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Length–weight relationships of an invasive cyprinid fish (*Carassius gibelio*) from 12 Greek lakes in relation to their trophic states

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Summary The length–weight relationships of the cyprinid fish *Carassius gibelio* (Bloch, 1782) are described for the 12 most important lakes of Greece. *Carassius gibelio* is an allogynogenetic fish species, which was introduced into Greek lakes during the late 1970s. The values of the exponent *b* of the length–weight relationships ranged from 2.33 to 3.38, and varied with the trophic state of the lake. In eutrophic lakes these *b* values were significantly ($P < 0.001$) lower than in oligotrophic or mesotrophic lakes. Relationships between the *b* values and phosphorus concentrations were logarithmic: $b = 1.37–0.13 \log (PO_4\text{-P})$; total length, fork length and standard length were linear (in all cases: $r^2 > 0.95$). In most of the lakes, populations consisted of females, with the exception of Pamvotis, Doirani and Koronia lakes where a small proportion were males.

Introduction

Length and weight relationships are useful for a wide number of studies, such as estimating growth rates, age structure, and other aspects of fish population dynamics. Length–weight regressions have been extensively used for: (i) estimation of weight from length due to technical difficulties and the amount of time required to record weight in the field; (ii) conversion of growth in length equations to growth in weight for use in stock assessment models; (iii) estimation of the biomass from length observations; and (iv) estimation of the condition factors of fish (Wootton, 1990; Petrakis and Stergiou, 1995; Gonçalves et al., 1996; Binohlan and Pauly, 1998). In addition to the above, length–weight relationships are useful for between-region comparisons of life histories of a certain species (Weatherley and Gill, 1987). The development of Fulton's condition factor of the studied species would provide a standard non-lethal method for research and management groups to be able to share and interpret meaningful data on the population of each lake.

The gibel carp *Carassius gibelio* (Bloch, 1782) is known as one of the most hazardous fish species for native fish communities (Crivelli, 1995; Kalous et al., 2004). It easily becomes one of the dominant species in stagnant and slow-running waters and may change the flow of nutrients in the entire ecosystem (Paulovits et al., 1998). According to Crivelli (1995), the turbidity of the water in Lake Mikri Prespa increased after the introduction of *C. gibelio*.

One remarkable feature of *C. gibelio* stocks is the predominance of triploid gynogenetic females with chromosome numbers of around 150 and diploid females and males with about 100 chromosomes, which reproduce sexually. Only comparably few diploid females and very few males occur. Triploid gynogenetic females are clonal sperm parasites on co-occurring fish species: they use males of other species for spawning, but the sperm of these males only induces the development of the egg, without genetic contribution (Penaz et al., 1979; Paschos et al., 2004). In Greece, the southern-most area of the Balkan Peninsula, the gibel carp has been poorly studied and very little biological information is available.

The aim of the present study is to describe the length–weight and length–length relationships for *C. gibelio* from 12 different lakes in Greece, and to make some comparisons among the different biotopes. The comparisons of some biological parameters of a given species in different ecosystems allow us to support opinions about the influence of the environment on species growth.

Materials and methods

Length and weight data ($n = 1333$, see Table 1) of *C. gibelio* were collected from 12 Greek lakes (Fig. 1) throughout February and March 2004. From these lakes, four (Lysimachia, Mikri Prespa, Doirani and Koronia) were classified as eutrophic to hypertrophic, six (Pamvotis, Chimaditis, Zazari, Kerkini, Volvi and Kastoria) as eutrophic, and two (Trichonis and Vegoritis) as oligotrophic to mesotrophic (Petridis and Sinis, 1997; Tafas and Economou-Amilli, 1997; Skoulikidis et al., 1998; Kagalou et al., 2003).

Fish were collected by trammel net with the aid of local professional fishermen. Fork length (FL), standard length (SL) and total length (TL) were measured to the nearest 0.1 mm. Individual total weight (*W*) was recorded to the nearest 0.1 g. All specimens were mature and were studied prior to the reproductive period. Sex was determined from gonad examination.

