.647	91.000
−95% *p*		19.333	29.834	39.715	50.923	62.902	69.636	75.064	78.013	
+95% *p*		20.555	31.575	42.422	55.140	65.754	75.070	82.856	91.281	

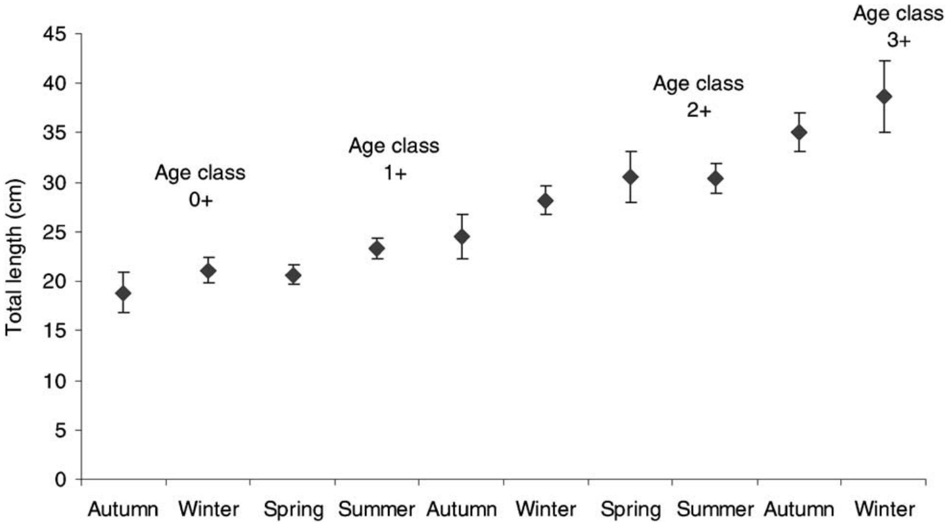

Fig. 1. *E. lucius*: seasonal length at age in Lake Trasimeno (average TL values and 95% confidence limits).

The length at age (Fig. 1) was calculated for the 0+, 1+ and 2+ age classes. During the first year, growth was retarded during the winter so it was not continuous. In the two following age classes, average size increased continuously, even during winter. The difference between the average lengths attained in winter and in spring were statistically significant for the specimens in their second winter (d.f. $= 15$, $t = 1.78$, $p = 0.048$) but not for those in their first winter (d.f. $= 13$, $t = 0.64$, $p = 0.266$) or those in their third winter (d.f. $= 11$, $t = 1.12$, $p = 0.144$).

The back-calculated lengths at the various ages for the total sample are reported in Table 1. There were no statistically significant differences ($p > 0.05$) between lengths of the two sexes at the various ages.

The total sample was used to verify the Lee phenomenon, without distinguishing between sexes (Table 2). The comparison of the lengths between specimens of the various age classes at age N and those of age $(N + i)$ show how the back-calculated lengths are always higher in the older specimens $(N + i)$. The differences are statistically significant (u-test) for the 2-year-old class and highly significant for the 3- and 4-year-old age classes. The back-calculated lengths of the specimens born between 1989 and 1993 captured in the two different sampling series were compared (Table 3). This analysis confirms that the average values of the back-calculated lengths of the specimens that survived until 1998 were higher than those of the specimens caught in 1994, with the exception of those in their first year of life. Using a paired t-test, the average values of back-calculated lengths at the various ages showed that the differences between the specimens, separated

Table 2
E. lucius: comparison of the lengths between specimens of the various age classes at age N and those of age $(N + i)$

Age	Lengths (L_N)				Lengths ($L_{(N+i)}$)				U	p
	No.	Mean	Median	S.D.	No.	Mean	Median	S.D.		
1	33	19.16	18.71	2.35	96	20.21	19.77	3.80	1296	0.120
2	47	29.71	29.17	3.95	49	31.66	31.37	4.44	841	0.023
3	27	38.42	38.69	3.18	22	44.32	44.46	4.26	82	0.000
4	10	49.80	49.18	3.91	12	55.73	56.78	3.64	15	0.003
5	5	63.63	63.50	2.00	7	64.83	64.42	2.42	12	0.372
6	3	71.53	70.80	3.66	4	72.97	73.45	2.68	4	0.480

Table 3
E. lucius: back-calculated lengths of individuals captured in 1994 and 1998

Birth year	1	2	3	4	5
Catch year 1994					
1993	19.09				
1992	22.43	29.59			
1991	18.80	30.60	38.33		
1990	20.73	33.89	42.18	49.72	
1989	19.21	30.48	45.49	55.45	63.23
No.	98	68	26	6	2
Means	20.53	30.17	39.47	51.63	63.23
Catch year 1998					
1993	18.02				
1992	20.88	33.75			
1991	18.77	40.91	50.07		
1990	16.57	25.83	39.79	49.37	
1989	26.75	38.64	49.16	58.71	69.43
No.	10	9	7	6	3
Means	19.53	33.21	44.70	52.48	69.43

according to sampling year were statistically significant ($t = 2.142$, $p = 0.049$).

