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Length-weight relationships of freshwater fish species caught in three Greek lakes

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Length-weight (L-W) relationships for 17 fish species (one hybrid included) from three natural, eutrophic lakes in Greece are presented. The calculated values (mean ± SE) of the exponent *b* ranged from 2.117 ± 0.116 to 3.550 ± 0.104 (global mean ± SE: 3.044 ± 0.066), with 87% of the observed *b* values of the species/lake combinations lying within the expected range of 2.5-3.5. For five out of the 17 species examined, the L-W parameters are given for the first time. The comparison of the *b* values for the common species among lakes revealed significant differences ($p < 0.05$) for *Carassius gibelio* and *Perca fluviatilis*. Moreover, significant differences ($p < 0.05$) were extracted after comparing the *b* values among different seasons for the most abundant species, and especially between spring and summer, indicating differences related with the beginning of the spawning period.

Key words: lakes, length-weight relationship, seasonal variability, Greece.

INTRODUCTION

Length-weight (L-W) relationship is one of the most widely used methods in fisheries research and its importance has been well documented (Pauly, 1993; Petrakis & Stergiou, 1995; Moutopoulos & Stergiou, 2002; Froese, 2006). Among others, L-W relationships are used for between-region comparisons of growth of a specific species (Wootton, 1999; Haniffa *et al*., 2006; Tsoumani *et al*., 2006), as well as for describing seasonal variation of growth within species (e.g. Hossain *et al.*, 2006; Karakulak *et al.*, 2006; Lalèyè, 2006). In Greek waters, L-W relationships are adequately studied for open sea (Stergiou & Moutopoulos, 2001; Moutopoulos & Stergiou, 2002; Karachle & Stergiou, 2008) and estuarine systems (Koutrakis & Tsikliras, 2003). In contrast, estimates of L-W relationships for freshwater systems are rather scarce (for review see: Kleanthidis & Stergiou, 2006).

In this paper we (a) present the L-W relationships for 17 fish species caught in three Greek lakes, (b) provide seasonal L-W relationships for the most abundant species in each lake and (c) explore for possible between-lake differences of the *b* values of the L-W relationships calculated for the same species.

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MATERIALS AND METHODS

Fish specimens were collected from two shallow eutrophic lakes, Lake Doirani (41° 11′ N, 22° 45′ E; altitude 148 m a.s.l., surface area 28 km^2 and maximum depth 5 m; Temponeras *et al*., 2000) and Lake Mikri Prespa (40° 45′ N, 21° 07′ E; altitude 850 m a.s.l., surface area 47.4 km^2 and maximum depth 8.4 m; Holis & Stevenson, 1997), and one deeper eutrophic lake, Lake Volvi (40° 41′ N, 23° 25′ E; altitude 37 m a.s.l., surface area 68.6 km^2 and maximum depth 19 m; Moustaka-Gouni, 1993). All lakes are located in northern Greece. Sampling took place seasonally in lakes Volvi and Doirani, for one year (summer 2005-spring 2006 and spring 2006-winter 2007, respectively), using gill nets with mesh size ranging from 12 to 90 mm (knot to knot). Samples from Lake Mikri Prespa were collected during autumn 2008 by gill nets with mesh size from 8 to 70 mm (knot to knot). All individuals (preserved frozen) were measured for total length (TL, in cm) to the nearest mm and weighted (W, total wet weight in g) to the nearest 0.01 g. Species scientific names are in accordance to the recent nomenclature (Kottelat & Freyhof, 2007; Froese & Pauly, 2009).

Length-weight relationships were estimated using the equation $W = aL^b$, where W is the total wet weight (g), L is the total length (TL, cm), and a and b are the equation parameters calculated by the least squares method. To determine significant differences from the isometric value of $b = 3$, a t-test was applied (Zar, 1999). Furthermore, for the most abundant species (n > 30 individuals per season), L-W relationships were separately estimated by season and lake. Analysis of covariance (ANCOVA; Zar, 1999) was used to test differences of the b values among seasons and lakes.