Weights and lengths were log transformed and the resulting linear relationship fitted by the least squares regression using weight as the dependent variable. Conversions among length measures can generally be accomplished with simple linear regression models. Therefore, length–length relationships were determined by the method of least squares to fit a simple linear regression model. The significance of the regression was assessed by analysis of variance (ANOVA) (Zar, 1999). To examine possible significant differences between sexes in the case of Lake Pamvotis where adequate numbers of males were found, the analyses of covariance (ANCOVA) were used for comparison of the two slopes (Zar, 1999).

The state of well-being of the fish in each lake was estimated using Fulton's condition factor ($K = W/L^3$) (Tesch, 1971), which is suitable for comparing different individual fish of the same species and indicates differences related to lake or sex

Table 1
Estimated parameters of length–weight relationships ($W = aTL^b$, in g and cm) for *Carassius gibelio* in 12 Greek lakes

			Length characteristics		Length–weight relationship parameters			
Lake	Sex	n	Min	Max	*a*	*b*	95% CI of *b*	r^2
Lysimachia	Female	267	24.0	29.9	0.066	2.58	2.20–2.96	0.80
Pamvotis	Female	494	19.0	34.9	0.019	3.06	2.97–3.14	0.94
Pamvotis	Male	13	14.5	28.0	0.044	2.78	2.45–3.10	0.97
Chimaditis	Female	205	20	32.9	0.060	2.74	2.60–2.87	0.88
Kerkini	Female	51	25.2	29.9	0.049	2.72	2.40–3.05	0.85
Volvi	Female	50	21.5	34.0	0.021	2.96	2.74–3.18	0.99
Kastoria	Female	52	15.3	33.3	0.026	2.89	2.73–3.04	0.97
Vegoritis	Female	49	16.2	33.2	0.009	3.25	3.06–3.44	0.96
Trichonis	Female	12	28.0	37.7	0.004	3.38	2.81–3.96	0.95
Mikri Prespa	Female	18	30.9	35.2	0.220	2.33	1.54–3.11	0.73
Doirani	Female	51	17.3	23.7	0.100	2.40	2.07–2.72	0.82
Koronia	Female	51	18.3	23.4	0.140	2.36	1.94–2.78	0.72
Zazari	Female	20	29.9	35.1	0.034	2.81	2.19–3.44	0.83

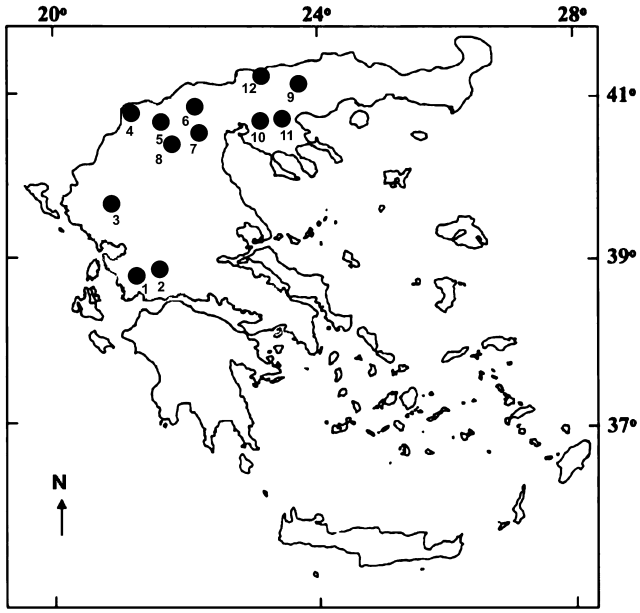

Fig. 1. Major Greek lakes: Lysimachia (1), Trichonis (2), Pamvotis (3) Mikri Prespa (4), Kastoria (5), Vegoritis (6), Zazari (7), Chimaditis (8), Kerkini (9), Volvi (10), Koronia (11), Doirani (12)

(Wootton, 1990). ANOVA was used to compare the factor values among the lakes (Zar, 1999).

