

Short communication

The morphology of saccular otoliths as a tool to identify different mugilid species from the Northeastern Atlantic and Mediterranean Sea



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ABSTRACT

In the Northeastern Atlantic and Mediterranean Sea there are 8 species of the Mugilidae family: *Mugil cephalus*, *Liza aurata*, *Liza ramada*, *Oedalechilus labeo*, *Chelon labrosus*, *Liza saliens*, *Liza carinata* and *Liza haematocheila*. The identification of mugilids is very important for local fisheries management and regulations, but it is difficult using gross morphological characters. This work aims to contribute to the identification of mullets present in the Northeastern Atlantic Ocean and Mediterranean Sea using saccular otolith features of each species. Specimens of *C. labrosus*, *L. aurata*, *L. ramada*, *L. saliens* and *M. cephalus* were obtained from Delta del Ebro (40°38'N–0°44'E) in artisanal catches. For *L. carinata* and *O. labeo* photographs extracted from AFORO online database were used. *L. haematocheila* was not studied for lack of otolith samples. A general pattern of the saccular otoliths for this family was identified: the shape of the otoliths are rectangular to oblong with irregular margins; they present a heterosulcoid, ostial *sulcus acusticus*, with an open funnel-like ostium to the anterior margin and a closed, tubular cauda, ending towards the posterior ventral corner, always larger than the ostium. In the present study, the mugilid species could be recognized using their saccular otolith morphology. Here we give the first key to identify Northeastern Atlantic and Mediterranean mullets. The distinctive features between the species were the position and centrality of the sulcus, the curvature of the cauda, the presence of areal depositions and plateaus, and the type of anterior and posterior regions. These features could be used not only to reinforce the identification keys through morphological and meristic characters of the species, but also to identify the species consumed by piscivores, being the otoliths the only identifiable remains of the individuals.

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1. Introduction

The Mugilidae family, with 17 genera and around 72 species (Nelson, 2006; Harrison et al., 2007; González Castro et al., 2008; Heras et al., 2009), is widely distributed worldwide. With the capacity of tolerating a wide gradient of salinity, this tropical and

subtropical fish have the ability of migrating long distances and inhabiting the sea, estuaries and even freshwater environments (Harrison, 2002; González Castro et al., 2006). They have commercial importance, especially in artisanal fisheries, supporting local communities as food or bait (Marín et al., 2003; Gallardo-Cabello et al., 2012). They are also used in aquaculture (Hsu et al., 2009; Ibáñez et al., 2012) mainly for their roe (Chang et al., 2004).

In the Northeastern Atlantic Ocean and the Mediterranean Sea there are 8 species of mullets, 7 of them are well-established in the area. *Chelon labrosus* (Risso, 1827), *Liza aurata* (Risso, 1810), *Liza ramada* (Risso, 1827), *Liza saliens* (Risso, 1810), *Mugil cephalus* Linnaeus, 1758 and *Oedalechilus labeo* (Cuvier, 1829) all have a wide distribution; while *Liza carinata* (Valenciennes, 1836), is known to

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inhabit the east coast of the Mediterranean arriving through the Suez Canal from the Red Sea, its original distribution (Thomson, 1997). The last species of mullet, *Liza haematocheila* (Temminck and Schelegel, 1845), has its native distribution in the Black Sea; with a few observations in the Mediterranean Sea on the coasts of Turkey, it is believed that this species entered through the Sea of Marmara (Kaya et al., 1998; Golani et al., 2002; Eschmeyer, 2014), but there is no clear evidence that it has a self-sustaining established population in the Mediterranean Sea (Minos et al., 2010).

The distinction of the species of the mugilidae family is very important for local fisheries management and regulation, as well as for trophic studies that involve its individuals. However, their taxonomic identification is very difficult due to their similarities in gross morphological and meristic characters, i.e. the count of dorsal and anal fin spines and rays (features usually used to identify species of some families) cannot differentiate mugilids because of the close overlap in counts within the family (Whitfield et al., 2012). Therefore, the use of otoliths could provide a proper tool to guarantee the identification of the species of this family. These calcium carbonate structures possess a specific morphology

that can be distinguished at species level (Hecht, 1987; Tombari et al., 2000; Volpedo and Echeverría, 2000, 2001; Tuset et al., 2008).

