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Otolith dimensions (length, width), otolith weight and fish length of *Sardinella sindensis* (Day, 1878), as index for environmental studies, Persian Gulf, Iran

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Abstract

Background: *Sardines are* the most important commercial fishes for Iran. However, information about biology and ecology of sind sardine in Persian Gulf and Oman Sea is scarce.

Methods: In this study, relationship between fish length and otolith length, -width and -weight of *Sardinella sindensis* from Bandar Lengeh and Qeshm Island, Persian Gulf were analyzed. In total, 128 and 120 fishes collected from Commercial catches during March 2011- February 2012 in the Bandar Lengeh and Qeshm Island respectively.

Results: There were no significant differences between left and right otolith (*t*-test, $P > 0.05$) or between males and females otoliths (ANCOVA, $P > 0.05$). For these reasons, only right otoliths were used for next analysis and data of both sexes were pooled. Relationships between fish length and otolith length, width and weight were described by linear regression models and high correlation was shown for all relationships. The highest correlation was between fish length and otolith length (Bandar Lengeh, $R^2 = 0.8722$; Qeshm Island, $R^2 = 0.8661$) and relationship between fish length and otolith width showed less correlation than other relationships (Bandar Lengeh, $R^2 = 0.7355$; Qeshm Island, $R^2 = 0.7275$).

Conclusions: The result from this study shows that fish length and otolith growth have a positive relationship, so can be a useful tool to evaluate the growth of fish and fish stocks and finally fisheries management.

Keywords: Fish length, Otolith, *Sardinella sindensis*, Persian Gulf

Background

The inner ears of all teleost fishes contain three calcified structures, which acts as balance and hearing organs (Popper et al. 2005). Otoliths serve as a permanent record of the life history of an individual fish (ICES 2004), and they hold a wealth of information on daily age, size, growth and ontogeny of fishes (Gerard & Malca, 2011). The otoliths continue to grow throughout their life and do not resorb in time of stress (Yaremko, 1996; Mendoza, 2006). Thus, they are one of the most reliable tools for identification of growth rates, structure of age in a certain population and for fisheries management, furthermore the analysis of microstructure otolith have greatly developed for stock identification, feeding ecology of predators, and the determination of migration direction in fishes species (Campana & Thorrold, 2001; Mendoza 2006, McFarlane et al. 2010). The application of otolith only is not restricted to ichthyology, but also extended widely for some aspects of palaeontology, stratigraphy, archaeology and zoogeography (Tuset et al. 2008). The size and shape of otoliths are variable according to species and size of fish (Eroglu & Sen, 2009). The relationship between fish length and otolith dimensions, can be useful to estimate the size and age of prey collected from stomach and feeding habits of fishes (Hunt, 1992; Granadeiro & Silva, 2000; Khodadai & Emadi, 2004, Pombo et al. 2005, Rizkalla & Bakhoum, 2009; Javor et al. 2011).

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Sardines are small pelagic fishes that live in coastal waters of many sea and ocean. They feed on planktons and are eaten by other fishes, so they are important in marine food web (Emmett et al. 2005; Salarpouri et al. 2009). In addition, sardines are consumed as fresh meal for humans and as commercial powder (Bennet et al. 1992; Hill et al. 2005; FAO, 2011). Many studies for sardine genus have been performed on the otolith structures, such as growth and mortality estimation, identification of fishes, determine the fish stock and trace migration pathway of fish (Nair, 1949; Krzeptowski, 1983; Cergole & Valentini 1994; Butler et al. 1996; Watanabe & Nakamura, 1998; Gaughan & Mitchell, 2000, Silva et al. 2008; Mehanna & Salem 2011; Ward et al. 2012; Dehghani et al. 2015). According to FAO (2011), *Sardinella sindensis* is the most important commercial fish for Iran and Pakistan. However, a few studies have been performed on the structure of otoliths in *S.sindensis* from Iran. The age and growth of *S.sindensis* was studied using annual rings of otoliths from Persian Gulf and Oman, Iran by Dehghani et al (2015). Otoliths tend to grow linearly in length and width with increasing fish size, and to grow linearly in thickness and weight with increasing fish age (Donkers, 2004). For most species, the relationship between otolith length and fish length can be described by a simple linear regression (Harvey et al. 2000).

