Relationships between otolith size and total length of bluefish, *Pomatomus saltatrix* (Linnaeus, 1766), in Black Sea (Turkey)

Bluefish (*Pomatomus saltatrix* (Linnaeus, 1766)) is a pelagic and migratory fish that is widely abundant all over the world except in the area of the North and Central Pacific Ocean (Briggs 1960). This species is distributed in warm-water areas during the colder months and when the surface temperature reaches a certain value, it migrates towards colder waters where the spawning occurs. They are warm water fishes and never found in temperatures lower than 14-16°C (at least in summer). They can tolerate temperatures of 11.8-30.4°C, but exhibit signs of stress at both extremes (Olla & 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 & Klimova 1996, Turan et al. 2006, Sebastes et al. 2012). Throughout these migrations, bluefish have been highly exploited, especially in the area of western Black Sea and Marmara Sea (Ceyhan & Akyol 2006). Bluefish mainly fed with atherinids, engraulids, cephalopods and crustaceans (Tortonese 1986, Juanes et al. 1996).

Although there are important articles about growth, reproduction, diet and stock characteristics of the bluefish (Hare & Cowen 1994, Buckel et al. 2004, Turan et al. 2006, Ceyhan et al. 2007, Robillard et al. 2008, Robillard et al. 2009, Villegas-Hernández et al. 2015), studies concerning the otolith morphology and its relation to the fish length are limited (Ceyhan & Akyol 2006, Cengiz et al. 2012).

Otoliths are important taxonomical and biological archives of fish populations. There are several benefits of studying the relationship between fish length and otolith dimensions. Namely, the age and size of the fish can be recalculated from the otolith obtained from the stomach of a predator (Treacy & Crawford 1981); also once the relationship between otolith length and total length in a species is determined, one can estimate the total length or standard length of a fish, or vice versa (Sen et al. 2001, Bostanci 2009, Battaglia et al. 2010, Basusta et al. 2013, Yilmaz et al. 2014, Zengin et al. 2015, Yazıcioğlu et al. 2016). Therefore, the otolith morphology is an additional characteristic that defines each fish species (Hossucu et al. 1999).

The aim of this study is to determine the relationships between the total length and otolith dimensions of this highly important commercial fish species in Turkey.

Bluefish specimens were monthly collected from commercial fishing boats operating in the offshore area of Samsun between October and December 2014. All captured individuals (N=125) were measured to the nearest 0.1 cm for total length (TL) and the weight of each fish was recorded to the nearest 0.01 g. Sex was determined by macroscopic examination of the gonads (71♀, 54♂). Pairs of the sagittal otoliths were removed in order to be used in further analysis distinctions between right and left otolith. Otolith weight (OW) was detected for left and right using Pressicia precision scales (0.0001 g). Otolith width (OB) and length (OL) (± 0.001 mm) were determined by Leica Application Suit Ver. 3.8 Imaging Software. All otoliths were photographed on the distal side with a Leica DFC295 digital camera. OL was defined as the greatest distance between anterior and posterior edge, and OB was described as the greatest distance from dorsal to ventral edge (Fig. 1).

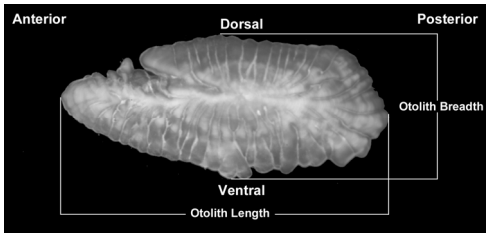

Figure 1. Image of sagittal otolith with indicated bluefish otolith measurements (Left otolith).

The total length and otolith measurements (OW, OL, OB) were tested by normality test ($p>0.05$). Power and linear regression models ($y=ax^b$ and $y=ax+b$, where y is the fish length and x is otolith measurement) were applied to estimate the relationships between the otolith measurements (OW, OL, OB) and fish total length (TL).

Statistical analyses were tested by Paired t-test, Wilcoxon test, Independent Two Sample t-test and Mann-Whitney U test. SPSS 20, Minitab 15.0 and the Excel software were utilized in the evaluation of data.