This work aims to contribute to the identification of mullets present in the Northeastern Atlantic and Mediterranean Sea using saccular otolith features of each species; not only to assess decision makers, so as to contribute to the correct management of Mugilidae fisheries resource, but also for trophic and paleoecological studies. An otolith key is presented to help in this process given that there are few identification keys (Trewavas and Ingham, 1972; Fischer et al., 1987; Thomson, 1997; Harrison, 2002) well developed that help differentiate this family and their species inhabiting the Northeastern Atlantic Ocean and the Mediterranean Sea.

2. Materials and methods

Specimens of *Chelon labrosus* ($N = 4$); *Liza aurata* ($N = 7$); *Liza ramada* ($N = 6$); *Liza saliens* ($N = 6$) and *Mugil cephalus* ($N = 6$), were obtained from Delta del Ebro ($40^{\circ}38'N - 0^{\circ}44'E$) in artisanal catches of the local community in October 2011. All specimens were

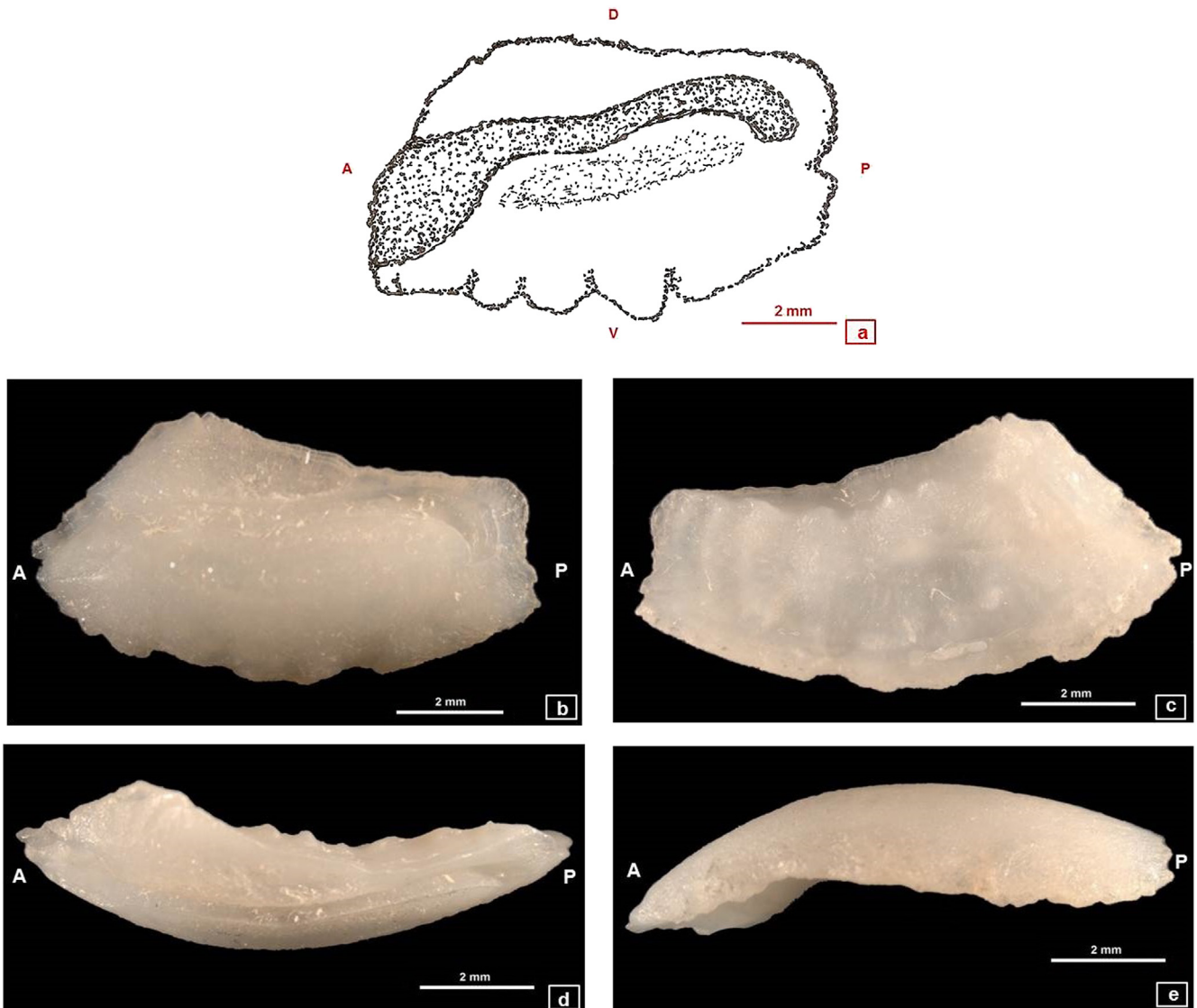


Fig. 1. Right sagitta of *Chelon labrosus* (43.3 cm TL). a–b: medial view; c: lateral view; d: dorsal view; e: ventral view.

adults of total length between 30 and 50 cm. Saccular otoliths were removed, dried and stored in plastic vials for later description. For the remaining two mullets that were not captured *in situ*, *Liza carinata* and *Oedalechilus labeo*, photographs taken from the AFORO online database (Lombarte et al., 2006) were analyzed to extract the otoliths features ($N = 5$ – Fish ID: 9460–64; and $N = 1$ – Fish ID: 8142, respectively). The rare observed species *Liza haematocheila* was not included in this study due to the lack of otolith specimens to perform the analysis.

To describe the general morphology of the otoliths, the criteria used were the ones proposed by Tuset et al. (2008). For cauda types their classification was as follows: Straight (angle = 0°); curved with four subdivisions, slightly curved (angle $<30^\circ$), strongly curved (angle from 30 to 60°), markedly