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Otolith Morphometry of Wels Catfish, *Silurus glanis* L., 1758

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ABSTRACT

The relationships between dimensions of the asteriscus and lapillus and fish length for Wels catfish, collected from Sıddıklı Dam Lake between September 2015 and August 2016, are presented. No significant differences were noted between the dimensions of the left and right otoliths, and between otolith dimensions of male and female. For analyses, the right-side data of otoliths were used regardless of sex. The strongest correlation coefficient was obtained from the linear model for all relationships. Thus, a linear model was used for determining relationships. The r^2 values of relationships between asteriscus dimensions and total length were more appropriate than relationships between lapillus dimensions and total length. Asteriscus height was more suitable than other otolith dimensions for predicting the length of Wels catfish. Results provided the first information on relationships between total length and otolith dimensions of Wels catfish. These relationships from this study can provide a reliable tool to reconstruct the predator diet, and to estimate the size of the prey, as well as also provide support to paleontologists in their research on fish fossils.

Keywords: Otolith dimension, fish length, otolith biometry, Wels catfish, Sıddıklı Dam Lake

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Yayın Balığı (*Silurus glanis* L., 1758)'nın Otolit Morfometrisi

Öz: Bu çalışmada Eylül 2015-Ağustos 2016 tarihleri arasında Sıddıklı Baraj Gölü'nden yakalanan yayın balığı için asteriskus ve lapillus boyutları ile balık boyutları arasındaki ilişkiler sunulmuştur. Sol ve sağ otolitlerin boyutları ile erkek ve dişi bireylerin otolit boyutları arasında anlamlı fark tespit edilmemiştir. Analizler için cinsiyetten bağımsız olarak sağ otolit ölçümleri kullanılmıştır. En güçlü korelasyon katsayısı tüm ilişkiler için doğrusal model kullanılarak elde edilmiştir. Bu nedenle ilişkilerin belirlenmesinde doğrusal model kullanılmıştır. Asterikus boyutları ile total boy arasındaki ilişkilerin r^2 değerleri, lapillus boyutları ile total boy arasındaki ilişkilere göre daha yüksek bulunmuştur. Asteriskus yüksekliğinin, yayın balığının uzunluğunu tahmin etmek için diğer otolit ölçümlerinde göre daha uygun olduğu tespit edilmiştir. Bu çalışma, yayın balığının total boyu ve otolit boyutları arasındaki ilişkiler açısından ilk bilgileri sağlamaktadır. Bu çalışmadan elde edilen ilişkiler; predator türlerin beslenme rejimini yeniden yapılandırmak ve mide içeriğinden elde edilen yayın balıklarının boyutunu tahmin etmek için güvenilir bir araç olarak kullanılabilir ve aynı zamanda paleontologlara balık fosilleri araştırmalarında destek sağlayabilir.

Anahtar kelimeler: Otolit boyutları, balık uzunluğu, otolit biyometrisi, Yayın balığı, Sıddıklı Baraj Gölü.

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Introduction

Otoliths are hard-paired calcified structures located in the inner ear, which are used for the maintenance of equilibrium and hearing in teleost fishes (Payan et al. 2002). They are massive calcium carbonate structures (Sweeting et al. 2004) and three pairs on either side of the brain, name as lapillus, asteriscus, and sagitta (Das 1994). The plural name of sagitta, lapillus, and asteriscus are sagittae, lapillus, and asteriscus, respectively (Campana 2004). Otoliths show differences in shape and size. The shape of sagittal and asteriscus otoliths show variability among species, but lapillus shape is more uniform (Campana 2004). The sagittae are the biggest pair of otoliths and the lapillus are the smallest in most bony fishes; however, in the members of ostariophysian fishes, the asteriscus are the largest otoliths and the sagittae are the smallest (Harvey et al. 2000; Campana 2004). Also, the fishes which are slowly swimming have larger otolith than ones that are faster moving (Javadzadeh et al. 2016).