In order to study the influence of the trophic state of each lake on the growth parameters of the fish, the mean annual PO_4-P concentrations were correlated with the slopes of the fork length: total weight equations. Information about water quality, lake maximum depth, area and renewal time was obtained from the Greek Ministry of Agriculture, Department of Irrigation and Water Protection (Koussouris et al., 1989; Zacharias et al., 2002).

Results and discussion

The length–length linear relationships were highly significant ($P < 0.001$), with most r^2 values being >0.90, and estimated for all specimens combined. The relationships between TL and FL were: $TL = 0.06 + 1.09\ FL$ ($n = 1333$; $r^2 = 0.96$

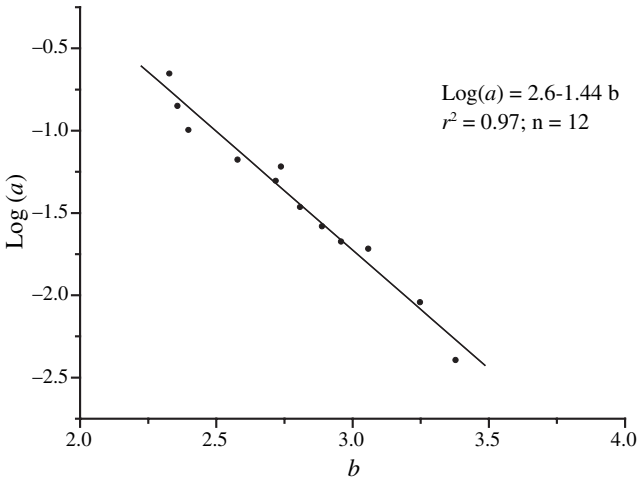

Fig. 2. Plot of length–weight relationships (log *a* vs *b*) for *Carassius gibelio* from 12 lakes in Greece

$P < 0.001$), between TL and SL: $TL = 1.02 + 1.19\ SL$ ($n = 1333$; $r^2 = 0.90$, $P < 0.001$) and between FL and SL: $FL = 1.53 + 1.06\ SL$ ($n = 1333$; $r^2 = 0.90$, $P < 0.001$).

Length–weight relationships of *C. gibelio* from the 12 Greek lakes are summarized in Table 1 and the plot of log (*a*) vs *b* is shown in Fig. 2. Sample size ranged from 12 for Trichonis Lake, to 507 for Pamvotis Lake. Fork length ranged from 14.5 to 37.7 cm. The samples did not include juveniles or small individuals for any of the studied lake. The age of specimens ranged from 2 to 5. The r^2 values ranged from 0.72 for Koronia Lake, to 0.99 for Volvi Lake and all regressions were highly significant ($P < 0.001$).

The estimated values of the *b* parameter ranged from 2.33 to 3.38 (Table 1). However, application of these relationships should be limited to the observed length ranges (Table 1). Low values were found in Lysimachia (2.58), Mikri Prespa (2.33), Doirani (2.40) and Koronia (2.36) lakes. These lakes are small, shallow (maximum depth 6–10 m), eutrophic, and affected by agricultural run-off so that moderate oxygen depletion and mass fish mortalities phenomena are common. According to Ricker (1975), *b* values outside the range of 2.5–3.5 are generally considered to be erroneous. Higher values of the *b* parameter (2.72–3.06) were found in lakes Pamvotis, Chimaditis, Zazari, Kerkini, Volvi and Kastoria. These lakes are eutrophic, relatively shallow and influenced by agricultural run-off and domestic wastewater input (in lakes Pamvotis and Kastoria). Fish mass mortality phenomena in the above lakes are rare.

Higher values of the *b* parameter were found in lakes Vegoritis and Trichonis (3.25 and 3.28, respectively). These lakes are deep (75 and 58 m, respectively), relatively large (surface area 43 and 97 km^2, respectively), with high values of renewal time (9.4 and 9.5 times per year, respectively). According to Skoulikidis et al. (1998), Vegoritis Lake is classified as mesotrophic and Trichonis Lake as an oligotrophic to mesotrophic lake. No significant differences ($P > 0.05$) were found in slopes of length–weight relationships between sexes in Pamvotis Lake, where an adequate number of males was found.

