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Research Article

Otolith shape analysis and relationships between total length and otolith dimensions of European barracuda, *Sphyraena sphyraena* in the Mediterranean Sea

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Abstract

Aims of the present study were to evaluate otolith shape and estimate the relationships between total length and otolith dimensions of *S. sphyraena* from the Mediterranean coast of Turkey. Two shape analysis methods were used for otolith shape and also two regressions models were used to estimate total length-otolith dimensions relationships. In the present study, 97 fish were examined during 2020-2021 fishing season. Otolith shape indices such as form factor, aspect ratio, ellipticity, circularity, rectangularity, and roundness were calculated for each *S. sphyraena* sample. Otolith contours were obtained using wavelet functions and ten otolith morphological characters for *S. sphyraena*. Morphological characteristics of *S. sphyraena* otoliths were variable both between left and right side of the otolith and total length groups. Otolith width and area measurements differed statistically between left and right otoliths ($p<0.05$). High-level morphological differences in anterior, posterior and dorsal part zones of the otoliths of *S. sphyraena* were detected between right and left otoliths. The relationships were determined between total length and otolith dimensions. The highest correlation value was calculated between otolith length and total length (r^2: 0.876). This is the first study to determine the otolith shape and relationships between total length and otolith dimensions of *S. sphyraena* from the Mediterranean coast of Turkey.

Keywords: Sagittal otolith, Shape indices, *Sphyraena sphyraena*, Otolith dimensions, Mediterranean Sea

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Introduction

Mediterranean Sea is considered the largest semi-enclosed basin and Mediterranean waters have been facing pollution for a long time due to many natural and anthropogenic environmental factors (Zorita *et al.*, 2007). Environmental monitoring studies can play an important role to provide scientific information in assessing the sustainability and health of this kind of aquatic ecosystem. Otoliths are important organs that play a role in many vital activities of fish, especially hearing and balance (Popper and Coombs, 1982). They keep their records in life stages of fish in the environment. Therefore, otoliths can be named as "flight recorders" of fish, such as the black box of the aircraft (Lecomte-Finiger, 1992). Otoliths are concretions of calcium carbonate ($CaCO_3$) and their color is white. Otoliths are in three pairs, including asteriscus, lapillus, and sagitta. They are located in the inner ears of fish (Popper and Coombs, 1980). The otolith shape is species-specific and is partially subject to genetics (Vignon and Morat, 2010). Otolith contour is one of the analyses which is used for identification and discrimination of the fish species in ichthyology in relation to other morphological options such as shape indices and geometric morphometry. However, compared to other methods, both intraspecies and interspecies separation are higher at a specific level (Sadighzadeh *et al.*, 2014; Yedier *et al.*, 2019; Bascinar, 2020; BASCINAR and Atilgan, 2020).

Although otoliths are used extensively in ichthyology, they are not only limited to this but also they have been used for many purposes in different studies such as feeding ecology (Gagliano and McCormick, 2004), stock identification (Morat *et al.*, 2012), stock discrimination (Zengin *et al.*, 2015), identification and classification (Bostanci *et al.*, 2015), environmental reconstruction (Izzo *et al.*, 2018) and age and growth (Havimana *et al.*, 2020). Furthermore, the relationship between sizes and total length in fisheries provides several benefits to researchers in estimating the size of the prey (Mehanna *et al.*, 2019). Once the relationships between the fish size in a fish species and the otolith dimensions are determined, the total length, standard length and fork length of a fish can be estimated from the otolith dimensions and vice versa (Yilmaz *et al.*, 2014; Bostanci *et al.*, 2017).

