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Length-Weight Relationship for Twelve Species of the Genus *Salmo* L., 1758 (Actinopterygii: Salmonidae) from Inland Waters of Turkey

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Abstract: This study presents the first estimation of the length-weight relationship (*LWR*) for nine species of the genus *Salmo* that have been caught during 2009–2014 along with three predefined species from the same genus in the inland waters of Turkey. The allometric coefficient *b* of the *LWR* ranged from 3.051 to 3.256, with a mean (± SD) of 3.127 ± 0.018. We also found a new maximum total length for *S. abanticus* (45.1 cm), *S. chilo* (34.4 cm) and *S. caspius* (29.9 cm).

Key words: allometric growth, Salmonidae, trout fish, Turkey

Introduction

The length-weight relationship (*LWR*) has many applications in fish stock assessments, biomass estimations, ecological studies and modelling aquatic ecosystems (Chanchal et al. 1978, Froese 2006, Hart & Reynolds 2008). Moreover, *LWR* also provides valuable information on the habitat where the fish lives, its condition, reproduction history, life cycle and the general health of fish species (Froese et al. 2011). The relationship between fish weight and length is generally described by a power of fish length using the equation

$W = aL^b$

where W is the fish weight and L is the length. The slope (b) is the allometric coefficient, which is used to describe the three-dimensional growth (e.g., length, width and depth) of a fish. According to Froese (2006), fish growth could be isometric (b=3.0), positive allometric (b>3.0; increase in relative body thickness or plumpness) or negative allometric (b<3.0; becomes slimmer as it increases in body length).

Recently, 12 distinct species of the genus *Salmo* L., 1758 (family Salmonidae) have been identified from inland waters in Turkey:

Salmo abanticus Tortonose, 1954 restricted to the basin of the Abant Lake.

Salmo caspius Kessler, 1877 from the Kura River drainage in the Caspian Sea Basin.

Salmo platycephalus Behnke, 1968 from the upper part of the Seyhan drainage in the Mediterranean Basin.

Salmo coruhensis Turan, Kottelat &t Engin, 2009 and *Salmo rizeensis* Turan, Kottelat & Engin, 2009, two sympatric species from the rivers of northern Anatolia draining to the Black Sea.

Salmo tigridis Turan, Kottelat & Bektaş, 2011 from the Tigris drainage in the Persian Gulf Basin.

Salmo chilo Turan, Kottelat & Engin 2012, *Salmo labecula* Turan, Kottelat & Engin 2012 and *Salmo opimus* Turan, Kottelat & Engin, 2012 from rivers and streams in the Mediterranean Basin.

Salmo kottelati Turan, Doğan, Kaya & Kanyılmaz, 2014 from the Alakır Stream draining to the Mediterranean Basin.

Salmo euphrataeus Turan, Kottelat & Engin, 2014 and *Salmo okumusi* Turan, Kottelat & Engin, 2014 from the Euphrates drainage.

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Table 1. Sampling areas, sampling date and number of sampled individuals of 12 trout species belonging to the genus *Salmo*. Abbreviations: BS, Black Sea; PG, Persian Gulf; CS, Caspian Sea; M, Mediterranean Sea

