Acta Aquatica Turcica

E-ISSN: 2651-5474 15(4), 507-516 (2019) DOI: https://doi.org/10.22392/actaquatr.559899

Otolith Shape Analysis of Bluefish, *Pomatomus saltatrix* (Linnaeus, 1766) in the Black Sea Region (Samsun, Turkey)

Melek OZPICAK*[1], Semra SAYGIN[1], Nazmi POLAT[1]

[1]Ondokuz Mayıs University, Faculty of Art and Sciences, Biology Department, Atakum, Samsun, Turkey

*Corresponding Author: melek.zengin@omu.edu.tr

Research Article

Received 02 May 2019; Accepted 13 June 2019; Release date15 December 2019.

How to cite: Özpıçak, M., Saygın, S., & Polat, N. (2019). Otolith Shape Analysis of Bluefish, *Pomatomus saltatrix* (Linnaeus, 1766) in the Black Sea Region (Samsun, Turkey) *Acta Aquatica Turcica, 15*(4), 507-516. https://doi.org/10.22392/actaquatr.559899

Abstract

In this study, otolith shape indices and relationships between otolith shape and otolith length of the bluefish *Pomatomus saltatrix* (Linnaeus, 1766), which was sampled from the Samsun offshore of the Black Sea were investigated. A total of 166 samples (94♀ and 72♂) were taken from commercial fishermen in two different fishing seasons (October-December 2014 and January 2018). Sagittal otoliths of each sample were removed and six different shape index (form factor, roundness, circularity, rectangularity, ellipticity and aspect ratio) were used in analyses. The linear model is preferred for calculating the relationships between otolith shape properties and otolith length. Paired *t*-test, Wilcoxon test, Independent *t* test and Mann-Whitney U test were used for statistical analysis. The minimum and maximum total lengths and weights of the captured samples are between 13.5-24.8 cm and 22.01-161.19 g, respectively. There is no difference between female and male in terms of total length and weight. When otolith dimensions of female and male were compared, there were no differences in terms of otolith length (*OL*), otolith breadth (*OB*), otolith perimeter (*OP*) and otolith area (*OA*) (P>0.05). However, according to left and right otoliths comparisons, there were differences in terms of otolith breadth and otolith perimeter (P<0.05). Ellipticity was found to have a much stronger relationship with otolith length than the other five parameters (r^2>0.590).

Keywords: Pomatomus saltatrix, Otolith dimensions, Shape indices, Black Sea

Karadeniz Bölgesi'ndeki (Samsun, Türkiye) Lüfer Balığının, *Pomatomus saltatrix* (Linnaeus, 1766) Otolit Şekil Analizi

Özet:

Bu çalışmada Karadeniz Bölgesi'nin Samsun ili açıklarından örneklenmiş olan lüfer balığının *Pomatomus saltatrix* (Linnaeus, 1766)'in otolit şekil özellikleri ve otolit şeklinin otolit boyu ile olan ilişkileri araştırılmıştır. Ticari balıkçılardan iki ayrı avcılık sezonu (Ekim-Aralık 2014 ve Ocak 2018) içerisinde toplamda 166 (94♀ ve 72♂) adet örnek alınmıştır. Her bir örneğin sagittal otolitleri çıkarılmış ve analizlerde altı farklı şekil indeksi (şekil faktörü, yuvarlaklık, dairesellik, dikdörtgensellik, ovallik ve en-boy oranı) kullanılmıştır. Otolit şekil özellikleri ile otolit boyu arasındaki ilişkilerin hesaplanması için linear model tercih edilmiştir. İstatistiksel analizlerde Paired t-testi, Wilcoxon testi, Independent t testi ve Mann-Whitney U testi gibi testler kullanılmıştır. Yakalanan örneklerin minimum ve maksimum total boy ve ağırlıkları sırasıyla 13,50-24,80 cm ve 22,01-161,19 g arasında değişmektedir. Total boy ve ağırlık bakımından dişi ve erkek bireyler arasında fark bulunmamıştır. Dişi ve erkek bireylerin otolit ölçümleri otolit eni, boyu, çevre ve alanı bakımından karşılaştırıldığında herhangi bir farklılık olmadığı belirlenmiştir (P>0,05). Fakat sağ-sol otolitlerin karşılaştırmalarında otolit eni ve çevresi bakımından farklılıklar saptanmıştır (P<0,05). Ovallik parametresinin diğer beş parametreye göre otolit boyu ile çok daha kuvvetli bir ilişkiye sahip olduğu belirlenmiştir (r^2>0,590).

Anahtar Kelimeler: Pomatomus saltatrix, Otolit özellikleri, Şekil indeksleri, Karadeniz

INTRODUCTION

Fish stocks are genereally described as a random group of fishes that are essentially selfreproducing, with members of each group having similar life history features (Hilborn and Walters, 1992). In terms of fisheries management and biology, it is important to determine the phenotypic variation caused by environmental factors.

However, these differences might be associated with phenotypic plasticity in response to different environmental factors in each locality (Murta, 2000). Stock identification is a basic requirement to describe the stock status and to support better stock assessment of fishery (Cadrin et al., 2005).Otolith shape analysis is a basic method for seperating fish stocks. Also there are a lot of studies about intraspecific variations of fish stocks from otolith shape (Vignon and Morat, 2010; Bostancı et al. 2015; Zengin et al., 2015; Hüssy et al., 2016; Avigliano et al., 2017; Saygin et al., 2017; Bostancı and Yedier, 2018; Song et al., 2018; Yedier et al., 2019). Otoliths are innate data archives that document information in their microstructure and chemistry at different spatial and temporal scales related to their growth and environment (Miyan et al., 2016). Otolith shape is a species specific character (L'abée-Lund, 1988; Campana and Casselman 1993), and thus partially subject to genetics and generally varies geographically within species in relation to environmental factors (Vignon and Morat, 2010). Therefore, otolith analysis has made important contributions to the understanding of fish evolution and phylogeny (Nolf, 1985; Nolf, 2013; Reichenbacher et al., 2007).