Sphyraena, a genus known as barracudas in the family of Sphyraenidae, is represented by 28 species worldwide (Froese and Pauly, 2020). The genus includes six species in the Mediterranean Sea such as *S. chrysotaenia* Klunzinger, 1884, *S. flavicauda* Rüppell, 1838, *S. intermedia* Pastore, 2009, *S. obtusata* Cuvier, 1829, *S. sphyraena* (Linnaeus, 1758), *S. viridensis* Cuvier, 1829. European barracuda, *S. sphyraena* lives in many different habitats. Commonly, European barracuda is present in eastern and western Atlantic, Angola, Canary Islands, Azores, Black Sea, and Mediterranean (Froese and Pauly, 2020). The fact that distribution, population density, and extinction risk of a species is not exactly clear can lead to difficulties in establishing conservation planning for fish species. For instance, *S. sphyraena* is classified as Data Deficient (DD) on IUCN Red List (Smith-Vaniz and Herrera, 2015). Moreover, *S. sphyraena* is one of the commercially important marine fish species all over the world (Allam *et al.*, 2004a). Although there is a high abundance of *S. sphyraena* in many marine habitats all over the world, the species is one of the least investigated species in the Mediterranean Sea. Most of the studies with this species in the Mediterranean Sea are related to biological features of the species such as age and growth (Allam *et al.*, 2004a), length-weight relationships (Ceyhan *et al.*, 2009), and reproductive biology (Allam *et al.*, 2004b). There is no detailed study on otolith biometry and shape of *S. sphyraena* in the Mediterranean Coasts of Turkey. Therefore, objectives of the present study were: (i) to evaluate otolith shape of *S. sphyraena* using two different methods (Contour analyses and shape indices) in the Mediterranean Sea; (ii) to estimate the relationships between total length and otolith dimensions of *S. sphyraena*. This is the first study, in which different methods were used together and give a comprehensive description of left and right otoliths of *S. sphyraena*.

Materials and methods

Sampling

S. sphyraena samples were collected during the 2020-2021 fishing season from Antalya Bay, Mediterranean Sea ,Turkey. The total length of each *S. sphyraena* sample was measured (nearest 1 mm) and they were sexed. Their left and right sagittal otoliths were removed, washed, and stored dry in the well plate. Undamaged right and left sagittal otoliths were photographed on distal and proximal surfaces using Leica S8APO microscope connected camera system. The otolith images were converted to a suitable format for the wavelength method by using Adobe® Photoshop CS6 software (Ver. 13.1.2) program.

Otolith shape analysis and measurements

Two different methods were used for detailed otolith shape analysis of this species. Firstly, contour analysis was used for *S. sphyraena* otolith shape. Because the total length of fish samples affected otolith morphology, the fish samples were divided into total length groups. In this study, the total length groups were arranged as I; 180-200 mm, II; 201-220 mm, III; 221-240 mm, IV; 241-260 mm, V; 261-280 mm, VI; 281-300 mm, VII; 301-320 mm. Besides, Scanning Electron Microscope (SEM) was used to record morphological characteristics of the sagittal otolith of *S. sphyraena* (Fig. 1).

Ten otolith morphological characters, including general shape, notch, rostrum shape, antirostrum shape, distal and proximal surfaces, anterior and posterior regions, dorsal and ventral margins were examined for each sample (Fig. 2).

S. sphyraena otolith shape was analyzed using wavelet functions whose advantage over other contour analyses in well known. In the contour analysis, a total of 512 equidistant cartesian coordinates on each orthogonal projection of *S. sphyraena* sagittal otolith was extracted (Fig. 3). They were analyzed according to Parisi-Baradad *et al.* (2005) wavelet transformed method. In this method, each sagittal otolith contour originated nine wavelets depending on otolith shape differences.

Figure 1: Distal surface SEM images of left and right sagittal otoliths from *S. sphyraena.*

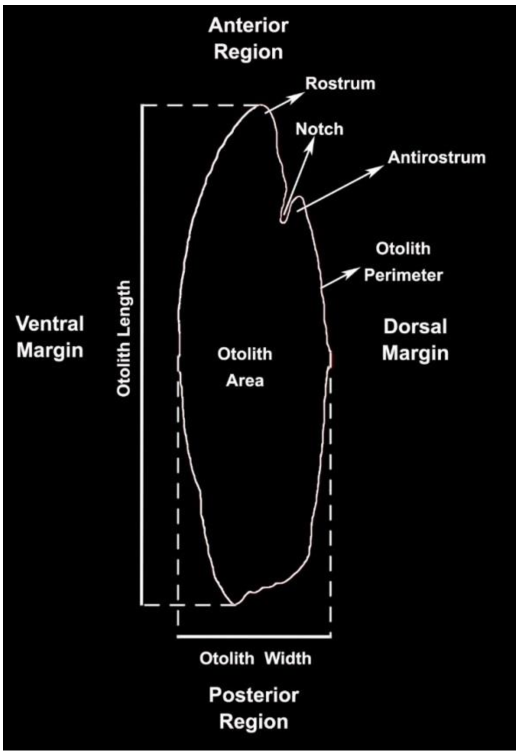

Figure 2: Otolith characters of *S. sphyraena* species evaluated in the study.