RESULTS AND DISCUSSION

Overall, 11797 specimens from 17 fish species, belonging to three families (Cyprinidae, Centrarchidae, Percidae) were examined (Table 1). The most abundant family was Cyprinidae (15 out of 17 species). In the list of species one hybrid (*Alburnus belvica* x *Rutilus prespensis*; Crivelli & Dupont, 1987) from Lake Mikri Prespa was also included. The number of individuals per species ranged from 11 (for *Cyprinus carpio*) to 3864 (for *A. macedonicus*), both from Lake Doirani (Table 1). The parameters of the estimated L-W relationships and the corresponding length ranges are also presented in Table 1. The calculated values of the parameter b ranged from (mean ± SE) 2.117 ± 0.116, for *Pseudorasbora parva* in Lake Mikri Prespa, to 3.550 ± 0.104, for *Scardinius erythrophthalmus* in Lake Volvi (for all species global mean ± SE: 3.044 ± 0.066; median = 3.113). For the majority of the species/lake combinations (20 out of 23 cases; 87%) the b values laid within the expected range of 2.5-3.5 (Froese, 2006). For most of the species/lake combinations (13 out of 23 cases; 56.5%) the b values were higher than 3 (t-test; $p < 0.05$), for three cases (13%) the b values were lower than 3 (t-test; $p < 0.05$), while for the rest of the species/lake combinations the b values of the L-W relationships did not differ significantly (t-test; $p > 0.05$) from 3 (Table 1).

For five (*A. macedonicus*, *Chondrostoma prespense*, *Pachychilon macedonicum*, *Rutilus prespensis*, and *Squalius prespensis*) out of the 16 studied species (excluding the hybrid) there is no information on L-W relationships recorded in FishBase (www.fishbase.org; Froese & Pauly, 2009) (Table 1). In the 11 remaining species for the majority of the species/lake combinations the estimated b and the 95% confidence limit ($CL_{95\%}$) values fell within the range reported in Fishbase, whereas for three species/lake combinations (*A. belvica*/Mikri Prespa, *P. parva*/Mikri Prespa and *Vimba melanops*/Volvi) the b values were lower than the minimum values recorded in FishBase. Furthermore, for two species/lake combinations (*A. brama*/ Volvi and *S. erythrophthalmus*/Volvi) the estimated b values were higher than the maximum values reported in FishBase (Table 1). Such differences in b values could be attributed to one or more of the following factors: (a) differences in the number of specimens examined, (b) area/season effects and (c) differences in the observed fish length ranges and the type of length used (Moutopoulos & Stergiou, 2002; Froese, 2006). Indeed, the lower b value estimated for *A. belvica* from Lake Mikri Prespa may be attributed to the smaller sized specimens used in the present study (6.8-19.7 cm TL) compared to those reported in FishBase (10.2-22.0 cm fork length). The opposite is true for *A. brama* and *S. erythrophthalmus* from Lake Volvi. For these species the estimated b values were calculated from samples with larger sized individuals (Table 1) when compared to those reported in FishBase (7-45 cm TL for *A. brama* and 10.4-23.5 cm TL for *S. erythrophthalmus*). In addition, the majority of the L-W relationships recorded in FishBase for the above mentioned species are derived from lakes from Central European countries and Russia. Among the environmental parameters that influence the L-W relationship (Froese, 2006) temperature is considered as an important factor affecting fish growth (Wootton, 1999), so higher b values should be expected (Froese, 2006) for *A. brama* and *S. erythrophthalmus* in Lake Volvi (a temperate Mediterranean lake). Furthermore, the L-W relationship of a species varies among localities (Froese, 2006). This area effect on the L-W relationships is also obvious for *P. parva* from Lake Prespa, since b values of 3.010 and 3.081 are recorded in FishBase from Iran and China water systems. However, it should also be mentioned that the estimated b

