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Dr. Chryssa Anastasiadou
a. Centre for Ecological and Evolutionary Synthesis, Department of Biosciences, University of Oslo, Blindern, Oslo, Norway
b. Fisheries Research Institute, Nea Peramos, Kavala, Macedonia, Greece

Moslem Daliri
Fisheries Department, Faculty of Marine and Atmospheric Sciences, Hormozgan University, Bandar Abbas, Iran

Anthi Oikonomou
Laboratory of Zoology, Department of Biological Applications and Technology, University of Ioannina, University Campus, Ioannina, Epirus, Greece

Leif Asbjørn Völlestad
Centre for Ecological and Evolutionary Synthesis, Department of Biosciences, University of Oslo, Blindern, Oslo, Norway

Correspondence
Dr. Chryssa Anastasiadou
a. Centre for Ecological and Evolutionary Synthesis, Department of Biosciences, University of Oslo, Blindern, Oslo, Norway
b. Fisheries Research Institute, Nea Peramos, Kavala, Macedonia, Greece

Length weight relationships, relative weight and relative condition factor of three freshwater shrimps from Greece

Dr. Chryssa Anastasiadou, Moslem Daliri, Anthi Oikonomou and Leif Asbjørn Völlestad

Abstract
Length-weight relationships (LWR), relative weight and relative condition factor were studied for three freshwater carideans (*Atyaephyra acheronensis, Atyaephyra thyamisensis* and *Palaemon antennarius*) from lotic and lentic habitats of northwestern Greece. The two atyids are Adriatic-Ionian endemics while the palaemonid is distributed in the Apennine Peninsula, Sardinia, Sicily and Adriatic-Ionian eco regions. Data were collected from 760 individuals and LWR parameters were estimated by the least-squares method. Kolmogorov-Smirnov and Levene tests were used to analyse data normality and homogeneity of variances. The b values ranged from 2.908 to 4.134. More specifically, in *A. acheronensis*, R^2 ranged from 0.93 to 0.96, (b values = 2.983 - 3.673), in *A. thyamisensis*, R^2 ranged from 0.61 to 0.91, (b values = 3.489 - 3,714), and in *P. antennarius* populations, R^2 ranged from 0.47 to 0.95 (b values= 2.908 - 4.135). The relative weight showed no significant differences between sexes and species for both *A. thyamisensis* and *A. acheronensis* while for *P. antennarius* ranged from 53.07% to 93.56% for males and from 66.78% to 85.82 for females among the studied sites. The relative condition factor in *A. thyamisensis* males found 0.9 ± 0.02 and in females 1 ± 0.02 ($P < 0.05$) while in *A. acheronensis*, showed no differences between sexes. The same parameter ranged from 0.84 ± 0.02 to 1.06 ± 0.02 and from 0.79 ± 0.02 to 1.06 ± 0.02 for *P. antennarius* males and females, respectively. The present study contributes to the first recording on the LWR for the studied species, providing basic and valuable information for shrimp fisheries management.

Keywords: Caridea, Decapoda, Atyidae, Palaemonidae, morpho-gravic data, allometric growth

