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Relationships between fish length and otolith size for five cyprinid species from Lake Ladik, Samsun, Turkey

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Abstract: The relationships between size (length and width) of the lagenar (asteriscus) and the utricular (lapillus) otoliths and body length for five cyprinid fish species, freshwater bream *Abramis brama*, white bream *Blicca bjoerkna*, Prussian carp *Carassius gibelio*, brond-snout *Chondrostoma regium*, and rudd *Scardinius erythrophthalmus*, collected from Lake Ladik from November 2009 through October 2010, are presented. The right and left side measurements of otoliths were pooled in all cases except asteriscus length in Prussian carp. Nonlinear and linear functions provided the best fit for 80% and 20% of all species, respectively. All relationships were highly significant ($P < 0.001$, $R^2 > 0.71$) and the mean percent prediction errors were less than 10%. The results showed that reliable original size estimates of all species studied are obtainable from their otolith biometrics. The regressions from this study can be useful for investigators examining food habits of piscivorous fauna and sizes of these fishes in archaeological samples.

Key words: Cyprinid fish, otolith size, fish length, Lake Ladik, Turkey

1. Introduction

The family Cyprinidae, commonly known as cyprinids, is the largest of all fish families found throughout the world (Nelson, 2006). There are about 2900 species of cyprinids worldwide (Eschmeyer and Fong, 2011). Members of the family have a wide geographical distribution and occur in Europe, Asia, Africa, and North America (Nelson, 2006). It is also the largest family of Turkish ichthyofauna, represented with about 130 species (Fricke et al., 2007; Geldiay and Balık, 2007). Cyprinids are primarily freshwater fishes and are found in all kinds of freshwater bodies (Mann, 1991; Kottelat and Freyhoff, 2007). The majority of these fishes are relatively small and important as prey for piscivorous animals (Winfield and Townsend, 1991).

Otoliths are hard calcified structures located in the inner ear of all teleost fishes (Mendoza, 2006). There are three pairs of otoliths, the sagitta, asteriscus, and lapillus (Das, 1994). Otoliths show differences in size and shape. The sagittae are the biggest pair of otoliths and the lapilli are the smallest in most bony fishes; however, in the members of Cypriniformes and Siluriformes, the asterisci are the largest otoliths and the sagittae are the smallest (Harvey et al., 2000; Campana, 2004). Due to their interspecific variation in shape and size, otoliths are used to estimate the taxon, age, and size of fishes. This knowledge is valuable for population management, prey–predator studies, and archaeological research (Harvey et al., 2000; Tuset et al., 2008).

The analysis of otoliths retrieved from the stomachs or feces of piscivorous predators can be used to provide information on the type, size, mass, and energetic content of their fish prey (Morley and Belchier, 2002). However, useful information can only be obtained from the otoliths if the relationship between otolith size and fish size is generated (Morley and Belchier, 2002; Longenecker, 2008). Otolith biometry–body length relationships have been determined for many fish species by different investigators (Gamboa, 1991; Harvey et al., 2000; Waessle et al., 2003; Longenecker, 2008; Battaglia et al., 2010; Zorica et al., 2010; Potier et al., 2011; Skeljo and Ferri, 2012). In Turkey, although a number of studies have been reported on relationships between otolith size and fish length (Şahin and Güneş, 1998; Can, 2000; Ceyhan and Akyol, 2006;

