

Life history characteristics of an invasive cyprinid fish (*Carassius gibelio*) in Chimaditis Lake (northern Greece)

By I. D. Leonardos¹, A. C. Tsikliras², V. Eleftheriou¹, Y. Cladas³, I. Kagalou¹, R. Chortatou¹ and O. Papigioti¹

¹Laboratory of Zoology, Department of Biological Applications and Technologies, University of Ioannina, Ioannina; ²Department of Zoology, School of Biology, Aristotle University of Thessaloniki, Thessaloniki; ³Department of Ichthyology and Fisheries, Technological Educational Institute of Epirus, Igoumenitsa, Greece

Summary

The life history characteristics of an invasive cyprinid fish, the Prussian carp (*Carassius gibelio*) were examined in Lake Chimaditis (northern Greece). The population is dominated by females that are able to reproduce gynogenetically. Fish samples were collected using trammel nets from August 2004 to July 2005. Their total length (TL) ranged between 21.9 and 37.0 cm. The length–weight relationship was $W = 0.0336TL^{2.81}$ ($r^2 = 0.92$, $n = 600$) and the mean Fulton condition factor exhibited monthly variation from 0.172 (May) to 0.186 (August). According to the annual growth marks present, the lifespan of the Prussian carp in Lake Chimaditis is 6 years. The growth parameters were estimated as $L_{\infty} = 34.46$ cm, $K = 0.297$ year⁻¹, $t_0 = -1.994$ year. Absolute fecundity (F_A) ranged between 26 000 and 176 600 oocytes (mean = 66990) and relative fecundity between 78 and 251 oocytes per gram of total weight (mean = 158). Absolute fecundity increased exponentially with length ($F_A = 0.286 \times TL^{3.66}$, $r^2 = 0.66$) and weight ($F_A = 17.93 \times W^{1.36}$, $r^2 = 0.73$) of the fish.

Introduction

The freshwater fishes are the most imperilled vertebrate group in Greece as about 30% of 126 species are extinct, endangered or vulnerable; only 12% are safe (Bobori et al., 2001). The reason for their vulnerability is their limited distributional range which makes them susceptible to pollution, overfishing and habitat modification or loss (Economidis, 1995). Of the 126 freshwater fish species in Greece, 50 are endemic to Greece and the southern regions of the adjacent Balkan countries while 19 are introduced (Economidis, 1991). The limnetic ichthyofauna of Lake Chimaditis consists of 11 species (*Carassius gibelio*, *Cyprinus carpio carpio*, *Tinca tinca*, *Barbus peloponnesius*, *Esox lucius*, *Oncorhynchus mykiss*, *Pachychilon macedonicum*, *Rhodeus amarus*, *Rutilus vegariticus*, *Gambusia affinis*, and *Silurus glanis*). *Carassius gibelio* was first introduced into Lake Chimaditis in the mid-1980s from a neighbouring Greek Lake (Doirani). It quickly became the most abundant species in the lake's ecosystem, influencing the water quality and the fish fauna (Crivelli, 1995; Leonardos et al., 2005). The asexual (gynogenetic) mode of reproduction of the Prussian carp in combination with its resilience to adverse environmental conditions (low oxygen concentrations, nutrient overload, adverse physicochemical parameters) is responsible for the ability to colonise ecosystems like Lake Chimaditis. According to Vrijenhoek (1998), the success of asexual organisms that

flourish in certain ecosystems has been attributed to a variety of factors, including reproductive efficiency and faithful reproduction of general purpose genotypes. The sexually reproducing populations create genetically diverse offspring that interact uniquely with the environment in each new generation, while in contrast, the asexual (gynogenetic) progeny are genetically identical to their mother. Thus, the study of the life history characteristics of an asexually reproducing (cloning) population is important, given that essential information has emerged about the interaction between fixed genotypes and environments that vary in time and space.