Pomatomus saltatrix (Linnaeus, 1766), Bluefish, is a migratory pelagic predators that are distributed over warm continental shelves and in estuaries of temperate waters throughout most of the world, with the exception of the northern and mid-Pacific Ocean (Briggs, 1960; Wilk, 1977; Juanes et al., 1996). Bluefish is one of the most important fish species of commercial fisheries in all Turkish seas. Bluefish are found all along the Turkish coast; migrating via the Aegean Sea northwards from the Mediterranean in spring and returning south in early autumn. They are warm water fishes and never found in temperatures lower than 14°C-16°C (at least in summer). They can tolerate temperatures of 11.8°-30.4°C, but exhibit signs of stress at both extremes (Olla and Studholme, 1972). Hence, within the Mediterranean, reproduction-related migrations have been described to take place in spring within the eastern basin, precisely in the Black Sea, while in autumn species returned the Aegan Sea (Gordina and Klimova, 1996; Turan et al. 2006; Sebastes et al. 2012). Throughout these migrations' bluefish have been highly exploited, especially in area of western Black Sea and Marmara Sea (Ceyhan and Akyol 2006). Because of the commercial importance of bluefish, most of the studies were focused on age determination (Ceyhan et al., 2007), growth parameters (Cengiz et al., 2013), length-weight relationshisps (Özpiçak et al., 2017; Cumplido et al., 2018), diet (Buckel et al., 2004; Lucena et al., 2006), otolith size-length relationships (Cengiz et al., 2012; Zengin et al., 2017; Bal et al., 2018a), selectivity (Acarlı et al., 2013; İlkyaz, 2018) and morphometric variation (Turan et al., 2006). On the other hand, there are limited studies about stock structure of bluefish (Graves et al., 1992). The aim of this study is to describe otolith shape and detect the relationships between otolith shape indicators and otolith length of this highly important commercial bluefish species in Turkey.

MATERIALS and METHODS

Study Area and Sampling.

Bluefish specimens were collected from commercial fishing boats operating in offshore area of Samsun Province (Black Sea) between October-December 2014 (36º35ˈ30.64ˈˈE, 41º51ˈ57.96ˈˈN) and January 2018 (36º38ˈ14.61ˈˈE, 41º48ˈ53.80ˈˈN), and measured to the nearest 0.1 cm for total length (TL) and weighed to the nearest 0.01 g. The sex was determined by macroscopic examination of the gonads.

Otolith Preparation for the Analysis.

Sagittal otoliths were removed by making left and right distinctions. Otoliths were weighted (OW) using precision scales (± 0.001 g). All otolith pairs were photographed on the distal side with a Leica DFC295 digital camera. Otolith morphometric measurements like otolith breadth (OB), otolith length (OL), area (OA) and perimeter (OP) (± 0.001 mm) were determined by Leica Application Suit Ver. 3.8 Imaging Software (Figure 1). Otolith shape indices such as aspect ratio, roundness, circularity, rectangularity, ellipticity, and form factor were calculated using the following formulas; Roundness (RD) = $(4OA)/(\pi OL^2)$; Circularity (C) = OP^2/OA; Form Factor (FF) = $(4\pi OA)/OP^2$; Ellipticity (E)=(OL-OB)/(OL+OB); Rectangularity (R) = OA/(OLOB) and Aspect Ratio (AR) = (OL/OB) (Tuset et al., 2003). Relationships between otolith length and shape indices were determined using linear regression equation (y = a+ bx, where y is shape indices and x is otolith length, a and b are equation parameters) for left and right otoliths.

Statistical Analysis.

All the variables were tested for normality and homogeneity of variance using the Shapiro and Levene's test. Different tests were implemented in statistical analysis (Paired t-test, Wilcoxon test, Independent two sample t-test, Mann-Whitney U test).

