www.trjfas.org
ISSN 1303-2712
Turkish Journal of Fisheries and Aquatic Sciences 13: 555-560 (2013) DOI: 10.4194/1303-2712-v13_3_21

SHORT PAPER

Weight-Length Relationships for 20 Fish Species in the Adriatic Sea

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Received 28 February 2013
Accepted 18 July 2013

Abstract

Weight-length relationships for 20 fish species in the Adriatic Sea are reported. Specimens were caught from 1999 to 2009 during fishing surveys with trammel nets at dephts ranging from 12 to 90 m. A total of 38562 individuals were collected, belonging to 20 fish species from 14 families. Sparidae included the highest number of species (4), followed by Scombridae, Carangidae and Gadidae (2 species), and by the remaining 10 families (1 species). In numerical terms, the most important species was *Chelidonichthys lucerna* (6616), followed by *Solea solea* (5401), and *Boops boops* (5257). The *b* values in the relationship $W = aL^b$ varied between 2.816 (for *Pagellus bogaraveo*) and 3.395 (for *Scomber scombrus*), and showed a mean value of 3.076 (±0.147 SD). To the authors' best knowledge, this study presents the first reference available on WLR for *P. bogaraveo* and *Alosa fallax* in the Adriatic Sea.

Keywords: Adriatic Sea, weight-length relationship, allometric growth.

Introduction

The weight-length relationship (WLR) is an useful tool in fish biology, physiology, ecology, and stock assessment. As a matter of fact, size is generally more relevant than age, mainly because several ecological and physiological factors are more size-dependent than age-dependent (Santos *et al*., 2002). Indeed, in sampling programs, it is usually easier to measure only length, while weight cannot be easily recorded. The WLR of a species allows the inter-conversion of these two parameters. In biological studies WRLs allow the assessment of seasonal variations in fish growth and the calculation of condition indexes (Richter *et al*., 2000), which is frequently used in the analysis of ontogenic changes (Safran, 1992), for between-region life-history comparisons (Weatherley and Gill, 1987; Petrakis and Stergiou, 1995) as well as to identify the spawning season (Olim and Borges, 2006). In fisheries studies WLRs have many different uses, including the estimation of weight from length (Beyer, 1991; Froese, 2006; Froese *et al*., 2011) and of weight-at-age (Petrakis and Stergiou, 1995), as well as the conversion of growth-in-length equations to growth-in-weight (Pauly, 1993).

Furthermore, WLRs allow life history and morphological comparisons between different fish species, or between fish populations from different habitats and/or regions (Gonçalves *et al*., 1997).

This study reports the WRLs of 20 fish species caught in the western portion of northern and central Adriatic Sea.

Materials and Methods

From January 1999 to December 2009 a total of 555 fishing trips using an experimental trammel net were carried out in the northern and central Adriatic Sea from 2.5 km to 80 km offshore and from 12 m to 90 m depth. In each site samplings were carried out on a monthly basis. Trammel net was chosen as sampling gear because it can be fished on a regular basis around rocky outcrops and artificial structures (artificial reefs, gas platforms, pipelines, mussel cultures, etc.). Despite its limitations in terms of selectivity and its low height relative to depth, the trammel net was chosen as being the most effective and manageable gear for carrying out investigations on different types of sea bottoms (sand, rocks, artificial reefs, etc.). In addition, trammel net are less selective than gill nets and, hence, it allows to sample fish belonging to a wider size range in comparison with other set gears (Fabi *et al*., 2002).

The length of trammel nets used in each fishing trip ranged from 600 to 1300 m.

The panels of trammel net were made of PA monofilament. The mesh opening was 72 mm for the inner panel (monofilament diameter 0.18 mm) and 400 mm for the outer panels (monofilament diameter 0.30 mm). The outer panels had a height of 3 m, while the inner panel was 6 m high. Such technical features allowed this net to be less selective in respect to the gillnets and trammel nets commonly used by fishermen in the study area.

The gear was lowered into the water at dusk and hauled in at dawn for an average fishing time of 12 h.

Fish in catches were removed from the net and preserved in ice. In the laboratory, all fishes were identified to the lowest taxonomic level, measured for total length (TL) to the nearest mm, and weighed to the nearest gram.

