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Bony structure dimensions-fish length relationships of pike (*Esox lucius* L., 1758) in Lake Ladik (Samsun, Turkey)

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Abstract. The relationships between otolith length (OL), otolith width (OW), otolith weight (OWE), cleithrum length (CL) and fish length (TL) of pike captured from Lake Ladik were evaluated using 11 different mathematical models. Total lengths of the samples ranged from 273 mm to 744 mm. The variations in the right and the left side measurements of the two bony structures were not statistically significant ($p>0.05$). There was significant difference in cleithrum lengths of females and males ($p<0.05$). The relationships between TL versus OL, TL versus OW and TL versus CL were determined as linear, whereas the relationship between TL versus OWE was determined as logarithmic.

Key words: *Esox lucius*, otolith biometry, cleithrum length, Lake Ladik, Turkey.

Otoliths or earstones that used for balance and hearing are calcareous structures and located in the inner ears of all teleosts (Campana 1999). There are three pairs of otoliths: sagittae, asteriscus and lapillus (Das 1994). Cleithra, the major bones of the pectoral girdle, are paired structures located on each side of the fish (Scharf et al. 1998). Otoliths and cleithra show differences in size and shape between fish species (Traynor et al. 2010, Yilmaz et al. 2015) and are used to investigate identify, age, and size of prey fishes. This information is very useful for fishery management, prey-predator studies and archaeological investigation (Harvey et al. 2000, Tuset et al. 2008)

Relationships between bony structure dimensions and fish length are commonly used in fisheries science. These mathematical associations enable the back-calculation of fish length in previous ages (Casselman 1990). Such relationships generally show dramatic differences from species to species. Hard parts such as otolith and cleithrum can stay for a long time without being digested in the stomach of piscivorous animals. Thus, the original size of ingested fish is commonly estimated with regression equations that relate body length to the size of a specific hard bone (Aydin et al. 2004, Dietrich et al. 2006). Also, undigested structures found in predator stomach are an important tool for identification of prey species (Tarkan et al. 2007, Mehanna et al. 2016). In addition, bony structures of fish also help paleontologists in their researches about fish fossils (Jawad et al. 2012).

Otoliths and cleithra have been used in age determination (Laine et al. 1991, Neuman et al. 1994, Faust et al. 2013), species-specific identification (Traynor et al. 2010), and estimation of growth parameters of pike (Rydell et al. 2008). However, the studies on morphometry of these bony structures are very limited for pike (Engstedt et al. 2010). The aim of this study was to determine the best mathematical models defining relationships between otolith and cleithrum dimensions and fish length of pike (*Esox lucius* L., 1758) caught from Lake Ladik (Samsun).

Lake Ladik is between 35° 40'-36° 05' east longitudes and 40° 50'-41° 00' north latitudes. The lake is 5 km long, 2 km wide and 2.5 - 6 m deep with an altitude of 867 m (Yılmaz et al. 2012). It has been classified as a eutrophic and shallow lake (Apaydin Yagci et al. 2015). *Esox lucius* samples were obtained from different parts of the lake between November 2009-October 2010 and February-March 2011. Total lengths of the samples were measured with a precision of ± 1 mm, samples were weighed with a precision of ± 0.01 g and sexes were determined through macroscopic examination of gonads. The sagittal otolith and cleithra pairs from each fish were removed, cleaned and preserved dry in labeled envelopes. Sagittal otoliths (OWE) were weighed with a precision of ± 0.0001 g. Broken and damaged otoliths were not examined. Otolith length (OL) was defined as the farthest distance between the anterior and posterior edges of otolith, and otolith width (OW) was defined as the farthest distance between the dorsal

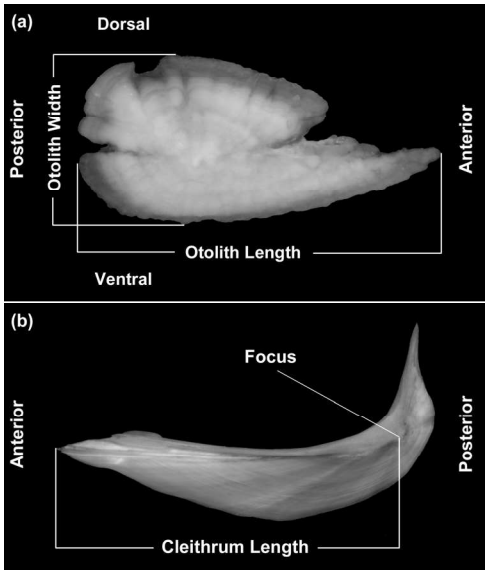

Figure 1. Right otolith (x10) (a) and right cleithrum (x3.2) (b) of pike and measurement lines.

and ventral edges (Fig. 1). OL and OW were measured to the nearest ±0.001 mm using Leica Application Suit imaging analysis program on Leica S8APO model stereo microscope. Cleithrum length (CL), which described as the distance from the center of cleithrum to the anterior edge (Casselman 1979) was measured by an electronic caliper of ±0.01 mm precision (Fig. 1).