Since otoliths show variation in size and shape, they are used to determine the taxon, age, and dimensions of fishes. These data are important for population management, prey-predator studies, and archaeological research (Yilmaz et al. 2015). Furthermore, the otoliths continue to grow along the life of fish (Fowler 1990). They do not resorb in stress time, because it is acellular (Tuset et al. 2006). Therefore, otoliths are one of the most reliable tools to estimate the growth rate and age of fish population, and for fisheries management (Campana and Thorrold 2001). Otoliths have been used in studies on the diet of piscivore predators (e.g., Pierce et al. 1991; Tollit et al. 1997), analysis of allometric (e.g., Aguirre 2003; Monteiro et al. 2005), ecomorphology (Volpedo and Fuchs 2010; Jaramillo et al. 2014), paleontology (Bosnakoff 2011), age determination (Yazıcı 2018), species-specific identification (Aguirre 2003; Tuset et al. 2006; Bostanci et al. 2015), and stock discrimination (Campana and Casselman 1993; DeVries et al. 2002).

Because prey fishes were digested partially or totally in the stomach of the predator, the identification and quantification of they are difficult in stomach content analysis. The otoliths are resistant to digestion and these hard structures can be used to determine species of prey fishes (Aguilar-Perera and Quijano-Puerto 2016). Otoliths can also be used to provide data on the size of the prey (Granadeiro and Silva 2000). Therefore, the importance of the regressions between otolith size and fish length is increased day by day. The relationships between otolith dimensions and fish length can be supply significant knowledge to determine fish length from otoliths in the stomach of predators and understand prey-predator relationships (Aguilar-Perera and Quijano-Puerto 2016). Although there have been a lot of studies on these relationships in many fish species (Viva et al. 2015; Bostancı et al. 2017; Yılmaz et al. 2019), there are no known studies for Wels catfish.

The purpose of this paper is to estimate relationships between otolith dimensions and fish length. Additionally, this study will provide the first information on relationships between otolith dimensions and fish length in Wels catfish.

Materials and Methods

A total of 203 fish samples were monthly collected from different regions of the Sıddıklı Dam Lake between September 2015 and August 2016. Sıddıklı Dam Lake located near Sıddıklı Küçükboğaz Village, 40 km west of Kırşehir province, was built for irrigation. The surface area of Sıddıklı Dam Lake is 1.65 km^2. Thanks to the dam, 4945 ha agricultural areas are irrigated. Also, fishery activities are carried out economically in the Sıddıklı Dam Lake (Yazıcı 2018). Fish were caught using trammel nets with a mesh size ranging from 18 to 20 mm 25 m long and gills nets with a mesh size ranging from 25 to 40 mm 50 m long and 45 to 80 mm 100 m long.

The total length (TL) of each fish specimens were measured to the nearest 0.1 cm. The sex of samples was determined by examination of gonads macroscopically. The lagenar (lapillus) and utricular (asteriscus) otoliths of each fish were removed, cleaned, and stored in Eppendorf tubes. Broken and damaged otoliths were excluded from the examines. Thus, 179 asteriscus (98 male and 81 female) and 193 lapillus samples (104 male and 89 female) were used for examining relationships between otoliths dimensions and total length.

All otoliths were photographed on the proximal side with a Mshot digital camera. Asteriscus and lapillus length (AL and LL) was defined as the greatest distance between anterior and posterior edge. Asteriscus height (AH) and lapillus width (LW) was described as the greatest distance from dorsal to the ventral edge (Figure 1). These parameters were measured to the nearest 0.001 mm using Mshot Digital Imaging Software.

The relationships between otolith dimensions and fish length were determined using both linear (y= a+bx) and non-linear (y= a*x^b) regression models for the following parameters: asteriscus length (AL)-fish length (TL), asteriscus height (AH)-fish length (TL), lapillus length (LL)-fish length (TL), and lapillus width (LW)-fish length (TL). The model with the highest coefficient of determination (r^2) was chosen to describe the above-mentioned relationships. The strength of all calculated regressions was assessed by the determination coefficient (r^2) and the mean percent prediction error values (PE %). The mean percent prediction error was calculated for a regression by averaging the percent prediction error computed for each observation. The percent prediction error (PE %) for an individual is computed by the following formula (Scharf et al. 1998).

$$PE\ \% = \frac{|Observed - Predicted|}{Predicted} \times 100$$

Paired t-test was used for determining the difference in left and right measurements of otolith. The t-test was used to compare otolith variables between sexes. When the equations for left and right otoliths did not differ statistically, one right or left otolith was selected randomly from each individual. Differences between regression coefficients for the relationship between fish length and the dimensions of left and right otoliths were tested using analysis of covariance (ANCOVA) (Zar 1999). The significance of the regressions was detected using an analysis of variance (ANOVA).