The relationship between weight and length was calculated using the expression: $W = aL^b$ where W is the weight (g), L the total length (mm), a the intercept (initial growth coefficient) and b the slope (growth coefficient). This equation can also be expressed in its logarithmic form: $\ln W = \ln a + b \ln L$ (Le Cren, 1951).

The parameters a and b of WLR were estimated by linear regression analysis (least-squares method) on log-transformed data. The allometry coefficient is expressed by the exponent b of the linear regression equation. In the relationships between different types of variables (linear and ponderal), WLR reflects an isometric growth when $b = 3$, i.e., relative growth of both variables is identical (Mayrat, 1970; Ricker, 1975; Quinn II and Deriso, 1999). When b value is < 3 it can be said to have a negative allometric growth and is defined hypoallometry; instead when b value is > 3 it showed a positive allometric growth and is defined hyperallometry (Shingleton *et al*., 2009; Shingleton, 2010). The b-value of each species was tested by a t-test (Sokal and Rohlf, 1987) with a confidential level of 95% in order to confirm if it was significantly different from the isometric value (H_0: b = 3).

The individual values of the condition factor were calculated using the formula $K = (W/L^b) \times 100$, where W is the weight (g), L the total length (mm) and b is the WLR growth coefficient (Bagenal and Tesch, 1978). The equation adopted reduce or eliminate the effects of allometry from estimation of fish condition. The traditional Fulton's Condition index (K=100W/L3; were K is condition factor, W is body mass and L is body length; Fulton, 1911) was excluded because this equation assumes isometric growth; i.e. that the relative proportions of body length, height and thickness do not change in fish of similar condition as these increase in weight. However, as demostrated by Bengal and Tesch (1978), fish often grow allometrically and these proportions are not constant.

Mean monthly values of condition factor were calculated for each species and compared with its spawning period reported in the literature (Froese and Pauly, 2010).

Results and Discussion

Sample descriptive statistics along with the WLR estimated parameters by species are reported in Table 1.

A total of 38562 individuals were collected, belonging to 20 fish species from 14 families. The family of Sparidae included the highest number of species (4), followed by Scombridae, Carangidae and Gadidae (2 species) and by the remaining 10 families (1 species).

The sample size ranged from 460 individuals for *P. bogaraveo* to 6616 individuals for *C. lucerna*.

Due to the gear selectivity, several samples did not include very small individuals. For this reason the use of WLRs should be limited to the size ranges applied in the estimation of the linear regression parameters (Petrakis and Stergiou, 1995; Santos *et al*., 2002) and, hence, it could be particularly dangerous to extrapolate data to fish larvae (Pepin, 1995) and juveniles (Safran, 1992).

All regressions were highly significant ($p<0.001$) and the coefficient r^2 values ranged from 0.902 for *Mullus barbatus barbatus* to 0.987 for *Merluccius merluccius*, corresponding to a mean value of 0.963 (±0.019 SD).

The highest value of parameter b was 3.395 for *S. scombrus* and the lowest one was 2.816 for *P. bogaraveo*. Mean b value was 3.076 (±0.147 SD) and median b value was 3.063.

In terms of growth type, *A. fallax*, *C. lucerna*, *Diplodus annularis*, *Gobius niger*, *Merlangius merlangus*, *M. merluccius*, *Scomber japonicus*, *S. scombrus*, *S. solea*, *Spicara maena* and *Trisopterus capelanus* showed positive allometric growth (b>3). *B. boops*, *Liza ramada*, *P. bogaraveo*, *Trachurus mediterraneus* and *Umbrina cirrosa* showed negative allometric growth (b<3). An isometric growth was observed for *Lithognathus mormyrus*, *M. barbatus barbatus*, *Scorpaena porcus* and *Trachurus trachurus*.

WLRs were not constant over the year, varying with food availability and spawning period (Bagenal and Tesch, 1978). As the samples were collected over a wide period of time, these data should be considered only as mean values, as suggested by Petrakis and Stergiou (1995) and Gonçalves *et al*. (1997). However, the parameter b is characteristic of the species (Mayrat, 1970) and generally does not vary significantly throughout the year.

