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Original Article

The sagittal otolith morphology of four selected mugilid species from Iranian waters of the Persian Gulf (Teleostei: Mugilidae)

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Abstract: The members of mugilid species are usually difficult to recognize because of the well-known similarity observed in their external morphology. Nevertheless, their identification is very important for local fisheries management and conservation action. Therefore, in the present study we applied otolith morphology to evaluate its significance in identification of four selected mugilid species; *Chelon subviridis* (Valenciennes, 1836), *Liza klunzingeri* (Day, 1888), *Ellochelon vaigiensis* (Quoy & Gaimard, 1825) and *Mugil cephalus* Linnaeus, 1758 occurring in the Iranian waters of the Persian Gulf in southern Iran. The results indicated several otolith features to be important for identification of the selected mugilid species as follow; the position and sulcus centrality, the curvature of the cauda, and the type of anterior and posterior regions. Based on the total approach evidences, we conclude that otolith morphology in mugilid fishes can be evidently used for the species identification and probably estimation of their phylogeny. The findings are in agreement with the previous studies which documented taxonomic importance of otolith morphology.

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Introduction

The members of the family Mugilidae with 17 genera and 72 species show a world-wide distribution in temperate to tropical coastal environments (Nelson et al., 2016; Eschmeyer and Fong, 2016). The fishes inhabit various coastal environment, brackish waters, and lagoons with high salinity (Golani et al., 2002). However, some species are even resident in freshwater ecosystems (Nelson et al., 2016).

Until date, four genera i.e. *Liza* Jordan and Swain, 1884; *Mugil* Linnaeus, 1758, *Chelon*; and *Ellochelon* Whitley, 1930 with seven species, including Abu mullet, *Liza abu* (Heckel, 1843), Golden grey mullet, *Chelon aurata* (Risso, 1810), Leaping mullet, *Chelon saliens* (Risso, 1810), Klunzinger's mullet, *Liza klunzingeri* (Day, 1888), Flathead grey mullet, *Mugil cephalus* Linnaeus, 1758, and Greenback mullet, *Chelon subviridis* (Valenciennes, 1836), and Squaretail mullet, *Ellochelon vaigiensis* (Quoy and Gaimard, 1824) have been recorded from Iranian waters, including brackish and Sea waters (Coad, 2015). In addition to the above mentioned species, some other taxa have also been reported from the Iranian waters but there are no acceptable scientific references for their existence. Therefore, we did not explain them here.

Since species of the mugilid fishes have valuable fisheries catch over the world, therefore, species distinction in this family is very important for the local fisheries management, and the trophic studies. However, owing to the wide variety and similarities seen in their external morphology and meristic characters, usually considerable doubt exists regarding of their systematic classification (Whitfield et al., 2012). Therefore, hypothesis is that using hard structures such as otolith may provide an appropriate tool to discriminate species in this family.

By considering the above mentioned hypothesis,

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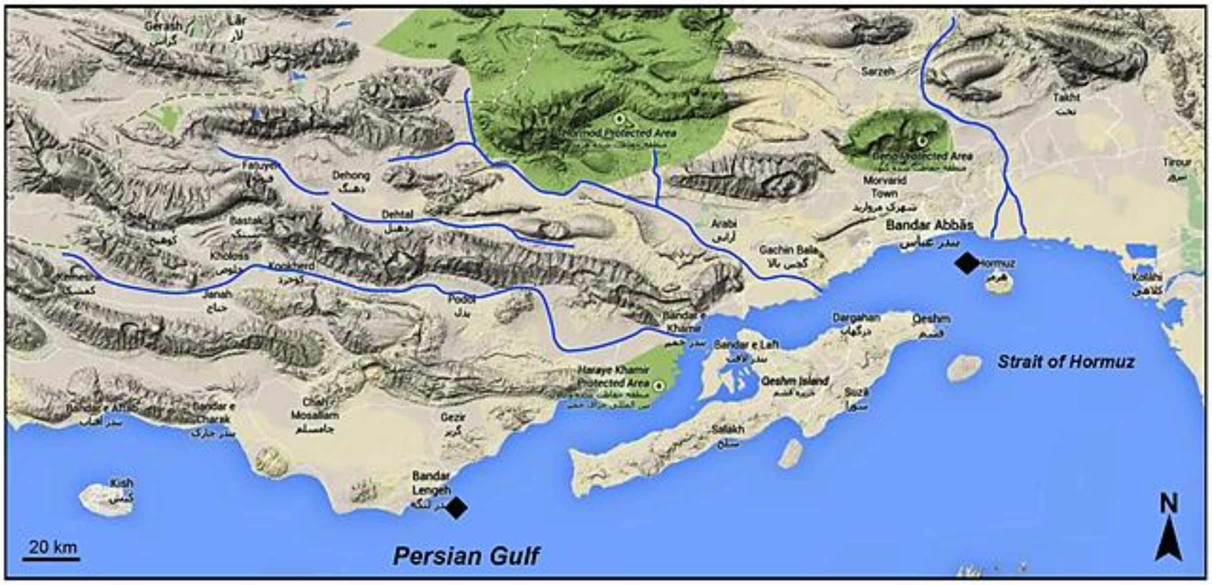