curved (angle from 60 to 100°), curled (angle $>100^\circ$), or sinuous (Tuset et al., 2008). Otolith thickness was measured and presented as a percentage of the otolith total length only for the species captured *in situ*. An index of sulcus centrality ($SC = SM$ (distance from the cauda superior margin to the dorsal margin)/ OW (otolith total width)) was calculated. The SC represents the relative position of the sulcus in relation to the otolith's anterior–posterior axis. A central sulcus has an $SC = 0.50$; an $SC < 0.50$ represents a sulcus shifted towards the dorsal margin and an $SC > 0.50$ a sulcus shifted towards the ventral one. This index was developed as another feature for distinction of the species. All otoliths measurements were made using image processing systems.

3. Results

3.1. Mugilidae general sagitta otolith description

A general aspect of the saccular otolith of the Mugilidae family could be recognized, after analyzing the 7 species used for this study. The *sagitta* shape is rectangular to oblong and presents irregular margins with conspicuous protuberances unevenly arranged. This laterally compressed structure is longer than wide, with a *sulcus acusticus* heterosulcoid, ostial and usually supra-median. The sulcus is formed by a funnel-like ostium, opened to the anterior margin, and a tubular cauda, closed towards the posterior one. The cauda is always longer than the ostium (two or three times). The anterior region presents a rostrum very short and broad; an antirostrum absent or not well defined; and an excisura relatively wide. These features could also be identified in adult specimens of *Mugil liza* and *Mugil curema* obtained in the west coast of the South Atlantic Ocean.

3.2. General saccular otolith description for Northeastern Atlantic and Mediterranean mullets

3.2.1. *Chelon labrosus* (Risso, 1827)

Common name: English (En.): Thicklip gray mullet; Spanish (Es.): Lisa, Corcón; French (Fr.): Mulet lippu; Catalan (Cat.): Llista vera, Llista calua blanca.

