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Relationships of Otolith Dimensions with Body Length of European Perch, *Perca fluviatilis* L., 1758 From Lake Ladik, Turkey

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Abstract.- The relationship between the otolith and body growth of the European perch ranging in total length from 8.7 to 25.9 cm was examined. Otolith length, height and weight were recorded for each pair of sagittae. The relationships between otolith variables and fish somatic growth were described with a non-linear function (power model). An analysis of covariance revealed differences in these relationships between females and males. The measurement most strongly related to fish body length was the otolith weight, with 87.5% of the variability in females and the otolith length, with 82.9% in males. The mean percent prediction errors were less than 8%. Therefore, the results confirmed that otolith growth reflected somatic growth, but that differed between sexes.

Key words: European perch, *Perca fluviatilis*, otolith morphometry, body length.

INTRODUCTION

The European perch, *Perca fluviatilis* L., 1758 (Perciformes, Percidae), is a freshwater fish living in lakes and streams, although it also occurs in brackish waters (Slastenenko, 1956). It is widespread in nearly all of Europe is found inland bodies of water of Thrace, Aegean and Black Sea regions in Turkey (Geldiay and Balik, 2007). This species is important both commercially and for sport fishing, and it has been successfully introduced beyond its native area, into Australia, New Zealand and South Africa (Thorpe, 1977; Craig, 2000). Females grow larger than males, attaining up to 21 years (Jellyman, 1980; Kottelat and Freyhoff, 2007; Ceccuzzi *et al*., 2011). Nevertheless, its growth varies widely depending on bodies of water (Ceccuzzi *et al*., 2011). The diet of European perch is variable, consisting zooplankton, benthic invertebrates and fish, and this species often undergoes one and two ontogenetic diet shifts during its development (Persson, 1987; Persson *et al*., 1991). The spawning period of European perch occurs from February to July, depending on latitude and altitude, when water temperature reaches about 6 °C (Thorpe, 1977; Kottelat and Freyhoff, 2007).

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Otolith, an organ of balance and hearing, is calcium carbonate structure found in both side of head of fishes except sharks, rays, and lampreys (Campana, 2004). All bony fishes have three pairs of otoliths: the sagittae, lapilli, and asterisci. The size and shape of otoliths vary significantly among species (Campana and Thorrold, 2001). The sagitta is often the largest otolith in the majority of fishes (Tuset *et al*., 2008); however, the asteriscus is greater in ostariophysian fishes (Harvey *et al*., 2000; Campana, 2004). Sagittal and asterisci otoliths differ among species, while lapillar shape is more uniform (Campana, 2004). Otoliths have been used in ageing (Vilizzi and Walker, 1995; Polat *et al*., 2005; Gumus *et al*., 2007), stock discrimination (Campana and Casselman, 1993; DeVries *et al*., 2002), eco-morphological studies (Aguirre and Lombarte, 1999; Velpedo and Echeverria, 2003; Tuset *et al*., 2010) and species-specific identification (Assis, 2003, 2005; Tuset *et al*., 2006; Bani *et al*., 2013).

Although *Perca fluviatilis* is a predator fish species, it is an important prey for top predators such as *Esox lucius*, *Sander lucioperca*, *Silurus glanis*, and *Lutra lutra* (Adams, 1991; Czarnecki *et al*, 2003; Copp and Kovac, 2003; Kangur *et al*., 2007). The reconstruction of the original length of this prey fish in stomach contents of these top predators is a necessary step for understanding of the feeding ecology of before-mentioned piscivorous animals. Investigations on relationship between bony structure morphometry and fish size of the European perch are practically absent (Copp and Kovac, 2003). Therefore, the aim of present study was to describe the relationships between otolith growth and somatic growth of European perch inhabiting Lake Ladik, Turkey.