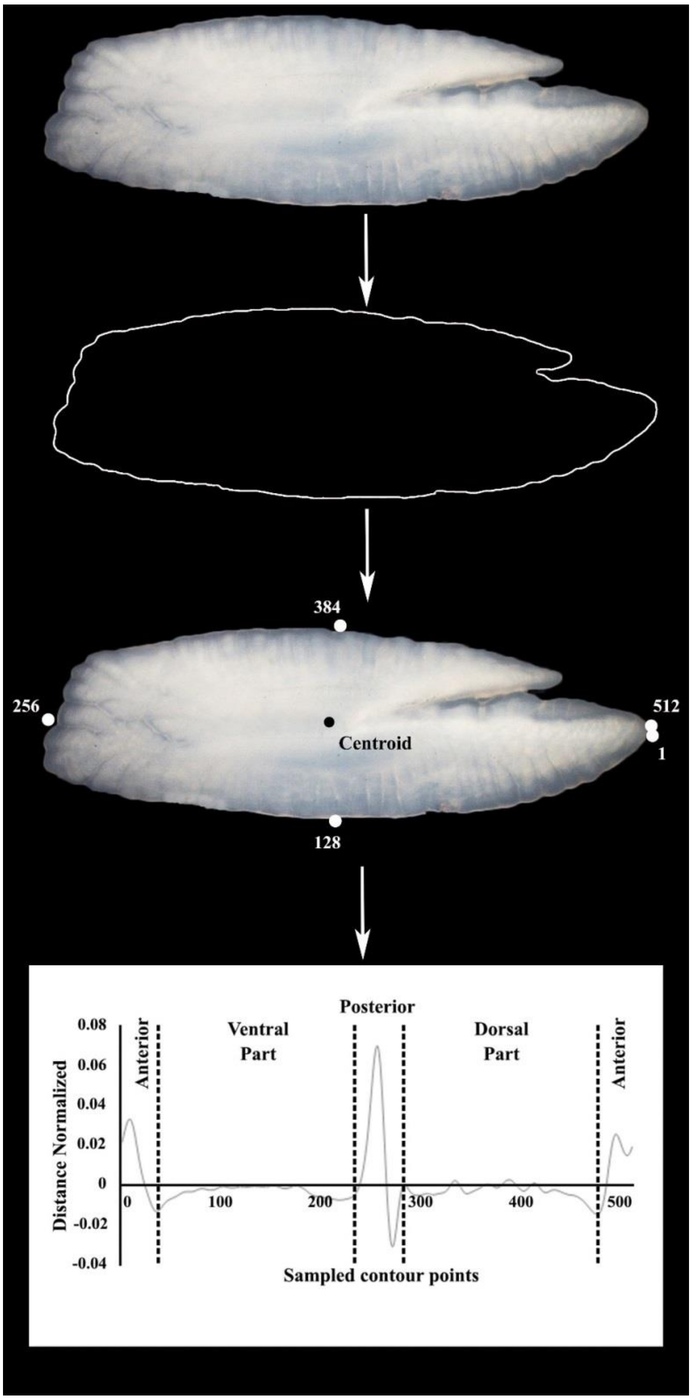

Figure 3: The procedure for obtaining wavelets of *S. sphyraena* otolith from the Mediterranean Sea.

Secondly, otolith shape indices such as aspect ratio (AR), circularity (C), ellipticity (E), form factor (FF), rectangularity (R), and roundness (RD) were used for otolith shape analysis of *S. sphyraena*. Sagittal otolith dimensions such as otolith area (OA), otolith perimeter (OP), otolith length (OL), and width (OW) were used for the otolith shape analysis using the following formulas: $FF=(4\pi OA)/OP^2$; $E=(OL-OB)/(OL+OB)$; $AR=(OL/OB)$; $R=OA/(OLOB)$; $RD=(4OA)/(\pi OL^2)$; and $C=OP^2/OA$ (Tuset *et al.*, 2003; Ponton, 2006). The otolith measurements were determined for each

S. sphyraena. OL, OW, OP, and OA were measured (nearest 0.0001 mm) using the ImageJ image analysis software (Ver. 1.50i).

Statistical analyses

The otolith measurements were tested for the assumption of homogeneity and normality of variance using Bartlett's test and Kolmogorov-Smirnov test for goodness-of-fit, respectively. In the currents study, the variables were not normally distributed; therefore, a comparison of mean values of left and right otolith was performed using a non-parametric test (Wilcoxon signed-rank test). The difference between otoliths of female and male individuals was checked by the Mann Whitney U test. Moreover, in the current study, two different regression models (Linear and Power) were used to estimate the relationships between total length and otolith dimensions of *S. sphyraena*. Power and linear regressions were calculated using the $y=ax^b$ and y=ax+b (where y is the total length of fish and x is otolith dimensions), respectively. The statistical analyses were performed with the Minitab 17 statistical software.

