Iran. J. Ichthyol. (December 2018), 5(4): 303-311
© 2018 Iranian Society of Ichthyology
P-ISSN: 2383-1561; E-ISSN: 2383-0964
http://www.ijichthyol.org

Received: August 29, 2018
Accepted: November 02, 2018
doi: 10.22034/iji.v5i4.312

Research Article

Morphological characteristics of otolith for four fish species in the Edremit Gulf, Aegean Sea, Turkey

Habib BAL*[1], Dilek TÜRKER[2], Kadriye ZENGİN[2]

[1]*Department of Fisheries, Livestock Research Institute, Bandırma, Balıkesir, Turkey.*
[2]*Department of Biology, Faculty of Science and Arts, Balıkesir University, Balıkesir, Turkey.*
**Email:* habipbal@hotmail.com

Abstract: Otolith morphology is important for species identification, fishery management and stock assessment. In this study, otolith (Sagitta) morphology of four fish species viz. *Pomatomus saltatrix*, *Sarpa salpa*, *Trachurus trachurus*, and *Belone belone* was investigated. The length (mm), width (mm), area (mm^2) and perimeter (mm) measurements of the otoliths were made and four different shape indices, including form factor (F_F), aspect ratio (A_R), roundness (R_D) and circularity (C_i) were calculated. In addition, relationships between total fish length and otolith morphology were investigated. Measurements of sagittal otoliths of four species were obtained by image analysis using tri-ocular microscope. Based on the results, the morphometric measurements and four examined shape factors of otolith varied among species. Coefficients of correlations (r) between total fish length and otolith morphology and otolith length-otolith morphology were generally highly significant (P<0.05) for studied fishes. The results show that the shape indices were significantly different in analyzed species even they indicated a similar pattern with maximal otolith length. These data provide information for species identification using sagittal otoliths in the fossils and diets of fish predators and also will contribute to the region's sustainable fisheries management.

Keywords: Otolith morphology, Species identification, Sustainable fisheries management.

Citation: Bal, H.; Türker, D. & Zengin, K. 2018. Morphological characteristics of otolith for four fish species in the Edremit Gulf, Aegean Sea, Turkey. Iranian Journal of Ichthyology 5(4): 303-311.

Introduction

The inner ears of all teleost fishes contain three calcified structures, which acts as balance and hearing organs (Popper et al. 2005). Otoliths commonly are used to determine the taxon and age of fishes (Esmaeili et al. 2014). This information is useful for fishery management, prey-predator studies and archaeological research (Harvey et al. 2000; Reichenbacher et al. 2009). Particularly fish and otolith size studies, predator's size distributions of fish consumed by are important evidence that can be used to detect. Firstly, Härkönen (1986) noticed that fish length can be detected using otolith length. Fishery biologists have used sagitta in different aspects of biological studies due to their large size and distinct growth rings (Boehlert 1985; Summerfelt & Hall 1987). On the other hand, paleontologists, oceanographers and marine biologists have used the species specific distinctive morphology of the sagitta and their dense structures that can resist certain degree of disintegration to determine the identity of fish species found in sediments and stomach contents of marine birds and mammals (Fitch 1964; Treacy & Crawford 1981; Trippel & Beamish 1987). However, the relationship between fish size and otolith size is not well-known enough for many fish species. Their form and size such as length, weight, growth, and consistency vary considerably among species (Labeelund 1988; Gauldie 1994; Yoshinaga et al. 2000). Thus, they are one of the most important and basic building blocks identification structure of age in a certain population and stock to help development of fishery management models. Furthermore, the analyses of