The mean annual values of PO_4-P concentrations were correlated with the values of the slopes of the total weight : fork length equations. It was found that the logarithmic equation best described the relationship between the two parameters: $b = 1.37–0.13 \log(PO_4\text{-P})$ ($r^2 = 0.44$,

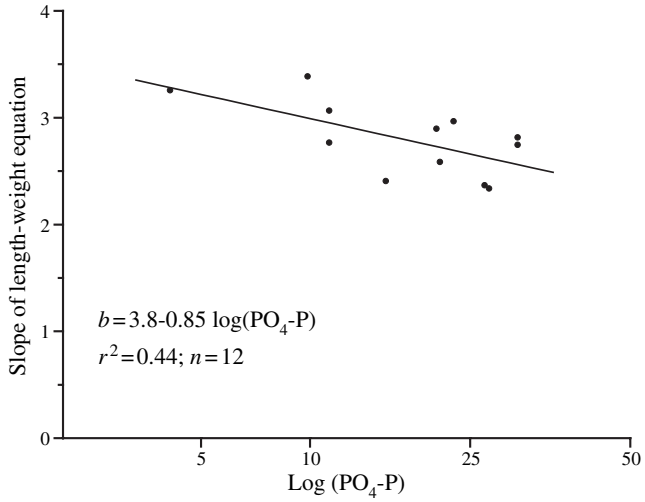

Fig. 3. Relationship between slope of length–weight equations of *Carassius gibelio* and mean annual PO_4-P ($\mu g\ l^{-1}$) concentrations in 12 Greek lakes

P = 0.02). As PO_4-P concentrations are indicative of the trophic state of lakes (OECD, 1982), it seems that the values of the *b* parameter decreased according to the trophic state increase in the lake (Fig. 3).

A number of factors are known to influence the length–weight relationship in fishes, including growth phase, season, degree of stomach fullness, gonad maturity, sex, size range, health, and general fish condition and preservation techniques (Tesch, 1971). During this study an attempt was made to eliminate most factors affecting the growth, and focus on the influence of the trophic state. It was found that fish grow very well in mesotrophic or oligotrophic lakes but are negatively influenced in eutrophic and hypertrophic small and shallow lakes. Jeppesen et al. (2000), using data from 71 Danish lakes with different phosphorous concentrations, also demonstrated that the body weight of cyprinids declined significantly with an increase in phosphorous.

In eight of the lakes only females were found, while in the remaining three lakes a small number of males were found. In Pamvotis Lake the proportion of males was 2.6%, in Koronia 6% and in Doirani 7.8%. The proportion of males in Greek lakes was significantly lower than that of other Northeast European or Asian lakes (Zhou et al., 2000). Statistically significant differences were found in Fulton's condition factor in relation to the lake (ANOVA: $F = 217.93$; $P < 0.001$).

In lakes where the slopes of the length–weight equation were higher than 3 (Trichonis, Vegoritis, Pamvotis), large specimens had higher condition factors than small individuals, while in lakes where the slope *b* of the length–weight equations was lower than 3 (Kerkini, Lysimachia, Koronia, Doirani, Mikri Prespa, Chimaditis, Zazari, Kastoria) the large specimens had lower condition than small individuals. This may be attributed to the food preferences of small vs large specimens. *Carassius gibelio* is an omnivorous fish species which feeds on detritus, zooplankton, zoobenthos and macrophyta (Specziar et al., 1997). Small specimens feed on plankton and detritus, while large specimens prefer benthos and relatively large plankton. In eutrophic lakes, the abundance of large zooplankton (Schindler and Scheuerell, 2002; Moustaka-Gouni et al., 2006) is frequently reduced and thus this reflects on fish growth.

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