Results

A total of 97 *S. sphyraena* (41% female and 59% male) samples that are suitable for measuring total length were used in the present study. Total lengths of Mediterranean barracuda samples ranged from 180 to 320 mm. *S. sphyraena* samples were divided into seven total length groups. In the current study, a total of 194 sagittal otoliths (left and right otoliths) that are removed from Mediterranean barracuda individuals of the Mediterranean Sea were examined. Since there was no statistical difference between the otolith measurements of female and male individuals (Mann Whitney U test; $p>0.05$), the otoliths of female and male individuals were evaluated together for each fish sample. According to the Wilcoxon signed-rank test results, the differences between right and left otolith measurements were statistically significant ($p<0.05$) for otolith area and otolith width characters (Table 1). However, otolith length and perimeter values were not significantly different between left and right otoliths ($p>0.05$). Therefore, both left and right otoliths were separately analyzed for each *S. sphyraena* sample.

Otolith shape analysis

The otolith shape indices were calculated for each *S. sphyraena* using the data obtained from the measured values of left and right sagittal otoliths. While significant differences were determined in roundness (RD), aspect ratio (AR), and ellipticity (E) ($p<0.05$), no significant differences were found in regards to circularity (C), form factor (FF), and rectangularity (R) ($p>0.05$) between right and left otoliths (Table 1). Ten otolith morphological characters that were examined in the present study, including general shape, rostrum and antirostrum shape, notch, distal and proximal surfaces, anterior and posterior regions, dorsal and ventral margins, were presented for seven total length groups of *S. sphyraena* in Table 2.

When sagittal otoliths in male and female individuals were compared in terms of ten otolith morphological characters, there were no distinct differences between male and female samples. Besides, there was no statistical difference between otolith measurements of female and male individuals ($p>0.05$), otoliths of female and male individuals were evaluated together. Overall left and right otolith shapes were presented for sagitta pairs of *S. sphyraena* (Fig. 1).

Table 1: Wilcoxon signed-rank test results between right and left otolith dimensions and shape indices of *S. sphyraena* from the Antalya Bay, Mediterranean Sea ,Turkey.

Otolith Dimensions	Side	N	Mean	Standard Error	Standard Deviation	Minimum	Maximum	P
Otolith Length (mm)	Left	97	7.9822	0.0659	0.6457	6.2592	9.3854	$p>0.05$
	Right	97	7.9844	0.0665	0.6515	6.1385	9.3565	
Otolith Width (mm)	Left	97	2.6250	0.0194	0.1900	2.1050	3.1543	$p<0.05$*
	Right	97	2.6461	0.0198	0.1938	2.1039	3.1014	
Otolith Area (mm^2)	Left	97	15.3260	0.2370	2.3270	9.5410	21.0920	$p<0.05$*
	Right	97	15.4160	0.2380	2.3340	9.5780	21.0160	
Otolith Perimeter (mm)	Left	97	19.6470	0.1810	1.7760	15.5550	25.4690	$p>0.05$
	Right	97	19.6220	0.1800	1.7660	15.3020	26.0240	
Otolith Shape Indices								
Aspect Ratio AR)	Left	97	3.0411	0.0123	0.1209	2.8050	3.2820	$p<0.05$*
	Right	97	3.0179	0.0123	0.1204	2.7761	3.2785	
Circularity (C)	Left	97	25.3290	0.1720	1.6900	22.6150	32.1430	$p>0.05$
	Right	97	25.1100	0.1580	1.5460	22.2230	32.2270	
Ellipticity (E)	Left	97	0.5047	0.0015	0.0148	0.4744	0.5329	$p<0.05$*
	Right	97	0.5018	0.0015	0.0149	0.4704	0.5326	
Form Factor (FF)	Left	97	0.4979	0.0031	0.0308	0.3908	0.5554	$p>0.05$
	Right	97	0.5019	0.0029	0.0284	0.3897	0.5652	
Rectangularity (R)	Left	97	0.7274	0.0011	0.0105	0.7020	0.7478	$p>0.05$
	Right	97	0.7258	0.0012	0.0118	0.6915	0.7552	
Roundness (RD)	Left	97	0.3051	0.0012	0.0119	0.2793	0.3314	$p<0.05$*
	Right	97	0.3068	0.0013	0.0125	0.2782	0.3353	

*Statistically different.