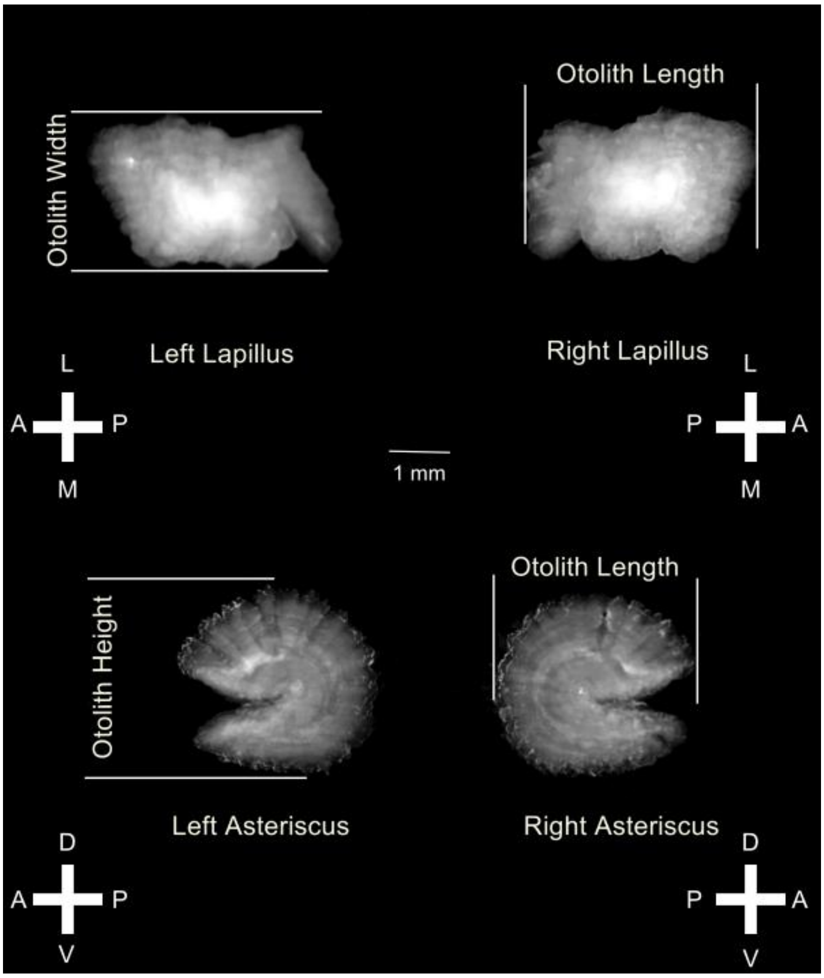

Figure 1. The proximal views of lagenar (asteriscus) and utricular (lapillus) otoliths of Wels catfish (A: anterior; P: posterior; D: dorsal; V: ventral; L: lateral; M: medial).

Results

In total, 203 specimens were caught in the study. However, 179 asteriscus and 193 lapillus samples were examined in this study in totally. The descriptive statistics of fish total length and otolith dimensions are given in Table 1 for females and males and in Table 2 for entire samples.

Table 1. Some descriptive statistics of total length (TL), asteriscus dimensions (AL: length. AH: height), and lapillus dimensions (LL: length. LW: width) in *S. glanis* from Sıddıklı Dam Lake.