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Samsun and Samsun, 2006; Tarkan et al., 2007; Bostancı and Polat, 2008; Eroğlu and Şen, 2009; Bostancı et al., 2009; Bostancı et al., 2012; Cengiz et al., 2012; Basusta et al., 2013; Bilge, 2013; İşmen et al., 2013), such information is still lacking for many members of the ichthyofauna. On the other hand, the studies on otolith features of cyprinid fishes have shown an increase in recent years (Şen et al., 2001; Aydin et al., 2004; Bostancı et al., 2007; Gumus et al., 2007; Tarkan et al., 2007; Bostancı, 2009; Bostancı and Polat, 2011; Kontaş, 2012; Basusta et al., 2013; Keskin, 2013). However, otolith–fish size relationship studies are unavailable for cyprinid species inhabiting Lake Ladik. Furthermore, these cyprinids are important prey species for northern pike *Esox lucius* and European perch *Perca fluviatilis* inhabiting the study area, and for pike-perch *Sander lucioperca*, wels *Silurus glanis*, and African catfish *Clarias gariepinus* living in other habitats (Adamek et al., 1999; Lozys, 2003; Kangur et al., 2007; Alp et al., 2008; Yazıcıoğlu et al., 2012; Yazıcıoğlu, 2014). The primary objective of this work is to establish predictive relationships between otolith dimensions and fish length for five cyprinid fish including freshwater bream *Abramis brama*, white bream *Blicca bjoerkna*, Prussian carp Carassius *gibelio*, brond-snout *Chondrostoma regium*, and rudd *Scardinius erythrophthalmus* from Lake Ladik, Turkey. The secondary objective of this study is to test the accuracy of the back-calculated lengths using predictive equations. Additionally, this paper provides the first information on the lagenar and the utricular otolith morphometry in freshwater bream.

2. Materials and methods

Lake Ladik (40°50′N to 41°00′N, 35°40′E to 36°05′E) is located within the borders of Samsun Province in the central Black Sea region of Turkey. It is situated on the north side of Akdağ Mountain in the Ladik district. A few small streams feed the lake. The Tersakan stream flowing to the Yeşilırmak River is the output stream of the lake. Its total surface area is about 10 km^2 and the depth varies from 2.5 to 6 m (Yılmaz et al., 2012). It has been classified as a eutrophic and shallow lake (Maraşlıoğlu, 2001).

A total of 1031 specimens representing five cyprinid fish species were caught in the study area using gillnets with a mesh size ranging from 17 to 80 mm at monthly intervals between November 2009 and October 2010. Each fish was measured to the nearest 0.1 cm for total length (TL). The lagenar (asteriscus) and the utricular (lapillus) otoliths were extracted, cleaned, and preserved dry in labeled envelopes. The asterisci and lapilli of the five cyprinid species were described morphologically according to the terminology used by Assis (2003) and Schulz-Mirbach and Reichenbacher (2006). The otoliths were photographed on both the distal and proximal sides with a Leica DFC295 digital camera. Otolith length (the greatest distance between anterior and posterior otolith margin) and otolith width (the greatest distance from dorsal to ventral otolith margin for the asteriscus and from lateral to medial margin for the lapillus) were measured to the nearest 0.001 mm using Leica Application Suit Ver. 3.8 Imaging Software (Skeljo and Ferri, 2012). The right and left otoliths were considered separately. Broken and damaged otoliths were excluded from the study.

The relationships between otolith dimensions and fish size were established using both linear ($y = bx + a$) and nonlinear ($y = ax^b$) regression models for the following parameters: asteriscus length (AL)–fish length (TL), asteriscus width (AW)–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. Differences between coefficients of regressions generated separately for right and left otoliths were tested by analysis of covariance (ANCOVA) (Zar, 1999). When equation coefficients did not differ statistically, a single regression was reported for each parameter using the mean of right and left otolith measurements. The significance of the regressions was determined by analysis of variance (ANOVA).

The strength of each of the regressions was evaluated by the R^2 values and by calculating 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 (Scharf et al., 1998):

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

3. Results

In this study, five fish species belonging to the family Cyprinidae were examined. The sample size and the total length range of each species are given in Table 1. The lagenar otoliths (asterisci) in all species were bigger than the utricular ones (lapilli).