Species	Sampling area		Basin	Sampling Date	n
	Province	Stream, River and Drainage			
Salmo abanticus	Bolu	Abant Lake	BS	04.09.2014	14
Salmo abanticus	Bolu	Yedigöller Lake	BS	26.11.2006	32
Salmo abanticus	Bolu	Elmalı Stream	BS	12.07.2007	24
				Total	**70**
Salmo caspius	Ardahan	Tora Stream, Kura River Drainage	CS	02.09.2006	24
Salmo caspius	Ardahan	Tora Stream, Kura River Drainage	CS	21.09.2014	19
				Total	**43**
Salmo chilo	Sivas	Akdere Stream, Ceyhan River Drainage	M	13.09.2006	28
Salmo chilo	Sivas	Akdere Stream, Ceyhan River Drainage	M	17.09.2012	4
				Total	**32**
Salmo coruhensis	Erzurum	Çayırbaşı Stream, Çoruh River Drainage	BS	25.08.2006	37
Salmo coruhensis	Bayburt	Kurtboğazı Stream, Çoruh River Drainage	BS	29.08.2007	7
Salmo coruhensis	Rize	Söğütlü Stream	BS	20.02.2007	15
Salmo coruhensis	Sivas	Yeşilırmak River	BS	12.09.2006	8
				Total	67
Salmo euphrataeus	Erzurum	Rizekent Stream, Fırat River Drainage	PG	28.10.2006	6
Salmo euphrataeus	Erzurum	Rizekent Stream, Fırat River Drainage	PG	29.08.2007	12
Salmo euphrataeus	Erzurum	Şenyurt Stream, Fırat River Drainage	PG	24.08.2006	16
				Total	**34**
Salmo kottelati	Antalya	Alakır Stream	M	15.09.2008	35
				Total	**35**
Salmo labecula	Isparta	Kartoz Stream, Köprüçay Drainage	M	26.07.2006	5
Salmo labecula	Niğde	Ecemiş Stream (upper station), Seyhan Drainage	M	04.07.2007	6
Salmo labecula	Niğde	Ecemiş Stream (upper station), Seyhan Drainage	M	27.06.2013	9
				Total	**20**
Salmo okumusi	Sivas	Gökpınar Stream, Fırat Drainage	PG	13.09.2006	15
Salmo okumusi	Sivas	Gökpınar Stream, Fırat Drainage	PG	17.09.2012	5
Salmo okumusi	Malatya	Surgu Stream, Fırat Drainage	PG	14.09.2006	12
Salmo okumusi	Sivas	Tohma Stream, Fırat Drainage	PG	22.06.2005	10
				Total	**42**
Salmo opimus	Antalya	Alara çayı (upper station)	M	05.07.2007	14
Salmo opimus	Kahramanmaraş	Çağlayan Stream, Ceyhan River Drainage	M	12.06.2005	10
Salmo opimus	Kahramanmaraş	Fırnıs Stream, Ceyhan River Drainage	M	04.07.2007	14
				Total	**38**
Salmo platycephalus	Kayseri	Pınarbaşı Stream, Seyhan River Drainage	M	12.06.2005	29
Salmo platycephalus	Kayseri	Pınarbaşı Stream, Seyhan River Drainage	M	15.09.2006	13
				Total	**42**
Salmo rizeensis	Artvin	Dörtkilise Stream, Çoruh River Drainage	BS	10.06.2007	6
Salmo rizeensis	Rize	Erenler Stream	BS	14.10.2006	10
Salmo rizeensis	Rize	Fırtına Stream	BS	05.11.2006	9
Salmo rizeensis	Rize	Salarha Stream	BS	11.08.2007	8
Salmo rizeensis	Rize	Çoruh River	BS	07.07.2004	3
				Total	**36**
Salmo tigridis	Van	Elma Stream, Dicle River Drainage	PG	05.09.2006	10
Salmo tigridis	Van	Çatak Stream, Dicle River Drainage	PG	10.07.2011	5
				Total	15
				All	474

The *LWR* of these fishes (except *S. coruhensis*, *S. opimus* and *S. rizeensis*) are unavailable in the literature and hence, for the first time this study reports the *LWR* and *LLR* (length-length relationship) for them along with their maximum total length. This study also aims to verify the previously reported the *LWR* of *S. coruhensis*, *S. opimus* and *S. rizeensis*.

Materials and Methods

Fishes were sampled from 28 localities of the inland waters of Turkey (Table 1) with 60-Hz pulsed DC electric fishing equipment. Sampled fishes were killed with an overdose anaesthesia (tricaine methanesulphonate, MS-222) prior to being preserved in 5% formalin for further laboratory study. The sampling area, date and quantity of sampled fish have been also recorded and are provided in Table 1.

In the laboratory, all fish were identified to species or subspecies level and were weighted to the nearest 0.01 g. The total length (*TL*), fork length (*FL*) and standard length (*SL*) of each specimen was measured to the nearest 0.01 mm. All specimens examined in this study are deposited in the Zoology Museum of the Faculty of Fisheries, Recep Tayyip Erdoğan University, Rize, Turkey.

The *LWR* of each species was determined according to the following equation:

$$W = aTL^b \Rightarrow \log W = \log a + \log TL \times b \quad (1)$$

While the *LLR* was calculated as:

$$FL = a + bTL \quad (2)$$

$$SL = a + bTL \quad (3)$$

$$SL = a + bFL \quad (4)$$

where *a* is the intercept while *b* is the slope.

The parameters *a* and *b* were calculated using least squares regression analysis with MS Excel software.