Figure 1. Sampling locations (Bandar Abbas and Bandar-e-Lengeh) of the Mugilid species along the Persian Gulf coast in southern Iran, Hormuzgan Province, and the Persian Gulf. Map modified from Google map 2015.

we selected four morphologically similar mugilid species (i.e. *Chelon subviridis*, *Ellochelon vaigiensis*, *Liza klunzingeri*, and *Mugil cephalus*) from the Iranian waters of the Persian Gulf, and applied morphology of the saccular otolith (sagitta) to evaluate the possible application of the otolith in identification of these species. This is the first comparative study on otolith morphology of the mugilid species in this region. The results could contribute to correct management of Mugilidae fisheries resource, and even for trophic and paleoecological studies in this poorly studied area.

Materials and Methods

Sampling: The four selected mullet species *Chelon subviridis* (ZM-FISBUK 1-10, N=10), *Ellochelon vaigiensis* (ZM-FISBUK 21-24, N=4), and *Liza klunzingeri* (ZM-FISBUK 11-20, N=10) were collected from Bandar-e-Lengeh (46°02'50.1"N, 37°01'53.5"E), and the *Mugil cephalus* (ZM-FISBUK 25-34, N=10) was obtained from Bandar Abbas (27°11'29.93"N, 56°20'32.01"E). Both locations are located in the coastal waters of Hormuzgan Province in the Persian Gulf, southern Iran (Fig. 1). All the specimens are adult, with total length between 111 mm and 276.6 mm (Table 1). The specimens were preserved in ethanol 70% as whole fish, and the otolith were kept dry in plastic boxes. The fish material and their otoliths are deposited in the collection of the Zoological Museum of Shahid Bahonar University of Kerman, Iran (ZM-FISBUK, see above).

Otolith preparation, description and measurement: To extract the otoliths, we follow the procedure explained in Reichenbacher et al. (2007). Four skulls per species were opened ventrally, and right and left otoliths were removed. The otoliths were cleaned from tissue remains with 1% potassium hydroxide solution for 6 hrs and rinsed in distilled water for 12 hrs. They were dried and stored in plastic vials for later description.

Description of general morphology of the otoliths was based on the criteria proposed by Tuset et al. (2008) and accordingly, the following definitions used to describe different parts of the otoliths (Figs. 2a-b):

Heterosulcoid sulcus: Sulcus with ostium and cauda clearly differentiated, but very different in shape (Fig. 2a).

Supramedian sulcus: Sulcus generally positioned above the longitudinal midline of the otolith and the ventral area is noticeably larger than the dorsal area (Fig. 2a).