The shape of left and right otoliths in *S. sphyraena* was spindle-shaped, and it was not varied among total length groups. Although rostrum shape was not varied between right and left otolith, it was varied among *S. sphyraena* total length groups. It was determined that the antirostrum shape differed between both right and left otolith pairs and among total length groups of *S. sphyraena*. Although there was no notch in the right and left otoliths of the individuals in the total length groups I and II, it was observed that there was a notch in the total length groups III, IV, and VI.

Table 2: The morphological characters of left and right sagittal otoliths for seven total length groups of *S. sphyraena* from Antalya Bay, Mediterranean Sea (Turkey).

Otolith Morphological Characters		Total Length Groups I	II	III	IV	V	VI	VII
General Shape	L	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped
	R	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped	Spindle-Shaped
Rostrum Shape	L	Pointed	Round	Round	Round	Pointed to Round	Round	Pointed
	R	Pointed	Round	Round	Round	Pointed to Round	Round	Pointed
Antirostrum Shape	L	Absent	Absent	Pointed to Round	Pointed	Pointed	Pointed	Absent
	R	Absent	Absent	Pointed	Pointed	Absent	Pointed	Pointed
Notch	L	Absent	Absent	Present	Present	Present	Present	Absent
	R	Absent	Absent	Present	Present	Absent	Present	Present
Distal Surface	L	Convex	Convex	Convex	Convex	Convex	Convex	Convex
	R	Convex	Convex	Convex	Convex	Convex	Convex	Convex
Proximal Surface	L	Flat	Flat	Flat	Flat	Flat	Flat	Flat
	R	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Anterior Region	L	Peaked	Double-Peaked	Double-Peaked	Double-Peaked	Double-Peaked	Double-Peaked	Peaked
	R	Peaked	Peaked	Double-Peaked	Double-Peaked	Double-Peaked	Double-Peaked	Double-Peaked
Posterior Region	L	Round	Flattened	Flattened	Flattened to Oblique	Flattened	Peaked	Round
	R	Round	Oblique	Oblique to Round	Flattened	Flattened to Oblique	Peaked	Oblique
Dorsal Margin	L	Crenate	Crenate	Crenate	Sinuate	Sinuate to Crenate	Entire	Angled to entire
	R	Crenate	Sinuate to Crenate	Crenate	Sinuate	Angled to entire	Angled to sinuate	Angled to sinuate
Ventral Margin	L	Sinuate to Entire	Entire	Entire	Entire	Entire	Entire	Sinuate to Entire
	R	Sinuate to Entire	Entire	Entire	Entire	Entire	Sinuate to Entire	Sinuate to Entire

L: Left side of the otolith, R: Right side of the otolith.

The presence of notch was also varied in the right and left otoliths of individuals in the total length groups V and VII. It was determined that the proximal and distal surfaces of sagittal otolith of *S. sphyraena* were flat and convex, respectively. These otolith features were not varied both between right and left otolith pairs and among total length groups. When the anterior and posterior regions of sagittal otoliths were examined, it was revealed that these regions were varied both between right and left otolith pairs and among total length groups. Similarly, it was revealed in the present study that the dorsal and ventral margins showed some differences in terms of both right and left otoliths and total length groups (Table 2).

In the current study, the 4th wavelet, which has the most difference between the nine wavelets formed due to contour and otolith shape differences, was selected and analyses were carried out over it. The contour data from female and male otoliths revealed no statistical difference (p>0.05) when the contour analysis of otoliths of female and male individuals of *S. sphyraena* were examined (Fig. 4).