The condition factor K varied between 0.2 for *S. scombrus* and 2.4 for *P. bogaraveo*. In terms of seasonality, K followed the reproductive cycle of most of species, decreasing during the spawning season and increasing after it (Figures. 1 and 2) and

Table 1. Sample descriptive statistics and parameters of the WLR of 20 fish species caught in the Adriatic Sea

Family	Species	n	Lenght characteristics				Weight characteristics				Parameters of the relationship				Kind of growth
			Max	Min	Mean	SD	Max	Min	Mean	SD	a	b	r^2	SE_b	
Clupeidae	*Alosa fallax*	573	60.0	11.6	33.4	6.8	1922	26	363.5	231.2	0.005	3.146	0.973	0.022	A+
Merlucciidae	*Merluccius merluccius*	1032	54.4	10.3	27.3	9.2	1676	6	218.7	197.2	0.003	3.239	0.987	0.011	A+
Gadidae	*Merlangius merlangus*	1282	42.5	7.2	18.2	4.4	593	2	55.3	53.1	0.005	3.152	0.976	0.014	A+
	Trisopterus capelanus	4007	31.5	9.2	17.7	3.4	408	6	70.8	53.1	0.004	3.344	0.966	0.010	A+
Carangidae	*Trachurus mediterraneus*	1671	38.5	7.0	26.2	4.4	504	2	152.9	68.5	0.010	2.933	0.976	0.011	A-
	Trachurus trachurus	696	36.5	9.1	21.8	3.9	363	6	97.2	51.0	0.009	2.972	0.966	0.021	I
Sciaenidae	*Umbrina cirrosa*	537	49.5	18.5	27.1	4.0	1281	93	240.9	133.6	0.015	2.917	0.963	0.025	A-
Mullidae	*Mullus barbatus barbatus*	1904	22.6	7.5	14.8	1.9	132	5.3	41.9	16.6	0.013	2.988	0.902	0.023	I
Sparidae	*Boops boops*	5257	35.2	10.1	20.1	3.2	403	10	84.2	45.7	0.011	2.961	0.944	0.010	A-
	Diplodus annularis	856	23.3	6.0	14.6	3.4	223	4	65.1	44.4	0.015	3.068	0.980	0.015	A+
	Lithognathus mormyrus	582	34.6	8.2	25.5	3.5	569	7	227.2	83.5	0.013	3.009	0.974	0.021	I
	Pagellus bogaraveo	460	31.0	9.5	16.2	3.1	417	16	66.4	46.3	0.024	2.816	0.963	0.026	A-
Centracanthidae	*Spicara maena*	1810	25.5	8.5	16.1	1.9	163	7	50.1	18.6	0.007	3.156	0.926	0.021	A+
Scombridae	*Scomber japonicus*	1079	43.2	13.1	33.9	4.9	698	16	375.5	137.0	0.005	3.181	0.963	0.019	A+
	Scomber scombrus	835	38.5	10.0	23.5	4.6	548	7	116.6	79.5	0.002	3.395	0.967	0.022	A+
Gobiidae	*Gobius niger*	511	15.5	5.1	11.7	2.5	50	1	22.7	11.6	0.009	3.127	0.968	0.025	A+
Mugilidae	*Liza ramada*	2204	64.3	16.1	39.3	5.3	2128	29	523.7	207.7	0.011	2.928	0.958	0.013	A-
Scorpaenidae	*Scorpaena porcus*	661	29.4	8.1	18.3	3.4	588	13	141.8	82.5	0.021	2.994	0.961	0.024	I
Triglidae	*Chelidonichthys lucerna*	6616	77.1	6.5	18.5	5.0	4900	3	73.9	108.5	0.006	3.132	0.976	0.006	A+
Soleidae	*Solea solea*	5401	37.4	12.2	22.5	3.6	425	17	108.3	54.0	0.007	3.057	0.967	0.008	A+

(n, number of specimens; max, min and mean, maximum, minimum and mean length in cm and weight in g; *a*, intercept of the relationship; *b*, slope of the relationship; r^2, coefficient of determination; SD, standard deviation; SE_b, standard error of *b*; *K*, condition factor; A+, allometric positive; A-, allometric negative; I , isometric).*