The aim of this study was to gain understanding of the relationships between fish length and otolith dimensions of *S.sindensis*, through regression analysis.

Methods

Fishes were selected, randomly, from commercial catches using purse seine nets. A total of 120 fishes were collected from coastal waters of Bandar Lengeh (26°55′27″N 54°88′14″E) and 128 fishes from Qeshm Island (26°41′43″N 55°37′06″E) in North of Persian Gulf (Iran) during March 2011 to February 2012 (Fig. 1). Fishes were transported to the laboratory of Persian Gulf and Oman Sea Ecological Research Institute, Bandar Abbas.

First, total fish length was measured to the nearest 0.1 mm, and then sex determination was done under stereomicroscope. Chi-square test was performed for sex differences. Otoliths were extracted from heads of samples, cleaned and dried. Otolith weight was measured by using digital balance to the nearest 0.0001 g. For measuring the otolith size, images were taken under a stereo microscope linked to a video camera (Motic Image Plus 2), and otolith length and -width were measured using imaging software (Motic 2) to the nearest 0.01 μm. Otolith length is the distance from the midpoint of the rostrum at point A through the primordium to the posterior edge at

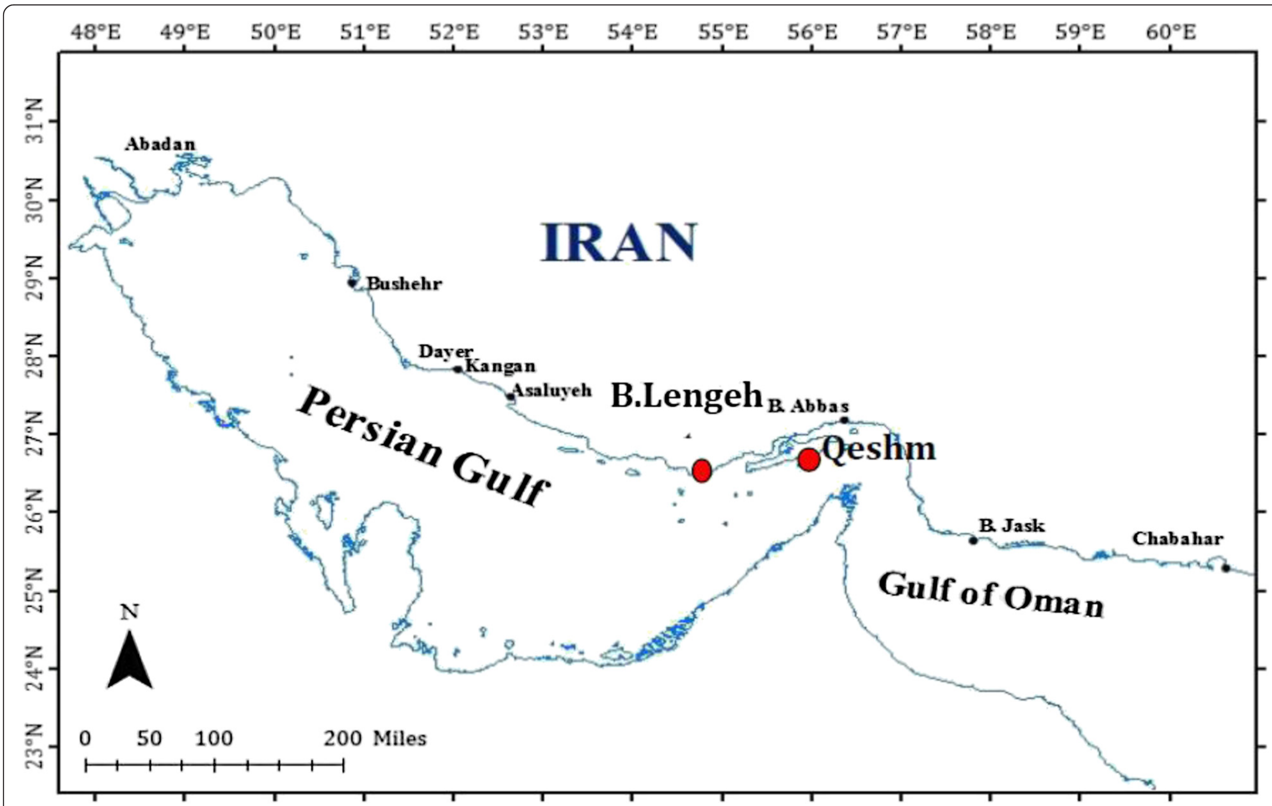

Fig. 1 Sampling areas of Sind sardine, *Sardinella sindensis,* Bandar Lengeh and Qeshm Island, Persian Gulf, Iran

