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Otolith Morphology and Relationships of the Common Pandora *Pagellus erythrinus* (Linnaeus, 1758) captured from the Eastern Coast of Libya

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ABSTRACT

This study was organized to establish the morphometric parameters of *Pagellus erythrinus* otolith and determine the relationship of these parameters to fish size. A total of 37 fish specimens collected from Benghazi shore, Eastern Libya, during winter 2022 were used in the study. Total length (TL) and total weight (TW) were measured for each fish individual. Mean TL and TW were 185.68±6.404 and 90.967±9.824, the length-weight relationship indicated an isometric growth ($TW=0.013TL^{2.99}$ $R^2=0.98$). Otolith weight (OW), length (OL), and height (OH) were measured. Differences between the parameters of the otolith on the left and the right were statistically insignificant. The otolith was pentagonal, and the ostium and the cauda were distinguishable. The ostium (OSL; 2.921±0.140) was funnel-like and shorter than the cauda (CUL; 3.793±0.147,) which is tubular. Percentages of SAL/SL%, OSL/SAL%, CUL/SAL%, SH/SL % and otolith relative size were calculated. The power model was used to determine relationships between OL, OH, OW, and fish size. Values of the coefficient of determination (R^2) were TL-OL ($TL=0.3632OL^{1.035}$, $R^2 = 0.85$), TL-OH ($TL=0.2891OH^{1.00}$, $R^2 = 0.86$), TL-OW ($TL = 2.570OW^{2.74}$, $R^2 = 0.95$), TW-OL ($TW=1.623OL^{0.347}$,$R^2 = 0.86$), TW-OH ($TW=1.236OH^{0.337}$,$R^2 = 0.87$), and TW-OW ($TW=0.0010OW^{0.915}$, $R^2=0.95$). The results suggest that the otolith dimensions are good indicators of fish size.

INTRODUCTION

Otolith or ear stones are calcareous structures found in the inner ear of bony fish, where they play a role in hearing and balance **(Campana, 1999)**. The morphological characteristics of fish dust vary greatly between species, some of which have an hourglass with sulcus homosulcoid (Canthigaster capistrata), an elliptic with sulcus heterosulcoid (*Boopa boops*), or a semicircular with sulcus archaesulcoid (*Lophius piscatorius*) **(Tuset *et al.*, 2006)**. Otoliths are considered the best for determining ages due to their accuracy **(Campana & Thorrold, 2001)**. Additionally, using morphological characteristics is useful for identifying fossils and the types of food in the stomachs of predatory fish **(Echeverria, 1987; Gamboa, 1991; Nielsen *et al.*, 2010)**; otolith measurements can be used to evaluate fish length since fish growth is positively correlated with otolith dimensions **(Munk, 2012)**.

The Sparidian family includes 100 species found in temperate and tropical regions; in the Mediterranean, there are twenty-five species. In Libya, 23 species were recorded, including: *Diplodus vulgaris* (Geoffroy Saint-Hilaire, 1817); *Lithognathus mormyrus* (Linnaeus, 1758); *Oblada melanura* (Linnaeus, 1758); *Pagellus bogaraveo* (Brünnich, 1768); *Pagrus auriga* (Valenciennes, 1843); *Pagrus caeruleostictus* (Valenciennes, 1830); *Pagrus pagrus* (Linnaeus, 1758); *Sparus aurata* (Linnaeus, 1758), and the Lessepsian species *Crenidens crenidens* (Forsskål, 1775) **(Golani *et al.* 2006; Elbaraasi *et al.*, 2019)**.

Pagellus erythrinus, the common pandora, is widespread along the Mediterranean, Black Sea and the Atlantic coasts between Cape Verde and Norway **(Bauchot & Hureau, 1986; Whitehead *et al.*, 1986; Fisher *et al.*, 1987)**. *P. erythrinus* depends mainly on crustaceans "56.03%" for its diet, followed by marine worms "19.83%" and fish larvae "17.64%" **(El-Kaber *et al.*, 2022)**. The *P. erythrinus* is generally found in sandy, muddy, and rocky habitats in shallow waters up to 200m **(Golani *et al.*, 2006)**.