MATERIALS AND METHODS

Fish were collected from different regions of the Lake Ladik on monthly basis between November 2009 and October 2010. This lake is a wetland with eutrophic character, has surface area of 10 km^2 and a maximum depth of 6 m (Yilmaz *et al*., 2013). The specimens were caught using gillnets with meshes of 20x20, 25x25, 30x30, 35x35, and 40x40 mm. A total of 495 specimens, 403 females and 92 males, were captured during the sampling period. To reduce the influence on the results of differences in the number of samples of both sexes, the sample size was adjusted to 92 for females by using random sub-sampling (Tuset *et al.*, 2003). Fish were measured to the nearest 0.1 cm for total length (TL). The sagittal otolith pairs from each fish were removed, cleaned and stored dry in properly labelled envelopes. The otolith weight (OW) was recorded to the nearest 0.1 mg. All otoliths were photographed on both distal and proximal side with a Leica DFC295 digital camera. Otolith length (OL), defined as the greatest distance between anterior and posterior edge, and otolith height (OH), described as the greatest distance from dorsal to ventral edge (Fig. 1), were measured to the nearest 0.001 mm using Leica Application Suit ver. 3.8 Imaging Software (Battaglia *et al*., 2010). Differences between the right and left otolith measurements were analyzed using a paired t-test. The t-test was used to compare fish and otolith variables between sexes. The relationships between otolith measurements and fish size were determined by fitting a power equation $Y = aX^b$, where Y is otolith dimension, X is fish length, a is the intercept, and b is the slope. The parameters a and b were estimated through the linear regression analysis based on logarithms, log Y = log a + b log X. The significance of the regressions was verified using the F-test (Zar, 1999). The statistical differences in regression slopes between sexes were examined with the analysis of covariance (ANCOVA), sex as the main factor and TL as the covariate. The t-test was used to compare the slopes with a value corresponding to isometry (Zar, 1999). The strength of each of relationships was evaluated from the determination coefficient (r^2) and the mean percent prediction errors. The mean percent prediction error for a regression is average of the percent prediction error (% PE) values calculated for all individuals. The percent prediction error (% PE) for an individual is computed by the following formula:

$$\%PE = \frac{\left| X_{\text{Predicted}} - X_{\text{Observed}} \right|}{X_{\text{Observed}}} \times 100$$

The difference between observed and predicted TL value was checked for each otolith measurement by using t-test, and the analysis of variance (ANOVA) was used to compare the differences between %PE values of three otolith parameters (Zar, 1999).

RESULTS

A paired t-test showed no considerable differences between the right and left otolith measurements (OL, t = -0.49, P = 0.626; OH, t = -1.20, P = 0.233; OW, t = 1.73, P = 0.085) (Table I). Therefore, the right otoliths were chosen for the generation of regression equations. The descriptive statistics of fish and otolith variables are given in Table II. The differences between sexes were found in TL (t = 5.73, P = 0.000), OL (t = 3.09, P = 0.002), and OH (t = 2.60, P = 0.010), while OW did not show variability between females and males (t = 1.71; P = 0.090). Thus, otolith dimensions-fish length relationships were generated separately according to sex.

Table I.- Comparison between right and left sides of otolith length (OL, mm), otolith height (OH, mm) and otolith weight (OW, mg) measurements of European perch sampled from Lake Ladik by the paired t-test.

Measure	n	Mean±SD	Min - Max
OL	184	5.56±0.84	3.54-7.72
		5.57±0.85	3.46-7.93
OH	184	2.86±0.40	1.82-3.99
		2.87±0.41	1.88-3.99
OW	184	14.53±5.86	3.2-31.6
		14.43±5.85	3.1-31.2

Table II.- The descriptive statistics of fish total length (TL, cm), otolith length (OL, mm), otolith height (OH, mm) and otolith weight (OW, mg) of European perch sampled from Lake Ladik and differences between females and males tested by t-test.