The Prussian carp, *Carassius gibelio* (Bloch, 1872), is a benthopelagic, potamodromous fish with relatively low commercial value in Greece. It is omnivorous and feeds on detritus, zooplankton, zoobenthos and macrophytes (Specziar et al., 1997). *Carassius gibelio* was introduced into Europe from Asia in the 17th century and has since become widely distributed throughout Europe. The species was accidentally introduced in several southern European countries, e.g. Slovenia in 1962 (Povž and Šumer, 2005) and Greece in 1950 (Leonardos et al., 2008). Similar to the pumpkinseed sunfish (*Lepomis gibbosus*) that was established because of its competitive advantage and opportunistic feeding (Bobori et al., 2006), the Prussian carp has been blamed for adverse ecological impact on the native fish fauna in Slovenia (Povž and Šumer, 2005) and Greece (Leonardos et al., 2001). The triploid gynogenetic females, with around 150 chromosomes, predominate in the Prussian carp populations (Tsoumani et al., 2006). Hence, practically all individuals of a population are females, which use males of other cyprinids, mainly the common carp (*Cyprinus carpio carpio*) and the roach (*Rutilus vegariticus*), as sperm donors.

With the exception of Lake Pamvotis (western Greece: Paschos et al., 2001) and Lake Lysimachia (western Greece: Leonardos et al., 2001), previous work on the Prussian carp was limited to Greek freshwater systems (Tsoumani et al., 2006). Its distribution, sex ratio and growth have been studied in Estonia (Vetemaa et al., 2005) where it was first introduced in 1948. By the mid-1990s the Prussian carp had spread along the entire Baltic coast of Estonian waters. Its growth, condition, maturity and mortality have been studied in Lake Eğirdir (Turkey) where it was introduced in the early 1990s, establishing a rapidly increasing population that soon dominated the ecosystem (Balik et al., 2004). The diet, reproduction and growth of the Prussian carp have also been studied in Slovakia (Peňáz and Kokeš, 1981).

The aim of the present work is to present the first data on some biological characteristics (length–weight relationship,

somatic condition, age, growth and fecundity) of the gyno-genetic Prussian carp in northern Greece.

Materials and methods

Samples were collected from Chimaditis Lake (northern Greece) using trammel-nets (length: 1000 m, height: 3 m, mesh size: 32 mm inner, 200 mm outer). Duration of net deployment was approximately 12 h, from dusk till dawn. Sampling was carried out on a monthly basis for a complete years' cycle (August 2004 to July 2005). Lake Chimaditis is a shallow, eutrophic lake covering an area of 10.8 km² with a mean depth of about 2 m (i.e. the deployed trammel net reached from the water surface to the lake bottom) and a maximum depth not exceeding 6 m.

All fish were preserved frozen, measured to the nearest mm (total length, TL, cm) and weighted to the nearest 0.01 g (total weight, *W*). Gonad weight (GW, g) was also measured to the nearest 0.01 g. Consequently, the length–weight relationship ($W = aTL^b$) was determined and tested for isometric or allometric growth using the *t*-test (Pauly, 1984). The Fulton condition factor, $K_C = (W/TL^3) \times 10^5$ (Le Cren, 1951), was calculated monthly for all individuals.

Scales from 600 specimens were used for age determination. Scales (8–10 from each fish) were extracted from the left flank, near the tip of the pectoral fin and viewed using an image processing system. Scales were read twice by the same author at an interval of two months at random to avoid bias in assigning ages. The scale radius (*S*) was measured from the focus to the end of the scale on the left dorsal rim. Interpretation of annuli patterns was based on the criteria provided in Bagenal and Tesch (1978). Age classes were assigned based on the number of growth marks, time of growth mark formation and the month the fish was collected. Date of birth for the species was set in May, which approximately corresponded to the peak spawning period based on information on maturity stages and the gonadosomatic index (GSI).

The relationship between total length and scale radius was examined using linear regression ($TL = a + bS$) from which back-calculated lengths at growth mark formation were estimated using the Fraser–Lee equation (Francis, 1990):

$$L_i = c + (TL - c) \times \left(\frac{S_i}{S}\right),$$

where L_i is the total length of the fish when growth mark *i* was formed, TL is the total length at time of capture, S_i is the distance from scale centre to growth mark *i*, *S* is scale radius and *c* is the intercept on length axis (ordinate) of the linear regression between total length and scale radius.

The growth curve was modelled using the von Bertalanffy growth equation (VBGE): $L_t = L_\infty(1 - e^{-K(t-t_0)})$, where L_t is the total length at age *t* (in cm), L_∞ is the asymptotic length (in cm), *K* is a constant expressing the rate at which L_∞ is approached (in year⁻¹) and t_0 is the theoretical age at zero length (in year). The VBGE was fitted on the mean back-calculated lengths at age to assign equal weight to all observations. Growth parameters of the model were estimated iteratively using the Simplex minimization algorithm.