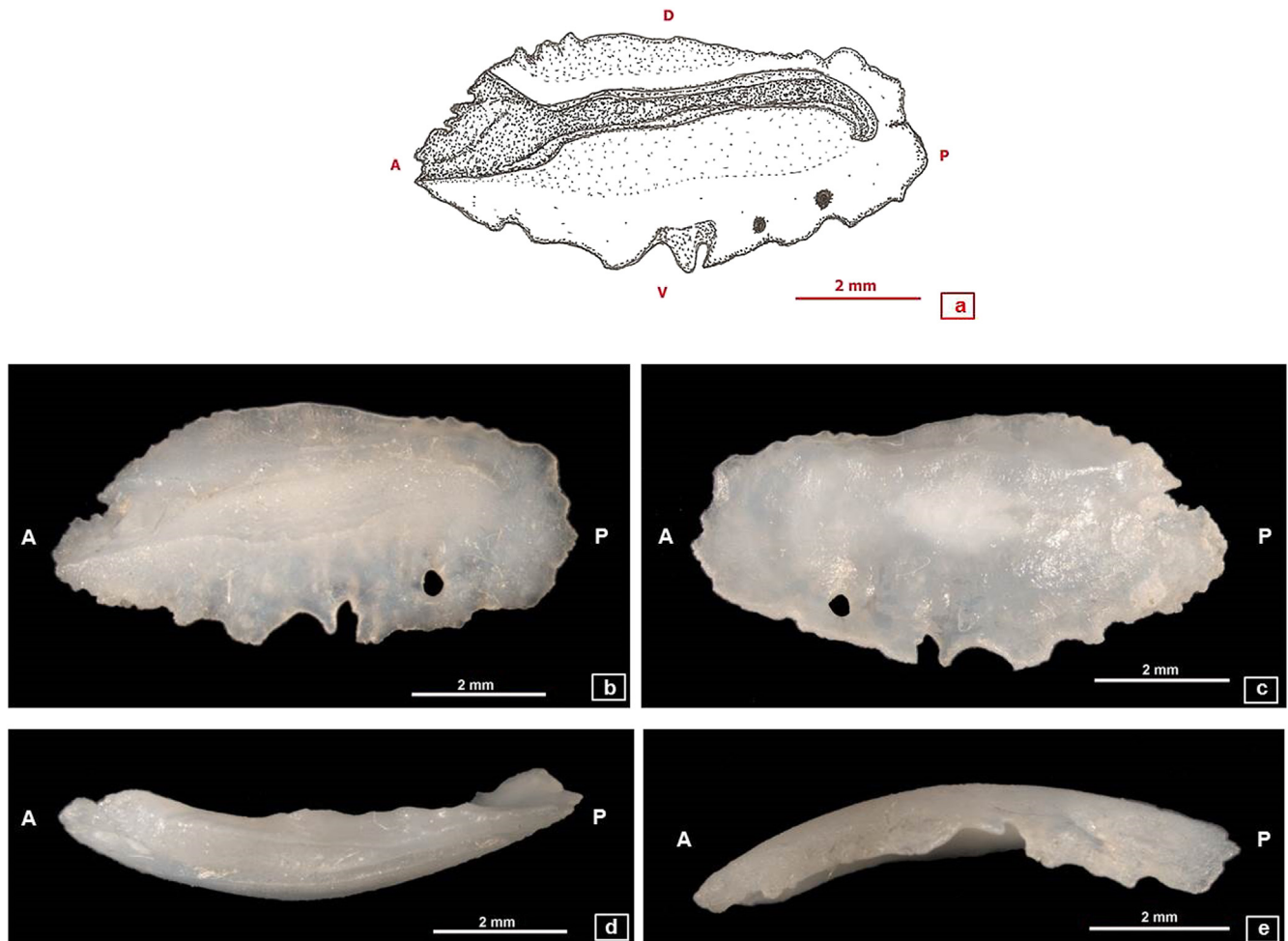


Fig. 2. Right sagitta of *Liza aurata* (32.2 cm TL). a–b: medial view; c: lateral view; d: dorsal view; e: ventral view.

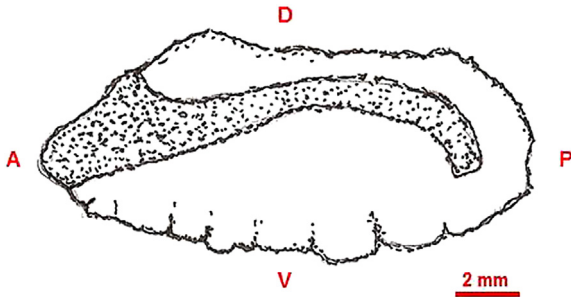


Fig. 3. *Liza carinata* sagitta otolith (N/A TL). Medial view.