Asterisci are disc-shaped and serrated edges. Their distal (lateral) surface is smooth and slightly convex. Proximal (medial) surface is slightly concave and has an acoustic pit (fossa acustica). The fossa acustica is surrounded by a larger lobe (lobus major). The fossa acustica and lobus major are separated by a conspicuous medial crest (crista medial). A large indentation is frequently formed in the middle of the anterior margin of the asteriscus due to excessive reduction of the smaller lobe (lobus minor). This indentation is limited by the antirostrum

Table 1. Samples sizes (N) and total length (TL) ranges of fish used in this study.

Species	Common name	N	TL range
Abramis brama	Freshwater bream	273	9.1–53.5
Blicca bjoerkna	White bream	189	13.2–27.8
Carassius gibelio	Prussian carp	155	14.3–28.8
Chondrostoma regium	Brond-snout	182	16.5–25.4
*Scardinius erythrophthalm*us	Rudd	232	10.1–23.3

and pseudoantirostrum, or by the dorsal and ventral ends of the medial crest. In *A. brama*, the antirostrum is slightly rounded. Pseudoantirostrum is often pointed. The antirostrum is usually aligned with the pseudoantirostrum or it is further back. There is an indentation relatively deep between the antirostrum and pseudoantirostrum (Figure 1, column I). The dorsal and ventral ends of the medial crest continue slightly in the direction of the antirostrum and pseudoantirostrum, respectively (Figure 1, column II). In *B. bjoerkna*, the antirostrum is generally longer and more pointed. Pseudoantirostrum is slightly rounded. The indentation between them is not very deep (Figure 1, column I). The ventral end of the medial crest makes further progress toward the pseudoantirostrum (Figure 1, column II). In *C. gibelio*, the antirostrum and pseudoantirostrum are always slightly rounded. The antirostrum is invariably longer than pseudoantirostrum. There is a larger indentation between the two. The dorsal and ventral margins are less serrated (Figure 1, column I). While the dorsal end of the medial crest grows toward the antirostrum, its ventral end is terminated at the junction of the antirostrum and pseudoantirostrum (Figure 1, column II). In *C. regium*, the antirostrum is slightly rounded. The pseudoantirostrum is more pointed and it is mostly longer than the antirostrum. The indentation between the two is not very deep (Figure 1, column I). The dorsal and ventral ends of the medial crest progress in the direction of the antirostrum and pseudoantirostrum, respectively (Figure 1, column II). In *S. erythrophthalmus*, the antirostrum is more pronounced, elongated, and slightly pointed. It is wider in the larger specimens. The pseudoantirostrum is commonly less pronounced, but more prominent in the smaller specimens and very close to the antirostrum. There is an indentation with much less depth between them (Figure 1, column I). While the dorsal end of the medial crest progresses toward the antirostrum, the ventral end covers the pseudoantirostrum completely (Figure 1, column II).

The dorsal region of the lapillus is convex-concave and smooth. There is a bump (cranial umbo) at its anterior portion and a slightly prominent concavity at its posterior part (Figure 2, column I). The ventral region of the lapillus is convex and bumpy. Its posterior end may be V-shaped. An incision appears at the junction of the anterior and lateral margin (Figure 2, column II). The overall shape of the lapillus in *A. brama* is elongate to ovate or almost rhombic. The anterolateral and anteromedial edges are similar developed, rounded, and well pronounced. The posteromedial edge is relatively less developed and rounded. The posterolateral edge is more pointed. The medial margin is often curved and undulated. However, it may also be almost smooth. The posterior margin displays a distinct concavity. The lateral margin is generally straight but may be also slightly rounded (Figure 2). The general shape of the lapillus in *B. bjoerkna* is semicircle-like in the anterior portion and tapering to a rounded tip in the posterior part. In the larger specimens, all edges are well developed, but the antero- and posteromedial edges are rounded and rather ambiguous in the small otoliths. In all samples, the anterolateral edge is well developed, whereas the posterolateral edge is less prominent. The posterior and lateral margins may be slightly crenulated (Figure 2). The lapilli of *A. brama* and *B. bjoerkna* are similar but *B. bjoerkna* has a more pronounced cranial umbo, usually are more elongated. The overall shape of the lapillus in *C. gibelio* may be defined as an irregular rhombohedron and they can be easily distinguished from the other species by their different shapes (Figure 2). The general shape of the lapillus in *C. regium* is oval. It is rounded like a semicircle in the anterior part and more or less trapezoidal in the posterior portion. All edges are rounded and distinctly visible. The medial margin is nearly straight. The lateral margin is slightly convex and crenulated. The posterior margin is slightly undulated and may display a distinct concavity (Figure 2). The overall shape of the lapillus in *S. erythrophthalmus* is semicircular in the anterior portion and trapezoidal in the posterior portion. The four edges are well developed. The medial and lateral margins of the smaller lapillus run straight and regularly. In contrast, those margins curve irregularly in the larger lapilli. The posterior margin shows a conspicuous concavity in all