The GSI [(GW/*W*) × 100] that is commonly used as an index of reproductive activity in fishes (Wootton, 1998) was calculated monthly. Absolute fecundity (F_A) was determined in a sample of 39 gonads collected in the first week of May 2005 (time of sampling: 06.00 hours; water temperature: 19.5°C), just prior to spawning (stage V: Nikolskii, 1963) and preserved in

Gilson's fluid (Bagenal and Braum, 1978). Total length of the females used ranged between 23.5 and 36.2 cm, i.e. including most of the size spectrum of the species. Oocytes were counted gravimetrically (Bagenal and Braum, 1978) and the diameter (mm) of at least 50 oocytes per female was measured under a microscope. The relationship between F_A and length or weight of the fish was described using the exponential equation $F_A = ax^b$, where *x* is either length or weight and *a*, *b* are the regression constants. After a logarithmic transformation the exponential equation takes the linear form: $\log F_A = \log a + b(\log x)$. Relative fecundity (F_R) was considered as the number of eggs per unit of body weight (Nikolskii, 1963).

Results

Total length of the sampled fish ranged between 21.9 and 37.0 cm. Length–weight relationship (Fig. 1) was $W = 0.0336TL^{2.81}$ ($r^2 = 0.92$, *n* = 600). The slope was not significantly lower than the theoretical value of 3 (*t*-test, *t* = -5.617, *P* = 0.112), indicating an overall isometric growth for the species. The Fulton condition factor varied between 0.172 (May) and 0.186 (August) (Fig. 2). Despite its small amplitude, the condition factor exhibited a clear seasonal variability, with two maxima, one in early spring (March–April) and another one in late summer/autumn (August–September), and one minimum, in late spring/early summer (May–June).

The size of the fish from which scales were extracted ranged from 21.9 to 36.2 cm TL. Out of the 600 specimens used for age reading, 562 (93.66%) were aged successfully, i.e. the two readings gave the same result. The remainder were damaged or inconclusive. According to the annual growth marks present, the lifespan of the Prussian carp in Lake Chimaditis is 6 years (Table 1). Two- and three-year-old fish were the dominant age classes in the catches, accounting for 41.10 and 41.99% of the total aged individuals respectively (Table 1).

Scale radius was linearly related to fish length. The regression of TL on *S* was:

$$TL = 18.469 + 0.175S (r^2 = 0.35, n = 562, SE_b = 0.01, P < 0.001).$$

The intercept (= 18.469) on the TL axis was used for the subsequent calculation of the mean back-calculated lengths at

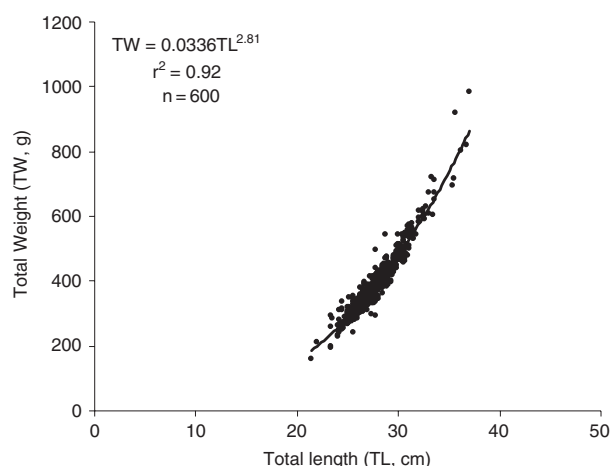


Fig. 1. Relationship between length (total length, TL, cm) and weight (total weight, *W*, g) for Prussian carp, *Carassius gibelio* in Lake Chimaditis, Greece (August 2004–July 2005) sampled with trammel net (32 mm inner mesh, 200 mm outer mesh)