Sagitta general shape: rectangular. Dorsal and ventral margins irregular (Fig. 1a,b). It presents a plateau in its proximal face. *Sulcus acusticus* heterosulcoid, ostial and supramedian. Ostium funnel-like, slightly deep and rough. Tubular and sinuous cauda strongly bent towards the ventral region, ending towards the posterior ventral corner; its length is three times the length of the ostium. SC index: 0.27. Anterior region: round to angled irregular; posterior region: round to flattened irregular (Fig. 1a,b). The distal face of the *sagitta* is concave (Fig. 1c). Otolith thickness represents 15.4% of otolith total length (OL) (Fig. 1d,e).

3.2.2. *Liza aurata* (Risso, 1810)

Common name: En.: Golden gray mullet; Es.: Galupe; Fr.: Mulet doré; Cat.: llissa galta-roja, llissa galtroij.

Sagitta general shape: rectangular to oblong. Dorsal and ventral margins irregular (Fig. 2a,b). The latter can present marked indentations (Fig. 2a,b). Sulcus heterosulcoid, ostial and supra-median. Ostium funnel-like, slightly deep and rough. Tubular and sinuous cauda strongly bent towards the ventral region, ending towards the posterior ventral corner; its length is bigger than two times the ostium. SC index: 0.17. Anterior region: round to angled; posterior region: round to irregular (Fig. 2a,b). The distal face of the *sagitta* is concave (Fig. 2c). Otolith thickness represents 13.3% of OL (Fig. 2d,e).

3.2.3. *Liza carinata* (Valenciennes, 1836)

Common name: Eng.: Keeled mullet; Es.: Lisa errante; Fr.: Mulet caréné.

Sagitta general shape: rectangular. Dorsal and ventral margins irregular (Fig. 3). Sulcus heterosulcoid, ostial and supramedian. Ostium funnel-like, slightly deep and rough. Tubular and sinuous cauda strongly bent towards the ventral region, ending towards the posterior ventral corner; its length is bigger than two times the ostium. SC index: 0.28. Anterior region: angled; posterior region: round (Fig. 3).

3.2.4. *Liza ramada* (Risso, 1827)

Common name: Eng.: Thinlip gray mullet; Es.: Morragute; Fr.: Mulet porc; Cat.: Sama, caluga, llisa calua negra.

Sagitta general shape: rectangular. Irregular dorsal and ventral margins. The first is variable; it can be sinuate in some cases. The ventral margin can present marked indentations (Fig. 4a,b).

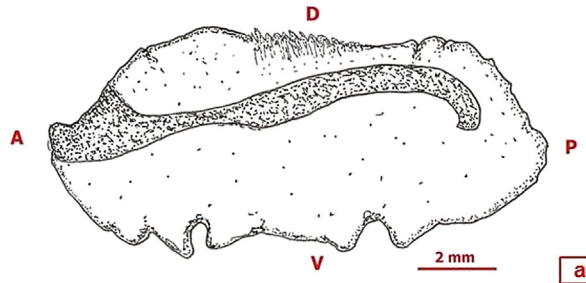


Fig. 4. Right *sagitta* of *Liza ramada* (50.3 cm TL). a–b. Internal view; c. External view; d. Dorsal view; e. Ventral view.