The Student's *t*-test and Pauly's *t*-test was used to check for statistical deviation of *b*, of each species, from that for the isometric range (3.0). The Pauly's *t*-test has been performed as:

$$t = \frac{Sd_{\log TL}}{Sd_{\log W}} \frac{|b-3|}{\sqrt{1-r^2}} \sqrt{n-2}$$

where Sd_{logTL} is the standard deviation of the log *TL* values, Sd_{logW} is the standard deviation of the log *W* values, n is the number of the fish species used in the computation. The value of *b* is different from *b* = 3 if the obtained *t*-value is greater than the critical *t* values for n-2 degrees of freedom (Pauly 1984).

Table 2. Basic data with the estimated intercept (*a*) and allometric coefficient (*b*, with95% CL) for 12 species of the genus *Salmo* calculated using $W = aTL^b$ $W = aTL^b$. Abbreviations: *TL,* total length; (n), No *LWR* reference in FishBase (http://www.fishbase.org); L, introducing new records of maximum total length. Growth pattern: i=isometry; p=positive allometry.

			Length characteristics (*TL*, cm)				Parameters of the length-weight relationship						
									95% CL (*b*)				
	Species	Sample size, *n*	Mean	S.E.	Min	Max	*a*	*b*	Lower	Upper	r^2	Pauly's t-test	*P*
1	*Salmo chilo*(n)(L)	32	21.6	1.1	11.4	34.4	0.009	3.129p	3.053	3.205	0.996	3.466	<0.05
2	*Salmo coruhensis*	67	17.5	0.7	6.7	34.0	0.010	3.084p	3.021	3.146	0.993	2.678	<0.05
3	*Salmo euphrataeus*(n)	34	17.8	0.9	6.9	28.7	0.011	3.051i	2.944	3.159	0.991	0.969	>0.1
4	*Salmo kottelati*(n)	35	16.6	0.5	11.3	24.5	0.008	3.160i	2.893	3.426	0.946	1.221	>0.1
5	*Salmo labecula*(n)	20	19.5	1.1	10.5	27.1	0.009	3.119p	2.995	3.243	0.994	2.019	<0.1
6	*Salmo okumusi*(n)	42	16.8	0.8	7.2	29.7	0.010	3.085p	3.028	3.142	0.997	3.018	<0.05
7	*Salmo opimus*	38	17.6	0.8	10.7	34.9	0.006	3.256p	3.148	3.364	0.990	6.452	<0.001
8	*Salmo rizeensis*	36	17.6	0.8	7.9	28.2	0.007	3.188p	3.090	3.286	0.992	3.898	<0.001
9	*Salmo tigridis*(n)	15	15.8	1.5	7.9	26.0	0.010	3.144p	3.052	3.236	0.998	3.367	<0.05
10	*Salmo abanticus*(n)(L)	70	16.3	1.0	5.6	45.1	0.008	3.112p	3.052	3.172	0.994	3.737	<0.001
11	*Salmo caspius*(n)(L)	43	20.6	0.8	7.7	29.9	0.008	3.132p	3.054	3.210	0.994	3.417	<0.05
12	*Salmo platycephalus*(n)	42	17.4	0.8	6.6	28.6	0.011	3.060i	2.953	3.166	0.988	1.130	>0.1

Table 3. The parameters of the length-length relationship of 12 species belonging to the genus *Salmo* together with the number of specimens measured (*n*).