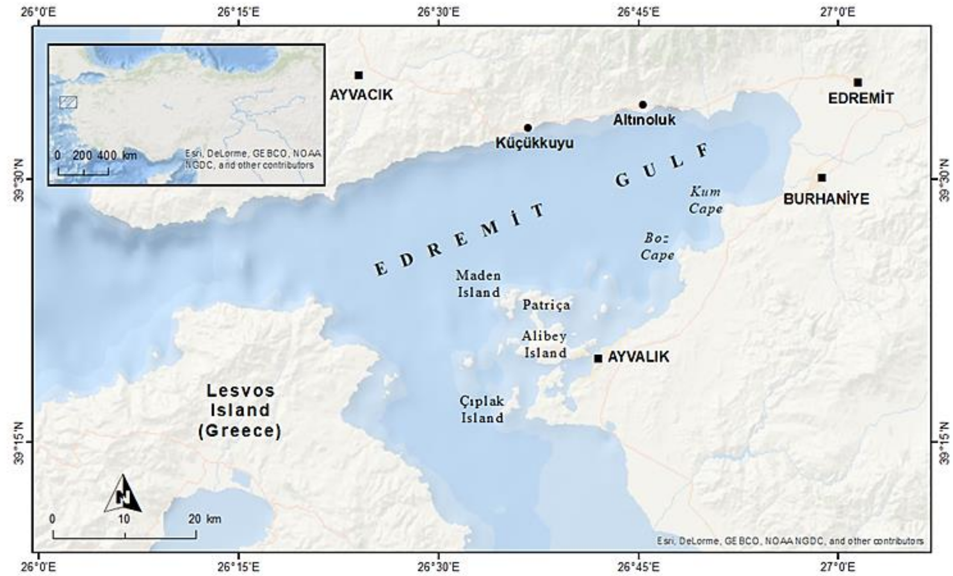


Fig.1. Map of the study area.

microstructure otolith have greatly developed for stock identification, feeding ecology of predators, and the determination of migration direction in fish species (Campana & Thorrold 2001; Mendoza 2006).

The aim of this study was to gain understanding of the relationships between fish length and otolith size and also, dimensional shape and structure analysis of otoliths of four marine fish species, through regression analysis. This study is an important contribution for sustainable fisheries management in the area.

Materials and Methods

A total of 200 individuals of four fish species were collected from commercial fishing boats operating in the Edremit Gulf, Aegean Sea between January and December 2014 (Fig. 1). All captured individuals were measured to the nearest 0.1cm for total length (TL) and weighted to the nearest 0.01g. The sagittae otoliths were removed, wiped clean and stored dry in U-plates prior to analyses. Right sagittal otolith was used for otolith morphological measurements. The right otolith was placed in a solution of glycerol to remove blood and debris before examination. Otolith was examined in glycerol under reflected light using a triocular microscope. Otolith length was defined as the greatest distance between anterior and posterior edge, and otolith width was described as the greatest distance from dorsal to ventral edge (Fig. 2).

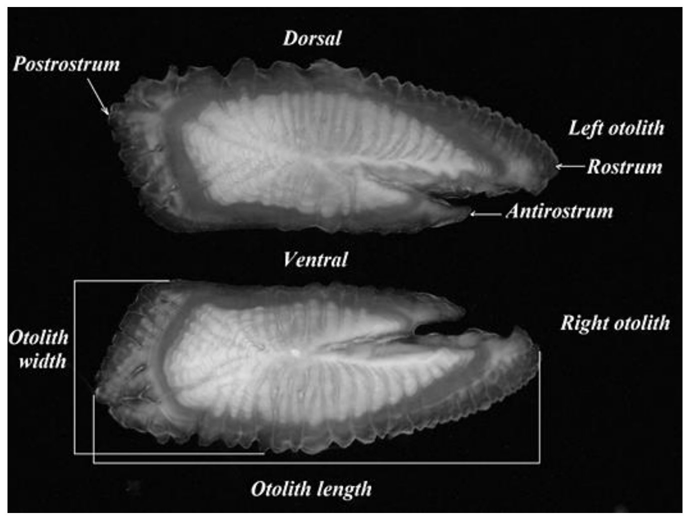


Fig.2. Measurement axes of the sagittal otolith of samples (Bal et al. 2018).

All morphometric measurement of otoliths (OL, mm; OWİ, mm; OP, mm; OA, mm^2) was measured to the nearest 0.001mm using triocular microscope (Leica M125). The obtained data were recorded and otoliths' shape factors were calculated. Formula of shape factors was shown in Table 1 (Ponton 2006).