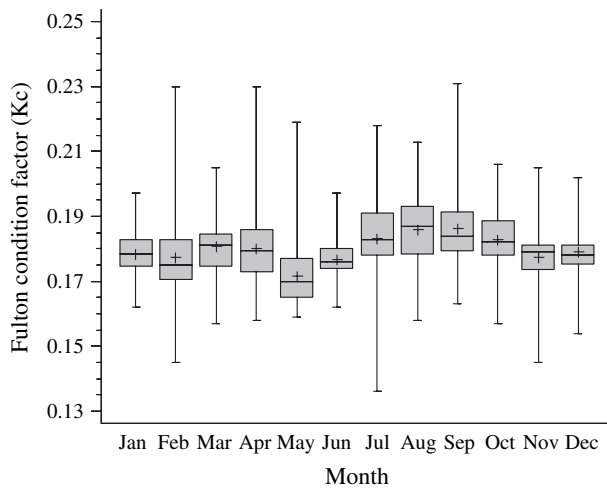


Fig. 2. Variation of average per month Fulton condition factor (K_C) of Prussian carp, *Carassius gibelio*, in Lake Chimaditis, Greece (August 2004–July 2005). Rectangular part of the plot extends from lower to the upper quartile; centre lines within each box show location of sample median and cross location of sample mean. Sample size, 40 individuals per month (except for April 2005: $n = 165$; May 2005: $n = 39$; June 2005: $n = 36$)

Table 1
Mean back calculated total lengths (in cm) at annulus formation, annual increment and % annual increment per age for *Carassius gibelio*, Lake Chimaditis (August 2004–July 2005)

Annuli	N	Mean back calculated total lengths at annulus formation					
		I	II	III	IV	V	VI
I	19	23.27					
II	231	20.06	23.09				
III	236	20.53	23.86	25.60			
IV	51	21.34	24.75	27.91	29.47		
V	22	21.83	25.33	27.52	29.20	30.77	
VI	3	21.20	24.44	26.75	28.32	30.15	30.72
	562						
	Weighted mean	20.56	23.68	26.12	29.35	30.69	30.72
	annual increment	20.56	3.12	2.44	3.23	1.34	0.03
	% annual increment	67.29	10.15	7.96	10.51	4.37	0.09

annulus (=age) formation. Mean back-calculated lengths at age indicated very rapid growth during the first year of life (67.29% annual growth increment) and rather constant growth during the second, third, and fourth year (Table 1). The growth drops rapidly in the fifth and sixth year of life.

The growth parameters were estimated as: $L_\infty = 34.46$ cm, $K = 0.297 \text{ year}^{-1}$, $t_0 = -1.994$ year upon which the VBGE is formed: $L_t = 34.46(1 - e^{-0.297(t+1.994)})$. According to the VBGE, the Prussian carp reached 58.9% of its L_∞ during the first year of life and 69.5% during its second year of life, values that are lower than the corresponding back-calculated lengths.

According to the GSI monthly variation, the gonadal maturation starts in March and peaks in April–May. Absolute fecundity (F_A) ranged between 26 000 and 176 600 oocytes, corresponding to females with $TL = 27.5$ cm and $TL = 36.2$ cm respectively (mean = 66 990, $SD = 30 294$, $n = 39$). Relative fecundity (F_R) ranged between 78 ($TL = 27.5$ cm, $W = 332.5$ g) and 251 ($TL = 31.1$ cm, $W = 511.2$ g) oocytes per gram of total weight. An average

of 158 ($SD = 34.4$) oocytes per gram of total weight was produced. Absolute fecundity increased exponentially with length and weight (Fig. 3):

$$F_A = 0.286 \times TL^{3.66}, r^2 = 0.66, P < 0.01, n = 39$$

$$F_A = 17.93 \times W^{1.36}, r^2 = 0.73, P < 0.01, n = 39$$

The average diameter of ovulated oocytes in a sub-sample of 39 females (total length ranged between 23.5 and 36.2 cm) collected just before spawning (stage V) was 1.065 mm (range: 0.35–2.03 mm). The oocyte diameter frequency distribution was multi-modal.