Measure	Sex	n	Mean±SD	Min - Max
TL	Female	92	15.81±3.31	8.7-25.9
	Male	92	13.37±2.38	9.2-20.6***
OL	Female	92	5.75±0.86	3.54-7.72
	Male	92	5.37±0.79	3.61-7.21***
OH	Female	92	2.94±0.42	1.82-3.99
	Male	92	2.79±0.36	1.93-3.70**
OW	Female	92	15.27±5.93	3.2-29.5
	Male	92	13.80±5.72	3.7-31.6

All regressions were highly significant (P<0.001) and analysis of otolith morphometric parameters versus TL indicated that the regression models explained more than 80% of the variance in most of cases (Table III, Fig. 2). The coefficients of determination (r^2) ranged from 0.836 to 0.875 in females, and from 0.778 to 0.829 in males, being higher for females in all cases. The variable most strongly related to fish size was the otolith weight (OW), with 87.5% of the variability in females and the otolith length (OL), with 82.9% in males. The ANCOVA test showed significant differences between slopes of females and males for TL-OL (F = 7.15, P = 0.008) and TL-OW (F = 7.11, P = 0.008) relationships, while no significant difference was observed in slopes of TL-OH relationship of females and males (F = 1.96, P = 0.163). The slopes of all equations were higher for males (Table III, Fig. 3). The relationships of otolith length and height against fish length were negative allometric (t-test; TL-OL, t = -10.26; TL-OH, t = -13.35; P < 0.001 for females and TL-OL, t = -4.79; TL-OH, t = -7.95; P < 0.001 for males), indicating that the growth of otolith length and height is relatively slower than fish body length. In contrast, TL-OW relationship was positive allometric (t-test; t = 11.79; P < 0.001 for females and t = 9.93; P < 0.001 for males), implying that the accretion of otolith weight is relatively faster than fish size.

The mean percent prediction errors ranged from 6.09 to 6.89 for females and from 5.97 to 7.31 for males (Table IV). The otolith height (OH) had the lowest value of mean %PE in females, while otolith length (OL) had the lowest value of mean %PE in males. For each otolith variable, there was no significant difference between observed and predicted TL values in both females (t-test; OL, t = 0.10, P = 0.919; OH, t = 0.09, P = 0.926; OW, t = 0.07, P = 0.945; d.f. = 182) and males (t-test; OL, t = 0.13, P = 0.893; OH, t = 0.15, P = 0.877; OW, t = 0.17, P = 0.868; d.f. = 182). Non-statistical significant differences were noted in the mean %PE values of otolith parameters in both females (ANOVA, F = 0.28, P = 0.756) and males (ANOVA, F = 0.31, P = 0.733).

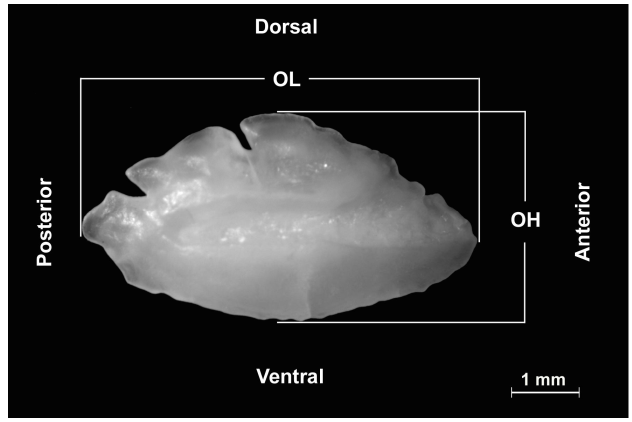

Fig. 1. Proximal view and measurement axes of the sagittal otolith of European perch from Lake Ladik.

DISCUSSION

Our results indicated that there was no significant difference between right and left otolith measurements. Therefore, one of the right or left otolith can be selected randomly when back-calculating fish size from otolith-somatic growth relationships. The considerable differences between right and left otolith variables are usually not observed for "round" fish (Morley and Belchier, 2002; Takabayashi and Ohmura-Iwasaki, 2003; Lychakov and Rebane, 2005; Megalofonou, 2006; Morat *et al.*, 2008; Jawad *et al.*, 2011; Bilge, 2013). In contrast, right versus left asymmetry is common in flatfish (Hunt, 1992; Campana, 2004; Merigot *et al.*, 2007). Toole *et al.* (1993) reported that the development of the asymmetry between right and

Table III.- Regression parameters of the relationships between otolith dimensions and fish size of European perch sampled from Lake Ladik and ANCOVA test for comparing the slopes between sexes.