There are many previous studies that have focused on estimating ages, growth rates, distribution, reproductive aspects and feeding **(Coelho *et al.*, 2010; Metin *et al.*, 2011; Busalacchi *et al.*, 2014; Saleh, 2018; Ayyidiz *et al.*, 2019; Elmajedeb *et al.*, 2019; Kale *et al.*, 2021; Elkaber *et al.*, 2022; Mehanna, 2022)**.

This study aimed to determine the length-weight relationship, condition factors, and morphometric characteristics of otoliths in addition to the relationship between body size and dimensions of otoliths.

MATERIALS AND METHODS

Thirty seven specimens of *Pagellus erythrinus* collected from Benghazi shore, Eastern Libya during winter 2022 were used in the study. The total length (TL), head length (HL), and total weight (TW) of the fish were measured.

The length-weight relationship (LWR) was estimated according to **Ricker (1975)**:

$$\mathbf{W = aL^b}$$

Where, L is the total length of the fish; W is its total weight; *a* is the intercept of the regression line on the y axis, and b is the slope of the line.

Fulton (1904)'s condition factor (K_F) was calculated implementing the succeeding equation:

$$\mathbf{K = 100\ TW/TL^3}$$

The relative condition factor (K_n) of **Le Cren (1951)** was calculated using the following equation:

$$Kn = W/\ aL^{\,b}$$

Where, K_n is the relative condition factor; L is the total length; W is the total weight of individuals; *a* is the intercept, and *b* is the slope obtained from the length-weight relationship estimation.

Next, the head region of each fish was dissected, right and left, and the otoliths were removed from their capsules, cleaned, dried and weighed to the nearest 0.0001 g as the otolith weight (OW). Otolith length (OL), otolith height (OH) and otolith area (OA in mm^2), sulcus length (SAL), ostium length (OSL), and cauda length (CL) were measured to the nearest 0.1mm using image processing (Digimizer software, version 4).

Percentage of otolith length from total fish length (OL/TL%), percentage of otolith length from head length (OL/HL%), and percentage of cauda length and ostium length from sulcus length (CL/SAL% and OSL/SAL%) were calculated. Otolith relative size (O_R) was calculated according to the equation of **Lombarte and Cruz (2007)**:

$$\mathbf{O_R = 1000 \times OA \times TL^{-2}}$$

Differences between the mean length, weight, height of left and right side of the otoliths were tested for significance by an independent t-test. The power equation ($y=ax^b$) was used to describe the relationship between fish size (TL), fish weight (TW) and otolith dimension (OL, OH and OW), aligned with the relationship between otolith length and the other otolith parameters (OH, OW, SAL, OSL, and CL).

All calculations and statistics were performed with Excel and SPSS (Version 21.0).

RESULTS

37 samples were collected from the Benghazi City coast, Western Libya. The total length ranged from 13.90 to 26.80cm, with an average of 18.568cm. The total weight ranged from 33.30 to 267.80g, with an average of 90.967gm. The Fulton's condition factor ranged between 1.13 & 1.51, with an average of 1.2883±0.0158. For the relative condition factor (K_n), it ranged between 0.88 & 1.17 and had an average of 1.009±0.0121 **(**Table 1**)**. The length-weight relationship was significant ($P< 0.0001$), and it was strong with a coefficient of determination (R^2) of 0.98. The value of the regression coefficient (b: 2.997) indicated that the growth was close to isometric **(**Fig. 1**)**. Table (2) displays the length, height, and weight of the otolith. Through the t-test, no statistical differences were detected between the right and left otoliths. Thus, one side was used for determining the rest of the measurements.