Discussion

Seasonality is very important in structuring the isometry/allometry of a fish species (Froese, 2006) because the length–weight relationships in fishes are largely determined by seasonally natural oscillating factors such as diet, habitat, reproductive activity and stress (Le Cren, 1951; for a review see Froese, 2006), as well as sampling-specific parameters (sample size and length range). The small sample size and lack of small sized specimens of the Prussian carp in Lake Chimaditis might have influenced the length–weight relationship, which, despite

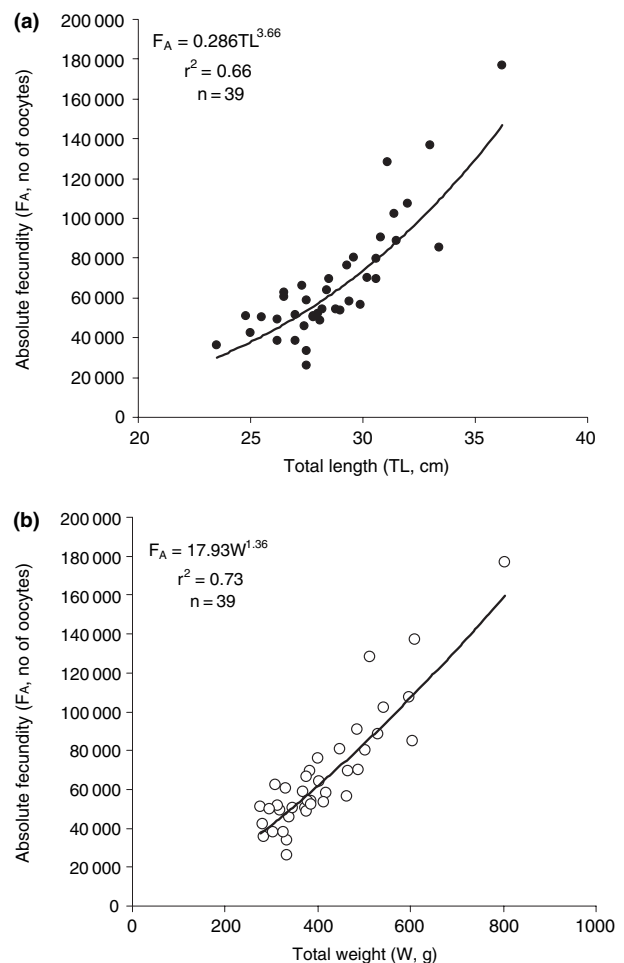


Fig. 3. Absolute fecundity (F_A) of Prussian carp, *Carassius gibelio*, as a function of (a) total length (TL , cm) and (b) body weight (W , g) in Lake Chimaditis, Greece (early May 2005). Total length of females ranged from 23.5 to 36.2 cm

the distance of the calculated value ($=2.81$) with the isometric 3, exhibits a statistically isometric growth. Because the trammel nets are size-selective and a single mesh size was used, the length–weight relationship for the Prussian carp is valid only for the specific size range (20–40 cm) and not for smaller or larger individuals. In other areas of its distribution, the length–weight relationship of the Prussian carp was positively allometric for each sex and for both sexes combined such as in Turkey (Lake Eğirdir: Balik et al., 2004) and for combined sexes in Greece (Lake Volvi: Kleanthidis et al., 1999). Tsoumani et al. (2006) in their study on the length–weight relationships of the Prussian carp in 12 Greek lakes reported a wide range of values for the exponent b (ranging from 2.33 to 3.38) that have been related to the trophic state of each lake. Variable sample sizes and length ranges may also result in varying values for the exponent b among populations (Froese, 2006).

The somatic well-being of the Prussian carp, as revealed by the condition factor, seems to alternate seasonally and, similarly to the length–weight relationship, is primarily dependent upon its reproductive state and the trophodynamics of the environment (Tsoumani et al., 2006). The minimum condition factor values were recorded in May, when spawning of the species occurs. Subsequent to reproduction, the Prussian carp improved its condition by consuming zooplankton species (Leonardos et al., 2008) that are abundant in late spring and early summer and characterise the temperate lakes (Scheffer, 1998). The condition of the Prussian carp progressively deteriorated in autumn and reached its minimum values between November and February. Winter temperatures of the high altitude northern Greece lakes are very low, often below the freezing point of water. Thus, the fish use up all the energy stored during the previous warm period and are in very poor condition during the winter months. Leonardos et al. (2001), based on the condition factor variation, reported that the Prussian carp of Lake Lysimachia was in a better somatic condition in spring and autumn. They also noted the inverse relationship between the condition factor and the gonadosomatic index (Leonardos et al., 2001), which may also be a valid scenario for Lake Chimaditis. The inverse relationship between the condition factor and fish size has been previously reported for this species in lakes where the exponent of the length–weight relationship is lower than 3 (Tsoumani et al., 2006).