	Species	n	Equation	*b*(± SE)	95% CL (*b*)	r2
1	*Salmo abanticus*	70				
	TL-FL		FL=-0.726+1.0081TL	1.0081 ± 0.0023	1.0036 — 1.0126	0.999
	TL-SL		SL=-0.622+0.8829TL	0.8829 ± 0.0035	0.8758 — 0.8899	0.999
	FL-SL		SL=0.0155+0.8756FL	0.8756 ± 0.0034	0.8689 — 0.8824	0.999
2	*Salmo caspius*	43				
	TL-FL		FL=-0.635+0.9940TL	0.9940 ± 0.0044	0.9852 — 1.0028	0.999
	TL-SL		SL=-0.438+0.8547TL	0.8547 ± 0.0079	0.8388 — 0.8706	0.997
	FL-SL		SL=0.114+0.8595FL	0.8595 ± 0.0078	0.8439 — 0.8752	0.997
3	*Salmo chilo*	32				
	TL-FL		FL=-0.589+0.9964TL	0.9964 ± 0.0037	0.9889 — 1.0039	0.999
	TL-SL		SL=-0.803+0.8837TL	0.8837 ± 0.0049	0.8736 — 0.8939	0.999
	FL-SL		SL=-0.270+0.8864FL	0.8864 ± 0.0067	0.8728 — 0.9000	0.998
4	*Salmo coruhensis*	67				
	TL-FL		FL=-0.452+0.9969TL	0.9969 ± 0.0024	0.9921 — 1.0016	0.999
	TL-SL		SL=-0.467+0.8779TL	0.8779 ± 0.0035	0.8708 — 0.8849	0.999
	FL-SL		SL=-0.066+0.8805FL	0.8805 ± 0.0034	0.8738 — 0.8873	0.999
5	*Salmo euphrataeus*	34				
	TL-FL		FL=-0.675+0.9978TL	0.9978 ± 0.0045	0.9887 — 1.0069	0.999
	TL-SL		SL=-0.691+0.8716TL	0.8716 ± 0.0058	0.8598 — 0.8835	0.999
	FL-SL		SL=-0.099+0.8735FL	0.8735 ± 0.0048	0.8636 — 0.8833	0.999
6	*Salmo kottelati*	35				
	TL-FL		FL=-0.494+0.978TL	0.9780 ± 0.0051	0.9675 — 0.9884	0.999
	TL-SL		SL=-0.349+0.8416TL	0.8416 ± 0.0150	0.8110 — 0.8723	0.989
	FL-SL		SL=0.084+0.8601FL	0.8601 ± 0.0156	0.8282 — 0.8919	0.989
7	*Salmo labecula*	20				
	TL-FL		FL=-0.595+1.001TL	1.0010 ± 0.0069	0.9864 — 1.0156	0.999
	TL-SL		SL=-0.767+0.8844TL	0.8844 ± 0.014	0.8549 — 0.9138	0.995
	FL-SL		SL=-0.242+0.8835FL	0.8835 ± 0.0125	0.8572 — 0.9098	0.996
8	*Salmo okumusi*	42				
	TL-FL		FL=-0.404+0.9852TL	0.9852 ± 0.0035	0.9782 — 0.9922	0.999
	TL-SL		SL=-0.459+0.8593TL	0.8593 ± 0.0048	0.8494 — 0.8692	0.999
	FL-SL		SL=-0.1025+0.8719FL	0.8719 ± 0.0049	0.8619 — 0.8819	0.999
9	*Salmo opimus*	38				
	TL-FL		FL=-0.374+0.9742TL	0.9742 ± 0.0041	0.9659 — 0.9826	0.999
	TL-SL		SL=-0.608+0.8646TL	0.8646 ± 0.0087	0.8469 — 0.8823	0.996
	FL-SL		SL=-0.273+0.8873FL	0.8873 ± 0.0086	0.8699 — 0.9048	0.997
10	*Salmo platycephalus*	42				
	TL-FL		FL=-0.279+0.9749TL	0.9749 ± 0.0038	0.9671 — 0.9827	0.999
	TL-SL		SL=-0.067+0.8373TL	0.8373 ± 0.0081	0.8209 — 0.8537	0.996
	FL-SL		SL=0.177+0.8587FL	0.8887 ± 0.0082	0.8422 — 0.8752	0.996
11	*Salmo rizeensis*	36				
	TL-FL		FL=-0.525+0.9974TL	0.9974 ± 0.0033	0.9907 — 1.0041	0.999
	TL-SL		SL=-0.174+0.8592TL	0.8592±0.0045	0.8501 — 0.8684	0.999
	FL-SL		SL=0.282+0.8612FL	0.8612±0.0048	0.8514 — 0.8710	0.999
12	*Salmo tigridis*	15				
	TL-FL		FL=-0.487+1.0026TL	1.0026±0.0035	0.9951 — 1.0101	0.999
	TL-SL		SL=-0.305+0.8696TL	0.8696±0.0055	0.8577 — 0.8815	0.995
	FL-SL		SL=0.118+0.8673FL	0.8673±0.0049	0.8569 — 0.8778	0.999

Table 4. Previously reported length-weight relationships for *Salmo coruhensis, Salmo platycephalus* and *Salmo rizeensis* along with the maximum length of *Salmo abanticus*, *Salmo chilo* and *Salmo caspius*. Abbreviations: *a*: intercept, *b*: allometric coefficient.