In this study, the *Pagellus erythrinus* otolith was pentagonal in shape and formed 4.04±0.0651% of the total length and 16.58±0.626% of the head length. The OH/OL% ranged from 68.58 to 77.58mm. The sulcus acusticus length ranged between 4.43 and 9.7 mm and constituted about 86.54±0.787% of the length of the otolith. While the ostium and cauda were 1.94 - 4.45mm and 2.47 - 5.20mm, respectively **(**Fig. 2**)**. The relative size of the otolith was 0.7206±0.0485; thus, the otolith is considered large **(**Tables 2, 3**)**. The relationship between the length of the otolith and other otolith measurements (height, weight, sulcus length, ostium length, and cauda length) are shown in Table (4**)**, all of which were significant ($P<0.001$).

The best coefficient of determination (R^2) of 0.97 was found between otolith length and height, and the lowest value of the coefficient of determination was recorded between otolith length and weight with ostium length (R^2: 0.84). The relationship was determined between body size (length and weight) and otolith dimensions (length, height,

and weight), all of which were strong. Values of the coefficient of determination (R^2) were TL-OL ($TL=0.3632OL^{1.035}$, $R^2 = 0.85$), TL-OH ($TL=0.2891OH^{1.00}$, $R^2 = 0.86$), TL-OW ($TL = 2.570OW^{2.74}$, $R^2= 0.95$), TW-OL ($TW=1.623OL^{0.347}$, $R^2 = 0.86$), TW-OH ($TW=1.236OH^{0.337}$, $R^2 = 0.87$), and TW-OW ($TW=0.0010OW^{0.915}$, $R^2=0.95$) **(**Table 4**)**.

Table 1. Descriptive statistics of the morphometric measurements of *P. erythrinus*

Morphometric measurement	Mean	SE	Min	Max
Total length, TL(mm)	185.68	6.4042	139	268
Total weight, TW(g)	90.9677	9.8245	33.30	267.80
Head length, HDL(mm)	43.8131	2.6420	20.15	74.83
Fulton's Condition factor, K_F	1.288	0.0158	1.13	1.51
Relative condition factor, K_n	1.009	0.0121	0.88	1.17

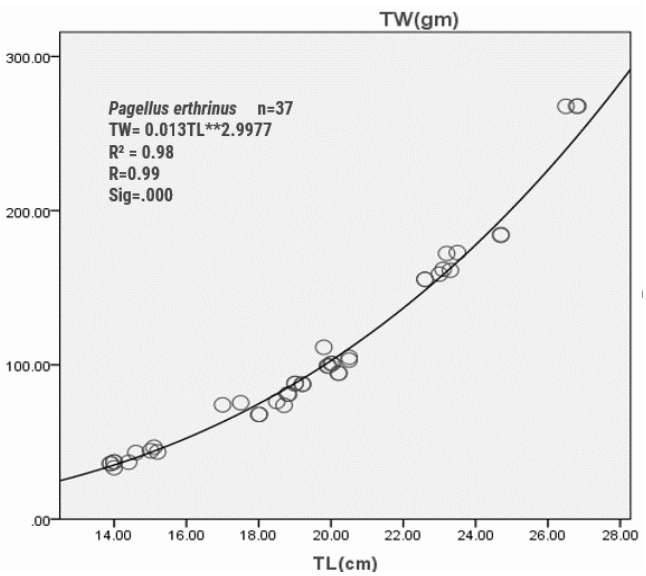

Fig. 1. The power length-weight relationship of *P. erythrinus* of the present study

Table 2. Descriptive statistics of right and left otolith

Parameter	side	Mean ± SE	*P*- value
Otolith length, OL(mm)	L	7.758±.339	0.895
	R	7.821±.339	
Otolith height, OH(mm)	L	5.638±.234	0.892
	R	5.680±.228	
Otolith weight, OW(g)	L	0.091±.0090	0.384
	R	0.108±.0167	
No statistical significant difference (*P*>0.05).			