Ostial sulcus: Sulcus with an ostium opens widely in

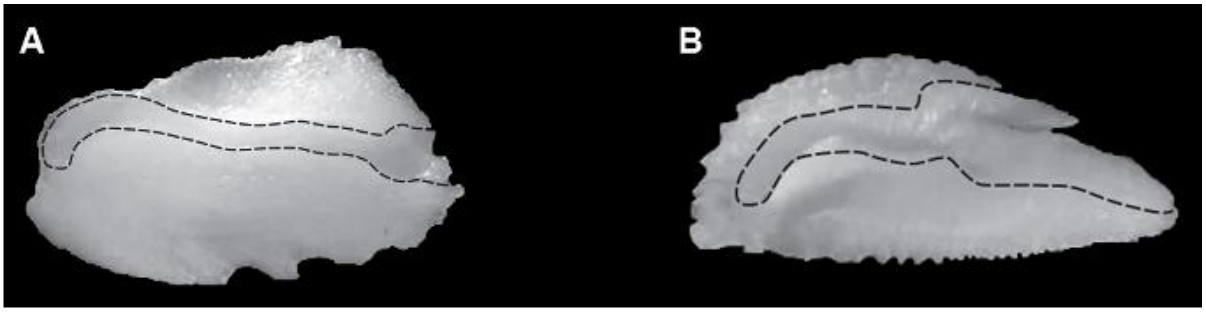

Figure 2. The definitions, which are used to describe different parts of the otoliths general morphology. (A) Represent heterosulcoid sulcus, supramedian sulcus and tubular cauda; and (B) show the ostial sulcus. The criteria modified from Tuset et al. (2008).

the anterior margin of the otolith, and with a cauda distinctly closed far away from the posterior margin (Fig. 2a).

Tubular cauda: The cauda is rather long and its walls are usually straight or curved (Fig. 2b).

Moreover, since the position of sulcus is particularly important for species identification, therefore, an index of sulcus centrality (SC) was calculated (Fortunato et al., 2014) to compare the degree of sulcus centrality in each studied species. According to Fortunato et al. (2014), the SC represents relative position of the sulcus in relation to the otolith's anterior-posterior axis. In this calculation, SC=SM (distance from the cauda superior margin to the dorsal margin) / OW (otolith total width). By considering the proposed index, a sulcus with an SC=0.50 has central position; a sulcus with an SC<0.50 shift towards the dorsal margin of otolith, and a sulcus with an SC>0.50 shift towards the ventral margin of otolith (Fortunato et al., 2014).

Results

The sagittal otoliths in the selected mugilids are rectangular to oblong in shape, laterally compressed, longer in length than width, and represent irregular margins with obvious protuberances irregularly arranged. Their otoliths are longer characterized by heterosulcoid and ostial sulcus acusticus, which are, are usually supramedian. The sulcus has funnel-like ostium, and open to the anterior margin. There is usually a tubular cauda, which is closed towards the posterior one. The cauda is always longer than the ostium (two or three times). There is a very short and broad rostrum in anterior region, while, antirostrum absent or not well defined. Excisura is relatively wide

Chelon subviridis: The sagitta is rectangular to trapezoid in shape. Dorsal rim is straight with a clear dorsal tip in anterior region, ventral rim irregular to sinuate (Fig. 3a-b). Sulcus is heterosulcoid, ostial and supramedian. Sulcus has a centrality (SC index) = 0.14, ostium funnel-like and slightly deep. Cauda obviously tubular and sinuous distinctly bent towards the ventral region, ending towards the posterior region; cauda length is bigger than three times of ostium. Anterior region angled, while posterior region is mostly rounded (Fig. 3a-b). The distal face of sagitta is concave (Fig. 3c). Relative otolith height (OH)/otolith length (OL) is 39.0%.

Liza klunzingeri: The sagitta is rectangular in shape. Dorsal rim is straight, ventral rim irregular and strongly serrated (Fig. 4a-b). Sulcus is heterosulcoid, ostial and supramedian. Sulcus has a centrality (SC index) = 0.13. Ostium funnel-like and in some individuals rectangular. Cauda obviously tubular and straight bent towards the ventral region, ending towards the posterior region; cauda length is bigger than three times of ostium. Anterior region is rounded to blunt, posterior region mostly rounded (Fig. 4a-b). The distal face of sagitta is concave (Fig. 4c). Relative otolith height (OH)/otolith length (OL) is 50.0%.

