ISSN: 0001-5113 AADRAY	ACTA ADRIAT., 60(1): 53 - 60, 2019	ORIGINAL SCIENTIFIC PAPER

Length-Weight relations and condition factor of roach *Rutilus rutilus* (Linnaeus, 1758) in Lake Volvi (Northern Greece)

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Length-weight relations (LWRs) and different indices of condition factor for roach from Lake Volvi (Northern Greece) were estimated. Results showed that roach are heavier of a given length in Lake Volvi than in other areas worldwide, with females exhibited higher weight than males of the same length. Significant differences ($P<0.05$) of LWRs were also exhibited between sexes depending on month. CLARK condition factor peaked at the end of summer displaying no significant difference between sexes, whereas the other three estimated condition factors (Allometric, FULTON, LE CREN) peaked in winter. The estimation of different proxies of condition factor disaggregated by sex might reduce the uncertainty raised by the estimation of fish growth.

Key words: seasonal variability, sex-specific, Fulton index, brackish water, Greece

INTRODUCTION

Length-weight relationship (LWR) is one of the most widely used and well documented method in fisheries research worldwide depending on many abiotic and biotic factors (i.e., seasonality, sex, size range, habitat, food availability and fishing pressure) (FROESE, 2006). The above relationship is also used as a proxy for fish condition (POPE & KRUSE, 2001), based on the assumption that heavier fish of a given length are in better condition.

In this study, we estimated the LWRs for roach, in Lake Volvi (Northern Greece) by season (monthly variability) and sex and we further explored different indices of condition factor. Although roach is one of the most abundant and commercially important species in Greek waters (ECONOMIDIS & BANARESCU, 1991; ECONOMOU *et al.,* 2007; BOBORI *et al.,* 2010, 2017) and LWR for this species have been elsewhere presented (PAPAGEORGIOU, 1979; TSOUMANI *et al.,* 2012; BOBORI *et al.,* 2010, 2017; PETRIKI *et al.,* 2010), neither LWR by sex and season nor different condition factor indices have been estimated in Greek and worldwide freshwaters. This is because most of the LWRs are derived from snapshot of annual samplings lacking sex disaggregation. In

this context, the estimation of sex-specific condition factor might also reduce the uncertainty raised by the estimation of fish growth (POPE & KRUSE, 2001).

MATERIAL AND METHODS

Roach samples were monthly collected from Lake Volvi (Northern Greece 40°41'N 23°28'E) using six separate panels of gill nets, with multiple mesh sizes of 16, 20, 24, 28, 34 and 40 mm from November 1997 to November 1998. Fish samples were separated per different mesh size and were placed in formaldehyde solution (10%) until their laboratory analyses. The period between sampling and laboratory analyses never exceeded three days. For each fish sample were measured the total length (TL) in mm and total (W) and eviscerated weight (Wn) in g.

The LWRs were determined according to the equation $W = a \times TL^b$ given by LE CREN (1951) where a and b are parameters of the LWR equation. These parameters were estimated by the least squares regressions method and, then, were log-transformed using the equation $\ln(W) = \ln(a) + b \times \ln(TL)$. The b-value was tested by Student's t-test to verify if it was significantly different from the isometric growth ($b = 3$, $P < 0.05$) (FROESE *et al.*, 2014). LWRs were separately estimated by season and sex and analysis of covariance (ANCOVA; ZAR, 1999) was used to test differences of the b values between season and sex.

Different indices of condition factors were also estimated; (a) LE CREN $K_1 = W/W_e$, where W_e is the predicted weight derived from the LWR (LE CREN, 1951; WOOTTON, 1999), (b) Allometric $K_2 = W/TL^b \cdot 10^6$ (RICKER, 1975; BOLGER & CONNOLLY, 1989), (c) FULTON $K_3 = W/TL^3 \cdot 10^5$ (BAGENAL & TESCH, 1978) and (d) CLARK $K_4 = Wn/TL^b \cdot 10^6$ (WOOTTON, 1999). The indices (a) to (c) describe the variation of total weight and (d) the variation of the eviscerated weight. NIKOLSKY (1963) proposed the use of CLARK'S condition factor, because it better describes the fish physical condition without the influence of the maturity of gonads and of the stomach fullness.