Relationships between the total fish length and otolith size (otolith length, otolith width, otolith area and otolith perimeter) were examined using the linear regression model as $y=a+bx$, where: x=total fish

Table 1. Formulas used in the calculation of shape indices.

Parameter	Shape indices	Formula
OP (Otolith Perimeter, mm)	Form factor (F_F)	$4.\pi.OA / OP^2$
OA (Otolith Area, mm^2)	Circularity (C_i)	$(OP)^2/OA$
OL (Otolith Length, mm)	Roundness (R_D)	$4.OA / \pi.(OL)^2$
OWi (Otolith Width, mm)	Aspect Ratio (A_R)	$OL.OW_i^{-1}$

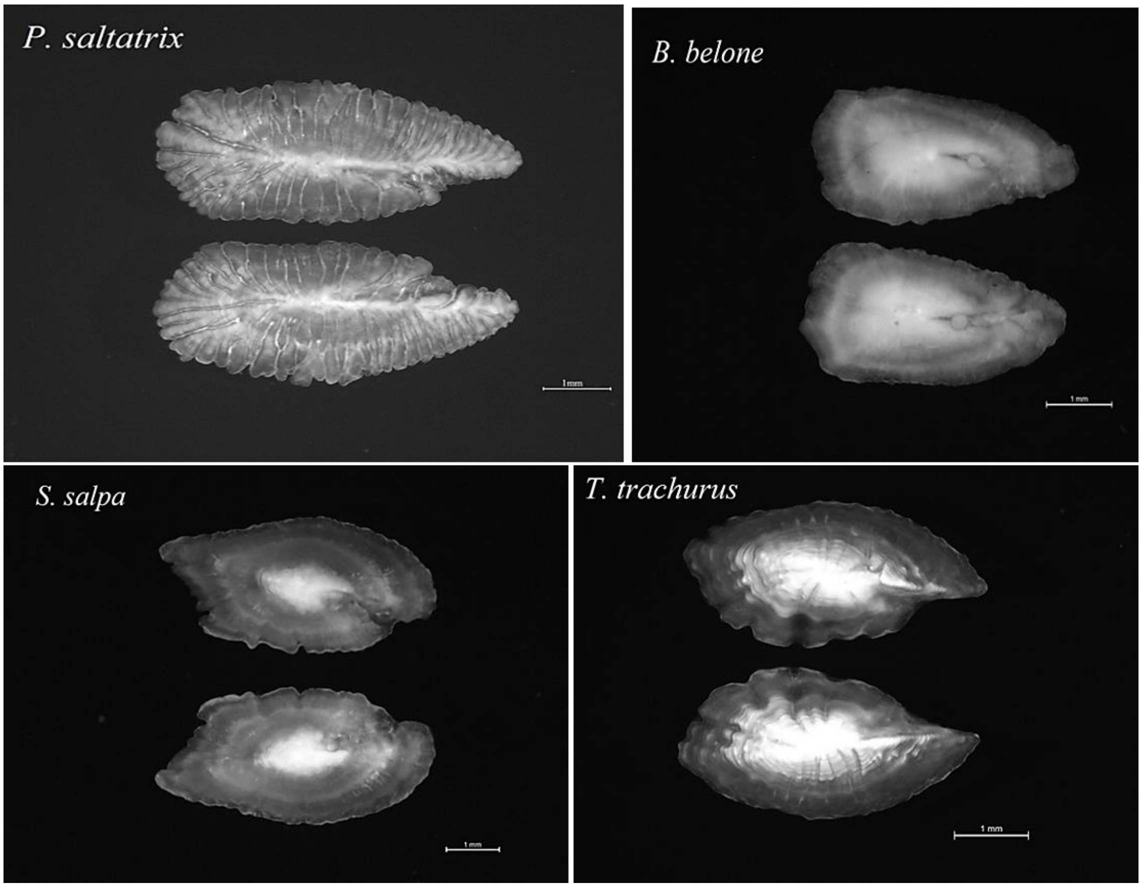


Fig.3. Images of the sagittae otoliths in four studied species (scale bar=1mm).

length, *y*=otolith length, otolith width, otolith area and otolith perimeter *a*=intercept value, and *b*=coefficient value and the relationships between otolith length-otolith size (otolith width, otolith area and otolith perimeter) using same equation, where: *x*=otolith length, *y*=otolith width, otolith area and otolith perimeter *a*=intercept value, and *b*=coefficient value (Sokal & Rholf 1981). All graphics and descriptive statistics were drawn using Excel (Microsoft Excel® 2010).