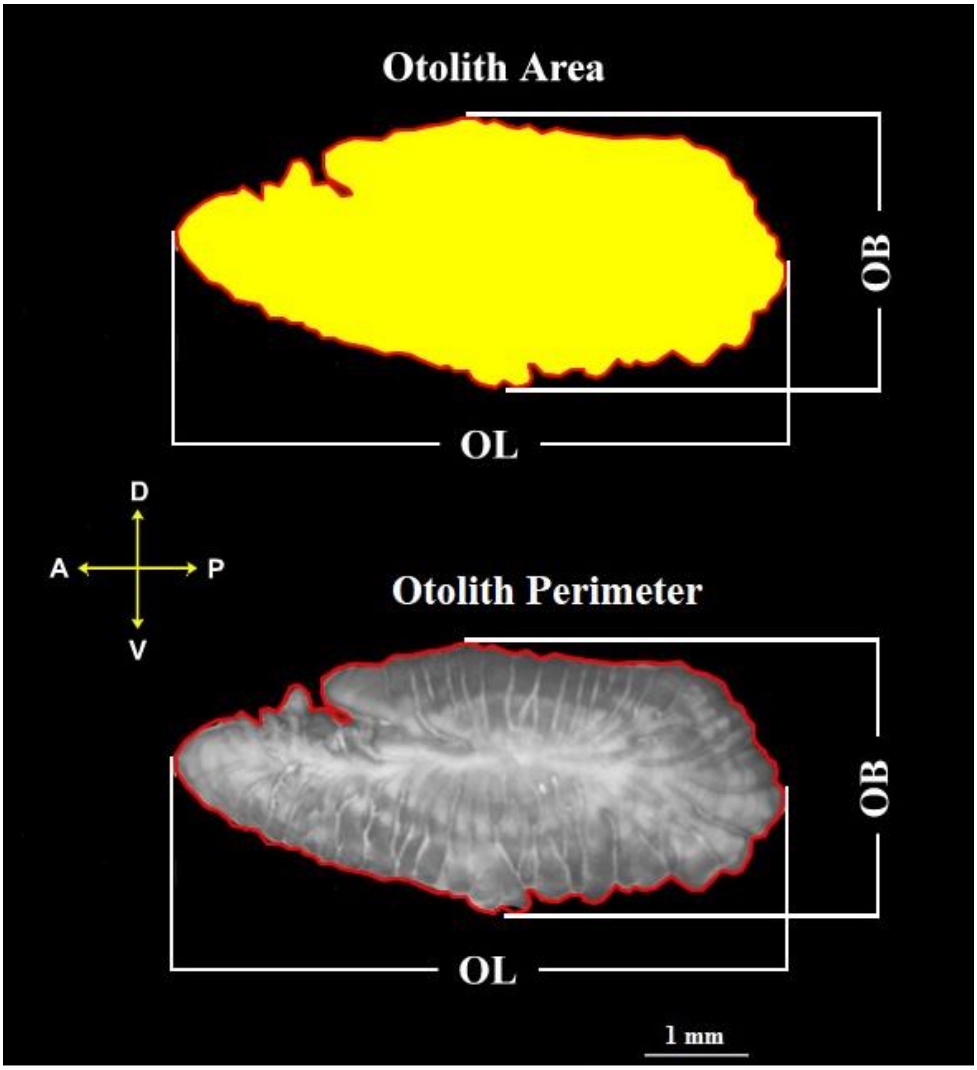


Figure 1. Otolith characteristics of sagitta (Left otolith) (OL: Otolith Length, OB: Otolith breadth, A: Otolith area (Yellow colour), P: Otolith perimeter (Red colour line).

RESULTS

In this study, a total of 166 bluefish samples (94♀ and 72♂) were investigated in terms of otolith shape indices and total length relationships. 56.63% were females and 43.37% were males of the total individuals. The minimum- maximum total lengths and weights of the individuals varies between 13.5-24.8 cm and 22.01-161.19 g, respectively (Table 1).

Table 1. Descriptive statisctics of *P.saltatrix* inhabiting Samsun region (F: Female, M: Male, N: Number of individuals, Min: Minimum, Max: Maximum, Se: Standard error, Sd: Standard Deviation)

		Total Length (cm)					Weight (g)				
Sex	**N**	**Mean**	**±Se**	**±Sd**	**Min**	**Max**	**Mean**	**±Se**	**±Sd**	**Min**	**Max**
F	94	19.22	0.256	2.478	13.50	23.60	73.75	2.741	26.581	22.01	161.19
M	72	19.45	0.235	2.000	14.00	24.80	76.55	2.726	23.132	25.92	146.59
F+M	166	19.32	0.177	2.279	13.50	24.80	74.83	1.948	25.101	22.01	161.19

There is no difference between female and male in terms of total length and weight (Mann-Whitney U Test, P>0.05. When sagittal otoliths of female and male were compared, there were no differences in terms of OL, OB, OP and OA (P>0.05). However, according to left and right otoliths comparisons, there were differences in terms of OB and OP (P<0.05). Because of there were no differences between sex, entire population were used in evaluation of data in statistical analysis (Table 2- Table 3).

Table 2. Descriptives of otolith characteristics for *P.saltatrix* (OB: Otolith breadth, OL: Otolith length, OA: Otolith area, OP: Otolith perimeter)

Variable		Mean(mm)	±Se	±Sd	Min (mm)	Max (mm)	N
OB	Right	2.575	0.013	0.157	2.004	2.938	166
	Left	2.968	0.013	0.161	2.004	2.698	166
OL	Right	6.074	0.042	0.546	4.271	7.222	166
	Left	6.060	0.042	0.544	4.315	7.161	166
OA	Right	11.108	0.116	1.497	6.401	15.348	166
	Left	11.091	0.117	1.506	6.319	15.333	166
OP	Right	15.294	0.109	1.398	10.833	18.318	166
	Left	15.003	0.101	1.304	11.266	18.735	166

Table 3. Statistical comparisons for right-left otolith pairs and sex

Comparison type	Variable	Test	P
Right-left	OB	Wilcoxon Test	**0.009***
	OL	Wilcoxon Test	0.055
	OA	Wilcoxon Test	0.482
	OP	Wilcoxon Test	**0.000***
Male-Female	ROB	Mann-Whitney U Test	0.662
	LOB	Mann-Whitney U Test	0.456
	OL	Mann-Whitney U Test	0.586
	OA	Mann-Whitney U Test	0.591
	ROP	Mann-Whitney U Test	0.583
	LOP	Mann-Whitney U Test	0.419

*Statistically different

Shape indices were calculated both right and left otolith pairs because of statistical differences between otolith dimensions (Table 4). And also, shape indices were compared between right and left otolith pairs. Because of differences between shape indices comparisons, equations were calculated for left and right otolith separately (Wilcoxon test) (P<0.001).