The theoretical growth curve for length is presented in Fig. 2; the values are $L_\infty = 162.76$ cm, $K = 0.089$ yr^{-1}, $t_0 = 0.291$ yr ($R^2 = 99.44\%$). The Φ value in Lake Trasimeno is 3.37.

The average relative weight value is 97.03; with a wide variability within the sample (S.D. = 10.52; min = 66.93, max = 139.94). Females (average values ± S.D. = 97.671 ± 12.60) appear to be in slightly better condition than males (96.785 ± 8.70). The differences between sexes are not statistically significant ($t = 0.05$, $p = 0.62$), so the subsequent analyses were carried out without distinguishing between sexes. The average W_r values in specimens separated into age classes were not statistically significant ($F = 1.18$, $p = 0.32$). The relative weight for the average seasonal values were the lowest in winter (no. = 59, average = 94.46, S.D. = 7.64) and in autumn the highest (no. = 41, average = 99.82, S.D. = 7.64). The intermediate values were in the spring (no. = 25, average = 98.24, S.D. = 7.71) and summer (no. = 31, average = 97.39, S.D. = 9.05). With the LSD test, significant differences were observed in autumn and winter ($p = 0.014$).

4. Discussion

Pike are well adapted to the shallow, vegetation-rich environment of Lake Trasimeno with its laminar structure that favours the development of an optimal habitat. From a trophic point of view, the high productivity of

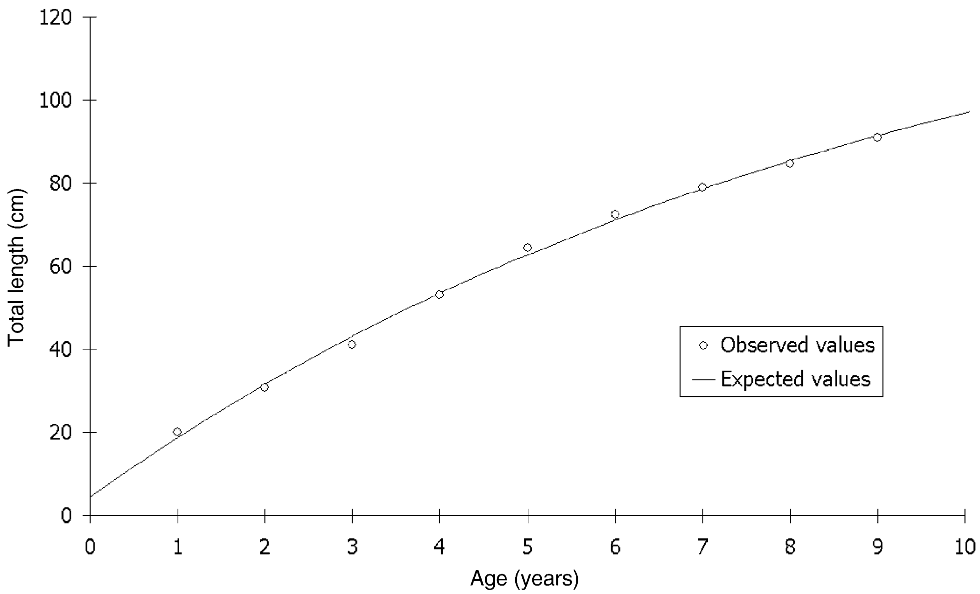

Fig. 2. *E. lucius*: theoretical growth in length in Lake Trasimeno.

the lake supports an abundant fish population by providing the basis of the fish diet. The regression coefficient in the TL/weight relationship (3.037) is always greater than 3, a value that indicates an isometric growth (Bagenal, 1978). The calculated value for the whole sample is similar to or higher than that reported in the literature (Froese and Pauly, 1998; Roche et al., 1999). There is no sexual dimorphism in length–weight relationships.