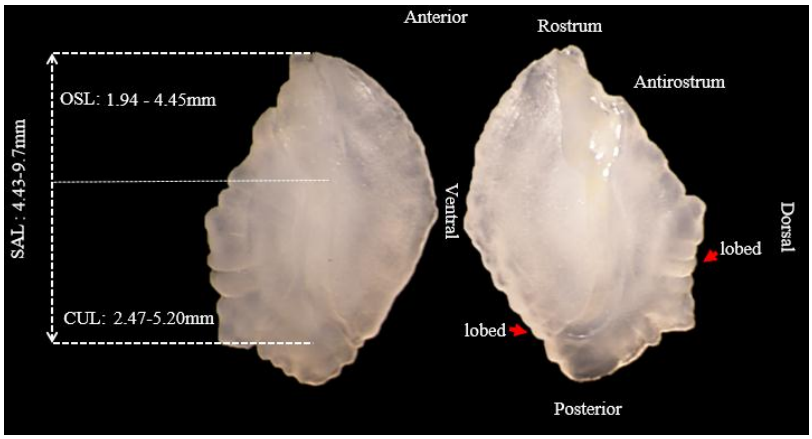

Fig. 2. Otolith of *P. erythrinus*, SAL showing: Sulcus acusticus length; OSL : Ostium length, and CUL: Cauda length

Table 3. Mean, standard error and range (Min-Max) of the morphological indices of *P. erythrinus*

Relative proportions	Min-Max	Mean±SE
OL/TL%	3.30-4.82	4.0411±0.0651
OL/HDL%	12.90-26.51	16.58±0.626
OH/OL%	68.58-77.69	72.85±0.520
SAL/OL%	77.58-92.08	86.54±0.787
OSL/SAL%	35.08-49.03	43.48±0.683
CUL/SAL%	51.75-68.92	56.86±0.752
Otolith relative size, O_R	0.4128-1.119	0.7206±0.0485

Table 4. Relationship between otolith length and otolith parameter, and relationship between otolith dimensions and fish size

Relationship	Power equation		Coefficient of determination
	a	b	
OL-OH	0.806	0.94	0.97
OL-OW	0.0007	2.29	0.84
OL-SAL	0.805	1.03	0.95
OL-OSL	0.360	1.01	0.84
OL-CUL	0.602	0.89	0.92
TL-OL	0.363	1.035	0.85
TL-OH	0.289	1.00	0.86
TL-OW	2.570	2.740	0.95
TW-OL	1.623	0.347	0.86
TW-OH	1.236	0.337	0.87
TW-OW	0.001	0.915	0.95
Abbreviations: OL; Otolith length; OH: Otolith height; OW: Otolith weight. SAL: Sulcus acusticus; OSL : Ostium length; CUL: Cauda length; TL: total length, and TW: Total weight.			

DISCUSSION

The value of the coefficient of determination in the length-weight relationship indicates an isometric growth, which agrees with numerous previous studies **(karakulk *et al.*, 2006; Ozaydin *et al.*, 2007; Ghailen *et al.*, 2010; Mehanna & Farouk, 2021)**. **Metin *et al.* (2011)** recorded that the relationship between length- weight was isometric in males ($W = 0.0125\ L^{2.99}$, $R^2 = 0.99$) and positive allometric growth in females ($W= 0.0107\ L^{3.06}$, $R^2= 0.98$). While, **Busalacchi *et al.* (2014)** recorded that growth was

negative allometric growth (sexes combined) ($W= 0.016\ L^{2.905}$, $R^2= 0.67$); whereas, **Kale *et al.* (2021)** showed that the relationship length-weight was positive allometric growth ($W = 0.00621\ L^{3.258}$, $R^2 = 0.93$). The difference in the length-weight relationship between this study and previous studies is due to various factors, including sample size, sample collection time, gender, age, stages of sexual maturity, diet, and environment **(Ricker, 1975; Moutopoulos & Stergiou, 2002)**.