Overall, 125 bluefish specimens were collected and analyzed. Females (N=71) slightly prevailed over the males (N=54) within the collected samples. The minimum and maximum total length (TL) of bluefish in fishing season 2014-2015 ranged between 13.5 and 23.6 cm, respectively. The minimum legal catch size for bluefish is determined as

Table 1. Descriptive statistics of TL, OW, OB, OL and tests used for comparison of left and right otolith pairs of bluefish *Pomatomus saltatrix* caught in Samsun offshore area, October-December 2014.

Parameter	Minimum	Maximum	Mean	SE	SD	Tests
Total Length (cm)	13.5	23.6	18.635	0.1846	2.0636	-
Otolith Weight (g)	0.0042	0.0126	0.0079	0.0001	0.0014	Paired t test
Otolith Breadth(mm)	2.004	2.968	2.5483	0.0153	0.1715	Willcoxon
Otolith Length (mm)	4.315	7.161	6.0060	0.5252	0.5872	Willcoxon

14.0 cm according to fisheries rules in all of the Turkish seas. Descriptive statistics of the bluefish samples are displayed in Table 1.

According to the results of the present study, there were no statistically significant differences in terms of otolith length (OL), otolith width (OB) and otolith weight (OW) between left and right otolith pairs (P>0.05; *df*=124). Left otoliths were used in comparison between sexes because there were not statistically significant differences between otolith pairs (P>0.05).

Pomatomus saltatrix is one of the fish species that is exploited in commercial and recreational fisheries worldwide (Robillard et al. 2008, Ozdemir et al. 2009). In Turkey, bluefish is the third most caught pelagic fish species with the annual catch of 19. 901 tons in 2004 (Ozdemir et al. 2009). There are many studies about fecundity, growth, reproduction, migration and catching of bluefish (Smith et al. 1994, Salerno et al. 2001, Shepherd et al. 2006, Ceyhan et al. 2007). However, there are limited studies about the relationships between otolith morphology values and total length (Ceyhan & Akyol 2006, Cengiz et al. 2012). The relationships between total length and otolith dimensions of bluefish, which exposed to an intense fishing pressure, were carried out with this study.

The relationships between TL-OW, TL-OL and TL-OB of bluefish were analyzed and showed that power model had higher coefficient of determination (r^2) (Table 2). Therefore, equations and graphics of the relationships between total length and otolith properties were drawn using power model. Overviewing the literature, findings obtained within this study were contrary to the findings by Cengiz et al. (2012) and Ceyhan & Akyol (2006) who used a linear model for the description of the bluefish total length and otolith properties relationships.

When analyzed, the regression coefficients of the relationship between TL and OW were found to be the highest (r^2> 0.8883) (Fig. 2). Generally, in studies that examined the relationship between fish length and otolith dimensions, OW was detected as an optimal parameter for estimating the fish length (Hossucu et al. 1999, Battaglia et al. 2010, Zorica et al. 2010, Basusta et al. 2013).

Table 2. Relationship between the total fish length-otolith weight (TL-OW), total fish length-otolith length (TL-OL) and total fish length-otolith width (TL-OB) along with its coefficents of determination (r^2) linear and power models.

	Model	r^2
TB-OB	Linear	0.7152
	Power	0.7322
	Model	r^2
TB-OL	Linear	0.6121
	Power	0.6588
	Model	r^2
TB-OW	Linear	0.8706
	Power	0.8883

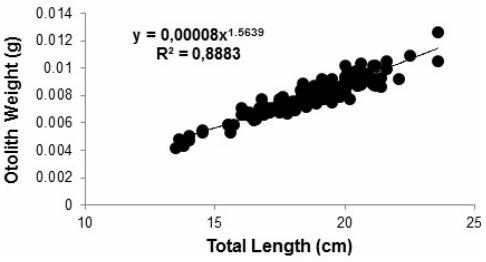

Figure 2. Relationship between bluefish total length (TL) and otolith weight (OW) caught in Samsun offshore area, October-December 2014.

This is the first study that examines the relationships between total length and otolith geometric measurements of bluefish sampled from the Black Sea. Results of this study indicated that otolith weight might be used in the estimation of the total length thus also the age in further studies concerning this commercially important fish species.

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