Relationship	Female						Male						ANCOVA	
	n	a	b	SE (b)	r^2	P	n	a	b	SE (b)	r^2	P		
TL vs OL	92	0.877	0.682	0.031	0.836	<0.001	92	0.646	0.817	0.039	0.829	<0.001	7.15	0.008
TL vs OH	92	0.486	0.653	0.026	0.869	<0.001	92	0.437	0.714	0.036	0.815	<0.001	1.96	0.163
TL vs OW	92	0.078	1.896	0.076	0.875	<0.001	92	0.035	2.281	0.129	0.778	<0.001	7.11	0.008

TL, total length; OL, otolith length; OH, otolith height, OW, otolith weight; n, sample size; a, constant; b, slope; SE, standard error; r^2, coefficient of determination; P, probability

Table IV.- The mean percent prediction error (%PE) value calculated for each variable of otolith of European perch in Lake Ladik.

Measure	Female				Male			
	n	Observed TL (Mean±SD)	Predicted TL (Mean±SD)	%PE±SD	n	Observed TL (Mean±SD)	Predicted TL (Mean±SD)	%PE±SD
OL	92	15.81±3.31	15.88±3.45	6.89±5.91	92	13.37±2.38	13.41±2.41	5.97±4.59
OH	92	15.81±3.31	15.83±3.44	6.09±4.98	92	13.37±2.38	13.45±2.43	6.31±4.81
OW	92	15.81±3.31	15.86±3.33	6.21±4.61	92	13.37±2.38	13.46±2.46	7.31±4.95

TL, total length; OL, Otolith length; OH, otolith height, OW, otolith weight; n, sample size; SD, standard deviation