Variable	Female			Male			t-test
	n	Range	Mean±SD	n	Range	Mean±SD	
TL (mm)	81	218-1075	562.9±135.8	98	201-1516	601.7±170.3	p> 0.05
AL (mm)		1.5113-4.3350	2.6216±0.4298		1.5375-4.9038	2.7506±0.4706	p> 0.05
AH (mm)		1.4750-4.2363	2.5487±0.4428		1.4213-4.9038	2.6680±0.4611	p> 0.05
TL (mm)	89	218-1075	574.2±131.1	104	201-1516	601.4±167.5	p> 0.05
LL (mm)		2.0038-5.8338	3.5396±0.6338		1.9675-6.6963	3.6191±0.7081	p> 0.05
LW (mm)		1.2787-3.6800	2.3189±0.3978		1.3238-4.1563	2.3485±0.4371	p> 0.05

Table 2. Statistical comparison between left and right side of asteriscus and lapillus measurements in *S. glanis* from Sıddıklı Dam Lake.

Variable	Area	n	Mean	Min	Max	Se	Sd	p
Asteriscus length (mm)	Left	179	2.7033	1.4938	5.0887	0.0345	0.0345	p>0.05
	Right		2.6922	1.5113	4.9038	0.0341	0.4559	
Asteriscus height (mm)	Left	179	2.6034	1.4400	4.5737	0.0333	0.4457	p>0.05
	Right		2.6141	1.4213	4.9038	0.0341	0.4556	
Lapillus length (mm)	Left	193	3.5677	1.9850	7.1725	0.0499	0.6930	p>0.05
	Right		3.5824	1.9675	6.6962	0.0485	0.6743	
Lapillus width (mm)	Left	193	2.3320	1.2787	4.2400	0.0288	0.4006	p>0.05
	Right		2.3348	1.2787	4.1563	0.0301	0.4186	

Asteriscus length data was bigger than its height data for both sexes. Similarly, Lapillus length measurement was higher than its width measurement both sexes. The differences in morphometric measurements of left and right otoliths in both asteriscus and lapillus were not statistically significant (paired t-test, p > 0.05) (Table 2). Hence, the right-side data of asteriscus and lapillus dimensions were used for morphometric analysis. No significant differences were observed between otoliths dimensions of females and males (t-test, p> 0.05). Therefore, otolith data of both the sexes were pooled. The determination coefficients (r^2) of linear regressions were higher than non-linear regressions, so all regressions were generated by a linear model. All linear regressions were highly significant (p< 0.001, ANOVA) and the regression models explained more than 80% of the variance in most of the cases (Figure 2 and 3). Asteriscus and lapillus dimensions were all positively related to total length, with r^2 values ranged from 0.847 to 0.944. Among the linear regressions, asteriscus height was recorded as the most appropriate model. The best fit model for the relationships between asteriscus dimensions and total length was TL-AH with r^2= 0.944, while the best fit model was TL-LL with r^2= 0.879 in between lapillus dimensions and total length.

Observed total length ranged from 201 to 1516 mm while the predicted total length obtained linear regressions ranged from 186.2 to 1348 mm (Table 3). Non-statistically significant differences were found between observed and predicted TL values for each otolith measurement (t-test, P> 0.05). The mean percent prediction errors ranged from 4.847 to 7.661 for asteriscus and lapillus measurements (Table 3). The value of the mean (PE%) obtained asteriscus height (AH) was lower than those of the other otolith measurement. The regressions with high r^2 have low mean PE% values for asteriscus and lapillus measurement.