TABLE 1. Estimated parameters of the length-weight relationship ($W = aL^b$) for 17 fish species (one hybrid included) from three lakes (D, Doirani; V, Volvi; and P, Mikri Prespa) in northern Greece. n: sample size; min and max: the minimum and maximum total length (TL, in cm) observed; a and b: parameters of the relationship and their standard errors ($SE_{(a)}$ and $SE_{(b)}$, respectively); r^2: coefficient of determination

Species/Family	Lake	n	TL range		L-W relationship					Range of b
			min	max	a	$SE_{(a)}$	b	$SE_{(b)}$	r^2	Fishbase[1]
Cyprinidae										
Abramis brama (Linnaeus, 1758)	V	207	17.5	44.0	0.0024	0.107	3.460*	0.074	0.914	2.88-3.38
Alburnus macedonicus (Karaman, 1928)	D	3864	10.0	15.8	0.0368	0.073	2.384*	0.028	0.624	
Alburnus belvica Karaman, 1924	P	1825	6.8	19.7	0.0064	0.019	3.160*	0.017	0.951	3.23-3.7
Alburnus sp. Volvi in Kottelat & Freyhof, 2007	V	119	10.2	14.9	0.0205	0.327	2.596*	0.133	0.765	2.7†
Carassius gibelio (Bloch, 1782)	D	205	8.4	30.7	0.0137	0.028	3.059*	0.023	0.989	2.06-3.25
	V	143	12.9	32.3	0.0214	0.058	2.945	0.042	0.972	
	P	49	8.3	33.5	0.0094	0.042	3.187*	0.036	0.994	
Chondrostoma prespense Karaman, 1924	P	36	13.8	27.2	0.0091	0.104	3.056	0.082	0.975	
Cyprinus carpio Linnaeus, 1758	D	11	16.0	55.0	0.0145	0.142	2.983	0.092	0.991	2.42-3.68
	V	19	21.5	49.0	0.0147	0.291	2.997	0.181	0.932	
	P	66	19.9	44.9	0.0137	0.089	2.989	0.059	0.975	
Pachychilon macedonicum (Steindachner,1892)	D	436	8.9	19.1	0.0105	0.058	3.158*	0.053	0.889	
Pseudorasbora parva (Temminck & Schlegel, 1846)	P	105	5.4	8.3	0.0472	0.096	2.117*	0.116	0.763	3.01-3.27
Rutilus prespensis (Karaman, 1924)	P	685	5.7	21.8	0.0060	0.019	3.283*	0.017	0.982	
Rutilus rutilus (Linnaeus, 1758)	D	392	8.7	28.1	0.0067	0.069	3.148*	0.026	0.974	2.77-3.61
Scardinius erythrophthalmus (Linnaeus, 1758)	D	20	9.7	18.1	0.0560	0.119	3.292*	0.102	0.982	2.71-3.48
	V	56	15.0	25.5	0.0029	0.135	3.550*	0.104	0.955	
Squalius prespensis (Fowler, 1977)	P	124	12.2	38.7	0.0112	0.037	2.991	0.028	0.989	
Vimba melanops (Heckel, 1837)	V	141	16.0	31.7	0.0077	0.099	3.127*	0.073	0.930	3.33-3.48
Alburnus belvica × *Rutilus prespensis* (Crivelli & Dupont 1987)	P	144	11.3	17.5	0.0078	0.076	3.113*	0.067	0.938	
Centrarhidae										
Lepomis gibbosus (Linnaeus, 1758)	P	777	4.1	17.6	0.0130	0.023	3.140*	0.025	0.952	2.98-3.33
Percidae										
Perca fluviatilis Linnaeus, 1758	D	2140	9.2	31.3	0.0112	0.019	2.991	0.017	0.933	2.61-3.53
	V	233	8.9	38.7	0.0063	0.051	3.289*	0.040	0.967	