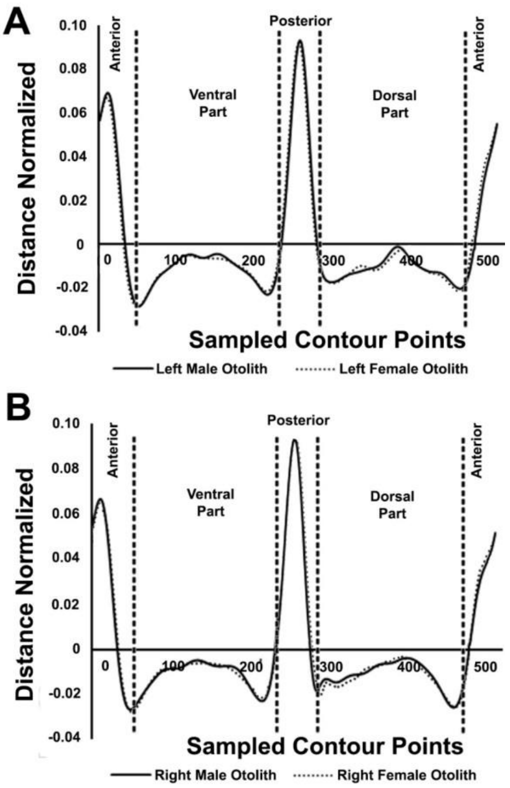

Figure 4: Signals and zones of wavelet 4 for *S. sphyraena* in left otolith of males and females (A) and right otoliths of males and females (B) from Antalya Bay, Mediterranean Sea, Turkey.

However, it was determined that there were statistical differences in the wavelet changes of otolith contour features of left and right otoliths (p<0.05). High morphological differences in the anterior, posterior, and dorsal part zones were detected in right and left otoliths of *S. sphyraena* (Fig. 5).

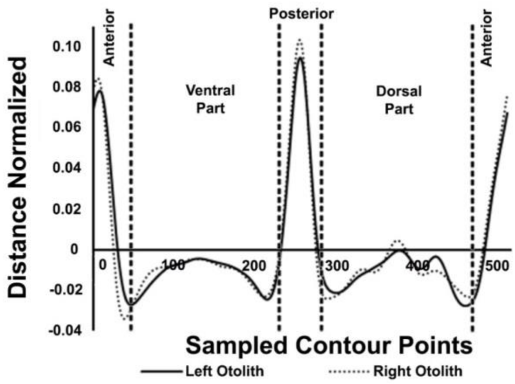

Figure 5: Signals and zones of wavelet 4 from the left and right otoliths of all (male and female) *S. sphyraena* samples from Antalya Bay, Mediterranean Sea, Turkey.

Relationships of total length-otolith dimensions

Plots of relationships between total length and otolith dimensions of *S. sphyraena* were presented in Figure 6. The relationships such as TL-OA, TL-OL, TL-OP, and TL-OW of European barracuda were analyzed and the results were given in Table 3.

When the regression models were compared, it was determined that the power regression model had a higher determination coefficient (r^2) than the linear model in terms of all otolith variables. The highest and lowest values of determination of correlations (r^2) were calculated for total length and otolith length (r^2: 0.876 for left otolith; r^2: 0.876 for right otolith) and total length and otolith area (r^2: 0.759 for left otolith; r^2: 0.768 for right otolith) relationships, respectively (Table 3). The positive correlations were found between total length and otolith dimensions of *S. sphyraena.*

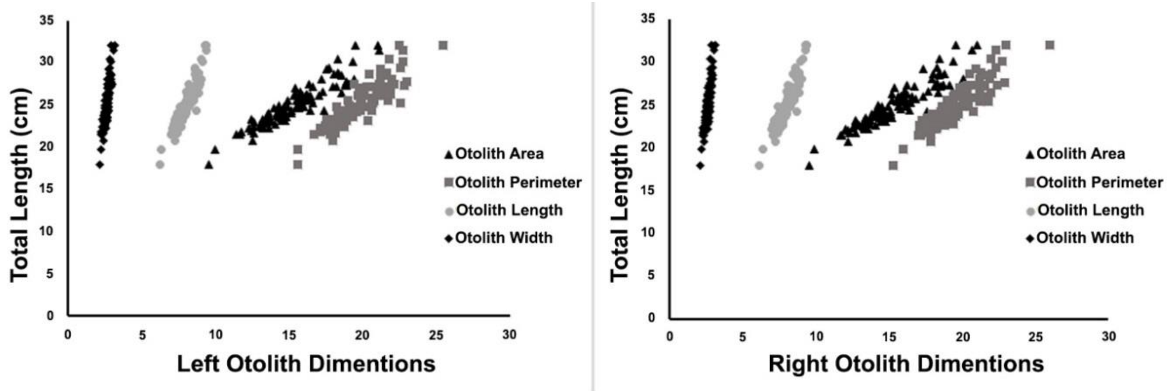

Figure 6: Total length-otolith dimensions relationships for left and right otoliths in *S. sphyraena* from Mediterranean Coasts of Turkey.