Table 4. Descriptives of shape indices for right and left sagittal otolith pairs (R: Right, L: Left)

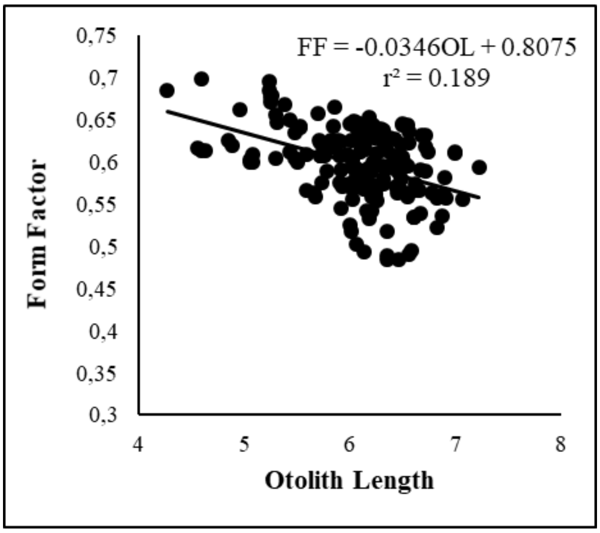
Shape Indices	Mean		Minimum		Maximum		±Se		±Sd	
	R	**L**	**R**	**L**	**R**	**L**	**R**	**L**	**R**	**L**
Form Factor	0.597	0.619	0.485	0.476	0.699	0.734	0.003	0.003	0.043	0.037
Circularity	21.144	20.381	17.975	17.106	25.924	26.371	0.124	0.098	1.602	1.264
Roundness	0.385	0.386	0.280	0.282	0.593	0.577	0.003	0.003	0.040	0.039
Rectangularity	0.708	0.714	0.581	0.584	0.978	0.978	0.003	0.004	0.043	0.045
Ellipticity	0.403	0.405	0.347	0.349	0.471	0.472	0.002	0.002	0.027	0.026
Aspect Ratio	2.357	2.366	2.064	2.074	2.783	2.788	0.012	0.011	0.151	0.147

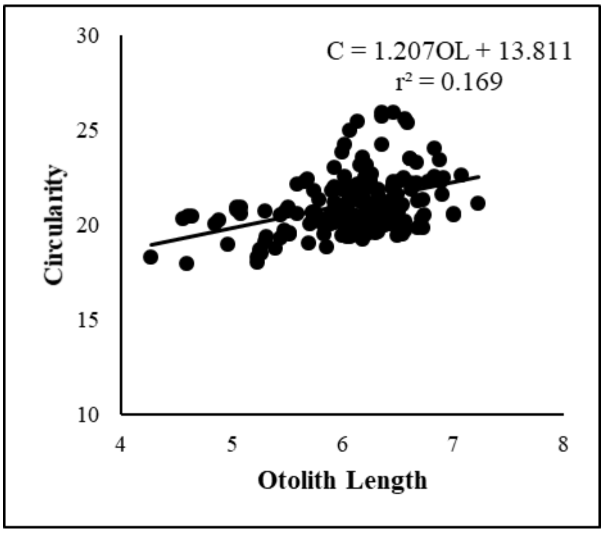
Relationships between otolith length and shape indices were determined using linear regression equation for left and right otoliths (Table 5) and best fit was obtained among OL and Ellipticity both right and left otoliths (r^2>0.590).

Table 5. Equations between shape indices and otolith length both right and left otoliths

Shape Indices	(Right/ left)	Equation	a	b	r^2
Form Factor	R	FF=a+bOL	0.8075	-0.0346	0.189
	L		0.7751	0.0258	0.143
Circularity	R	C=a+bOL	13.811	1.207	0.169
	L		15.176	0.8568	0.137
Roundness	R	Ro=a+bOL	0.6789	-0.0484	0.447
	L		0.6789	-0.0484	0.447
Rectangularity	R	REC=a+bOL	0.8722	-0.027	0.117
	L		0.8486	-0.0222	0.072
Ellipticity	R	E=a+bOL	0.1763	0.0373	0.590
	L		0.2173	0.0309	0.453
Aspect Ratio	R	AR=a+bOL	1.0874	0.2091	0.574
	L		1.3164	0.1729	0.412

Since the relationships between the shape indices of the right and left otoliths were stronger in the right otoliths, the representations of the right otoliths were preferred in the graphical representation (Figure 2). FF, C, RD, R, E and AR were associated with otolith length. When otolith length increased, form factor, roundness and rectangularity values decreased; AR, C and E values increased.