Results

Fish specimens (n=200) representing four different species belonging to four families, including the bluefish *Pomatomus saltatrix* (Pomatomidae), dreamfish *Sarpa salpa* (Sparidae), Atlantic horse mackerel *Trachurus trachurus* (Carangidae) and sea needle, *Belone belone* (Belonidae). The otolith morphology of the species was found to be different. The rostrum and antirostrum sections of the *P. saltatrix* and *T. trachurus* otoliths were more pronounced than the two others. The otoliths of *B. belone* and *S. salpa* species had a more rounded shape. The otolith images of four examined species are presented in Figure 3.

Although the mean length values of the examined species were close to each other, the size of morphometric measurement of bluefish otoliths (OL,

Table 2. Fish size-otolith measurements and shape descriptors of otolith.

Species	n	Fish size and otolith measurements						Shape descriptors			
		TL (cm) Min.-max. Mean±SE	W (g) Min.-max. Mean±SE	OL (mm) Min.-max. Mean±SE	OW_I (mm) Min.-max. Mean±SE	OA (mm^2) Min.-max. Mean±SE	OP (mm) Min.-max. Mean±SE	C_I Min.-max. Mean±SE	F_F Min.-max. Mean±SE	R_D Min.-max. Mean±SE	A_R Min.-max. Mean±SE
P. saltatrix	50	15.9-36.6	32.5-452.6	5.49-9.83	2.17-3.51	9.94-23.85	13.22-24.99	17.57-28.84	0.43-0.71	0.30-0.43	2.12-4.11
		26.9±1.76	196.2±3.8	7.98±0.33	2.81±0.06	18.56±1.26	20.45±0.93	22.21±0.42	0.55±0.01	0.33±0.009	2.82±0.05
B. belone	50	22.5-65.2	11.4-221.6	1.19-3.98	0.90-2.09	1.22±5.84	4.38-9.88	14.78-18.40	0.68-0.84	0.41-0.62	1.17-2.21
		30.2±3.47	29.9±18.91	2.35±0.11	1.30±0.05	2.25±0.25	5.94±0.28	16.20±0.06	0.78±0.02	0.49±0.01	1.80±0.03
S. salpa	50	17.2-29.2	74.1-338.4	4.10-5.72	1.99-2.80	5.70-10.9	10.30-14.1	15.79-21.16	0.59-0.79	0.36-0.52	1.71-2.35
		22.1±0.45	164.8±9.8	4.78±0.07	2.41±0.01	8.03±0.23	11.99±0.16	17.98±0.04	0.70±0.01	0.45±0.01	1.79±0.01
T. trachurus	50	10.3-14.2	8.8-25.2	3.89-5.99	2.30-3.41	6.32-12.42	9.97-15.16	15.69-20.61	0.60-0.80	0.37-0.58	1.56-2.09
		11.8±0.18	14.07±0.84	4.98±0.21	2.69±0.11	8.66±0.60	12.43±0.51	17.97±0.49	0.70±0.01	0.44±0.02	1.84±0.05

TL: Total fish length (cm); W: Total fish weight (g); C_I: Circularity; F_F: Form factor; R_D: Roundness; A_R: Aspect ratio; OL: Otolith length (mm); OW_I: Otolith width (mm); OA: Otolith area (mm^2); OP: Otolith perimeter (mm); SE: Standard error.

Table 3. Relationships between OL and OWi, OP, OA in four studied species.