RESULTS AND DISCUSSION

LWRs were highly significant ($P < 0.05$) with R^2 values being greater than 0.93 (Table 1). The mean annual value of the exponent b for combined sexes was significantly (t-test, $P<0.05$) higher than 3 (3.684; SD= 0.166). For between-sex comparison of b values females exhibited significantly higher weight at specific length (ANCOVA, $P<0.05$) than males of the same length (b = 3.700 and 3.653, respectively). With respect to seasons, LWRs were significantly positive allometric during winter, summer and autumn (t-test, $P<0.05$), whereas this was not true for spring when LWR was significantly negative allometric (t-test, $P<0.05$) (Table 2). The b values ranged between 2.71 and 3.61 and were within the expected ones as reported in Fishbase (FROESE & PAULY, 2016). Roach in Lake Volvi exhibited the highest b values when compared to other ecosystems worldwide and in the same ecosystem in different period of time (i.e. PAPAGEORGIOU, 1979; TSOUMANI *et al.,* 2012; BOBORI *et al,.* 2017) (Table 3), and thus, specimens

Table 1. Estimated parameters of length-weight relationships ($W = aTL^b$, in g and mm) by sex and for combined sex for Rutilus rutilus in Lake Volvi. n is the sample size, min and max the minimum and maximum total length, a and b are the parameters of the L-W relation and their standard errors $SE_{(a)}$ and $SE_{(b)}$ and r^2 is the coefficient of determination.

	Total Length characteristics			Parameters of the length-weight relationships				
	n	min	max	-ln(a)	$SE_{(a)}$	b	$SE_{(b)}$	r^2
Combined sex	2439	91.5	220.3	-14.820	0.081	3.684	0.166	0.95
Male	444	92.5	183.5	-14.660	0.231	3.653	0.048	0.93
Female	1995	91.5	220.3	-14.907	0.093	3.700	0.019	0.95

Table 2. Estimated parameters of Length-Weight relationships ($W = aTL^b$, in g and mm), per season, per sex for Rutilus rutilus *in Lake Volvi. n is the sample size, min and max the minimum and maximum total length, a and b are the parameters of the L-W relation and their standard errors ($SE_{(a)}$ and $SE_{(b)}$ and r^2 is the coefficient of determination*

Season	n	TL-range		L-W relationship				
		min	max	-ln(a)	$SD_{(a)}$	b	$SD_{(b)}$	r^2
		Combined sexes						
Spring	815	91.5	218.1	-14.65	0.16	3.63	0.03	0.94
Summer	726	96.5	190.0	-13.92	0.12	3.51	0.02	0.96
Autumn	617	98.0	220.0	-13.36	0.12	3.40	0.02	0.97
Winter	282	98.0	188.0	-14.16	0.21	3.56	0.04	0.96
		Male						
Spring	199	92.5	183.5	-14.44	0.30	3.59	0.06	0.94
Summer	120	97.0	160.0	-9.57	0.87	2.66	0.18	0.64
Autumn	103	98.0	171.5	-12.77	0.38	3.27	0.08	0.95
Winter	22	101.0	162.0	-14.05	1.02	3.61	0.21	0.94
		Female						
Spring	206	91.5	218.1	-14.77	0.19	3.65	0.04	0.93
Summer	606	96.5	190.0	-10.97	0.29	2.95	0.06	0.80
Autumn	514	101.0	220.0	-13.58	0.19	3.44	0.04	0.94
Winter	260	98.0	188.0	-15.27	0.54	3.75	0.19	0.82

were assumed to be heavier of a given length.

Differences in LWRs of roach among other studies could be attributed to one or more of the following factors (MOUTOPOULOS & STERGIOU, 2002; FROESE, 2006; MATIĆ-SKOKO *et al.,* 2011; TUTMAN *et al.*, 2018): (a) differences in the number of specimens examined, (b) area/season effects, and (c) differences in the observed length ranges and the type of length used. Seasonal differences in LWR can be attributed to biological (e.g., reproduction, sex, food availability) and/or abiotic (e.g., water temperature) factors (WOOTTON, 1999; BOBORI *et al,.* 2010). Yet, the spawning and gonad activity might affect the seasonal variations in the b values of the LWR. In the present study, b values were significantly lower during summer than in other seasons due to spring spawning period of the roach in lake Volvi (March to April) (Table 2).

The temporal variation of the condition factor may be attributed either to reproduction or to nutrition/ecological issues (MURPHY *et al,.* 1991). Most of the estimated condition factors peaked in February one month before the reproduction (Fig. 1); K_1=1.11 and, 1.13 for males and females; K_2=0.48 and 0.38, respectively; and K_3=1.25 for females. Exceptions were K_3 for males (1.17) that peaked one month earlier (January) and K_4 that peaked in August (0.35 and 0.31 for males and females). LE CREN index was slightly decreased for both sexes during February-May, likely due to the energy costs during the reproduction (Fig. 1) (WOOTTON, 1999). During autumn and winter LE CREN