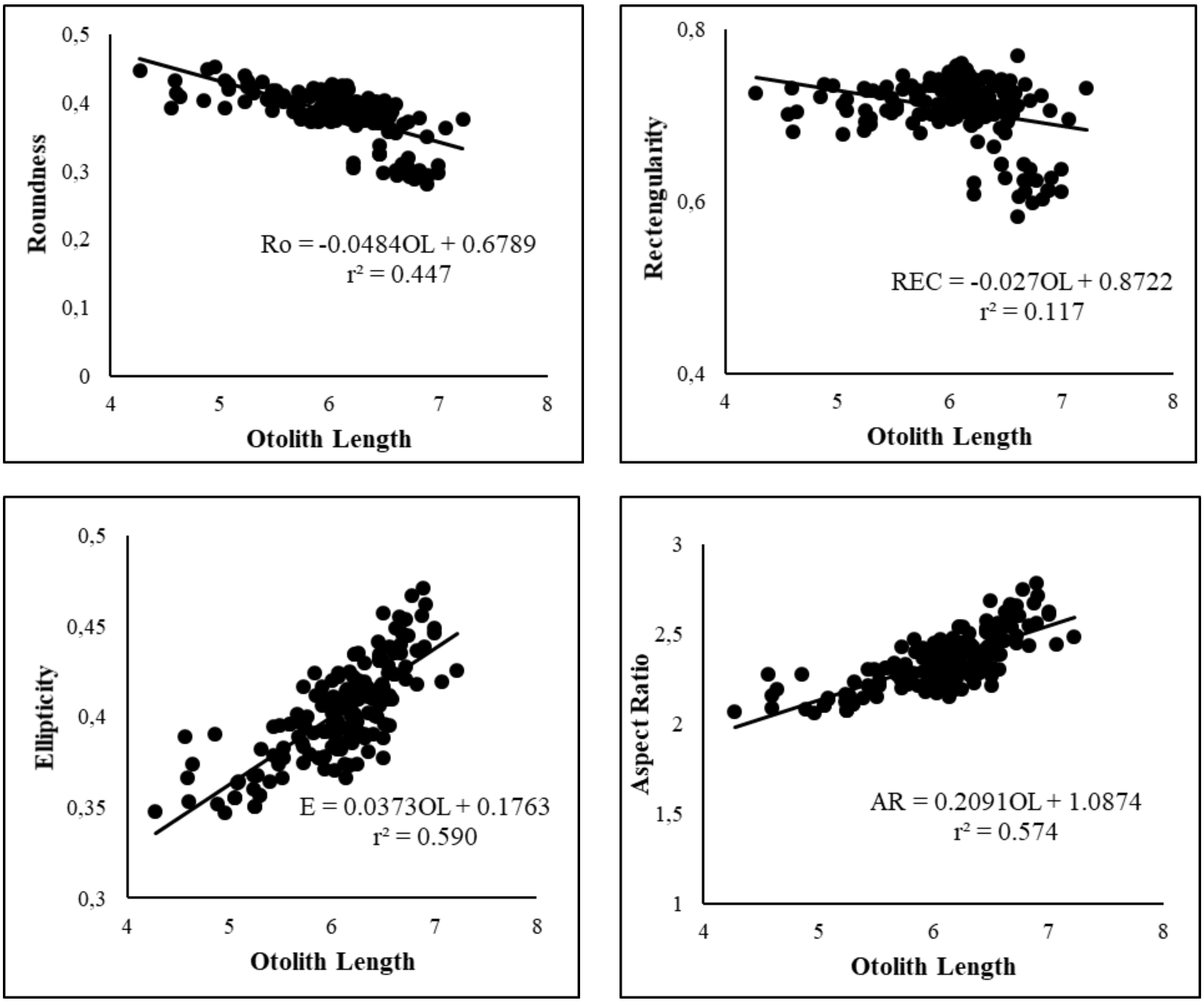


Figure 2. Relationships between otolit shape indices and otolith length

DISCUSSION

Otoliths are calcified structures involved hearing and balance system, and also they are flight recorders of fishes (Lecomte-Finiger, 1999) containing reliable fingerprints that are considered as an invaluable source of information for reconstructing a fish's entire life cycle (Campana and Thorrold, 2001). In recent years, otoliths are preferred in many studies (Short et al. 2006; Bostancı et al. 2015; Zengin et al., 2015; Pavlov 2016; Moreira et al., 2019), because otolith shape is species specific.

Otolith morphology and shape analysis are often used for stock discrimination (Campana and Casselman, 1993; Begg and Brown, 2000; Vignon and Morat, 2010; Bostancı et al. 2015; Zengin et al., 2015; Pavlov 2016; Avigliano et al., 2017; Saygıın et al., 2017; Bostancı and Yedier, 2018; Song et al., 2018, Özpiçak et al., 2018; Yedier et al., 2019). The morphometrics (e.g., weight, length, breadth, perimeter, area) of otoliths are usually correlated with each other. Additionally, they are commonly correlated with fish growth and show relatively large individual variations. The shape indices are comparatively independent on otolith size (OL, OB, OA, OP). In this study OL, OB, OA and OP were calculated as 6.074±0.546, 2.575±0.157, 11.108±1.197 and 15.294±1.398, respectively. Bal et al. (2018a) were investigated relationship total length -otolith length of bluefish sampled from Marmara Sea and calculated OL and OB as 6.71±0.55 and 2.60±0.24. These results are similar with present study. The relationship between fish size and otolith shape reflects both effects of ontogeny and the environment on otolith shape. Zengin et al. (2017) investigated the relationships between otolith dimensions (OL, OB and OW) and total length of bluefish and found a strong relationship between TL and OW. However, Bal et al. (2018a) found a strong relationship between OL and TL. These differences can be arrise from environmental differences between Marmara and Blacksea regions. And also Bal et al. (2018a) have not examined otolith weight. The otolith shapes have been evaluated based on morphometric measurements (Short et al. 2006) and the mathematical computation of shape indices (Russ, 1990; Tuset et al., 2006).

In the present study, the shape analysis of sagittal otoliths from *Pomatomus saltatrix* samples were determined. FF, C, RD, R, E and AR for sagitta were calculated and the realtionships between otolith length and shape descriptors were revealed. The usefulness of otolith shape analysis for stock identification and differentiation have already been supported for several fish species (Campana 1999; Tuset et al. 2006; Ferguson et al. 2011; Zengin et al. 2015; Renán et al. 2016; Avigliano et al. 2017; Teimori and Eslami 2017). Otolith shape can be described in some ways, one of the simplest and useful method is distance measurement. Such measurements can be used in a series of mathematical equations that calculate shape indices (Russ, 1990). FF is used to estimate the surface area irregularity, taking values of 1.0 when it is a perfect circle and <1.0 when it is irregular. RD and C give information on the similarity of various features to a perfect circle. RE describes the variations of length and breadth with respect to the area (Tuset et al., 2003). E indicates if the changes in the axes are proportional (Russ, 1990). And also, when otolith length increased, form factor, roundness and rectangularity values decreased; AR, C and E values increased. In this study the best fit was obtained among OL and Ellipticity ($r^2>0.590$).

The otolith shape analysis is becoming increasingly popular in population studies, as is evidenced by the large number of papers published. When the literature were investigated, there were a lot of study about otolith shape and morphometrics of different fish species (Torres et al., 2000; Tuset et al., 2003; Zischke et al., 2016; Afanasyev et al., 2017; Avigliano et al., 2017; Song et al., 2018; Özpiçak et al., 2018; Doustdar et al., 2019; Moreira et al., 2019; Neves et al., 2019; Yedier et al., 2019). The otolith shape analysis' major advantages is the relatively low cost of analysis as compared to genetic research. However there are limited studies about morphometrics, length-weight relationships and otolith shape of bluefish (Tuset et al., 2008; Zengin et al., 2015; Bal et al., 2018a; Bat et al., 2018b). Bal et al. (2018b) calculated FF, C, RD and AR for bluefish from Aegean Sea as 0.55±0.01, 22.21±0.42, 0.33±0.009 and 2.82±0.05. The results of these studies are similar with findings of our study.