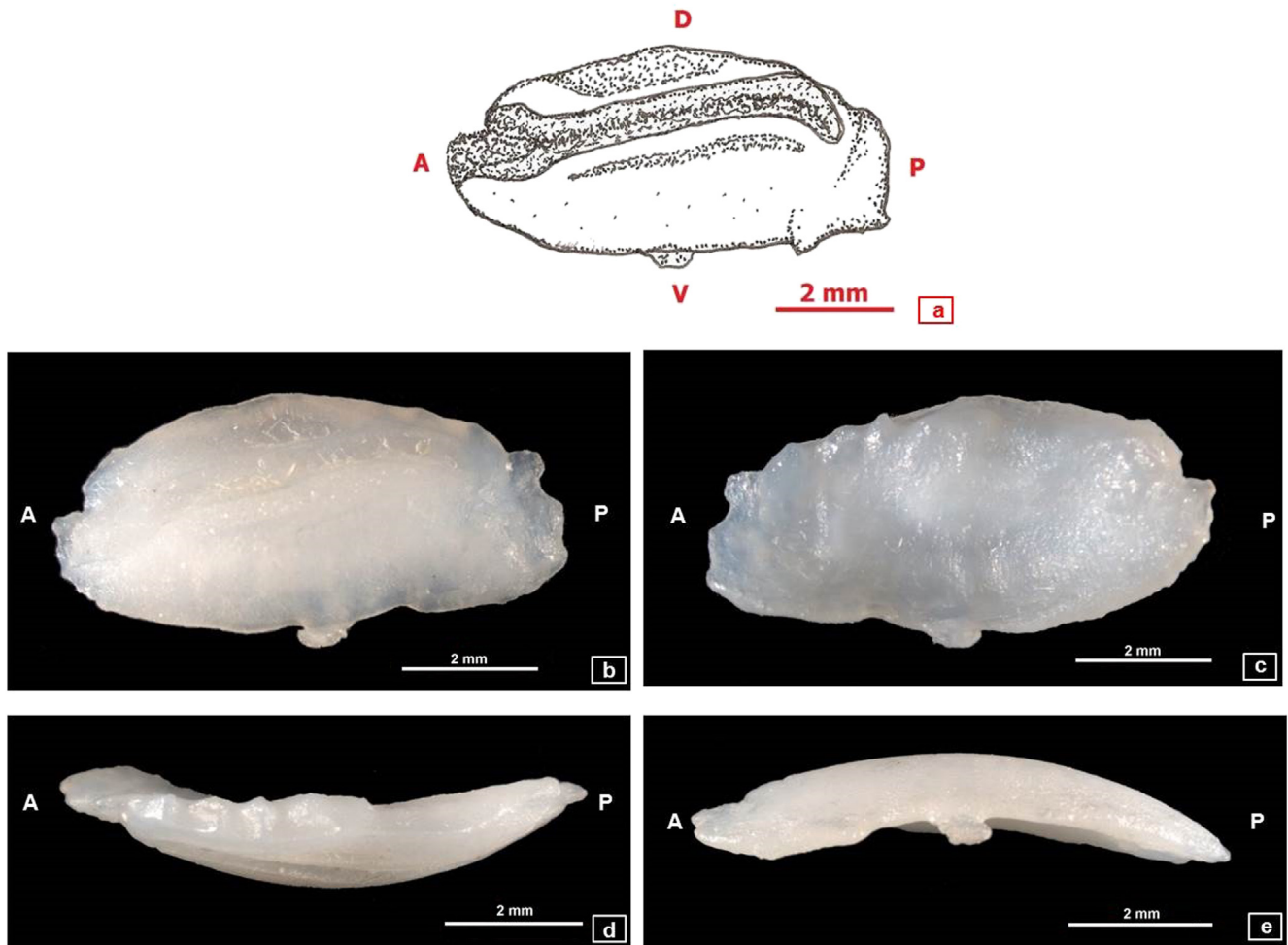


Fig. 5. Right sagitta of *Liza saliens* (32.1 cm TL). a–b. Internal view; c. External view; d. Dorsal view; e. Ventral view.

Sulcus heterosulcoid, ostial and suprmedian. Ostium funnel-like, slightly deep and rough. Tubular and sinuous cauda markedly bent towards the ventral region, ending towards the posterior ventral corner its length is bigger than three times the ostium. SC index: 0.20. Anterior region: round to irregular; posterior region: round to angled (Fig. 4a,b). The distal face of the *sagitta* is concave (Fig. 4c). Otolith thickness represents 12.2% of OL (Fig. 4d,e).

3.2.5. *Liza saliens* (Risso, 1810)

Common name: Eng.: Leaping mullet; Es.: Galúa; Fr.: Mulet sauteur; Cat.: llissa de cap chiquet, llissa fusany.

Sagitta general shape: rectangular. Dorsal and ventral margins irregular to sinuate (Fig. 5a,b). It presents a ventral areal depression, parallel to the straight portion of the cauda. Sulcus heterosulcoid, ostial and suprmedian. Ostium funnel-like slightly deep and rough. Tubular and sinuous cauda markedly bent towards the ventral region, ending towards the posterior ventral corner; its length is bigger than two times the ostium. SC index: 0.13. Anterior region: round to irregular; posterior region: round to flat (Fig. 5a,b). The distal face of the *sagitta* is concave (Fig. 5c). Otolith thickness represents 13.9% of OL (Fig. 5d,e).