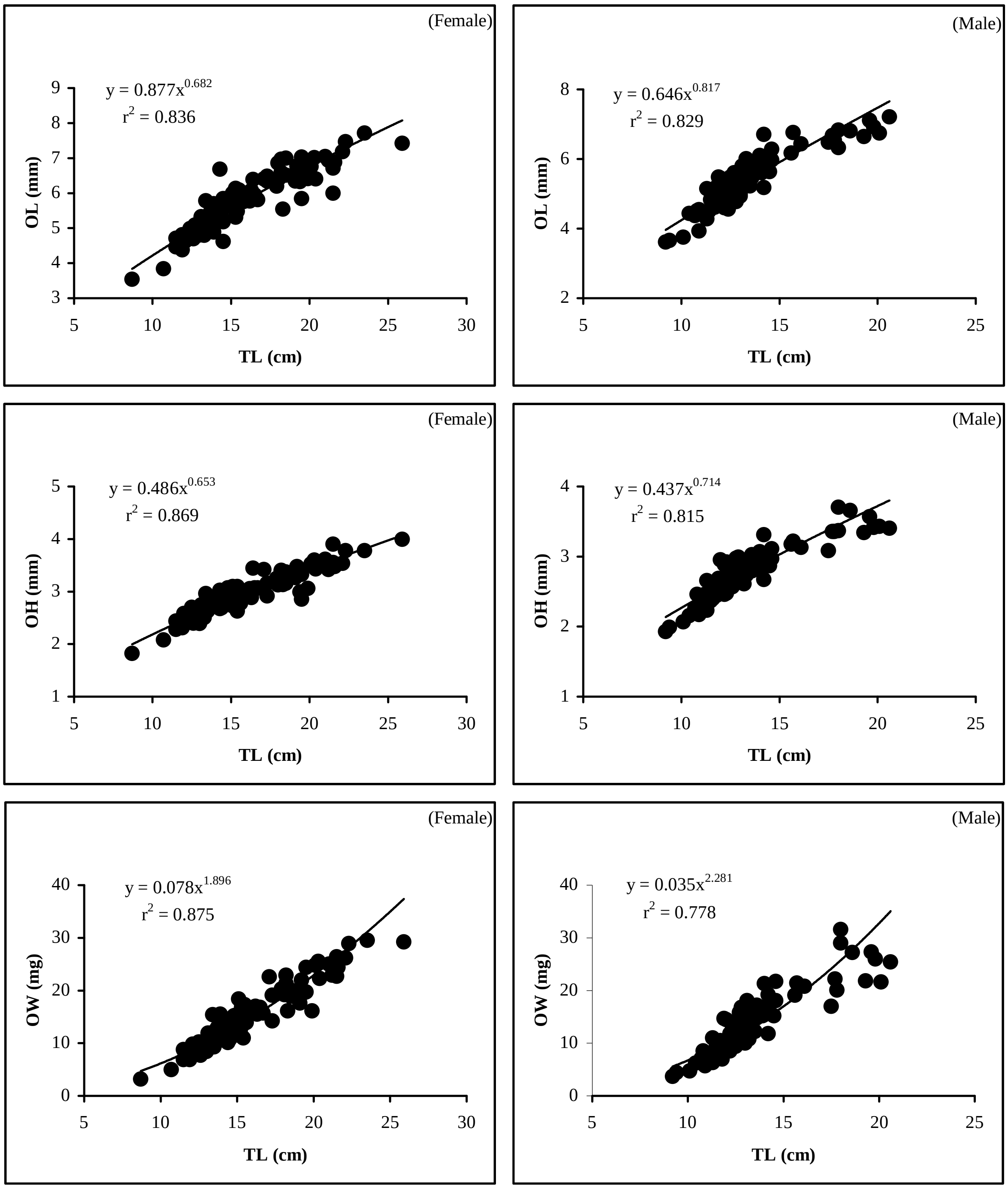

Fig. 2. Relationships of otolith length (OL), height (OH) and weight (OW) versus fish total length (TL) observed in females and males of European perch.

left otoliths in these fish occurs after metamorphosis or after settlement on soft-bottoms.

In comparison with other similar studies on the relationship of fish and otolith sizes (Echeverria, 1987; Gamboa, 1991; Sahin and Gunes, 1998; Harvey *et al*., 2000; Ceyhan and Akyol, 2006; Longenecker, 2008; Zorica *et al*., 2010; Battaglia *et al*., 2010; Basusta *et al*., 2013; Felix *et al*., 2013), this work supplies additional information by considering three otolith measurements (OL, OH, and OW). Generally, it is more reliable to calculate more than one equation, since the tip of the otolith rostrum may be damaged, making it impossible to measure the OL or OW. However, the right and left otoliths may not provide the same results of prey fish length estimates (*e.g.*, Harvey *et al*., 2000; Waessle *et al*., 2003; Tarkan *et al*., 2007b; Bostanci *et al*., 2009; Kumar *et al*., 2012).

The sexual differences in relationships between fish size and otolith size were detected in our study, which they have been reported for many species (Echeverria, 1987; Sahin and Gunes, 1998; Sen *et al*., 2001; Munday *et al*., 2004; Tarkan *et al*., 2007a; Vallisneri *et al*., 2008; Bostanci *et al*., 2012). This variability seems to be associated to changes in somatic growth between males and females. Vallisneri *et al*. (2008) stated that if otolith and somatic growth were closely coupled, the difference in otolith size between females and males, corresponding to differences in somatic size would be expected. However, otolith and somatic growth are not always tightly coupled and otoliths continue to grow in the absence or slowing of somatic growth (Mosegaard *et al*., 1988; Munday *et al*., 2004). In this case, slower growing specimens often have relatively larger otoliths (Reznick *et al*., 1989; Francis *et al*., 1993). In our study, somatic growth and otolith growth was approximately 78-88% overlap, demonstrating that otolith morphometrics might be good indicators of fish size. Campana (2004) reported that otolith size and shape often changed with the growth of the fish.

The results showed that the somatic size of this species can be obtained reliably from otolith variables such as length, height and weight. But, different equations should be used for females and males. In spite of all data fitted well with the non-linear regression model, it is advisable to use these equations within the fish size range limits given in Table II. The regressions from this study can be useful for investigators examining food habits of predators of species in question.

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