Tuset et al (2008) described the shape of bluefish otolith as rectangular, some deep and irregular indentations mainly in the posterior-ventral margin, anteriorventral margin dentate and *Sulcus acusticus* is heterosulcoid, ostial, median. *Ostium* of blufish is funnel-like, shorter than the cauda. *Cauda* is tubular, curved, slightly flexed posteriorly, ending very close to the posterior margin. Furthermore Tuset et al (2008) calculated AR, C and R for bluefish as 31.0-33.4, 23.0-25.5 and 0.5, respectively. All the results are similar with present study, too. Differences in otolith morphometric and biometric variables among fish populations can occur for a number of reasons such as habitat complexity and environmental conditions as well as demographics such as sex, age, population, can influence otolith morphology (Nielsen et al., 2010; Bostanci et al., 2015).

The otolith shape analysis is becoming increasingly popular in population studies, as is evidenced by the large number of papers published. This method definitely deserves close attention. One of its major advantages is the relatively low cost of analysis as compared to genetic research. In relation to the obtained results, this research provides information for this commercially important fish species identification using sagittal otoliths in the fossils and can be used in sustainable fishery management studies. The present investigation of bluefish from middle Black Sea region population would certainly add to the knowledge of the relationships (between otolith length and otolith shape indices) and otolith shape description, and also encourage further research on the subject involving many other freshwater and marine species from different regions in the world.

REFERENCES

Acarlı, D., Ayaz, A., Özekinci, U., & Öztekin, A. (2013). Gillnet Selectivity for Bluefish (*Pomatamus saltatrix*, L. 1766) in Çanakkale Strait, Turkey. *Turkish Journal of Fisheries and Aquatic Sciences, 13,* 349-353

Afanasyeva, P. K., Orlova, A. M., & Yu Rolskye, A. (2017). Otolith shape analysis as a tool for species identification and studying the population structure of different fish species. *Fisheries Research*, *176,* 39–47.

Avigliano, E., Domanico, A., Sánchez, S., & Velpado, A.V. (2017). Otolith elemental fingerprint and scale and otolith morphometry in *Prochilodus lineatus* provide identification of natal nurseries. *Fisheries Research, 186*, 1-10.

Bal, H., Yanık, T., & Türker, D. (2018a). Relationships between total length and otolith size of bluefish *Pomatomus saltatrix* (Linnaeus, 1766) in the Marmara Sea of Turkey. *Natural and Engineering Sciences, 3*, 38-44.

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

Bat, L., Sahin, F., Sezgin, M., Gonener, S., Erdem, E., & Ozsandikci U. (2018). Fishery of Sinop Coasts in the Black Sea Surveys. *European Journal of Biology, 77(1)*, 18-25.

Begg, G. A., & Brown, R. W. (2000). Stock identification of Haddock *Melanogrammus aeglefinus* on Georges Bank based on otolith shape analysis. *Transactions of American Fisheries Society*, *129*, 335–345.

Bostancı, D., & Yedier, S. (2018). Discrimination of invasive fish *Atherina boyeri* (Pisces: Atherinidae) populations by evaluating the performance of otolith morphometrics in several lentic habitats. *Fresenius Environmental Bulletin, 27(6)*, 4493-4501.

Bostancı, D., Polat N., Kurucu, G., Yedier S., Kontaş, S., & Darcın, M. (2015). Using otolith shape and morphometry to identify four *Alburnus* species (*A. chalcoides*, *A. escherichii*, *A. mossulensis* and *A. tarichi*) in Turkish inland waters. *Journal of Applied Ichthyology*, *31(6)*, 1013-1022.

Briggs, J.C. (1960). Fishes of world-wide (circumtropical) distribution. *Copeia, 3*, 171-180.

Buckel, J.A., Sharack, B.L., & Zdanowicz, V.S. (2004). Effect of diet on otolith composition in *Pomatomus saltatrix,* an estuarine piscivore. *Journal of Fish Biology, 64,* 1469-1484.

Cadrin, S.X., Friedland, K.D., & Waldman, J.R. (Eds.) (2005). Stock Identification Methods. Elsevier Academic Press.

Campana, S.E. (1999). Chemistry and composition of fish otoliths: pathways, mechanisms and applications. *Marine Ecology Progress Series*, *188*, 263–297.

Campana, S.E., & Thorrold, S.R. (2001). Otoliths, increments, and elements: keys to a comprehensive understanding of fish populations? *Canadian Journal of Fisheries and Aquatic Science, 58*, 30 –38.

Campana, S. E., & Casselman, J. M. (1993). Stock discrimination using otolith shape analysis. Canadian *Journal of Fisheries and Aquatic Sciences*, *50*, 1062–1083.

Cengiz, O., Ozekinci, U., & Oztekin, A. (2012). The relationships between total length-otolith length of bluefish, *Pomatomus saltatrix*, (Linnaeus, 1766) from Gallipoli Peninsula and Dardanelles (North-eastern Mediterranean, Turkey). *Journal of the Institute of Science and Technology*, *2*, 31-34.

Cengiz, O., Ozekinci, U., Oztekin, A., & Kumova, C. (2013). Growth parameters and mortality of bluefish (*Pomatomus saltatrix* Linnaeus, 1766) from Gallipoli peninsula and Dardanelles (northeastern Mediterranean, Turkey). *Marine Science Technology Bulletin*, *2(1)*, 1-7.