1. Introduction
In order to properly evaluate a fishery information on the growth processes is important to record the major morphometric and gravimetric parameters of the individuals. The growth processes of the different organisms can be assessed in various ways. One alternative way is to describe how the body mass changes with various length measures. Such length-weight relationships (LWRs) are commonly used as predictive scientific tools in fisheries (Petrakis and Stergiou, 1995; Vaslet *et al.*, 2008) [20, 24]. Knowledge on LWRs may be important for biomass estimation, evaluation of the stock condition, and when forecasting stock development. Such information is needed in order to properly manage marine and freshwater ecosystems (Ecoutin *et al.*, 2005, Daliri *et al.*, 2012a, b) [13, 9, 10]. Despite the importance of having access to LWRs, to date, little such information is available for shrimps. This is unfortunate as there is large global interest for harvested (Chu *et al.*, 1995; Guéguen, 1997; Guijarro *et al*., 2012) [8, 16, 17] and cultured marine shrimps (Araneda *et al.*, 2008) [2] and also to a lesser degree for estuarine/freshwater shrimps (Enin, 1994; Brouwer *et al.*, 2007; Deekae and Abowei, 2010) [14, 4, 11]. More information is thus needed.
The recent revisions of two freshwater natant decapod genera *Atyaephyra* de Brito Capello, 1867 and *Palaemon* Weber, 1795 (Christodoulou *et al*., 2012; Tzomos and Koukouras, 2015; Carvalho *et al*., 2014; Christodoulou *et al.*, 2016) [6, 23, 5, 7] along with the descriptions of six new species revealed a high Balkan endemism in the Mediterranean region. Seven species have been described within the genus, four of which are Balkan endemics (*A. acheronensis, A. stankoi, A. strymonensis* and *A. thyamisensis*) (Christodoulou *et al*., 2012) [6], while nine *Palaemon* species have been reported from the area with *P. antennarius* being distributed only in the Apennine Peninsula, Sardinia, Sicily and Adriatic-Ionian ecoregions

(Tzomos and Koukouras, 2015) [23]. Although there is published information on the bionomy of various species of the two genera (Christodoulou *et al*., 2016 and references herein) [7], LWRs have not been published. Further, for crustaceans such as shrimps it is not evident which length metrics are best suited for describing LWRs. Based on the above, the present study aims at: 1) reporting the LWRs, the relative weight, and the relative condition factor of three species (*Atyaephyra acheronensis*, *Atyaephyra thyamisensis* and *Palaemon antennarius*), and 2) evaluating three different body lengths in order to optimize the LWR analyses.

2. Materials and Methods

Shrimp individuals were collected during April 2004 from four sites of NW Greece [S1: Lake Pamvotis (39.3920º N, 20.5214º E), S2: Louros River (39.0314º N, 20.4626º E), S3: Acheron River (39.1396º N, 20.2914º E), S4: Thyamis River (39.3228º N, 20.0976º E)] by means of a handnet with a mesh size of 2mm and preserved *in situ* with 4% formalin solution. Species and sex were determined via stereo-microscopic inspection (LEICA MZ12^5). Gravimetric data were collected by means of a digital caliper (0.01 mm; Vogel DigiPlus) and a digital scale (0.01 g; Ohaus-Adventurer). Three body length measurements were taken on each individual: 1) CL: distance from the orbit to the posterior point of carapace, 2) TL1: distance from the orbit to the posterior point of sixth somite and 3) TL2: distance from the tip of rostrum to the posterior end of the uropodal exopod. LWRs were estimated by the equation $W = aL^b$, where W is the total weight in g, L is the measured length (CL, TL1 and TL2) in mm, a is the intercept, and b is the exponent. Parameters a and b were estimated by the least-squares method based on the logarithmic equation: logW = log a + b logL. For each specimen, Relative Weight (RW) and Relative Condition Factor (RK) were calculated using the following equations respectively:

a) RW = 100 (W/Ws), where W is the weight of a specimen and Ws is the standard weight representing the 75th percentile of observed weights at that length (Froese, 2006) [15]

b) $RK = W/aL^b$, where W is the body weight, L is CL, and a and b are the parameters of the LWR (Le Cren, 1951) [18].

Kolmogorov-Smirnov and Levene tests were used to analyse for normality of the data and homogeneity of variances. Two independent samples t-tests (5% level) were used for the comparison of the condition of males and females individuals in each ecosystem. Ovigerous females were excluded from analysis, so that the maturation state of the egg masses could not influence the comparisons. All the analyses were conducted using SPSS 11.