Table 3: Equations of relationships between total length and otolith dimensions of *S. sphyraena* from Antalya Bay, Mediterranean Sea (Turkey).

Otolith Dimensions	Regression Models	Left Side			Right Side		
		Formulas	r^2	*P*	Formulas	r^2	*P*
Otolith Area (OA)	Linear	TL=11.937OA-6.3059	0.759	<0.001	TL=11.772OA-6.1209	0.768	<0.001
	Power	$TL=7.5361OA^{1.2416}$	0.767	<0.001	$TL=7.5695OA^{1.227}$	0.779	<0.001
Otolith Length (OL)	Linear	TL=1.0432OL+9.041	0.869	<0.001	TL=1.0394OL+9.0052	0.868	<0.001
	Power	$TL=4.5092OL^{0.6286}$	0.876	<0.001	$TL=4.4888OL^{0.6289}$	0.876	<0.001
Otolith Perimeter (OP)	Linear	TL=3.7423OP-4.8427	0.861	<0.001	TL=3.6864OP-4.4045	0.851	<0.001
	Power	$TL=2.1586OP^{1.1791}$	0.869	<0.001	$TL=2.2341OP^{1.1624}$	0.860	<0.001
Otolith Width (OW)	Linear	TL=1.2985OW-0.4815	0.784	<0.001	TL=1.3274OW-1.0172	0.811	<0.001
	Power	$TL=1.1789OW^{1.0256}$	0.796	<0.001	$TL=1.1094OW^{1.0465}$	0.820	<0.001

Discussion

For a long time, otolith morphology has been a very useful approach in taxonomic definition of many fish species (L'Abée-Lund and Jensen 1993; Tuset *et al.,* 2008; Pavlov, 2019). The general otolith morphology of *S. sphyraena* was reported in previous studies (Tuset *et al.*, 2008; Bourehail *et al.*, 2015), but the otolith morphology was not determined in detail according to both right and left pairs and total length groups. For this reason, this is the first study conducted from the Turkish Mediterranean Sea coast that covers these deficiencies related to the species. In the present study, no consistent morphological difference was observed between the otoliths of female and male *S. sphyraena* individuals (Fig. 4). Besides, the morphological characters such as otolith shape, distal and proximal surfaces were not varied among total length groups and left-right otolith pairs. However, other morphological characters such as rostrum shape, antirostrum shape, notch, anterior region, posterior region, dorsal margin, and ventral margin were varied among both left-right pairs and total length groups (Table 2; Fig. 5). General otolith morphology was determined as spindle-shaped for *S. sphyraena*. The proximal and distal surfaces were flat and convex, respectively. The anterior region was mainly peaked and double peaked types in the sagittal otoliths of *S. sphyraena*. The ventral margin of otoliths was also varied such as sinuate and entire. The dorsal margin of sagittal otoliths was also varied such as sinuate, crenate, and angled to entire with different types of posterior regions such as round, oblique, flattened, and peaked. Similar results were obtained in previous studies with *Sphyraena* species in different marine habitats. For instance, *S. sphyraena* and *S. viridensis* from the western Mediterranean (Tuset *et al.*, 2008), *S. sphyraena, S. intermedia* and *S. viridensis* from the central Mediterranean Sea (Pastore, 2009), *S. chrysotaenia* from the central and eastern Mediterranean (Tuset *et al.*, 2012), *S. sphyraena* and *S. viridensis* from the Algerian coast (Bourehail *et al.*, 2015) and *S. barracuda, S. guachancho* and *S. tome* from southern Brazil (Santificetur *et al.*, 2017). Although other otolith characters obtained in the present study were similar to previous studies (Tuset *et al.*, 2008; Bourehail *et al.*, 2015), no detailed comparison was made from the information deficiencies of the total length group, sex, and otolith side information in these data.

It was reported in many studies that the otolith shape is species-specific and is not varied within the same species (L'Abée-Lund 1988; Tuset *et al.*, 2008; Bostanci *et al.*, 2015). In the present study, when the otolith shapes of *S. sphyraena* individuals from different total length groups were examined, it was once again revealed that the otolith shape is species-specific. However, it was determined that other otolith features can change according to right-left and total length groups. It was shown that otoliths can represent different fish sizes with different morphologic characters (Table 2). The main variations of morphological otolith characteristics were found on the dorsal margin, anterior and posterior regions in *S. sphyraena*, which was similar to the results of the contour analysis (Fig. 5). There is no study to compare the contour analysis of otoliths for *S. sphyraena*. This study is the first study in which contour analysis of left-right otoliths and male-female otoliths is performed from the Turkish Mediterranean Sea coast. For this reason, evaluation of the characters is difficult in discrimination studies, but it is crucial for a better understanding of fish species in different aquatic habitats. Moreover, intra-species variation also should be well understood in species discrimination studies.