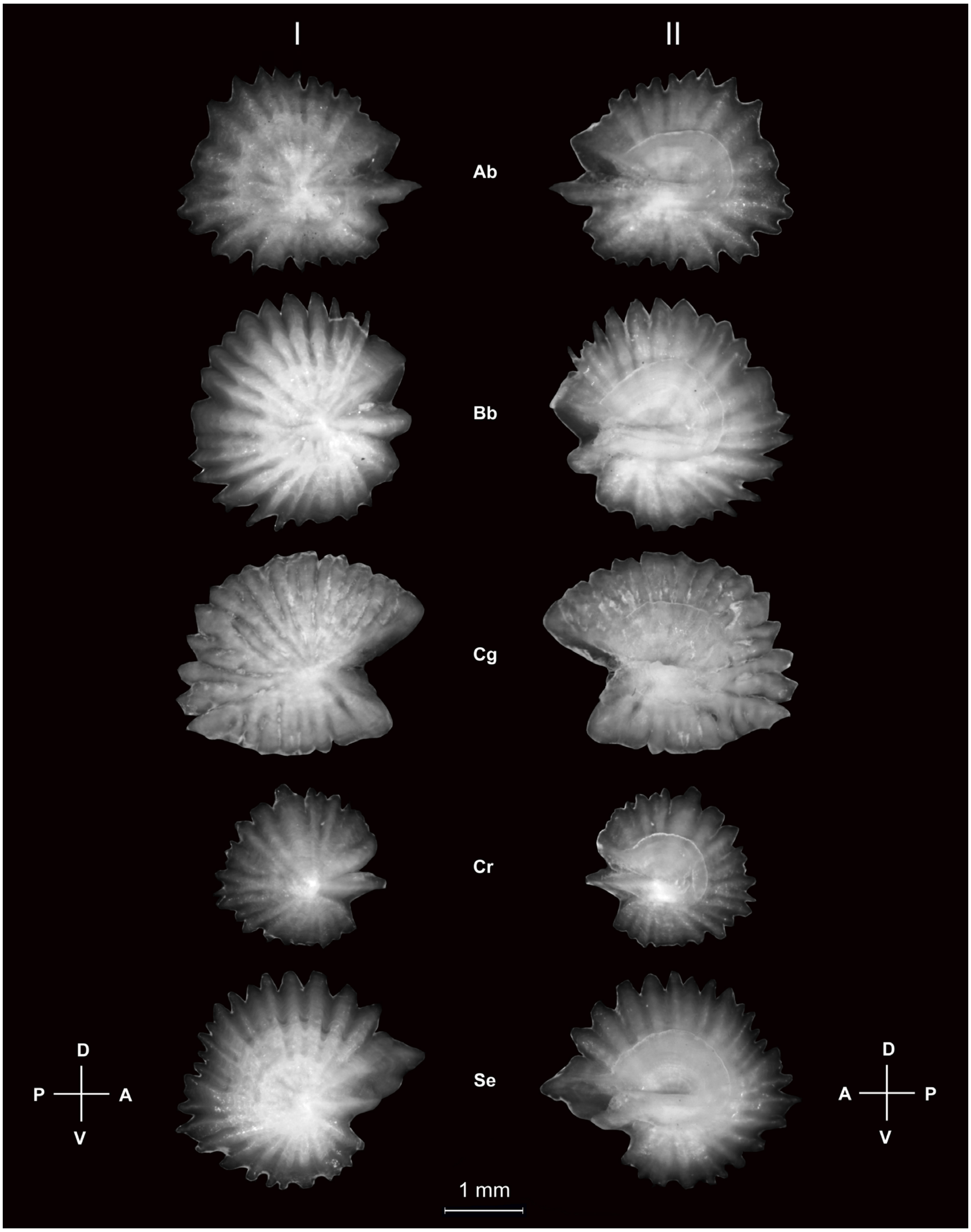

Figure 1. The distal (I) and proximal (II) views of the right asterisci of the five cyprinid fish species from Lake Ladik. Ab: *Abramis brama* (17.2 cm TL), Bb: *Blicca bjoerkna* (17.2 cm TL), Cg: *Carassius gibelio* (17.2 cm TL), Cr: *Chondrostoma regium* (17.2 cm TL), Se: *Scardinius erythrophthalmus* (17.2 cm TL), D: dorsal, V: ventral, A: anterior, P: posterior.

specimens. The lapilli of this species are well characterized with regard to the other studied species due to their wide rectangular shape with four pronounced edges (Figure 2).

The right- and left-side data of otolith measurements (AL, AW, LL, and LW) were pooled for all studied species; however, one measurement (AL) was analyzed separately for Prussian carp. The nonlinear regression model provided the best fit for *A. brama*, *B. bjoerkna*, *C. gibelio*, and *S. erythrophthalmus*, but linear regression was the most appropriate model for *C. regium*. All relationships