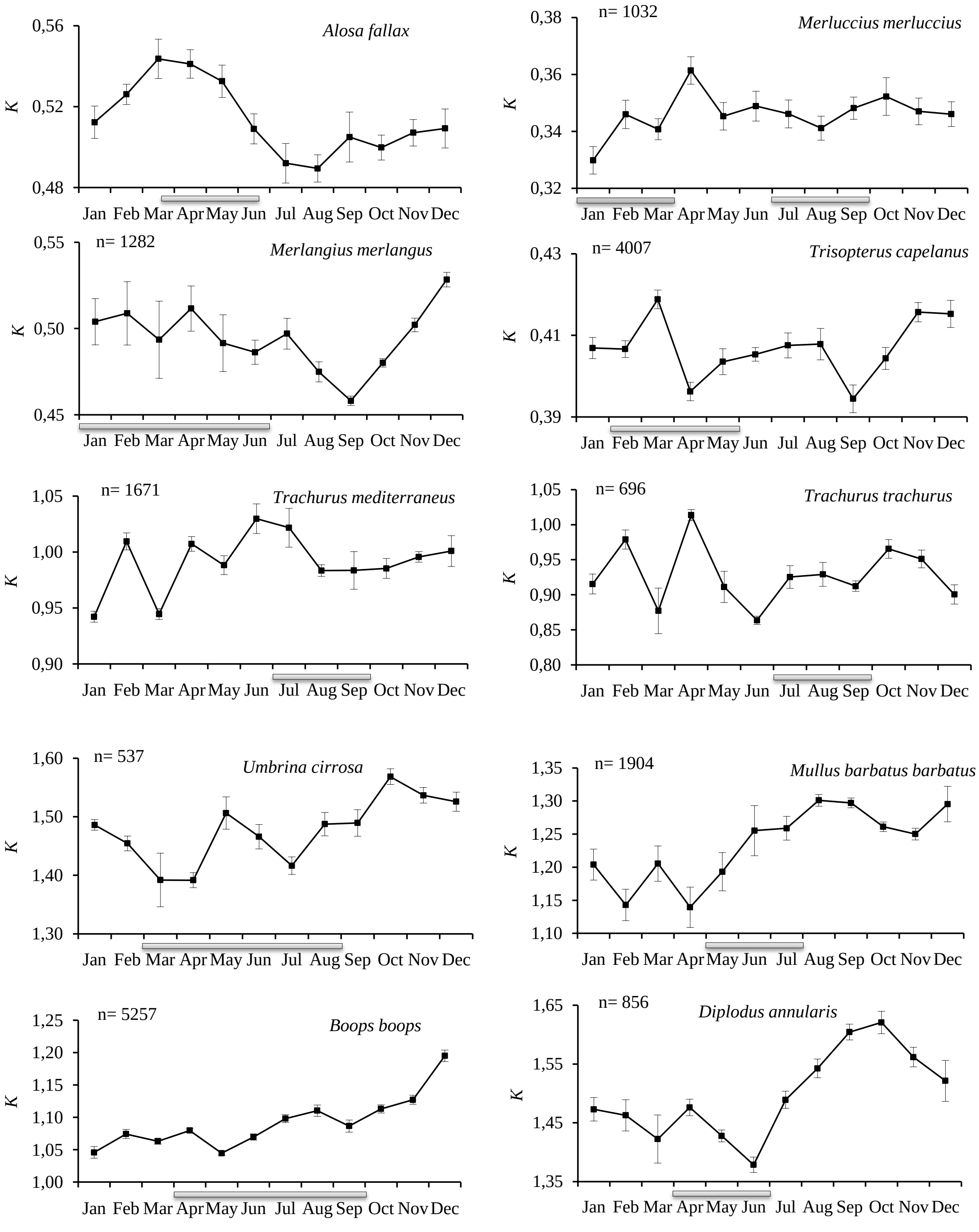

Figure 1. Monthly condition factor (K±SD) of 10 fish species caught in the Adriatic Sea. Shaded bars indicate the spawning period.

well matched with their reproductive cycle described by several authors (Froese and Pauly, 2010).

To the authors' best knowledge, this study presents the first available references on WLR for *P. bogaraveo* and *A. fallax* in the Adriatic Sea. *A. fallax* is listed in the Habitat Directive and included in the protected fauna list of the Bern Convention on the Conservation of European Wildlife and Natural Habitats.