Mugil cephalus: The sagitta is rectangular in shape. Dorsal rim is straight, ventral rim irregular and strongly serrated (Fig. 5a-b). Sulcus is heterosulcoid, ostial and supramedian. Sulcus has a centrality (SC index) = 0.16. Ostium funnel-like. Cauda obviously tubular and bent towards the ventral region, ending

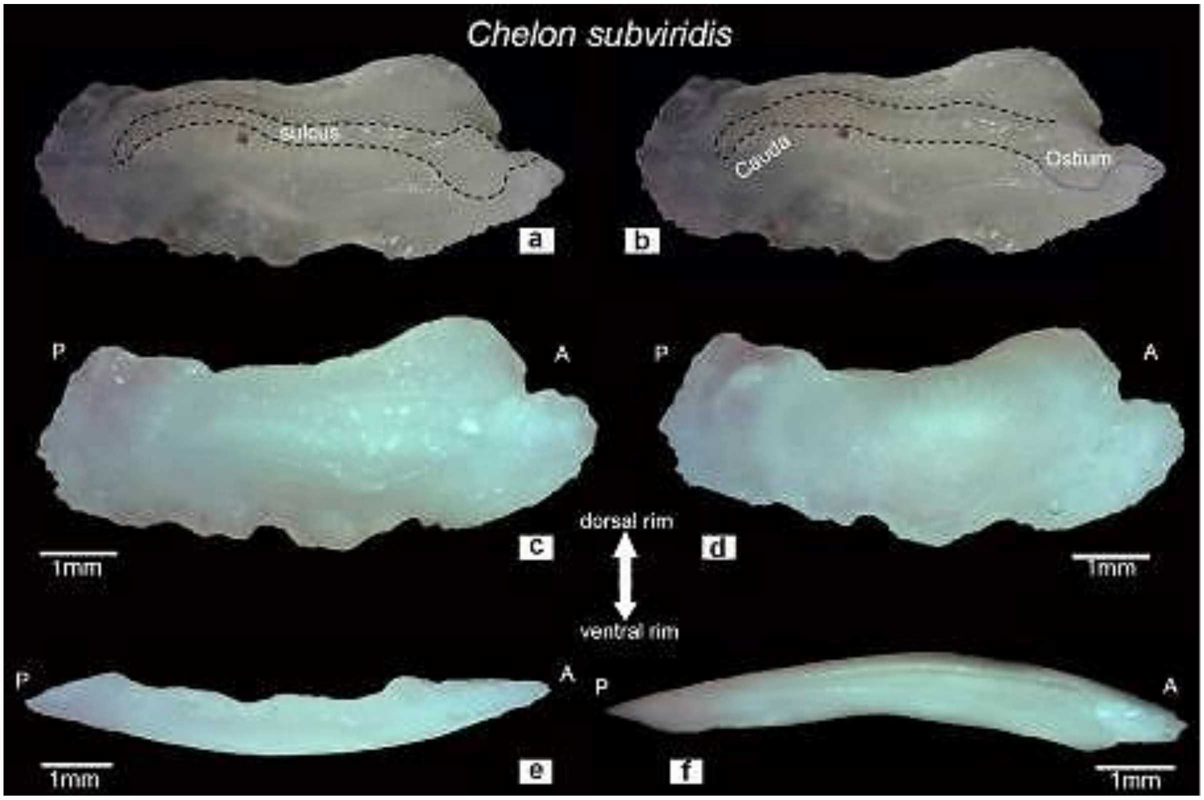

Figure 3. Left sagitta of *Chelon subviridis* (21.5 cm SL, ZM-FISBUK1). a-c. Internal view; d. External view; e. Dorsal view; f. Ventral view; A. anterior part; P. posterior part.