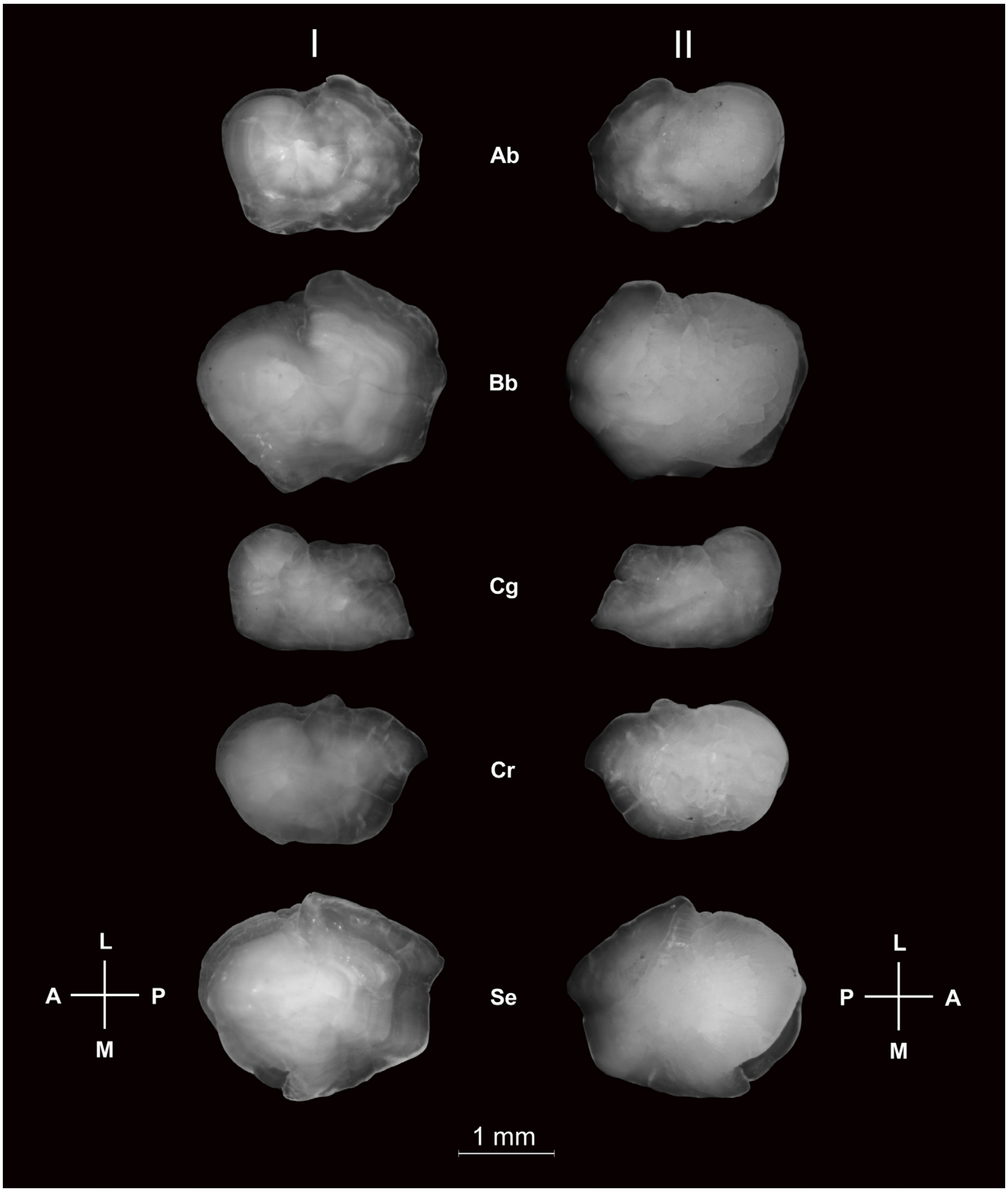

Figure 2. The distal (I) and proximal (II) views of the right lapilli of the five cyprinid fish species from Lake Ladik. Ab: *Abramis brama* (17.2 cm TL), Bb: *Blicca bjoerkna* (17.2 cm TL), Cg: *Carassius gibelio* (17.2 cm TL), Cr: *Chondrostoma regium* (17.2 cm TL), Se: *Scardinius erythrophthalmus* (17.2 cm TL), L: lateral, M: medial, A: anterior, P: posterior.

were highly significant ($P < 0.001$). The coefficients of determination (R^2) ranged from 0.717 to 0.975 and the regression models explained more than 80% of the variance in most cases (Table 2). The lapillus length had higher values of R^2 than the lapillus width in all species. The asteriscus length had the greatest values of R^2 among the asteriscus measurements for freshwater bream and rudd, while the asteriscus width had the greatest values of R^2 among the asteriscus biometrics for white bream, Prussian carp, and brond-snout. The mean percent prediction errors ranged from 2.53 to 8.91. The values of the mean % PE of different otolith measurements for Prussian carp were lower than those of the other species. The regressions with high R^2 yielded low mean % PE values (Table 2).

Table 2. Nonlinear and linear relationships relating otolith measurements versus total length and the mean percent prediction errors of each regression for five cyprinid fish species from Lake Ladik, Turkey.