Acknowledgements

The authors would like to acknowledge the crews of the R/V "Tecnopesca II" and of the fishing vessels "Vulcano", "Nuova Simba", "Samurai", "Gio", "Banana Joe", and "Sayonara" for their

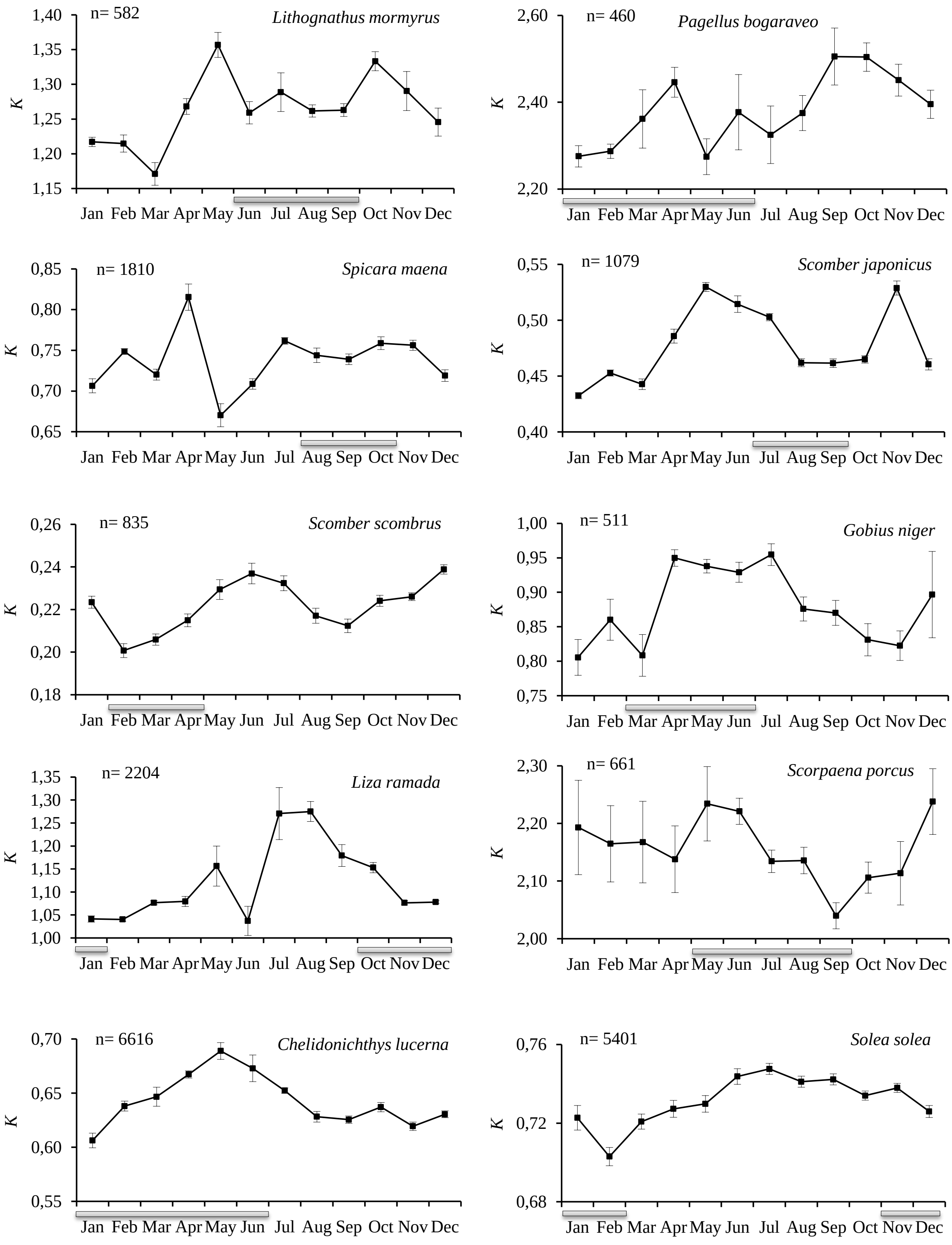

Figure 2. Monthly condition factor (*K*±*SD*) of 10 fish species caught in the Adriatic Sea. Shaded bars indicate the spawning period.

professional skill in conducting the fishing surveys. We are also very grateful to staff of CNR-ISMAR of Ancona for their collaboration during fish sampling. The authors also would like to thanks to four anonymous reviewers for their useful comments on the manuscript.

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