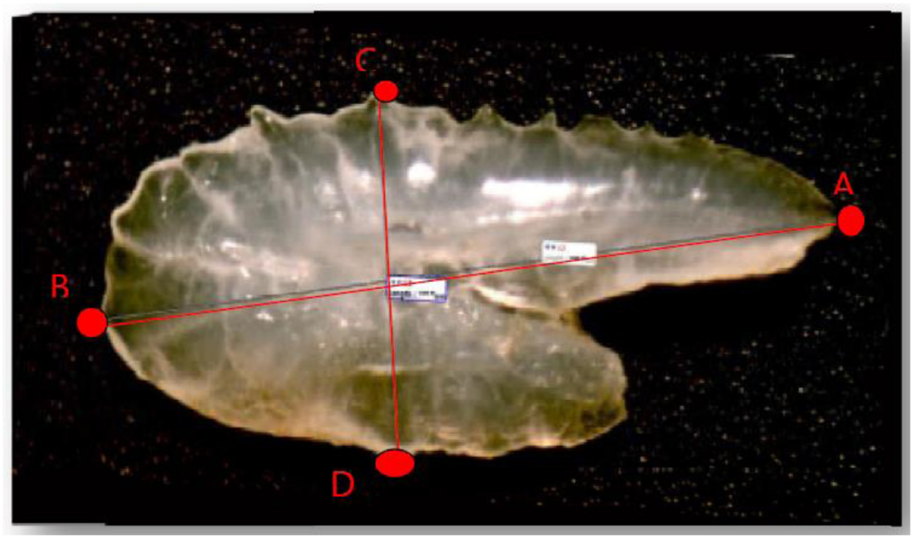

Fig. 2 Otolith of *S. sindensis,* distance between point A and B indicating otolith length and distance between point C and D indicating otolith width

point B. Width is the distance perpendicular to the length passing through the primordium (Fig. 2) (Javor et al. 2011). Differences between left and right otolith were tested by paired *t*-test and between males and females by using ANCOVA (Matic-Skoko et al. 2011). ANOVA was used to test for significant differences in area. Relationships between total fish length and otolith length and -width described by linear equation as TL = a (L) b, where TL is total fish length, L is otolith length or otolith width, and a, b are constant coefficients. For express relationship between total length fish and otolith weight was used a linear equation like above equation that described as TL = a (OW) b, where OW is otolith weight. Regression method was analyzed by using Excel software (version 2007) for determining the relationships between fish length and otolith length,-width and -weight.

Results

In total, 128 fishes from Qeshm Island and 120 fishes from Bandar Lengeh collected (Fig. 3). Chi-square test was performed assuming equal sex ratio and results with a degree of freedom, did not show significant differences between the sexes ($X^2 = 1.2$, $df = 1$, $p > 0.05$) and ($X^2 = 1.125$, $df = 1$, $p > 0.05$) for Bandar Lengeh and Qeshm, respectively.