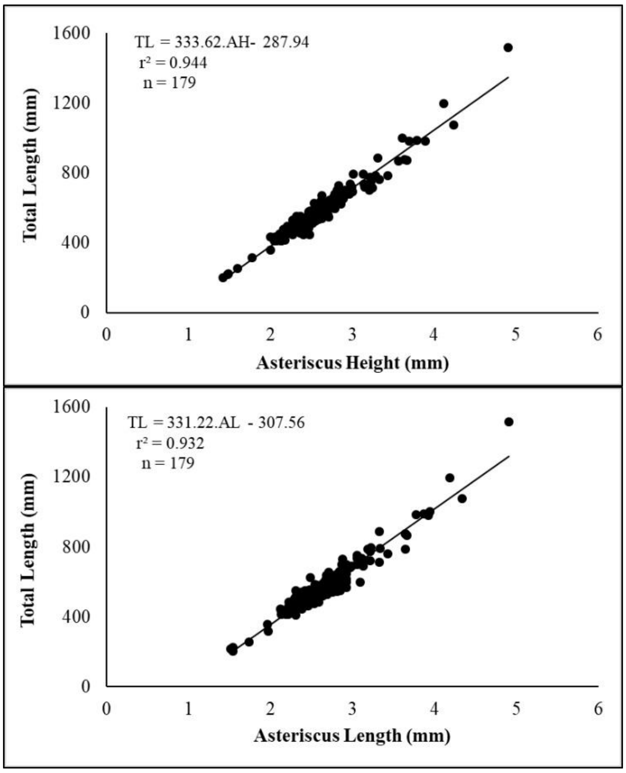

Figure 2. Relationships between fish length and asteriscus dimensions in Wels catfish.

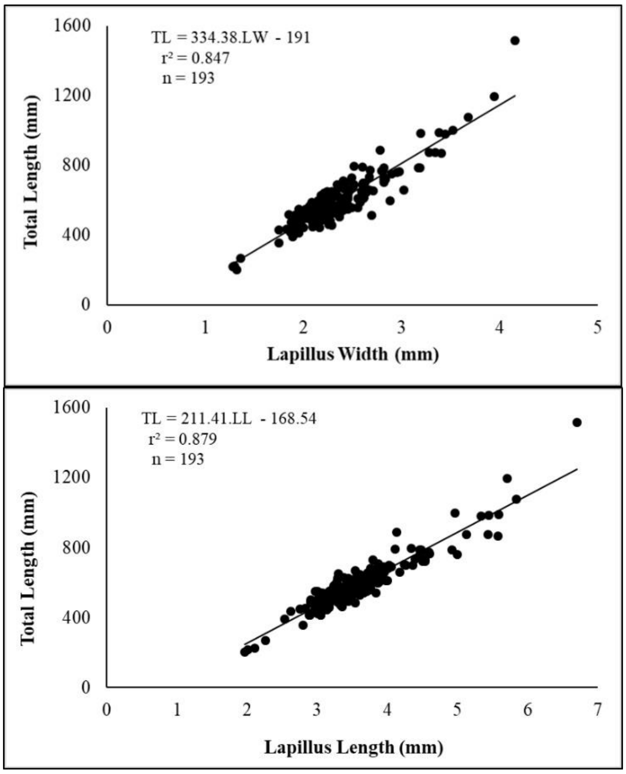

Figure 3. Relationships between fish length and lapillus dimensions in Wels catfish.

Discussion

There are many studies on the relationships between fish length and otolith size for different species (Granadeiro and Silva 2000; Yilmaz et al. 2015; Aneesh Kumar et al. 2017; Kanjuh et al. 2018; Kurucu and Bostanci 2018). However, there is no information is available on the otolith biometry of *S. glanis* in Worldwide. For this reason, information on relationships between otolith dimensions and total length is given the first time in this study.

The studies on otolith biometry have focused on the relationship between fish length and otolith length (Granadeiro and Silva 2000; Viva et al. 2015; Yılmaz et al. 2019). Also, the relationships between fish length and different measurements (width, height) of otolith were frequently defined in recently (Yilmaz et al. 2015; Aneesh Kumar et al. 2017; Kanjuh et al. 2018; Kurucu and Bostanci 2018). Because the tip of the otolith rostrum or post-rostrum may often be damaged, it is impossible to predict fish length from the otolith length alone. Therefore, the use of different measurements from otolith is more reliable to calculate relationships in studies on otolith biometry (Yilmaz et al. 2015).

Table 3. The mean percent prediction error (PE %) values for each variable of otolith in *S. glanis* from Sıddıklı Dam Lake.