Ceyhan, T., & Akyol, O. (2006). Age distribution and relationship between fork length and otolith length of bluefish (*Pomatomus saltatrix* L., 1766) in the Sea of Marmara (in Turkish). *E.U. Journal of Fisheries & Aquatic Sciences*, *23(1-3)*, 369-372.

Ceyhan, T., Akyol, O., Ayaz, A., &Juanes, F. (2007). Age, growth, and reproductive season of bluefish (*Pomatomus saltatrix*) in the Marmara region, Turkey. *ICES Journal of Marine Science, 64*, 531-536.

Cumplido, R., Netto, E.B.F., Rodrigues, M.T., de Melo Junior, U.G., & da Costa, P.A.S. (2018). A Review and the Length-Weight Relationship of Bluefish, *Pomatomus saltatrix* (Linnaeus, 1766), Pisces: Pomatomidae, at the Marine Extractive Reserve (RESEX-Mar) of Arraial do Cabo, Rio de Janeiro State, Brazil. *Open Access Library Journal*, *5*, e4770.

Doustdar, M., Kaymaram, F., Seifali, M., Jamili, S., & Bani, A. (2019). Stock identification of Arabian yellow fin Sea bream (Acanthopagrus arabicus) by using shape of otolith in the Northern Persian Gulf &Oman Sea. *Iranian Journal of Fisheries Sciences*, *18*(1), 60-70.

Ferguson, G. J.; Ward, T. M. & Gillanders, B. M. (2011). Otolith shape and elemental composition: complementary tools for stock discrimination of mulloway (*Argyrosomus japonicus*) in southern Australia. *Fisheries Research*, *110* (1), 75-83.

Gordina, A.D., & Klimova, T.N. (1996). On bluefish (*Pomatomus saltatrix* L.) in the Black Sea. *Marine and Freshwater Research*, *47*, 315-318.

Graves, J.E., McDowell, J.R., Beardsley, A.M., & Scoles, D.R. (1992). Stock Structure of the Bluefish *Pomatomus saltatrix* along the Mid-Atlantic Coast. *Fishery Bulletin, 90*, 703-710.

Hilborn, R., & Walters, C.J. (1992). Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty. Chapman & Hall, New York, 570 pp.

Hüssy, C., Mosegaard, H., Albertsen, C. M., Nielsen, E. E., Hemmer-Hansen, J., & Eero, M. (2016). Evaluation of otolith shape as a tool for stock discrimination in marine fishes using Baltic Sea cod as a case study. *Fisheries Research*, *174*, 210–218.

İlkyaz, A. T. (2018). Estimating gillnet selectivity of Bluefish (*Pomatomus saltatrix)* by morphology. *Ege Journal of Fisheries and Aquatic Sciences*, *35*, 89-94

Juanes, F., Hare, J.A., & Miskiewicz, A.G. (1996). Comparing early life history strategies of *Pomatomus saltatrix*: a global approach. *Marine and Freshwater Research, 47,* 365-379.

L'abee-lund, J. H. (1988). Otolith shape discriminates between juvenile Atlantic salmon, *Salmo salar* L., and brown trout, *Salmo trutta* L. *Journal of Fish Biology*, *33*, 899-903

Lecomte-Finiger, R. (1992). The crystalline ultrastructure of otolith of the eel (*A. anguilla* L. 1758). *Journal of Fish Biology, 40*, 181–190.

Lucena, F.M., Vaske Jr., T., Ellis, J.R. & O'Brien, C.M. (2000). Seasonal variation in the diets of bluefish, *Pomatomus saltatrix* (Pomatomidae) and striped weakfish, *Cynoscion guatucupa* (Sciaenidae) in Southern Brazil: ımplications of food partitioning. *Environmental Biology of Fishes, 57*, 423-434.

Miyan, K., Khan, M.A., Patel, D.K., Khan. S., & Ashari, N.G. (2016). Truss morphometry and otolith microchemistry reveal stock discrimination in *Clarias batrachus* (Linnaeus, 1758) inhabiting the Gangetic river system. *Fisheries Research, 173*, 294–302.

Moreira, C., Froufea, E., Vaz-Piresa, P., & Correia, A.T. (2019). Otolith shape analysis as a tool to infer the population structure of the blue jack mackerel, *Trachurus picturatus*, in the NE Atlantic. *Fisheries Research, 209*, 40–48.

Murta, A.G. (2000). Morphological variation of horse mackerel (Trachurus trachurus) in the Iberian and North African Atlantic: Implications for stock identification. *ICES Journal of Marine Science, 57,* 1240-1248.

Nevesa, A., Vieira, A.R., Sequeira, V., Paiva, R.B., Janeiro, A.I., Gaspar, L.M., & Gordo, L.S. (2019). Otolith shape and isotopic ratio analyses as a tool to study *Spondyliosoma cantharus* population structure. *Marine Environmental Research, 143*, 93–100.

Nielsen, J. R., Methven, D. A., & Kristensen, K. (2010). A statistical discrimination method using sagittal otolith dimensions between sibling species of juvenile cod *Gadus morhua* and *Gadus ogac* from the Northwest Atlantic. *Journal of Northwest Atlantic Fishery Science, 43*, 27–45.

Nolf, D. (1995). Studies on fossil otoliths-the state of the art. In: D.H. Secor, J.M. Dean, and S.E. Campana (eds.), Recent Developments in Fish Otolith Research, 513–544. University of South Carolina Press, Columbia, South Carolina.

Nolf, D. (2013). The diversity of fish otoliths, past and present. Brussels: Royal Belgian Institute of Natural Sciences. 222 p.