The paired t-test was used for the comparison of the right and left measurements of the two bony structures. Also, this test was used to find out whether the same measurements were different between the sexes or not. The analysis of variance (ANOVA) was applied to determine the best model out of 11 different mathematical models (Linear, Logarithmic, İnvers, Quadratic, Cubic, Compound, Power, S, Growth, Exponential and Logistics) defining each relationship (TL-OL, TL-OW, TL-OWE, and TL-CL) with SPSS-16 package program. The model with the lowest standard deviation and the highest regression coefficient (r^2) was used to explain the mathematical relationships (Can 2000).

Of the total 210 *Esox lucius* samples caught for the study, 114 were females and 96 were males. While the cleithrum measurements were made for all the samples, otolith measurements were taken from

Table 1. The measured values of fish total length, otolith length, and cleithrum length in female, male and all individuals of pike from Lake Ladik (Min: minimum, Max: maximum, SE: standard error, SD: standard deviation).

	Variable	n	Mean	Min	Max	SE	SD
Cleithrum	Female						
	Total length (mm)	114	459.8	273.0	744.0	8.28	88.43
	Cleithrum length (mm)	114	45.64	27.78	73.64	0.83	8.84
	Male						
	Total length (mm)	96	415.2	283.0	584.0	8.55	83.80
	Cleithrum length (mm)	96	41.39	28.41	58.83	0.86	8.44
	All samples						
	Total length (mm)	210	439.4	273.0	744.0	6.14	88.97
	Cleithrum length (mm)	210	43.70	27.78	73.64	0.61	8.89
Otolith	All samples						
	Total length (mm)	134	443.4	273.0	744.0	7.55	87.45
	Otolith length (mm)	134	6.428	4.506	9.958	0.092	1.060
	Otolith width (mm)	134	3.251	2.368	5.030	0.043	0.492
	Otolith weight (g)	134	0.0161	0.0067	0.0516	0.0006	0.0079

Table 2. Statistical comparison between right and left side of otolith and cleithrum measurements in pike from Lake Ladik (mm: millimeter, g: grams).

Variable	Area	n	Mean	Min	Max	SE	SD	P
Otolith length (mm)	Left	134	6.417	4.425	9.907	0.094	1.083	$p>0.05$
	Right	134	6.428	4.506	9.958	0.092	1.060	
Otolith width (mm)	Left	134	3.231	2.270	4.898	0.042	0.485	$p>0.05$
	Right	134	3.251	2.368	5.030	0.043	0.492	
Otolith weight (g)	Left	134	0.0159	0.0062	0.0508	0.0006	0.0076	$p>0.05$
	Right	134	0.0161	0.0067	0.0516	0.0006	0.0079	
Cleithrum length (mm)	Left	210	43.44	27.78	73.16	0.62	8.92	$p>0.05$
	Right	210	43.70	27.78	73.64	0.61	8.89	