During this study, difficulties such as those reported by Frost and Kipling (1961), Bregazzi and Kennedy (1980) and Margenau et al. (1998) when using back-calculation and scalimetry to determine age in pike were not encountered. Size-related sexual dimorphism in pike is debatable. There are numerous reports of a faster growth rate in females than in males (Frost and Kipling, 1961; Alessio, 1975b; Wolfert and Miller, 1978; Bregazzi and Kennedy, 1980; Roche et al., 1999). In contrast, Avian et al. (1998) did not find any differences between the sexes in a population from northern Italy. Calderoni (1965) and Natali and Gennari (1989) reported sexual dimorphism in the Lake Trasimeno population but their results were not confirmed by the present study. Since sexual dimorphism is generally more pronounced in the older specimens (Roche et al., 1999), the analysis in this study could have been negatively affected by the size composition of the analysed sample.

The parameter values of the von Bertalanffy equation are $L_\infty = 162.76$ cm, $K = 0.098\ \text{yr}^{-1}$ and $t_0 = 0.291$ yr ($R^2 = 99.44\%$). The maximum theoretical length value was high, while the growth rate (K) was quite modest. The minimum legal size for pike harvest, 40 cm, is reached at about 2.75 years of age and corresponds to a weight just above 600 g. According to Natali and Gennari (1989) at this size only about 35% of the females have reached sexual maturity. Therefore, the 40 cm minimum limit does not safeguard reproduction in the population. The value of Φ for Lake Trasimeno is 3.37, which is less than the value reported by Bertolo et al. (1994) for some Italian environments $(3.7 < \Phi < 4.0)$ but higher than the average value $(\Phi = 3.14)$ reported by Froese and Pauly (1998) for 19 American and European pike populations $(2.81 < \Phi < 3.51)$.

The average relative weight of 97.039 in Lake Trasimeno is notably higher than the average value $(W_r = 92.00)$ calculated by Margenau et al. (1998) for 19 North American lakes. Constructed in this way, W_r is independent of the type of growth and permits individuals and populations to be compared even if they are of different sizes (Wege and Anderson, 1978). W_r values greater than 100 indicate that the specimens are in good condition.

Generally, an inverse Lee phenomenon is caused by an overestimation of the intercept in the back-calculation or by predation and/or competition among the young fish causing a selective mortality to the disadvantage of the smaller specimens (Ricker, 1975; Bagenal, 1978; DeVries and Frie, 1996). The presence of an inverse Lee phenomenon in the Lake Trasimeno pike population in the 2-, 3- and 4-year age classes indicates a differential survival, which favours the larger fish and excludes individuals in the first year of life. A comparison between the back-calculated lengths with the various age rings of specimens from the same group captured in the two different sampling periods supports this hypothesis. The average back-calculated values for the specimens that survived and were captured in 1998 were higher than those captured in 1994 and differences were statistically significant. The only exception was first year age group.

In Lake Trasimeno there is a major overlap between *E. lucius* and *M. salmoides* diets which does not exclude a strong negative interaction between the two species (Lorenzoni et al., 1998). This diet overlap is more accentuated for pike less than 40 cm long and probably begins at the end of the first year when the fish shift to a diet prevalently based on crustaceans and fish (Filleul and Le Louarn, 1998; Kangur and Kangur, 1998). These facts support the hypothesis of a negative interaction between largemouth bass and the younger age classes of pike, which causes a differential survival starting in the second year of life. Competition for food resources could cause a greater mortality in the smaller specimens, as verified by the inverse Lee phenomenon.

This mortality occurs prevalently in winter when the relative weights of pike in Lake Trasimeno are lowest. A size-dependent selective mortality during the winter after the first year would also explain the differences recorded in seasonal growth trends. In Lake Trasimeno during the first winter of life growth of the 1-year-old pike stops because of the lower water temperatures and reduced food availability (Lorenzoni et al., 1998). In contrast, the average size of the specimens in the upper age classes increases during the winter. In the light of the above consideration, a size-dependent mortality rather than the lack of growth in certain individuals would seem to be the best explanation. Winter is a critical period for many fish species due to increased mortality, particularly among smaller, undernourished specimens caused by intra- and inter-specific competition (Buijse and Houthuijzen, 1992; Cargnelli and Grosa, 1996; Ludsin and Devries, 1997). This confirms the doubts and concerns that were expressed following the introduction of largemouth bass into Lake Trasimeno.

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