Species	Relationships between OL and OW_I, OP, OA						
	n	OL-OW_I	r^2	OL-OA	r^2	OL-OP	r^2
P. saltatrix	50	OW_I=0.22OL+1.01	0.81	OA=3.12OL-7.55	0.92	OP=2.46OL-0.15	0.90
B. belone	50	OW_I=0.43OL+0.28	0.65	OA=1.83OL-2.07	0.90	OP=2.74OL+0.59	0.93
S. salpa	50	OW_I=0.31OL+0.92	0.46	OA=2.61OL-4.47	0.80	OP=2.51OL-0.01	0.91
T. trachurus	50	OW_I=0.34OL+0.96	0.55	OA=2.76OL-5.09	0.82	OP=2.16OL+1.67	0.88

OL: Otolith length (mm); OWİ: Otolith width (mm); OA: Otolith area (mm2); OP: Otolith perimeter (mm).

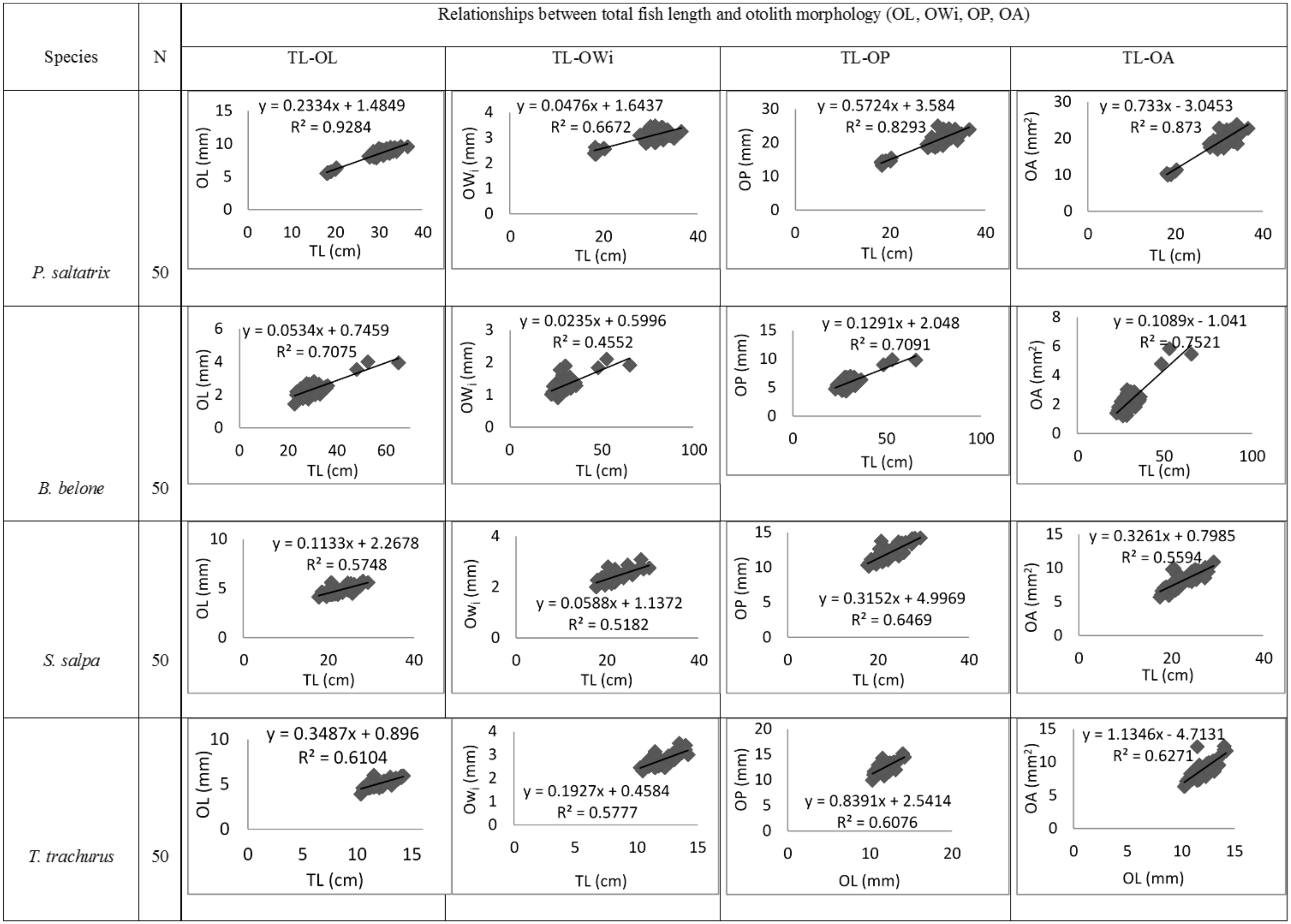
$OW_İ$, OP and OA) were found to be larger than the other three species. The morphometric measurements and four examined shape factors of otolith varied significantly among species (Table 2). The values of individual mean values of otolith length (OL) were between 2.35±0.11mm (*B. belone*), 7.98±0.33mm (*P. saltatrix*). Otolith width ($OW_İ$) was between 1.30±0.05mm (*B. belone*), 2.81±0.06mm (*P. saltatrix*). Also otolith area and otolith perimeter of bluefish (*P. saltatrix*) was higher than others. Otoliths of *B. belone* had the smallest values of all observed parameters (OL, $OW_İ$, OP and OA). According to the mean values of four examined shape factors, the otoliths of *P. saltatrix* had the smallest form factor ($0.435<F_F<0.714$) and factor of roundness ($0.309<R_D<0.405$), however aspect ratio ($2.12<A_R<4.11$) and circularity ($17.57<C_İ<28.84$) were high than others, while, the mean values otoliths of *B. belone* had the largest values of those two shape factors ($0.68< F_F<0.84$; $0.41<R_D<0.62$). The least circular were the otoliths of *B. belone,* especially in comparison to bluefish. It was found that as the length of fish increased, the values of form factor (F_F) and roundness (R_D) were generally decreased (*T. trachurus*, *S. salpa* and *P. saltatrix*). Shape factors related to the relationship between minimum and maximum measurements of fish species and otolith morphology were calculated and given in Table 2.