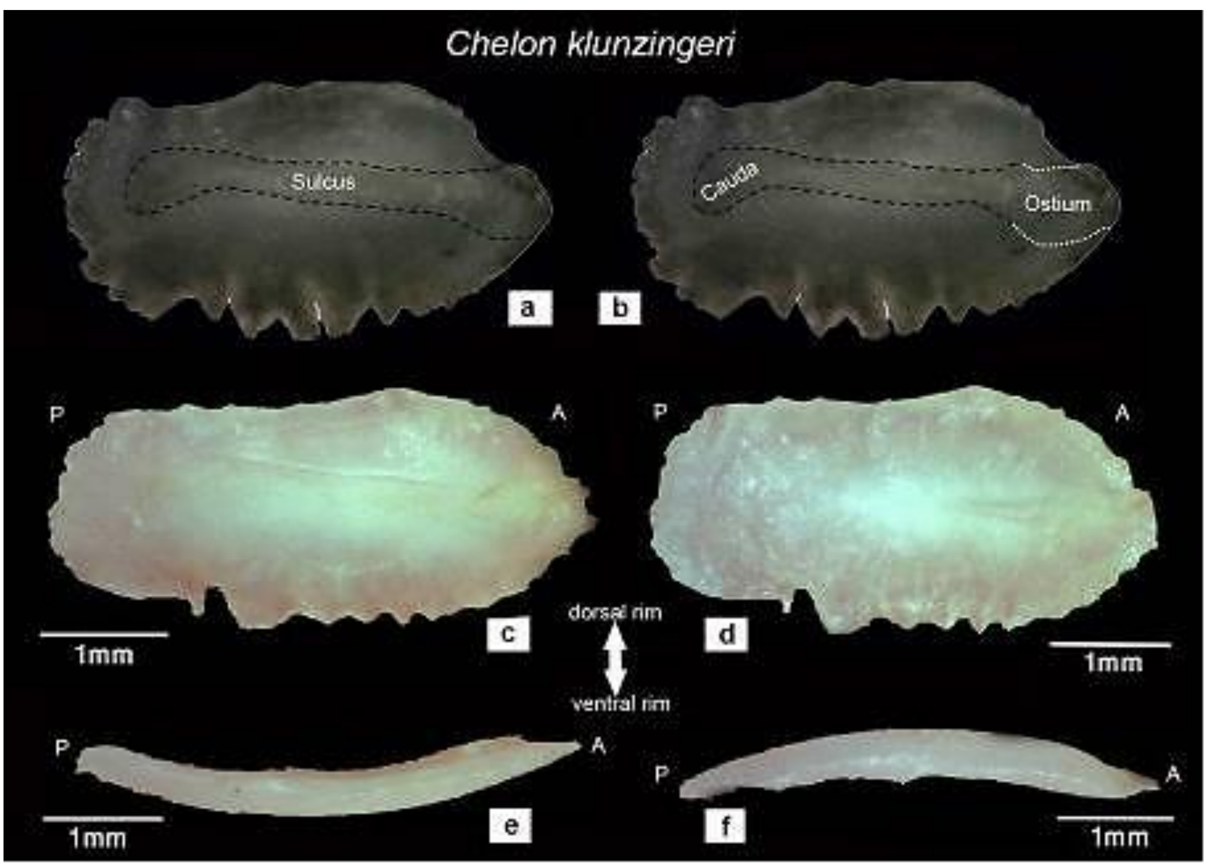

Figure 4. Left sagitta of *Chelon klunzingeri* (12.6 cm SL, ZM-FISBUK14). a-c. Internal view; d. External view; e. Dorsal view; f. Ventral view; A. anterior part; P. posterior part.