Minimum-maximum and mean fish lengths for Bandar Lengeh were 8.1-18.3 and 12.7 cm respectively and those for Qeshm were 7.9-18.6 and 12.9 cm, respectively. All measurement of left and right otoliths were tested and no significant differences were observed between left and right otolith (*t*-test, $P > 0.05$) and between otoliths of female and males (ANCOVA, $P > 0.05$), therefore, only right otolith used for next analysis and data of both the sexes were pooled. Otolith length, -width and -weight measurements in addition fish length and weight are recorded in Table 1.

Relationships between fish length and otolith length, -weight and -width were described by regression model and linear equation. The equation for otolith length and fish length was ($OL = 171.51$ TL+ 257.63; $R^2 = 0.8661$) for Qeshm Island and ($OL = 165.06$ TL+ 401.64; $R^2 = 0.8661$) for Bandar Lengeh. Regression models and linear equations of all relationships are shown in Figs. 4, 5 and

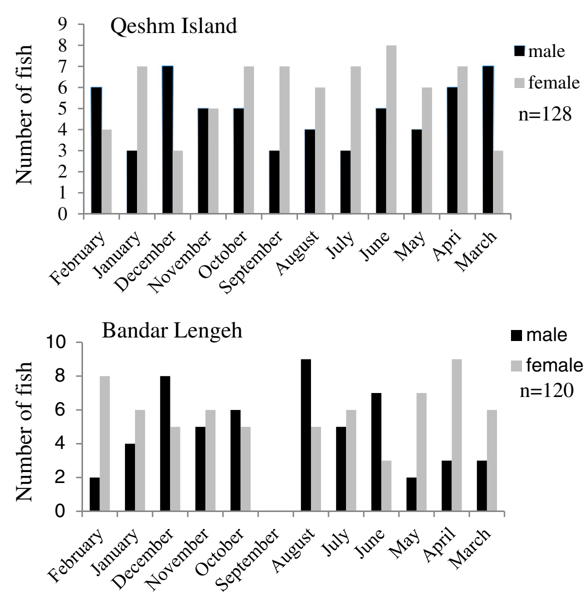

Fig. 3 Number of *S.sardinella* collected from Bandar Lengeh and Qeshm Island (Persian Gulf) during March 2011 to February 2012

Table 1 Maximum, minimum, mean and standard deviation (SD) of fish length and otolith length, -width and -weight of *S.sindensis* from Bandar Lengeh and Qeshm Island (Persian Gulf)

Area		Number	Minimum	Maximum	Mean	SD
Bandar Lengeh	Total fish length (cm)	120	7.9	18.6	13	2.7
	Otolith length (μm)	118	1620.06	3389.02	2503.06	511.37
	Otolith width (μm)	118	954.24	1504.88	1250.78	153.52
	Otolith weight (g)	118	0.0004	0.0026	0.0013	0.00061
Qeshm Island	Total fish length (cm)	128	8.1	18.3	12.9	2.7
	Otolith length (μm)	124	1610.28	3556.98	2533.7	476.5
	Otolith width (μm)	124	973.43	1533.05	1237.7	132.8
	Otolith weight (g)	124	0.0003	0.0027	0.0014	0.00064

6. There were no significant differences in these analyses for two areas (ANOVA, $P > 0.05$).

Discussion

In this study, relationship between fish length and otolith length, -width and -weight was analyzed by linear model. Otolith dimensions and weight was linearly correlated to total fish length. Relationships between fish length and otolith length for each area showed highest positive correlation, that is similar to results of *Sardina Pilchardus* from Adriatic Sea, Crotia (Zorica et al. 2010), those of *Sardinops sagax* from North America (Javor 2013), *S.sagax* from Australia (Gaughan et al. 2008) and other fish species (Hunt, 1992; Megalofoou 2006; Ilkyaz et al. 2011).