The highest descriptive coefficient in the equation of relationship between otolith length and otolith morphology (OL, OWi, OP, OA) was found in bluefish (between TL and OL; R^2=0.92) while, the lowest found in *B. belone* (between TL and OW_I; R^2=0.45). Their regression parameters and all graphic were given in Figure 4. Generally, there are highly significant ($P<0.05$) relationship in studied fishs. Also, relationships between OL and OW_i, OP, OA were calculated for all fish species which are given in Table 3.

Discussion

The sagitta otolith is one of the most important fish structures in comparative taxonomy of fishery research. It used length, weight, width and other morphometric measurement for distinctive degree of the fish species variations (Nolf 1985). In this study, otolith morphology of four fish species was investigated for the first time. Our results suggest that differences in otolith geometric measures are detectable in the studied species. Though there are many approaches to defining the otolith shape, we used four standard shape descriptors from the scientific literature (Rosin 2005): Form Factor (F_F), Roundness (R_D) Aspect Ratio (A_R) and Circularity ($C_İ$). The results show that the shape indices differed significantly in analyzed species though they indicate a similar pattern with maximal otolith length. Namely, the aspect ratio (A_R) was in proportion to the maximal otolith length, while form factor (F_F) and roundness (R_D) were inversely proportional to it. There is only one study on otolith-shaped factors on otolith of belone fishes. In Adriatic Sea (Zorica et al. 2010), the mean values of the shape factors of the sagittal otoliths for the *B. belone* was calculated as Aspect Ratio=1.76, Form Factor=0.54, Roundness= 0.52, Circularity ($C_İ$). These results were determined to be close to the result of the current study. We also examined the relationships between otolith length (OL) and otolith morphology ($OW_İ$, OP and OA). Relationship types are generally higher for four types; the results of this study suggested that otolith dimensions increases as fish length increases and therefore, otolith growth can be correlated with fish growth, but relationship ratings differ. The main reason for this is thought to be metabolic activities depending on environmental factors (Lombarte & Lleonart 1993; Torres et al. 2000; Vignon & Morat 2010). Lombarte & Lleonart (1993) suggested that otolith development occurs under dual regulation: genetic conditions regulate the form of the otolith, while environmental conditions, mainly temperature in carbonate-saturated waters, regulate the quantity of material deposited during the formation of the otolith. In this study, for *B. belone,* the relationship between total fish length and otolith length was found higher than Adriatic Sea (Zorica et al. 2010) but