Variable	n	Observed TL (mm)			Predicted TL (mm)			PE %±SD		
		Range	Mean	±SD	Range	Mean	±SD	Range	Mean	±SD
AL	179	201-1516	584.2	156.4	193.0-1316.7	584.1	151.0	0.077-19.925	5.182	4.054
AH		201-1516	584.2	156.4	186.2-1348.0	584.2	152.0	0.140-20.038	4.847	3.438
LL	193	201-1516	588.8	152.1	247.4-1247.1	588.8	142.6	0.034-23.089	6.871	5.056
LW		201-1516	588.8	152.1	236.6-1198.8	589.7	140.0	0.067-38.269	7.661	5.835

In this study, relationships between fish length and length, width, and height of otolith were analyzed. Similarly, the relationships between otolith dimensions and fish length were determined in various fish species to predict fish length from otolith dimensions (Yilmaz et al. 2014; Aneesh Kumar et al. 2017; Kanjuh et al. 2018; Kurucu and Bostanci 2018).

Otoliths can also be used to estimate the size of the prey and to reconstruct the predator diet (Granadeiro and Silva 2000; Harvey et al. 2000). Fish size can be functionally related to suitable otolith dimensions and calculating relationships can be used for predicting the size of fish (Granadeiro and Silva 2000). In general, linear model was preferred to determine relationships between otolith dimensions and fish size in previous studies (Harvey et al. 2000). However, the best regression model for otolith biometry can change in the same fish species inhabiting different habitats (Bostancı et al. 2017). Therefore, several models should be used for explaining relationships the best in the manner that. The model with the highest coefficient of determination is chosen to explain the relationship (Zar 1999). In the current study, both linear and non-linear model was used to describe otolith dimensions-fish total length relationships. According to the results of the analysis using both models, linear model provided the best fit for all relationships in this study. Similar results were obtained in previous studies in various fish species (Hunt 1992; Amouei et al. 2013; Ider et al. 2017). Granadeiro and Silva (2000) reported that non-linear functions provided the best fit for *Micromesistius poutassou* and *Merluccius merluccius*, while linear functions were the best suitable relationships for *Trisopterus luscus* and *Trachurus species*. Yilmaz et al (2015) stated that the nonlinear model best explained the relationships between fish length and otolith dimensions for *Abramis brama*, *Blicca bjoerkna*, *Carassius gibelio*, and *Scardinius erythrophthalmus*, however linear model was the most suitable model for *Chondrostoma regium* in Lake Ladik.

Otoliths are often used in stomach content studies of predator animals such as seabirds, mammalia, and fishes (Pascoe 1986; Kemp et al. 2011; Polito et al. 2011), in paleontological studies (Bosnakoff 2011), and in the detection of larval fish in the digestive tract (Gómez et al. 2017). But the sex and length of the prey fish are not known (Echeverria 1987). The regressions obtained from all samples are needed for those occasions when the sex is not known or when the regressions were not considerably different between sexes (Yilmaz et al. 2015). Among the sex, measurements of the otolith do not always provide the same estimate of prey fish length (Yilmaz et al. 2014), hence the measurements should be pooled after adequate statistical analysis (Yilmaz et al. 2015). In this study, as there was no difference in otolith measurements (AL, AH, LL, and LW) between males and females, otolith data were pooled according to statistical examinations. Besides, no significant differences were found between all measurements of the left and right otolith, so right otolith data was used for all analyses. These findings agree with the results of previous studies (Hunt 1992; Alwany and Hassan 2008; Jawad et al. 2011). The results of this study showed that there were positive linear relationships between otolith dimensions and total length of *S. glanis*. The r^2 values of the regression equations generated from each measurement of asteriscus, and lapillus were higher than 0.847. Besides, the values of the mean PE % were lower than 7.661. This result showed that asteriscus and lapillus parameters can be used for the back-calculation of fish total length. However, the strongest linear relationship was calculated between AH-TL, with r^2= 0.944 for predicting total length in Wels catfish.

In conclusion, this study represents the first reference on the relationship between otolith dimensions and fish length for Wels catfish population. The linear model offered the best fit for relations between otolith dimension and fish length. The relationship between asteriscus height (AH) and fish length (TL) was determined as a good indicator for predicting the length of fish.

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