3. Results and Discussion

Overall, 760 individuals were collected, measured and analyzed. The results of the LWR regressions, and the relative weight and relative condition factor estimates are presented in Table 1. Among the studied species, CL ranged from 3.6 to 11.8mm, TL1 from 11.7 to 32.9mm, TL2 from 17.2 to 46.6mm and TW from 0.028 to 0.981g (Tab. 1). *A. acheronensis* and *A. thyamisensis* showed isometric ($b \approx 3$) to positive allometric ($b > 3$) growth (b= 2.983 and b=3.489, respectively), a fact that has been previously been shown for *Macrobrachium macrobrachion*, especially from estuarine ecosystems (Enin, 1994) [14]. High b values are usually correlated with eutrophic conditions and abundant food (Froese, 2006, Liasko *et al.*, 2011) [15, 19].

Among the studied ecosystems (denoted S1-S4), *P. antennarius* showed isometric [b(S4) = 2.908] to positive allometric growth patterns [b(S1) = 4.135, b(S2) = 3.477 and b(S3) = 3.294], with R^2 ranging from 0.79 to 0.95. Only the *P. antennarius* population from Acheron River (S3) demonstrated low R^2 values (Tab. 1). Similar b values have been reported for *Macrobrachium acanthurus*, *M. olfersii, Palaemon northropi* (Anger and Moreira, 1998) [1], *Palaemon serratus* (Reeve, 1969) [21], *Palaemonetes argentinus* (Donatti, 1986) [12], *M. vollenhovenii* (Willführ-Nast *et al.*, 1993) [26], *M. rosenbergii* (Wickins, 1972) [25] and *M. lamarrei* (Shafi *et al*., 1977) [22]. For the three selected lengths, the best fit for LWR was given by TL2 measurement, as has also been proposed by Anger and Moreira (1998) [1].

The relative weights (RW), which is the most valuable factor for comparative studies (Blackwell *et al.*, 2000; Daliri *et al.*, 2012a, b) [3, 9, 10], differences between the sexes in *P. antennarius* populations (Kruskal-Wallis test, $\chi^2 = 14.035$ and $P < 0.001$) (Tab. 1). The Mann-Witney U test (α=0.5) showed that the conditions are favorable for females in Lake Pamvotis (S1) and for males in Louros River (S2). Moreover, the data of the present study reveal that *A. acheronensis* had better performance (RW=89%) than *A. thyamisensis* (RW = 68%). A general linear model (GLM) analysis which was used to analyze the effect of the three factors (sex, type of species and ecosystem with interactions) on RW, showed a statistically significant interaction between the type of species and sex ($P < 0.001$). Finally, RK showed almost the same values for *Atyaephyra* species while the lowest values were observed for *P. antennarius* from the lentic habitat (S1) (Tab. 1).

This study constitutes the first report on the LWRs for 3 freshwater shrimps (*Atyaephyra acheronensis*, *Atyaephyra thyamisensis* and *Palaemon antennarius*) two of which (atyids) are Balkan endemics. Moreover, the relative weights and the relative condition factors of the studied species are given for the first time and comparatively for the four main ecosystems of north-western Greece.

Table 1: Calculated parameters of LWR, relative weights and relative condition factors for the studied species. NI: number of individuals, CL: carapace length, TL1: total length 1, TL2: total length 2, TW: total weight. Study sites: S1, S2, S3, S4 (are detailed in Material and Methods).

Species (Site)	NI	CL (mm)		TL1 (mm)		TL2 (mm)		TW (g)	
		Min	Max	Min	Max	Min	Max	Min	Max
A. acheronensis (S3)	100	3.6	7.3	11.7	21.4	17.2	29.7	0.028	0.234
A. thyamisensis (S1)	91	4.1	7.3	13.8	21.6	20.5	31.4	0.047	0.268
P. antennarius (S1)	273	5.1	11.8	15.4	32.9	22.6	46.6	0.069	0.981
P. antennarius (S2)	100	4.6	9.4	13.0	25.4	20.0	35.8	0.076	0.427
P. antennarius (S3)	95	4.4	9.1	12.9	26.1	19.1	35.5	0.044	0.435
P. antennarius (S4)	101	4.8	8.9	16.3	23.9	22.4	34.4	0.088	0.363
				Length-weight parameters					
Species (Site)	Type of Length			a		b (95% CI of b)		R^2	P
A. acheronensis (S3)	CL			$6x10^{-4}$		2.983 (2.903-3.063)		0.93	<0.001