Olla, B.L., & Studholme, A. L. (1972). Daily and seasonal rhythms of activity in the bluefish *Pomatomus saltatrix.* pp. 303-326. In: Winn, H.E., Olla, B.L. (eds), Behavior of Marine Animals: Recent Advances: Plenum Publishing Press.

Özpiçak, M., Saygin, S., & Polat, N. (2017). The length-weight and length-length relationships of bluefish, *Pomatomus saltatrix* (Linnaeus, 1766) from Samsun (middle Black Sea region). *Natural and Engineering Science, 2(3)*, 28-36.

Özpiçak, M., Saygin, S., Aydın, A, Hançer, E., Yılmaz, S., & Polat, N. (2018). Otolith shape analyses of the *Squalius cephalus* (L., 1758) (Actinopterygii: Cyprinidae) inhabiting a few inland waters of the Middle Black Sea Region (Turkey). *Iranian Journal of Ichthyology, 5(4)*, 293-302.

Pavlov, D.A. (2016). Differentiation of three species of the genus *Upeneu*s (Mullidae) based on otolith shape analysis. *Journal of Ichthyology, 56 (1),* 37–51.

Reichenbacher, B., Gaudant, J., & Griessemer, T.W. (2007). A late Burdigalian gobiid fish, Gobius brevis (AGASSIZ, 1839), in the Upper Hydrobia Beds in the middle Upper Rhine Graben (W-Germany). *Palaontologische Zeitschrift, 81(4),* 365–375.

Renán X., Montero-Muñoz, J., Garza-Pérez, J.R. & Brulé, T. (2016). Age and stock analysis using otolith shape in Gags from the Southern Gulf of Mexico. *Transactions of the American Fisheries Society, 145(6),* 1252-1265.

Russ, J.C. (1990). Computer-assisted microscopy: the measurement and analysis of images. Plenum Press, New York. 453 pp.

Saygin, S., M. Ozpiçak, M. Elp, N. Polat, A.A. Atıcı, N., & Akçanal Odun N. (2017). Comparative analysis of the otolith features of tarek (*Alburnus tarichi* (Güldenstädt, 1814)) from different lakes across Van Basin (Van, Erçek, Nazik, Aygır) (Turkey). *Limnofish, 3 (2*), 91-99.

Sebastes, A., Martín, P., & Raya, V. (2012). Changes in life-history traits in relation to climate change: bluefish (*Pomatomus saltatrix*) in northwestern Mediterranean. *ICES Journal of Marine Science*, *69 (6),* 1000–1009.

Song, J., Zhao, B., Liu, J., Cao, L., & Dou, S. (2018). Comparison of otolith shape descriptors and morphometrics for stock discrimination of yellow croaker along the Chinese coast. *Journal of Oceanology and Limnology, 36(5)*, 1870-1879.

Short, J. A., Gburski, C. M., & Kimura, D.K. (2006). Using otolith morphometrics to separate small Walleye Pollock Theragra chalcogramma from Arctic cod Boreogadus saida in mixed samples. *Alaska Fishery Research Bulletin, 12,* 147-152.

Teimori, A., & Eslami A. (2017). Morphological-based variation of the fish populations using groupwise registration; applied to microscopic images of fish otolith using *Aphanius dispar* as a model. *Iranian Journal of Science and Technology, 41 (4),* 1083-1091.

Torres, G. J., Lombarte, A., & Morales-Nin, B. (2000). Variability of the sulcus acusticus in the sagitta otolith of the genus *Merluccius. Fisheries Research 46,* 5–13.

Turan, C., Oral, M., Öztürk, B., & Duzgunes, E. (2006). Morphometric and meristic variation between stocks of Bluefish (*Pomatomus saltatrix*) in the Black, Marmara, Aegean and northeastern Mediterranean Seas. *Fisheries Research, 79,* 139-147.

Tuset, V.M., Lombarte A., González, J.A., Pertusa, J.F., & M. Lorente, J. (2003). Comparative morphology of the sagittal otolith in Serranus spp. *Journal of Fish Biology, 6 (1),* 1491-1504.

Tuset, V. M., Lombarte, A., & Assis, C. A. (2008). Otolith atlas for the western Mediterranean, north and central eastern Atlantic. *Scientia Marina, 72S1,* 7-198.

Vignon, M., & Morat, F. (2010). Environmental and genetic determinant of otolith shape revealed by a non-indigenous tropical fish. *Marine Ecology Progress Series, 411(1)*, 231–241.

Wilk, S. J. (1977). Biological and fisheries data on bluefish, *Pomatomus saltatrix* (Linnaeus). NMFS, NEFC, Sandy Hook Lab. Tech. Ser. Rep. No. 11, 56 p.

Yedier, S., Bostancı, D., Kontaş, S., Kurucu, G., Apaydin Yagci, M., & Polat, N. (2019). Comparison of otolith morphology of invasive big-scale sand smelt (*Atherina boyeri*) from natural and artificial lakes in Turkey. *Iranian Journal of Fisheries Sciences, DOI: 10.22092/ijfs.2018.116980 (In Press).*

Zengin, M., Saygin, S., & Polat, N. (2015). Otolith shape analysis and dimensions of the anchovy *Engraulis encrasicolus* L. in the Black and Marmara Seas. *Sains Malaysiana, 44 (1),* 657-662.

Zengin, M., Saygin, S., & Polat, N. (2017). Relationships between otolith size and total length of bluefish, *Pomatomus saltatrix* (Linnaeus, 1766) in Black Sea (Turkey*). North-Western Journal of Zoology, 13* (1), 169-171.

Zischke, M.T., Litherland, L., Tilyard, B.R., Stratford, N. J., Jones E. L., & Wange, Y.G. (2016). Otolith morphology of four mackerel species (*Scomberomorus* spp.) in Australia: Species differentiation and prediction for fisheries monitoring and assessment. *Fisheries Research, 176,* 39–47.