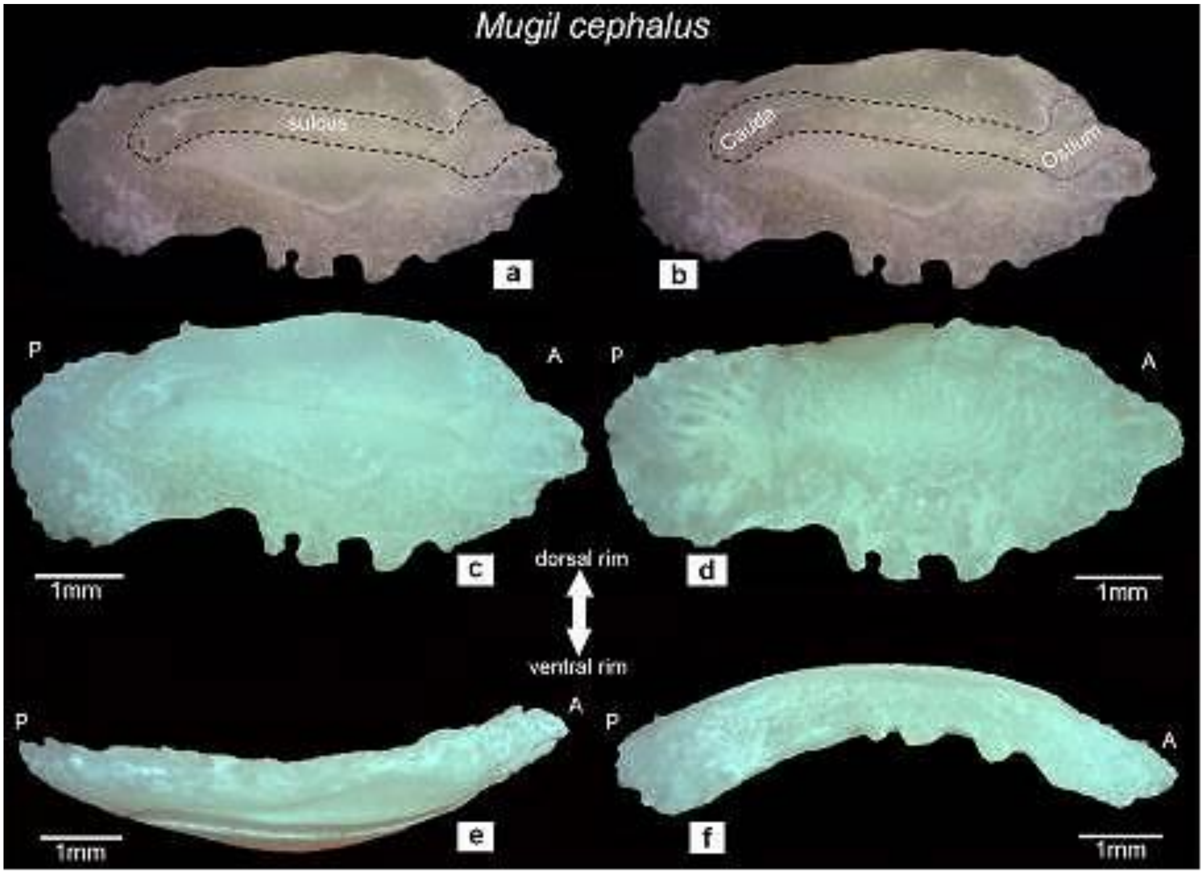

Figure 5. Left sagitta of *Mugil cephalus* (24.0 cm SL, ZM-FISBUK28). a-c. Internal view; d. External view; e. Dorsal view; f. Ventral view; A. anterior part; P. posterior part.

towards the posterior region; cauda length is bigger than three times of ostium. Anterior region peaked, while posterior region is rounded (Fig. 5a-b). The distal face of sagitta is concave (Fig. 5c). Relative otolith height (OH)/otolith length (OL) is 42.1%.

Ellochelon vaigiensis: The sagitta is clearly rectangular in shape. Dorsal rim irregular with obvious dorsal tip in anterior end, ventral rim serrated (Fig. 6a-b). Sulcus is heterosulcoid, ostial and supramedian. Sulcus has a centrality (SC index) = 0.12. Ostium is funnel-like and tubular in some individuals. Cauda obviously tubular and bent towards the ventral region, ending towards the posterior region; cauda length is bigger than two times of ostium. Anterior region peaked, while posterior region is rounded with clear processes (Fig. 6a-b). The distal face of otolith is concave (Fig. 6c). Relative otolith height (OH)/otolith length (OL) is 47.2%.