*: Indicates significant difference of *b* value from 3 (t-test; $p < 0.05$); †: since taxonomic position of *Alburnus* species from Lake Volvi is not yet clear, this value refers to the previously known from this lake population of *Alburnus alburnus*; [1] Froese & Pauly (2009)

TABLE 2. Estimated parameters of the length-weight relationship ($W = aL^b$) for the most abundant fish species caught in lakes Doirani and Volvi per season (SP, spring; SU, summer; AU, autumn; and WI, winter). n: sample size; min and max: the minimum and maximum total length (TL, in cm) observed; a and b: parameters of the relationship and their standard errors ($SE_{(a)}$ and $SE_{(b)}$, respectively); r^2: coefficient of determination

Lake	Species	Season	n	TL range		L-W relationship				
				min	max	a	$SE_{(a)}$	b	$SE_{(b)}$	r^2
Doirani	*A. macedonicus*	SP	196	10.8	14.7	0.0368	0.289	2.384	0.114	0.692
		SU	671	10.3	14.9	0.0288	0.180	2.492	0.072	0.642
		AU	2742	10.0	15.8	0.0552	0.095	2.238	0.037	0.571
		WI	256	11.9	14.5	0.1938	0.255	1.722	0.100	0.539
	C. gibelio	SP	77	9.3	30.7	0.0204	0.098	2.912	0.035	0.989
		SU	59	8.4	29.8	0.0126	0.126	3.087	0.045	0.988
		AU	56	10.1	27.3	0.0111	0.108	3.138	0.039	0.992
		WI	13	16.0	25.5	0.0130	0.857	3.099	0.271	0.915
	P. macedonicum	SP	335	8.9	14.5	0.0063	0.137	3.367	0.055	0.918
		SU	54	9.5	15.0	0.0253	0.444	2.826	0.173	0.833
		AU	47	9.7	19.1	0.0310	0.491	2.696	0.192	0.810
Volvi	*A. brama*	SP	49	19.7	44.0	0.0010	0.255	3.585	0.175	0.898
		SU	37	20.4	38.3	0.0080	0.398	3.105	0.120	0.949
		AU	56	17.5	37.0	0.0025	0.558	3.452	0.163	0.890
		WI	65	17.5	29.8	0.0390	0.214	2.574	0.153	0.904
	Alburnus sp. Volvi	SP	47	10.4	12.4	0.3175	0.641	1.463	0.265	0.390
		SU	25	10.9	14.9	0.0734	0.451	2.127	0.180	0.853
		AU	34	10.5	14.1	0.0099	0.536	2.909	0.216	0.846
		WI	39	10.2	12.7	0.0634	0.543	2.102	0.222	0.699
	C. gibelio	SP	12	22.6	26.3	0.0256	0.679	2.852	0.212	0.942
		SU	50	14.8	28.7	0.0225	0.215	2.935	0.070	0.973
		AU	40	21.3	32.3	0.0189	0.268	2.994	0.082	0.971
		WI	41	12.9	31.0	0.0121	0.224	3.111	0.068	0.981
	P. fluviatilis	SP	58	14.5	34.3	0.0058	0.144	3.294	0.046	0.989
		SU	70	8.9	24.3	0.0108	0.171	3.094	0.062	0.973
		AU	35	12.9	36.0	0.0067	0.348	3.298	0.113	0.962
		WI	56	14.5	38.7	0.0023	0.481	3.639	0.165	0.898

value for this species was considerably lower than that recorded in FishBase for the same species from Lake Mikri Prespa for the periods 1984-85 and 1990-92, even though the length ranges of the samples used are almost the same. Some other factors apart from the above mentioned (e.g. intraspecific trophic interactions due to population increment; Rosecchi *et al*., 1993) could explain such differences.