Fig.3. Relationships between total fish length and otolith morphology of four fish species.



lower than Gökçeada Island (Altın & Ayyıldız 2018). In addition, relationship between total fish length and otolith length of *P. saltarix* was similar to the results of Çanakkale Peninsula (Cengiz et al. 2012). It is believed that similarity or difference of the results might be due to habitat characteristics of ecosystems. As there are very few studies on otolith morphology of these four studied fish species, especially on the measurement otolith morphology of these species in Edremit Gulf, therefore, no any comprehensive comparison was made.

Conclusions

This is the first study on otolith shape and dimensions of *P. saltatrix, S. salpa, B. belone* and *T. trachurus* inhabiting Edremit Gulf. Hence, this research provides information for species identification using sagittal otoliths in the fossils of closely related taxa, and diets of fish predators and can be used in sustainable fishery management.

Acknowledgments

We would like to thank Balıkesir University for financial support.

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Iran. J. Ichthyol. (December 2018), 5(4): 303–311
© 2018 Iranian Society of Ichthyology
P-ISSN: 2383-1561; E-ISSN: 2383-0964
http://www.ijichthyol.org
Received: August 29, 2018
Accepted: November 02, 2018
doi: 10.22034/iji.v5i4.312

مقاله پژوهشی

ویژگی‌های ریخت‌شناختی سنگ‌ریزه شنوایی چهار گونه ماهی خلیج ادرمیت، دریای اژه، ترکیه

حبیب بال[*1]، دیلک تورکر[2]، کادریه زنگین[2]
[1]گروه شیلات، انیستیتو تحقیقات علوم دامی، باندیرما، بالیک‌اسیر، ترکیه.
[2]گروه زیست‌شناسی، دانشکده ادبیات و علوم، بالیک‌اسیر، ترکیه.

چکیده: ریخت‌شناسی سنگ‌ریزه شنوایی (اتولیت) برای تشخیص گونه‌ها، مدیریت شیلاتی و ارزیابی ذخائر بسیار مهم است. در این مطالعه ریخت‌شناسی اتولیت ساژیتای چهار گونه ماهی *Pomatomus saltatrix*، *Sarpa salpa*، *Trachurus trachurus* و *Belone belone* مورد بررسی قرار گرفت. طول (میلی‌متر)، عرض (میلی‌متر)، سطح (میلی مترمربع) و محیط (میلی‌متر)، اتولیت اندازه‌گیری شده و بر اساس داده‌های به‌دست آمده چهار نمایه ریختی اتولیت شامل فاکتور فرم (F_F)، نمایه نسبی ابعاد (A_R)، نمایه گردی (R_D) و نمایه مدور بودن (C_I) اندازه‌گیری شد. همچنین رابطه بین طول کل ماهی و اتولیت مورد بررسی قرار گرفت. اندازگیری های اتولیت ساژیتا به‌وسیله نرم‌افزار آنالیز تصویر و میکروسکوپ سه چشمی لیکا انجام شد. اندازه‌گیری‌های ریخت‌سنجی و نمایه‌های محاسبه شده بین چهار گونه مطالعه شده متغییر بودند. ضریب همبستگی (r)، بین طول کل ماهی و شکل اتولیت و نیز طول ماهی و طول اتولیت برای چهار گونه بالا و معنی‌دار بود ($P<۰/۰۵$). نتایج نشان داد که شاخص‌های ریختی اتولیت در گونه‌های مورد مطالعه به‌طور معنی‌داری متفاوت است، گرچه روند مشابهی از نظر طول بیشینه اتولیت داشتند. این داده‌ها اطلاعاتی را برای شناسایی گونه‌های فسیلی و رژیم غذایی شکارگرها در اختیار قرار داده و نیز در مدیریت پایدار شیلاتی منطقه مورد استفاده قرار خواهد گرفت.

کلمات‌کلیدی: ریخت‌شناسی اتولیت، شناسایی گونه، مدیریت شیلاتی پایدار.