Valid name	Synonym	*Sample size, n*	Sex	Length (cm)			*a*	*b*	r^2	Study area	References
					Minimum	Maximum					
Salmo abanticus	————	6	♀	SL	112.2	19.0	——	——	——	Abant Lake, Bolu	Turan et al. (2009)
	————	7	♂		11.3	22.2	——	——	——		
Salmo caspius	————	11	♀	SL	13.0	24.0	——	——	——	Caspian Sea, Kura River, Ardahan	Turan et al. (2009)
		12	♂		16.0	25.0	——	——	——		
Salmo coruhensis	*Salmo trutta labrax*	25	Combined	TL	9.5	37.9	0.0110	3.070	0.980	Göbekli Lake, Upper Coruh River	Yıldırım et al. (2012)
Salmo coruhensis	*Salmo trutta labrax*	38	Combined	TL	16.5	42.2	0.0120	3.040	0.980	Koyun Lake, Upper Coruh River	Yıldırım et al. (2012)
Salmo opimus	*Salmo trutta macrostigma*	118	♀	FL	8.0	48.5	0.0163	2.971	0.990	Fırnız Stream, Ceyhan River	Alp et al. (2005)
		79	♂		9.0	34.0	0.0149	3.009	0.988		
		197	Combined		8.0	48.5	——	——	——		
Salmo platycephalus	————	10	Juvenile	FL	11.34	19.0	——	——	——	Zamantı Stream, Seyhan River Drainage	Kara et al. (2011)
		57	♀		13.68	40.06	——	——	——		
		46	♂		15.15	39.2	——	——	——		
		113	Combined		11.3	40.1	0.0162	2.938	0.989		
Salmo platycephalus	————	10	♀	SL	15.8	21.8	——	——	——	Mediterranean Sea, Seyhan River, Kayseri	Turan et al. (2009)
		10	♂		13.7	21.7	——	——	——		
Salmo rizeensis	*Salmo trutta macrostigma*	85	♀	FL	22.8		0.015	2.939	——	Upper Aksu Stream	Arslan et al. (2007)
		78	♂		21.8		0.015	2.928	——		
		163	Combined		5.7	22.8	0.015	2.932	——		

Table 4. Continuation.

Valid name	Synonym	*Sample size, n*	Sex	Length (cm)			*a*	*b*	r^2	Study area	References
					Minimum	Maximum					
Salmo rizeensis	*Salmo trutta macrostigma*	124	♀	TL	9.5	30.4	0.0176	2.788	0.848	Uzungöl Stream	Kocabas et al. (2011)
		134	♂		9.0	3 7.8	0.0115	2.949	0.948		
		258	Combined		9.0	37.8					
Salmo rizeensis	*Salmo trutta macrostigma*	250	♀	FL	——	——	0.0141	2.96	0.960	Kan Stream, Coruh Basin	Arslan et al. (2004)
		239	♂		——	——	0.0147	2.96	0.980		
		509	Combined		——	——	0.0141	2.97	0.980		
Salmo rizeensis	*Salmo trutta macrostigma*	163	Combined	FL	5.0	30.0	0.0112	2.950	0.974	Uzungöl Stream	Kocabas et al. (2012)
Salmo rizeensis	*Salmo trutta macrostigma*	163	Combined	TL	6.6	21.7	0.0150	2.930	0.980	Aksu Stream, Upper Coruh River	Yıldırım et al. (2012)

Results

This study introduced new maximum length for *S. abanticus*, *S. chilo* and *S. caspius* (Table 2). Furthermore, the results indicated that the *LWR* and the *LLR* were highly correlated ($r^2 > 0.98$).

We report here, for the first time from the inland waters of Turkey, the *LWR* for *S. chil*o, *S. euphrataeus*, *S. kottelati*, *S. labecula*, *S. okumusi*, *S. tigridis*, *S. abanticus*, *S. caspius* and *S. Platycephalus*, including the re-examination of *S. opimus*, *S. rizeensis* and *S. coruhensis*. The results showed that nine out of 12 species had positive allometric pattern of growth, while the others had isometric growth (Table 2). The estimated *LLR* parameters are given in Table 3.

Discussion

The *LWR* of *S. coruhensis* we recorded in the present study (Table 4), was consistent with that previously reported (Yildirim et al. 2012); determining its growth pattern as positive allometric. This study has also revealed that *S. opimus* and *S. rizeensis* grow in positive allometric rather than negative allometric which is in contrast with the results from other study (see Table 4).

According to Fish Base data (http://www.fishbase.org) accessed in January 2017, the present study introduced three new records for maximum length for *S. abanticus* (45.1 cm), *S. chilo* (34.4 cm) and *S. caspius* (29.9 cm). The previous records of maximum length (standard length) for these species were 30.0 cm for *S. abanticus* (Turan et al. 2014), 23.5 cm for *S. chilo* (Turan et al. 2014) and 24.0–25.0 cm for *S. caspius* (Turan et al. 2009).

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