The comparison of the L-W relationships among the studied lakes for the species found in more than one lake and in adequate number of individuals showed (Table 1) that the slope *b* did not differ significantly (ANCOVA: $p > 0.05$) for *Carassius gibelio* in lakes Doirani and Volvi, whereas it was significantly (ANCOVA: $p < 0.05$) greater in Lake Mikri Prespa. For this species, *b* values have been found (Tsoumani *et al*., 2006) to be negatively correlated with the trophic state (based on PO_4-P concentrations) of several Greek lakes, including (among others) the lakes of the present study. More specifically, higher *b* values were estimated for Lake Volvi and lower ones for lakes Mikri Prespa and Doirani. In contrast, the *b* values estimated in the present study seemed to be positively correlated with the Chl *a* concentrations measured in the studied lakes (Vardaka *et al*., 2005). Thus, for *C. gibelio* the highest *b* value (3.187; Table 1) was estimated in Lake Mikri Prespa, where the highest concentrations of Chl *a* were also measured (Vardaka *et al*., 2005). Accordingly, lower values of *b* were estimated for specimens from lakes Doirani and Volvi, which are characterized by lower Chl *a* concentrations. Furthermore, significant difference (ANCOVA: $p < 0.05$) in the slope *b* was also observed for *Perca fluviatilis* between lakes Doirani and Volvi. Such difference may be attributed to the greater length range of the specimens caught from Lake Volvi compared to those from Lake Doirani (Table 1).

Seasonal L-W relationships were estimated for the five most abundant species in lakes Doirani (*A. macedonicus*, *C. gibelio*, *P. macedonicum*, *P. fluviatilis* and *Rutilus rutilus*) and Volvi (*A. brama*, *Alburnus* sp. Volvi, *C. gibelio*, *P. fluviatilis* and *V. melanops*). The comparison of the seasonal estimates of the *b* values showed that for three out of the five studied species in Lake Doirani (*A. macedonicus*, *C. gibelio* and *P. macedonicum*) and for four out of the five species in Lake Volvi (*A. brama*, *Alburnus* sp. Volvi, *C. gibelio* and *P. fluviatilis*) there were significant differences (ANCOVA: $p < 0.05$) among pair season combinations (Table 2). For all these species, except for *A. brama*, the comparison of the seasonal slopes between spring and summer were significantly different (ANCOVA: $p < 0.05$), indicating differences related with the beginning of the spawning period (Froese & Pauly, 2009). Moreover, the differences in the seasonal *b* values could be attributed to both biotic (food availability, maturity stage, degree of stomach fullness and reproduction) and abiotic (physical, chemical, hydrological) parameters (Wootton, 1999).

From Table 2 it becomes evident that although most of the seasonal *b* values were between 2.5-3.5 (18 out of 27; 70.4%), seven were lower than 2.5 (22.2%) and two were greater than 3.5 (7.4%). It is maintained that such out of the 'normal range' values are often derived from samples with narrow size ranges (Froese, 2006). This might explain the extremely low *b* values in the cases of *A. macedonicus* in Lake Doirani and *Alburnus* sp. Volvi in Lake Volvi, both estimated during winter and spring (Table 2). However, for the remaining low *b* values observed for the same species during autumn and summer, as well as for the high *b* values calculated for *A. brama* in Lake Volvi during spring and autumn (Table 2), the size range does not seem to be the only reason. For these cases, the seasonal *b* differences could be attributed to other factors such as spawning season and sampling artifact (individuals with size larger than the annual mean size for *A. brama* in Lake Volvi during spring and autumn), low number of individuals (*Alburnus* sp. Volvi in Lake Volvi during summer).

In conclusion, it could be assumed that the estimated L-W relationships from the two lakes (Doirani and Volvi) sampled on a seasonal basis approximate an annual average. However, all three lakes were sampled with multi-mesh gillnets with size-selective properties. As a result, no small-sized individuals of all species were included in our data sets. Hence, the resulted L-W relationships should be limited to the observed length ranges (Moutopoulos & Stergiou, 2002) or should be considered cautiously when referred to small length ranges as in the case of *Alburnus* species. Finally, the results of the present study represent the first contribution for Lake Doirani and shall be of great importance in evaluating the relative condition of fish populations, biology, species and fisheries management in this lake.

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