In current study, results of testing the difference between right and left otoliths showed no significant difference, and no significant difference between males and females otoliths. In addition, this test was similar for the two sampling regions. These results agree with results of other studies (Jawad et al. 2011), but differ from studies done on *Sardina Pilchardus* from Adriatic Sea, Crotia (Zorica et al. 2010), *Sardinops sagax* from west coast of North America (Javor et al. 2011) and were different from results of other fishes (Clark, 1992; Sen et al. 2001; Aydin et al. 2004). It can be stated that fishes from different regions have different allometric growth of the otolith (Butler et al. 1996), the reason for these

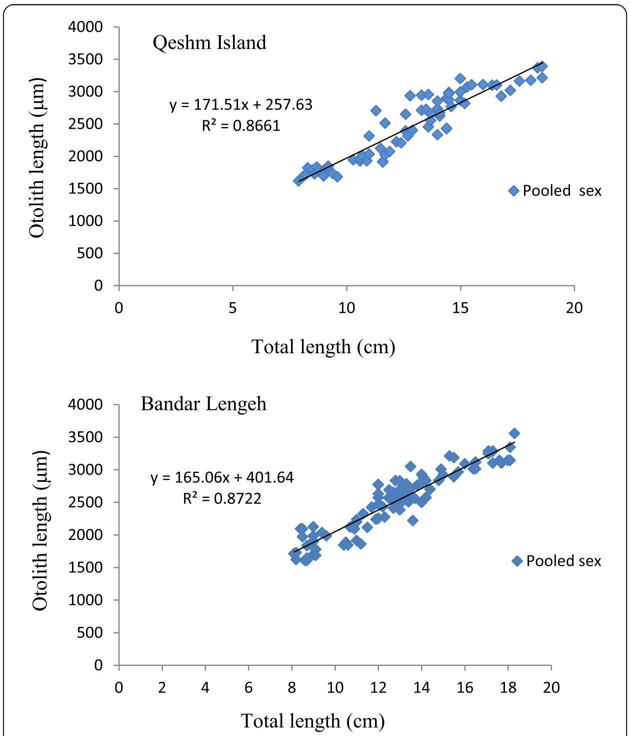

Fig. 4 Relationship between total fish length and otolith length of *S.sindensis* from Bandar Lengeh and Qeshm Island (Persian Gulf)

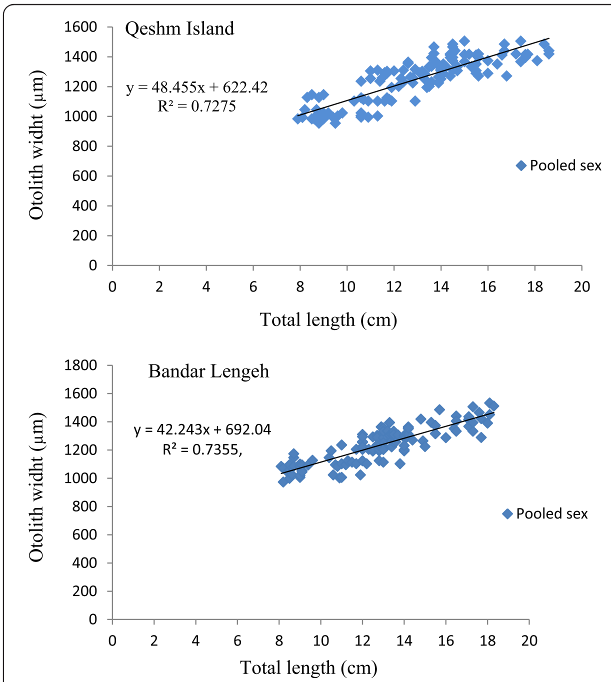

Fig. 5 Relationship between total fish length and otolith width of *S.sindensis* from Bandar Lengeh and Qeshm Island (Persian Gulf)