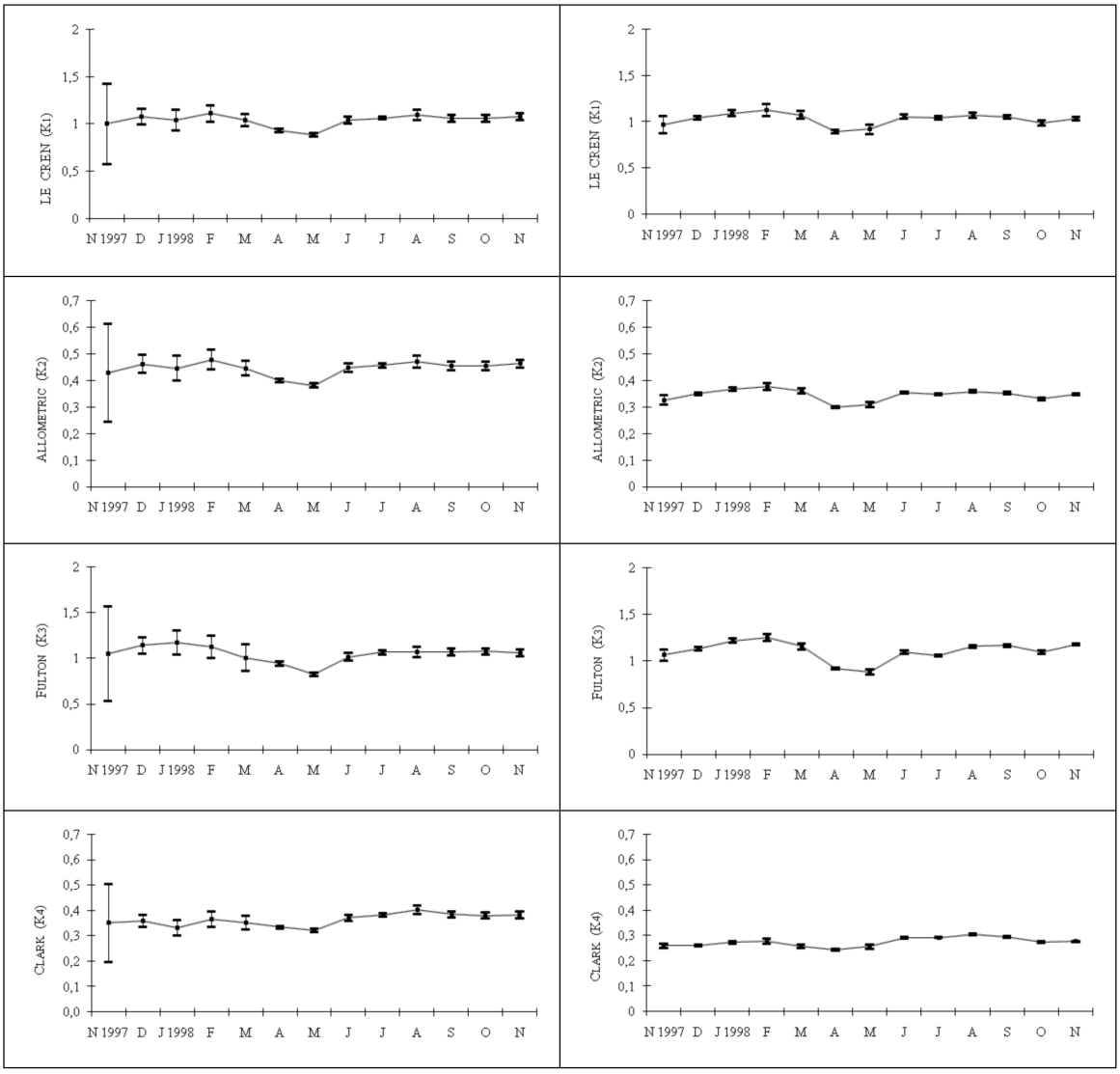

Fig. 1. Monthly variation (averages, 95% C.I) of LE CREN (K_1), Allometric (K_2), FULTON (K_3) and CLARK (K_4) condition factors per sex, male (left) and female (right) of Rutilus rutilus *in Lake Volvi*

index also exhibited a considerable increase independently of sex, because of the increase of food availability (surplus of benthic organisms that is observed during these months; WOOTTON, 1999).

FULTON index (mean value 0.99 for males, 1.07 for females and 1.06 for both sex combined) exhibited the lowest values when compared to others studies conducted worldwide for roach; Lake Aydat: 1.65 and 1.57, for males and females (JAMET & DESMOLLES, 1994); Sapanca: 1.11 and 1.17, respectively (TARKAN, 2006); Seyhan Dam: 1.472 ±0.24 and 1.404 ±0.26, respectively (ERGÜDEN *et al.,* 2008), Błotno: 1.20, Sierakowo: 1.16, and Wapnickie: 1.25 for both sex combined (RACZYŃSKI *et al.,* 2008). LE CREN and FULTON indices were higher in females than males (JAMET & DESMOLLES, 1994), whereas the inverse was true for the Allometric and CLARK indices. This is because the Allometric and CLARK indices incorporate the value of the exponent b of LWR, whereas, LE CREN and FULTON indices not. When the b values were estimated independently of sex, the Allometric and CLARK indices were also exhibiting similar results compared with the corresponding ones