In the current study, statistical differences were determined between some left and right measurements of *S. sphyraena* and similar results were reported for Algerian coast population of *S. sphyraena*. As in our study, it was stated that left and right otoliths were used separately for the Algerian coast population. The mean values of left and right otoliths form factors of *S. sphyraena* on Algerian coast were 0.381±0.039 and 0.372±0.035, respectively (Bourehail *et al.*, 2015).

However, in the present study, the

mean values of the form factors were bigger than those of the Algerian coast population as 0.4979±0.0031 for left otolith and 0.5018±0.0029 for right otolith. The roundness values were reported as 0.332±0.019 for left otolith and 0.333±0.017 for the right. We reported these values as 0.3051±0.0012 for left otolith and 0.3068±0.0013 for right otolith in *S. sphyraena* from the Mediterranean coast of Turkey. The circularity values of left and right otoliths of *S. sphyraena* from Algerian coast was found to be much higher than our results as 33.340±3.586 (for left otolith) and 34.010±3.466 (for right otolith) for Algerian coast and 25.329±0.172 (for left otolith) and 25.110±0.158 (for right otolith) for the Mediterranean coast. Rectangularity values were similar for both Algerian and Mediterranean coasts. Rectangularity values were 0.727±0.018 (for left otolith) and 0.727±0.022 (for right otolith) for the Algerian coast and 0.7274±0.0011 (left) and 0.7258±0.0012 (right) for the Mediterranean coast. In the present study, ellipticity values of left and right otolith were higher than those of Algerian coast populations as 0.5047±0.0015 (for left otolith) and 0.5018±0.0015 (for right otolith) for Mediterranean coast and 0.454±0.034 (for left otolith) and 0.457±0.033 (for right otolith) for Algerian coast.

In the Algerian coast population of *S. sphyraena*, it was reported that there is a statistically significant difference in form factor and circularity values between left and right otoliths but not in other shape indices. Contrary to Bourehail *et al.*, (2015), there was a statistical difference in aspect ratio, ellipticity, and roundness values between left and right otoliths in the present study while there was no difference in other shape indices. The reason for this observed difference in the same species may be the effects of fish and sample sizes and environmental factors. Estimating the original size of the prey fish in fisheries plays an important role in determining ecological and biological information such as selectivity of a particular predator, the biomass of the consumed prey, and predator consumption rates (Watanabe *et al.*, 2004; Battaglia *et al.*, 2010). Otoliths are also used to estimate the original size of prey fish by piscivorous predators (Pitcher, 1980). The relationships between otolith dimensions and total length provide valuable information about the back-calculation of the fish's total length from otolith measurements (Tuset *et al.*, 2010; Zan *et al.*, 2015). Munk (2012) reported strong correlation between otolith dimensions and total length suggesting that somatic growth has a significant influence on otolith growth. Similar results about somatic and otolith growth were reported in different aquatic habitats by many researchers (See *et al.*, 2016; Aneesh *et al.*, 2017; Jawad *et al.*, 2017). In the current study, otolith length was the strongest indicator of somatic growth in *S. sphyraena.* Similar to the results of our study, it was stated in many studies that otolith length is the strongest indicator of somatic growth in many marine fish species

(Altin and Ayyildiz, 2017; Aneesh *et al.*, 2017; Jawad *et al.*, 2017). Therefore, the relationship between total length and otolith measurements given in this study may be useful for researchers who examine the stomach contents of piscivorous predators by using the equations.

In many studies, otolith morphological characters are indicated as informative characters in identification of fish species and can be used in differentiation of the species (Sadighzadeh *et al.*, 2014; Bostanci *et al.*, 2015). Investigating population characteristics of fish species with different methods can be helpful in determining appropriate fisheries management strategies by making an extra contribution to the field. Moreover, total length-otolith measurement studies are important in prey-predator relationships. Such relationships are very useful in establishing prey-predator models for fisheries management (Christensen, 1996). In the present, it was revealed that morphological otolith characters may differ according to both left and right otolith pairs and fish size. In future studies in this field, otoliths should be evaluated according to left-right side and fish size in species identification and discrimination studies on otoliths.

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