The condition factor determines the state of health of the fish and gives information about its physiology; a value greater than one indicates that the fish is in good condition **(Abobi & Ekau, 2013; Nehemia *et al.*, 2021)**. In northern Aegean Sea, Fulton's condition and the relative condition factors were 1.26–0.02 and 1.01–0.02, respectively. This is close to what we found in our study, being 1.28–0.015 and 1.009–0.0121 for Fulton's condition and the relative condition factors, respectively.

The *P. erythrinus* otolith has a pentagonal shape; the anterior and posterior regions are angled; some characteristics of the sulcus, such as its shape, location, and opening are among the most important features used in species identification **(Tuset *et al.*, 2003)**. In our study, the sulcus is heterosulcoid, located in the middle and opened wide in the anterior region, and forms 86.54% of the length of the otolith; the ostium is funnel-shaped and forms 43.48% of the length of the sulcus. With respect to the cauda, it was found longer than the ostium, with a tubular, curved shape, forming 56.86% of the length of the sulcus. The morphological description is similar to that found by **Tuset *et al.* (2003)**. In addition, the current result coincide with that described by **Kinacigul *et al.* (2000)** in a systematic study of otolith characters in Sparidae in the Gulf of Izmir, reporting that they have cube-shaped and irregular pentagonal otoliths. While, for **Alwany and Hassan (2008)**, they described the otolith as oval in shape with irregular edges and 1.2mm thickness. **Tuset *et al.* (2003)** showed relative proportions of OL/TL and OH/OL of 3.2–4.7% and 63.2–97.7%, in the same line, our values for the relative proportions ranged from 3.30–4.82% (4.0411±0.0651), 68.58–77.69% (72.85±0.520), respectively, and OL/HL% ranged between 12.90–26.51% (16.58±0.626). According to **Santos *et al.* (2023)**, relative proportions (such as the OL/TL%, OL/OH%, OH/OT%, and OL/OT%) revealed ecological patterns related to habitats more than shape indicators. Their study has supported this conclusion. Additionally, otolith morphology is strong when based on the comparative technique application, taking into account the usage of suitable sample sizes in relation to morphometric methods and the ongoing updates of fish taxonomy.

In this study, the value of the relative size of the otolith was 0.7206±0.0485 (0.4128-1.119); therefore, it is classified as large in size (O_R>0.65). This value is higher than that recorded by **Lombarti and Cruz (2007)**, (O_R: 0.69, TL: 183 mm). However, the mean value of volume in this study is lower than what was found in the Adriatic Sea (O_R 0.84, 14.0–25.7 cm) by **Milosevic *et al.* (2021)**. Numerous previous studies suggested the hypothesis that the larger relative size of the otolith improves auditory abilities associated with vocal acuity in order to compensate for the reduction of light with depth. Generally, otoliths in related species are larger in temperate or cold seas **(Gauldie, 1988; Gauldie, 1993; Lychakov & Rebane, 2000, 2002; Paxton, 2000; Torres *et al.*, 2000; Cruz & Lombarte, 2004)**.

In this study, there were no significant differences between the left and right otoliths, and accordingly, the left side was used to calculate the regression. The results concluded the relationship between body size (length and weight) and the dimensions of the otolith; the weight of the otolith was the best indicator of the body size, followed by the height of the otolith, and the length of the otolith, On the contrary, the relationship was stronger between the length of the otolith and the fish size in the study of 3 species, including *P. erythrinus* collected from the east side of the Adriatic Sea (OL = 0.604 +0.039 TL, R^2=0.88, N=47) **(Milosevic *et al*., 2021)**. The results of several studies on fish species indicate that the weight of otolith dust is the best to be used for determining the length and weight of fish **(Tuset *et al*., 2006; Zorica *et al*., 2010; Fox & Weisberg, 2011; Nguyen & dinh, 2020; Aufy *et al*., 2023)** In addition to supporting palaeontologist's study of fish fossils, these relationships offer a trustworthy tool for feeding investigations, However, **Alwany and Hassa (2008)** suggested that fish weight should not be estimated directly from otolith weight measurements, which are likely to vary with the spawning condition.

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