Species	Measure	N	Orientation	Regression equation	R^2	Observed TL range	Predicted TL range	% PE ± SD
A. brama	AL	226	Pooled	$TL = 4.655\ AL^{1.180}$	0.953	9.1–49.6	7.8–50.4	6.07 ± 4.74
	AW	229	Pooled	$TL = 4.664\ AW^{1.335}$	0.944	9.1–49.6	7.9–46.8	6.68 ± 5.41
	LL	254	Pooled	$TL = 5.723\ LL^{1.306}$	0.948	9.1–53.5	8.4–53.8	6.68 ± 5.24
	LW	251	Pooled	$TL = 7.713\ LW^{1.339}$	0.910	9.1–53.5	8.0–55.9	8.91 ± 6.81
*B. bjoer*kna	AL	169	Pooled	$TL = 5.563\ AL^{0.999}$	0.789	13.2–27.8	12.6–24.8	5.39 ± 3.89
	AW	168	Pooled	$TL = 5.228\ AW^{1.148}$	0.803	13.2–24.5	12.5–23.7	5.24 ± 3.54
	LL	175	Pooled	$TL = 6.281\ LL^{1.074}$	0.779	13.2–27.8	12.5–24.3	5.49 ± 3.94
	LW	174	Pooled	$TL = 8.315\ LW^{0.941}$	0.718	13.2–24.5	12.4–24.4	6.21 ± 4.16
C. gibelio	AL	114	Right	$TL = 4.828\ AL^{1.124}$	0.946	14.3–28.8	14.4–30.8	3.87 ± 2.96
	AL	111	Left	$TL = 4.097\ AL^{1.210}$	0.958	14.3–28.8	14.1–29.7	3.46 ± 2.52
	AW	113	Pooled	$TL = 4.523\ AW^{1.328}$	0.975	14.3–28.8	14.3–29.7	2.53 ± 2.13
	LL	116	Pooled	$TL = 5.654\ LL^{1.517}$	0.970	14.3–28.8	14.0–29.5	3.18 ± 3.30
	LW	115	Pooled	$TL = 10.935\ LW^{1.419}$	0.941	14.3–28.8	14.4–31.1	4.06 ± 3.64
C. regium	AL	93	Pooled	TL = 6.864 AL + 2.158	0.761	16.5–24.5	17.2–26.2	4.76 ± 3.42
	AW	92	Pooled	TL = 7.422 AW + 1.876	0.866	16.5–24.5	17.1–26.7	3.56 ± 2.49
	LL	164	Pooled	TL = 8.462 LL – 0.814	0.830	16.5–24.5	15.6–26.2	4.09 ± 2.96
	LW	162	Pooled	TL = 8.711 LW + 3.026	0.717	16.5–24.5	15.7–25.6	5.11 ± 3.72
S. erythrophthalmus	AL	197	Pooled	$TL = 5.096\ AL^{1.026}$	0.893	11.1–23.3	10.6–23.0	5.20 ± 3.75
	AW	198	Pooled	$TL = 4.485\ AW^{1.243}$	0.867	11.1–23.3	10.7–23.6	5.86 ± 4.22
	LL	200	Pooled	$TL = 5.126\ LL^{1.187}$	0.903	10.1–23.3	10.1–23.1	4.93 ± 3.65
	LW	203	Pooled	$TL = 6.111\ LW^{1.206}$	0.765	10.1–23.3	9.2–22.8	7.78 ± 5.54

N, number of otoliths; AL, asteriscus length; AW, asteriscus width; LL, lapillus length; LW, lapillus width; TL, fish total length; R^2, coefficient of determination; PE, prediction error; SD, standard deviation