The lifespan of the Prussian carp in Lake Chimaditis was similar to that reported for the species in western Greece (Leonardos et al., 2001), Turkey (Balik et al., 2004) and Estonia (Vetemaa et al., 2005). Its lifespan is higher (reaching 9 years) in its original environment, i.e. the rivers and lakes of Asia (see Table 4 in Vetemaa et al., 2005), than in European waters where it was introduced (lifespan rarely exceeding 7 years). According to a recent review (Copp et al., 2004) the growth rate among distant populations of the pumpkinseed (*Lepomis gibbosus*), may significantly differ, with the adult growth in North American (native) populations being faster than that of European populations (introduced). The growth rate and lifespan may differ between native and introduced populations of the same species because the adaptation of introduced species to new environments is a time-consuming process often impeded by unfavourable conditions such as competition with local species. Competition can be an important factor in structuring communities because it largely determines the distribution and resource partitioning among organisms, and hence their population growth and mortality (Krebs, 1994).

The growth parameters of the present study closely agreed with those estimated for Lake Lysimachia (Leonardos et al., 2001) in a similar dataset. The proximity of Greece and Turkey and the possibility of a common origin between the two populations is probably the reason for the agreement in the growth parameters estimated in lakes Eğirdir (Balik et al., 2004) and Chimaditis (present study). Indeed, the asymptotic length and the rate at which it is approached were almost identical for the two populations, with the t_0 being the only parameter that differed. This is attributed to the lack of small-sized specimens in our samples, which forced the growth curve to intersect the age axis at a higher negative value ($t_0 = -1.994$ year) compared to the Turkish ($t_0 = -0.302$ year) and western Greece ($t_0 = -0.51$ year) datasets. The high growth rate during the first 2 years of life and its subsequent decrease as observed for Lake Chimaditis has been also reported for Lake Lysimachia (Leonardos et al., 2001) and seems to be characteristic for the species. The fast initial growth, its ability to tolerate low oxygen levels and its intense reproductive activity (Leonardos et al., 2001) offer a competitive advantage for the Prussian carp against its competitors and may lead to the establishment of viable and resistant populations. The northern European Prussian carp populations exhibit lower initial growth compared to the southern populations (see Table 4 in Vetemaa et al., 2005). Sex-specific differences in growth, lifespan and mortality have been reported for the Prussian carp (e.g. Vetemaa et al., 2005). However, testing this hypothesis was not possible in Lake Chimaditis because the population was dominated by the triploid gynogenetic females.

The high reproductive potential of the Prussian carp might explain its ability to establish large populations. The species produces on average 66 990 oocytes in northern Greece (Lake Chimaditis: present study) and 60 610 in western Greece (Lake Lysimachia: Leonardos et al., 2001). A range of 42 000–141 000 oocytes are produced in Lake Eğirdir (Balik et al., 2004) for individuals with similar size range. However, the mean relative fecundity is higher in Lake Lysimachia (234 oocytes per gram of weight: Leonardos et al., 2001) and Lake Eğirdir (204 oocytes per gram of weight: Balik et al., 2004) than in Lake Chimaditis (158 oocytes per gram of weight). The exponents of the relationships between fecundity and length and weight were similar in Lake Lysimachia ($F = 0.38L^{3.72}$, $F = 34.67W^{1.34}$: Leonardos et al., 2001) and in the present study (Fig. 3). In Lake Eğirdir, the fecundity–length relationship was rather similar ($F = 0.657L^{3.694}$: Balik et al., 2004), but the exponent of the fecundity–weight relationship was lower ($F = 208.86W^{0.991}$: Balik et al., 2004). Part of the difference could be due to the use of different length and weight measurements among researchers (e.g. total instead of fork or standard length and net instead of total or gutted weight).

The life history characteristics of the Prussian carp in Lake Chimaditis generally agree with those previously reported for the species, at least at its southern European distribution, and partially support its opportunistic strategy and the ability to establish large and persistent populations.

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Author's address: Ioannis Leonardos, Biological Applications and Technology Department, University of Ioannina, GR-45110 Ioannina, Greece.
E-mail: ileonard@uoi.gr