Table 3. Estimates of coefficient b per sex of length-weight relationships of Rutilus rutilus from other ecosystems worldwide

Area	Regression coefficient b			Length type	Reference
	f	m	f+m		
Southern England (Stour river)	3.15	3.19	–	FL	MANN 1973
Southern England(Fromeriver)	–	–	3.30	FL	MANN 1973
England (Rostherne lake)*	3.45	3.39	–	FL	GOLDSPINK 1978
	3.34	3.04	–	FL	GOLDSPINK 1978
	3.01	3.02	–	FL	GOLDSPINK 1978
	3.71	–	–	FL	GOLDSPINK 1978
Netherland (Tjeukmeer lake)*	3.30	3.08	–	FL	GOLDSPINK 1979
	3.37	3.22	–	FL	GOLDSPINK 1979
	3.38	3.25	–	FL	GOLDSPINK 1979
	3.18	2.76	–	FL	GOLDSPINK 1979
	3.04	–	–	FL	GOLDSPINK 1979
	3.13	–	–	FL	GOLDSPINK 1979
	3.17	–	–	FL	GOLDSPINK 1979
Greece (Volvi lake)	3.61	3.40	–	TL	PAPAGEORGIOU 1979
North Iran (Gomishan wetland)	3.17	3.11	–	TL	NADDAFI et al. (2005)
North Iran (Anzali wetland)	3.22	3.20	–	TL	NADDAFI et al. (2005)
Greece (Volvi lake)	–	–	3.48	TL	TSOUMANI et al.(2012)
Greece (Chimaditida lake)			3.27	TL	TSOUMANI et al.(2012)
Greece (Doirani lake)			2.81	TL	TSOUMANI et al.(2012)
Greece (Kastoria lake)			2.97	TL	TSOUMANI et al.(2012)
Greece (Petron lake)			3.03	TL	TSOUMANI et al.(2012)
Greece (Vegoritida lake)			3.01	TL	TSOUMANI et al.(2012)
Greece (Zazari lake)			3.11	TL	TSOUMANI et al.(2012)
South-East Australia (Eildon lake)	2.81	2.90	2.98	FL	STOESSEL 2014
Greece (Volvi lake)	–	–	3.39	TL	BOBORI et al. (2017)
	3.70	3.65	3.68	TL	Present study

* multiple measurements throughout the year; FL and TL are fork and total length of fish, respectively.

estimated by LE CREN and FULTON indices exhibited better condition for the females than for males (data not shown).

CONCLUSIONS

The knowledge of Length-Weight relationship (LWR) is one of the most widely used method in fisheries research, as a proxy for fish condition based on the assumption that heavier fish of a given length are in better condition (FROESE, 2006, POPE & KRUSE, 2001). These results suggest that much of the observed variation among roach populations represent adaptations to local conditions and pressures. LE CREN and Fulton condition factors indices did not differ between sexes. However, in Allometric or CLARK indices prior knowledge of sex of roach would produce different condition factors between sexes in Lake Volvi. Consequently, differentiation of b values, between males and females, of Allometric and CLARK indices might reduce the bias produced in the estimation of fish condition. Moreover, the peak of CLARK's index condition factor in roach of Lake Volvi differentiate in terms of time with the other indices.

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Received: 26 February 2019
Accepted: 27 March 2019

Dužinsko-maseni odnos crvenoperke *Rutilus rutilus* (Linnaeus, 1758) u jezeru Volvi (sjeverna Grčka)

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SAŽETAK

Procijenjeni su odnosi duljine i težine (LWR) i različiti indeksi uvjeta za crvenperku u jezeru Volvi (sjeverna Grčka). Rezultati su pokazali da je ženka crvenperke iz jezera Volvi jednake dužine kao i primjerci iz cijelog svijeta teža nego u drugim područjima širom svijeta. Također, ženke su pokazivale veću težinu od mužjaka iste duljine.

Značajne razlike ($P < 0,05$) LWR-a također su bile između spolova, ovisno o mjesecu. Clarkov kondicijski čimbenik dosegnuo je vrhunac krajem ljeta, ne pokazujući značajnu razliku između spolova, dok su ostala tri procijenjena čimbenika stanja (alometrija, Fulton, Le Cren) dosegla vrhunac zimi. Procjena različitih zastupljenih faktora stanja prema spolu može smanjiti nesigurnost koja se javlja procjenom rasta ribe.

Ključne riječi: sezonska varijabilnost, spolno specifična, Fultonov indeks, bočate vode, Grčka