4. Discussion

In general, linear functions are preferred to describe otolith size–fish size relationships. However, Campana (2004) noted that the relationship between fish and otolith length is not necessarily linear, and that the relationship for larvae is often very different from that for adults. Otolith biometry–body length relationships were defined using linear models for various fish species (Echeverria, 1987; Şahin and Güneş, 1998; Harvey et al., 2000; Şen et al., 2001; Morley and Belchier, 2002; Bostancı, 2009; Battaglia et al., 2010; Zorica et al., 2010; Jawad et al., 2011; Bostancı et al., 2012; Basusta et al., 2013; Felix et al., 2013). However, nonlinear models were used to generate the mentioned relationships for some fishes (Waessle et al., 2003; Tarkan et al., 2007; Kumar et al., 2012; Skeljo and Ferri, 2012). In this study, curvilinear and linear functions provided the best fit for 80% and 20% of all species, respectively. The right and left otoliths are very similar, but not identical (Campana, 2004). Therefore, the right and left measurements of otoliths may not always provide same estimates in back-calculation of prey size (Tarkan et al., 2007). Thus, adequate statistical analysis should be performed for the combination of right and left otolith data (Morley and Belchier, 2002; Tarkan et al., 2007; Skeljo and Ferri, 2012). In the analysis of morphometric parameters (otolith length and width) versus fish total length, no statistical differences between right and left otoliths were detected, and so the right- and left-side measurements were mostly pooled in the current study. In food habit investigations, otoliths are frequently found, but the sex and size of prey fish are unknown. The regressions obtained from entire samples are needed for those occasions when the sex is not known or when the regressions were not considerably different between sexes (Echeverria, 1987). This work provides the relationships in question for combined sexes as seen in Table 2.

Because there is no study on relationships between otolith dimensions and body length for freshwater bream, we could not do any comparisons. The regressions generated for white bream, Prussian carp, brond-snout, and rudd could also not be compared with those from the literature (Aydin et al., 2004; Bostancı et al., 2007; Gumus et al., 2007; Tarkan et al., 2007; Bostancı, 2009) due to differences in the used models, lengths, and orientations of otoliths. However, all of the previous studies on the species in question reported that strong and positive relationships were determined between otolith size and fish size. Tarkan et al. (2007) stated that the lapillus length is suited to the prediction of fish length for only five (Baltic vimba, roach, white bream, rudd, Prussian carp) of eleven cyprinid species. Our findings are in agreement with their results.

In studies on the relationship between otolith and fish size, the otolith length was usually used (Echeverria, 1987; Gamboa, 1991; Şahin and Güneş, 1998; Harvey et al., 2000; Şen et al., 2001; Aydin et al., 2004; Uçkun et al., 2006; Tarkan et al., 2007; Longenecker, 2008; Cengiz et al., 2012; Felix et al., 2013). This paper supplies additional information by considering both the otolith length (OL) and width (OW). In most cases, it is more suitable to determine more than one equation (OL–TL, OL–OW), because the tip of the otolith rostrum may be damaged and it is then impossible to measure the OL.

The lengths of all species studied may be reconstructed from the regressions obtained in this work, but their weights are incalculable. In this case, the equations of the length–weight relationships can be used to estimate fish weights. The parameters of the length–weight relationships for fishes studied in the present study were given in the works of Erbaşaran (2012), Yılmaz et al. (2012), Yazıcıoğlu et al. (2013), Yazıcı (2013), and Saylar and Yılmaz (2014).

In order to determine the consumption rates of piscivorous predators in aquatic ecosystems, it is necessary to gather information on the sizes of the prey fish consumed. However, it is difficult to estimate the original size of a prey fish from stomach content data because of the complications caused by digestion. Erosion of the prey bones and otoliths from digestive juices can lead to measurement error or bias when prey sizes are back-calculated from digested hard structures (Scharf et al., 1998; Woods, 2005). Despite such concerns noted in various studies, bones and otoliths of fishes are excellent indicators of original prey size (Radtke et al., 2000; Wood, 2005; Tarkan et al., 2007; Radhakrishnan et al., 2010; Jawad et al., 2011; Masson et al., 2011).

Consequently, our results demonstrated that the biometric relationships between asteriscus and lapillus measurements and total length were quite convenient for reliable original size estimates of all species studied. However, these predictive equations obtained from the present research should be used within the fish size ranges given in Table 1. Additionally, this study is the first reference on the otolith morphometric features of five cyprinid fish species inhabiting Lake Ladik. These data will help investigators studying food habits of top predators to determine the size of prey fish from the length and width of recovered otoliths.

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