	TL1		$8x10^{-6}$		3.303 (3.143-3.823)	0.94	<0.001
	TL2		$8x10^{-7}$		3.673 (3.523-3.823)	0.96	<0.001
A. thyamisensis (S1)	CL		$3x10^{-4}$		3.489 (3.319-3.659)	0.91	<0.001
	TL1		$5x10^{-6}$		3.499 (2.975-4.019)	0.66	<0.001
	TL2		$7x10^{-7}$		3.714 (3.194-4.234)	0.69	<0.001
P. antennarius (S1)	CL		$2x10^{-4}$		3.591 (3.481-3.701)	0.79	<0.001
	TL1		$2x10^{-6}$		3.746 (3.526-3.966)	0.81	<0.001
	TL2		$1x10^{-7}$		4.135 (3.925-4.345)	0.85	<0.001
P. antennarius (S2)	CL		$9x10^{-4}$		2.758 (2.628-2.888)	0.95	<0.001
	TL1		$8x10^{-6}$		3.381 (3.171-3.627)	0.91	<0.001
	TL2		$2x10^{-6}$		3.477 (3.327-3.627)	0.95	<0.001
P. antennarius (S3)	CL		$9x10^{-4}$		2.646 (2.056-2.846)	0.46	<0.001
	TL1		$3x10^{-5}$		2.846 (2.116-3.576)	0.39	<0.001
	TL2		$2x10^{-6}$		3.294 (2.574-4.014)	0.47	<0.001
P. antennarius (S4)	CL		$2x10^{-3}$		2.393 (2.173-2.613)	0.82	<0.001
	TL1		$4x10^{-5}$		2.836 (2.586-3.086)	0.84	<0.001
	TL2		$1x10^{-5}$		2.908 (2.688-3.128)	0.88	<0.001
Species (Site)	Sex	Ws (g)	Mean RW (%) [SE of RW]	P	Mean RK [SE of RK]		P
A. acheronensis (S3)	Males	0.0587	86.34 [4.72]	<0.25	1 [0.01]		<0.788
	Females	0.1054	88.78 [4.12]		1 [0.01]		
	Both	0.0913	79.00 [3.67]				
A. thyamisensis (S1)	Males	0.0710	88.92 [2.23]	<0.836	0.9 [0.02]		<0.002
	Females	0.2085	89.45 [2.48]		1 [0.02]		
	Both	0.1748	67.91 [3.96]				
P. antennarius (S1)	Males	0.3994	53.07 [3.22]	<0.001	0.84 [0.02]		<0.082
	Females	0.4417	84.11 [3.55]		0.79 [0.02]		
	Both	0.3998	74.65 [2.85]				
P. antennarius (S2)	Males	0.1581	93.56 [5.95]	<0.001	1.06 [0.01]		<0.927
	Females	0.3454	66.78 [5.12]		1.06 [0.02]		
	Both	0.2154	82.65 [4.46]				
P. antennarius (S3)	Males	0.1199	83.03 [3.52]	<0.466	0.91 [0.04]		<0.007
	Females	0.1753	84.95 [6.20]		1.06 [0.04]		
	Both	0.1431	86.27 [4.34]				
P. antennarius (S4)	Males	0.1529	88.00 [3.00]	<0.077	1.02 [0.02]		<0.076
	Females	0.2335	85.82 [5.48]		0.96 [0.02]		
	Both	0.1900	88.26 [3.98]				

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