Sagittal otolith morphology key to identify four studied mugilid species:

1a Tubular cauda distinctly bent towards the ventral region…………………………………….……..…... 2

1b Tubular cauda straight bent towards the ventral region………………...…………... *Liza klunzingeri*

2a The relative otolith height (OH)/otolith length (OL) is bigger than 42%…………………………..… 3

2b The relative otolith height (OH)/otolith length (OL) is 39%…………………...… *Chelon subviridis*

3a Sagitta has sulcus with a centrality (SC) index of 0.16……………………………….. *Mugil cephalus*

3b Sagitta has sulcus with a centrality (SC) index of 0.12…………………………. *Ellochelon vaigiensis*

Discussion

Several studies have recently indicated that general morphology of otolith and its morphological features contain taxonomic and even genetic data, and therefore, are very useful tools for identification of fish species (e.g., Esmaeili et al., 2014; Teimori et al., 2012a, 2014; Gholami et al., 2014;) and populations (e.g. Reichenbacher et al., 2007;

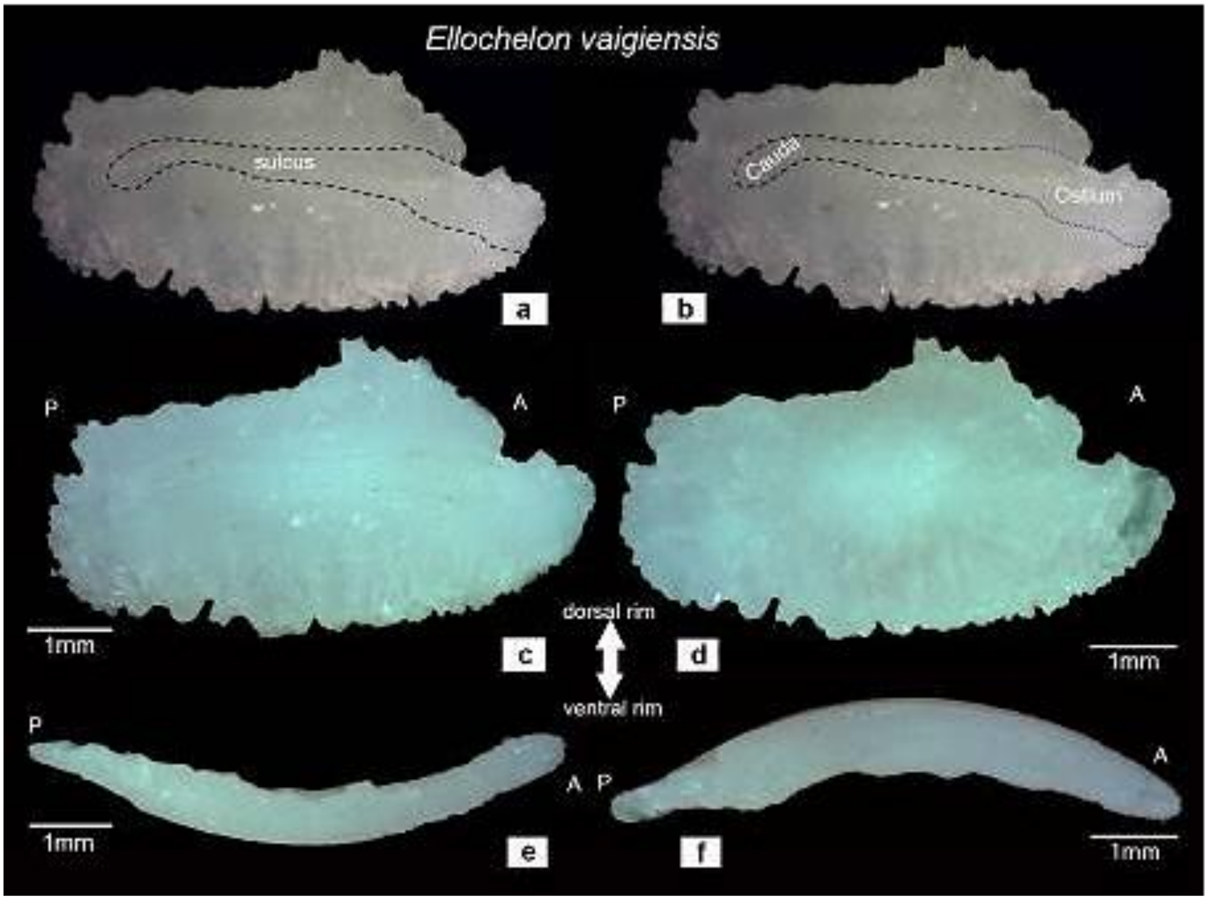

Figure 6. Left sagitta of *Ellochelon vaigiensis* (27.6 cm SL, ZM-FISBUK24). a-c. Internal view; d. External view; e. Dorsal view; f. Ventral view; A. anterior part; P. posterior part.