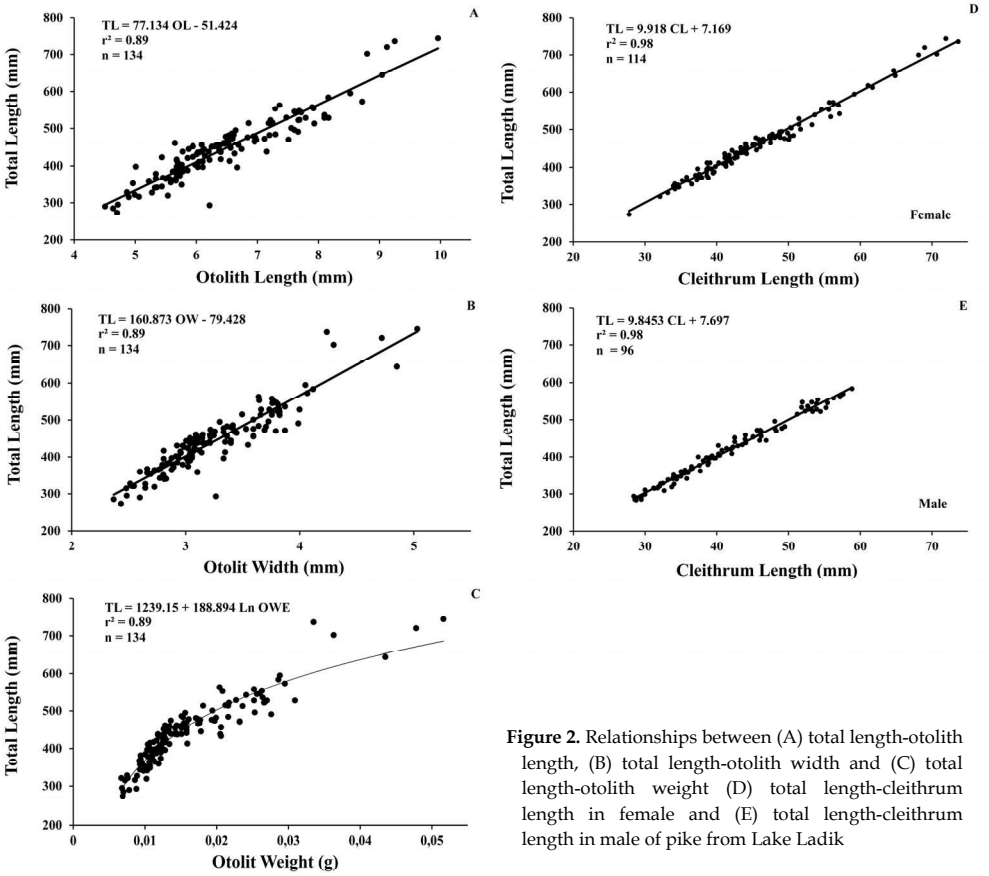

Figure 2. Relationships between (A) total length-otolith length, (B) total length-otolith width and (C) total length-otolith weight (D) total length-cleithrum length in female and (E) total length-cleithrum length in male of pike from Lake Ladik

only 134 samples.

The total lengths of the fish were between 273-744 mm. Cleithrum lengths were between 27.78-73.64 mm (Table 1). The lengths, widths, and weights of otoliths varied between 4.506-9.958 mm, 2.368-5.030 mm, 0.0067-0.0516 g, respectively (Table 1).

There was no significant difference in the measurements of otolith's length, width, weight, and cleithrum length between the right and the left areas (paired t-test, $p>0.05$) (Table 2). No significant difference was also observed in the same measurements of females and males (t-test, $p>0.05$). Thus, the right side measurements were used for regression models regardless of sex difference. On the contrary, since cleithrum length differed between sexes (paired t-test, $p<0.05$), regressions were generated separately according to female and male.

As a result of the analysis of 11 different mathematical models applied on the otolith data, it was found that the linear model best explained the relationships between TL-OL and TL-OW, while the logarithmic model was found to be more suitable for the relationship between TL-OWE (Table 2). The r^2 values of the regression equation generated from each measurement of otoliths were same (0.89). This result showed that all three parameters can be used for the back-calculation of fish total length (Fig. 2). A strong linear relationship (r^2=0.98) was seen between TL-CL of the female and male pikes; approximately 10 times of the cleithrum length was found to be equal to fish total length (Fig. 2).

Since growth of fish can differ between species and the populations of the same species, the relationships between bony structures and fish length can also differ. It is possible to determine the aforementioned relationships in the most correct way through comparing various mathematical models. Gamboa (1991) explained the relationships between fish length-otolith length and fish

length-otolith weight of 11 different fish species in the Pacific shore of California through linear and power models, respectively. Granoderio & Silva (2000) reported a power relationship between the otolith length and total length of *Micromesistius poutassou* and *Merluccius merluccius* in the Atlantic Ocean while they found a linear relationship in *Trisopterus luscus*, *Trachurus trachurus*, *T. picturatus* and *T. mediterraneu* species. Can (2000) reported that there was a power relationship between the total length-otolith length and fish length-otolith length of *Pagellus erythrinus* in İskenderun Gulf, while this relationship was exponential between total length-otolith weight and linear between otolith length-otolith weight. Bostancı et al. (2009) found a linear relationship between the otolith length and fork length of *Sander lucioperca* samples in Lake Eğirdir. Yilmaz et al. (2014) indicated a non-linear function (power model) between total length-otolith length, total length-otolith height and total length-otolith weight in females and males of *Perca fluviatilis* in Lake Ladik. Yilmaz et al. (2015) investigated the relationships between dimensions (length and width) of the asteriscus and the lapillus otoliths and total length for five cyprinid species (*Abramis brama*, *Blicca bjoerkna*, *Carassius gibelio*, *Chondrostoma regium* and *Scardinius erythrophthalmus*) inhabiting Lake Ladik. They found nonlinear (power) relationships between total length and otolith (asteriscus and lapillus) size in *A. brama*, *B. bjoerkna*, *C. gibelio* and *S. erythrophthalmus* in this lake. The same researchers suggested linear regression was the most appropriate model for *C. regium*.

Casselman (1979, 1996) stated that cleithrum length was a significant indicator of fish length in Esocid species and the relationships could be defined correctly through linear regression. The same researcher made an important contribution to the practical usage of such relationships by showing that approximately 10 times of the cleithrum length was equal to fish total length. Engstedt et al. (2010) explained the relationship between total length and otolith length in pikes caught from two areas of the Swedish shores of the Baltic Sea by using power model. Our results were similar to Casselman's (1979, 1996) results, yet different from the findings of Engstedt et al. (2010).

The strong relationships were found between the otolith and cleithrum dimensions and fish total lengths of *Esox lucius* in Lake Ladik. In addition, cleithrum length was found to be more convenient in the back computation of fish length when compared with the different otolith measurements. The data of this study can be used to back-calculated fish length from recovered otolith and cleithrum found in the stomachs of piscivorous animals such as fishes and water birds. We are of the opinion that the regression equations obtained in this study will be useful for the ichthyologist who investigating the feeding habits of top predator and paleontologist who studying about fish fossils.

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