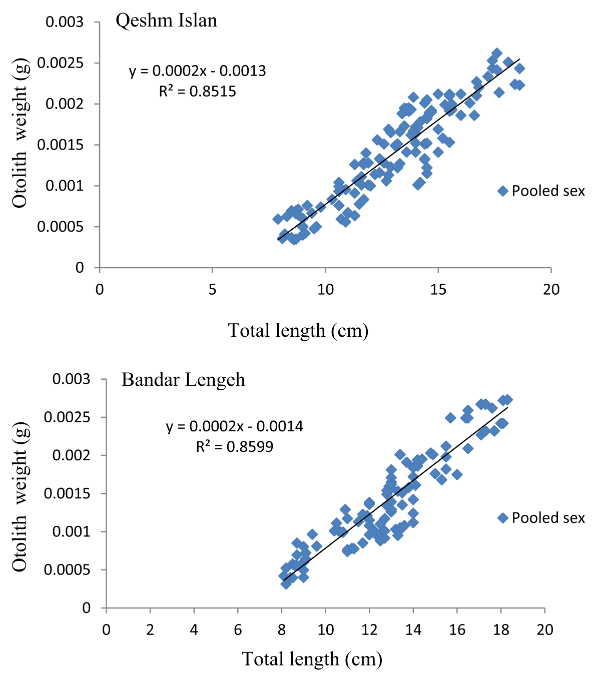

Fig. 6 Relationship between total fish length and otolith weight of *S.sindensis* from Bandar Lengeh and Qeshm Island (Persian Gulf)

difference in relationship in different studies, could be the differences in fish species, habitat, food availability and physiochemical factors of waters of environment that lives there (Aydin et al. 2004; Javor et al. 2011). There are a number of things that could conceivably produce a shift in the otolith size-body size relationship in the commercial catch, including large changes in age or sex composition, or changes in regulations, gear, or fishing strategies, even different methods used for analysis (Clark, 1992; Ma et al. 2010).

The results of this study suggested that otolith dimensions increases as fish length increases and therefore, otolith growth can be correlated with fish growth. In addition, the results showed that the otolith length had more correlation to the fish length than otolith weight and -width, respectively, it is similar to study done on *S.lemuru* from Australia (Gaughan and Mitchell, 2000) and other fishes (Metin & Ilkyaz 2006; Matic-Skoko et al. 2011).

Lombarte and 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. Butler et al (1996) reported that it was not possible to use otolith weight with other data to estimate age of Pacific sardine. The regression method is very appealing in its simplicity but has two drawbacks. It will often be necessary to transform predictors and (or) the predict to obtain linear relationships, and even then, this is likely to achieve only approximate linearity. The second, and more serious, drawback is that this method produces asymptotically biased estimates of proportions at age (Francis & Campana, 2004), however, linear regressions between age-otolith size, unlike annulus counting methods, to estimate the age structure of the Sardines population need lesser time and cost (Ward et al. 2005; Ward et al. 2012).

Conclusions

morphometric relationships are useful tools for testing feeding and for research on fish fossils, especially for determining the size of fish that it is important factor for fish stock monitoring and management. However, for better understanding of otolith growth, it can be recommended for future studies to use the relationships between otolith weight and age, and to measure other otolith factors such as area, perimeter, thickness, circularity, and rectangularity.

Abbreviations

Ancova, analysis of covariance; Anova, analysis of variance; Df, degree of freedom; OL, otolith length; OW, otolith weight; P, probability; R^2, coefficient of determination; Sd, standard deviation; TL, total length

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Availability of data and materials

The data will not be shared with a reason, in this section.

Authors' contributions

MD carried out biometric and otoliths analysis of fishes, statistical analysis, and writing of paper; EK was superviser and the overall structure of paper was confirmed by him; AS assisted in sampling of fishes, and extracting of otoliths; SS cooperated in statistics analysis and writing of paper. All authors have read and approved the final manuscript.

Competing interests

The authors declare that they have no competing interests.

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