Teimori et al., 2012b-c; Annabi et al., 2013). The otolith morphology could even be more important for discrimination of closely related species where external morphology of fish specimens could not help. The potential power of otolith morphology in discriminate of closely related fish species has already been examined in several genetically close species of the genus *Aphanius* within Iranian inland waters (Teimori et al., 2012a; Esmaeili et al., 2014), in which they have separated several endemic *Aphanius* species by using otolith morphology.

The utility of otolith morphology for identification of mugilid species has already been examined in Northeastern Atlantic Ocean and the Mediterranean Sea region (Fortunato et al., 2014). They concluded that general shape of the saccular otolith, presence of an ostial sulcus acusticus, type of ostium and cauda and characteristics of dorsal and ventral margins could be sufficient to identify species in this family.

Our comparative study is in agreement with the founding of Fortunato et al. (2014), in which several otolith features such as type of ostium and cauda, and characteristics of dorsal and ventral margins considered to be important for discrimination of the studied mugilid species from Iranian waters of Persian Gulf. The further otolith features that could play role in separation of mugilid species in Iranian waters of Persian Gulf are position of sulcus (sulcus centrality), curvature of cauda, and type of anterior and posterior regions. These features have also recognized in adult specimens of *Mugil liza* and *Mugil curema* from the west coast of Southwestern Atlantic Ocean (Fortunato et al., 2014).

Since members of Mugilidae family form an important part of the feeding regime of the local people in coastal parts of the Persian Gulf and probably other parts of the world, therefore, this type of study are particularly relevant for determination of the species. It can also be important even in trophic ecology where otoliths present in stomach contents of ichtyophagus organisms (Bustos et al., 2012; Veen et al., 2012; Riet-Sapriza et al., 2013).

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چکیده فارسی

ریخت‌شناسی اتولیت ساژیتا در چهار گونه کفال ماهی از آب‌های ایرانی خلیج فارس

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چکیده:
به‌خاطر شباهت ظاهری زیادی که در بین اعضای کفال ماهیان وجود دارد، شناسایی آنها با تکیه بر صفات ریختی ظاهری اغلب دشوار است. با این وجود، شناسایی دقیق آنها برای مدیریت شیلاتی و حفاظت آنها بسیار مهم می‌باشد. بنابراین، در مطالعه حاضر ریخت‌شناسی سنگریزه شنوایی برای شناسایی چهار گونه از کفال ماهیان خلیج فارس (شامل *Chelon subviridis*، *Liza klunzingeri*، *Ellochelon vaigiensis* و *Mugil cephalus*) مورد ارزیابی قرار گرفت. نتایج نشان داد که چندین صفت ریختی سنگریزه شنوایی برای تفکیک گونه‌های مورد مطالعه مهم می‌باشند؛ موقعیت و مرکزیت سولکوس، انحنای شیار کوادا (cauda) و شکل نواحی قدامی و عقبی اتولیت. بر اساس یافته‌های این مطالعه نتیجه‌گیری می‌شود که ریخت‌شناسی اتولیت در کفال ماهیان در تشخیص گونه و احتمالاً روابط فیلوژنتیکی آنها مهم می‌باشد. یافته‌های این مطالعه منطبق با مطالعات گذشته است و تایید می‌نماید که صفات ریختی اتولیت در شناخت جایگاه تاکسونومیکی ماهیان اهمیت زیادی دارند.

کلمات کلیدی: ساژیتا، فیلوژنی، تاکسونومی، مدیریت شیلاتی.