3.2.6. *Mugil cephalus* Linnaeus, 1758

Common name: En.: Flathead gray mullet; Es.: Pardete; Fr.: Mulet à grosse tête; Cat.: cabeçut, llisa cabuda.

Sagitta general shape: rectangular. Dorsal and ventral margins irregular with great variability (Fig. 6a,b). Sulcus heterosulcoid, ostial and median to suprmedian. Ostium funnel-like slightly deep and rough. Tubular cauda straight or slightly curved; its length is approximately two times bigger than the ostium. SC index: 0.23. Anterior region: short and markedly angled; posterior region: flattened to round (Fig. 6a,b). The distal face of the *sagitta* is concave (Fig. 6c). Otolith thickness represents only 10.5% of its total length (OL) (Fig. 6d,e).

3.2.7. *Oedalechilus labeo* (Cuvier, 1829)

Common name: Eng.: boxlip mullet; Es.: Caluga; Fr.: Mulet labéon; Cat.: llissa morruda.

Sagitta's general shape: rectangular. Dorsal and ventral margins irregular (Fig. 7). Sulcus heterosulcoid, ostial and suprmedian. Ostium funnel-like slightly deep and rough. Tubular and sinuous cauda markedly bent towards the ventral region, ending towards the posterior ventral corner; its length is larger than two times the ostium. Anterior region: round to irregular; posterior region: flattened to irregular (Fig. 7).

Using the descriptions previously given we managed to elaborate the following key to identify the different mugilids present in the Northeastern Atlantic Ocean and the Mediterranean Sea using the morphology of the saccular otolith.

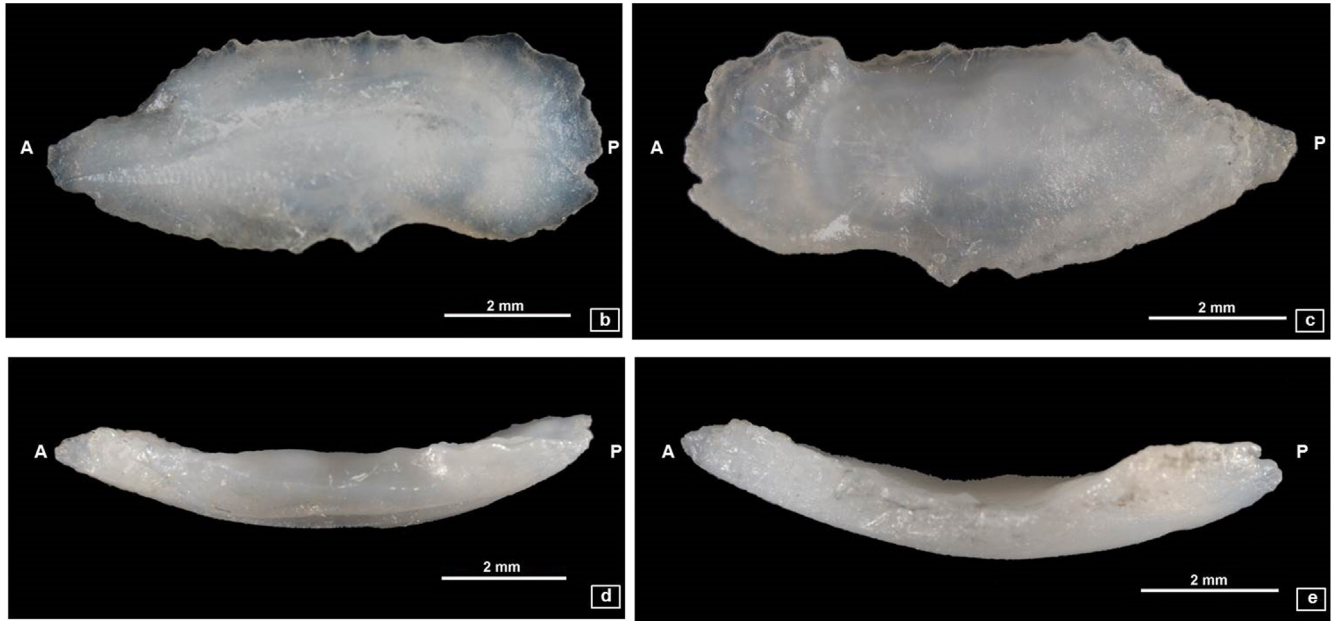
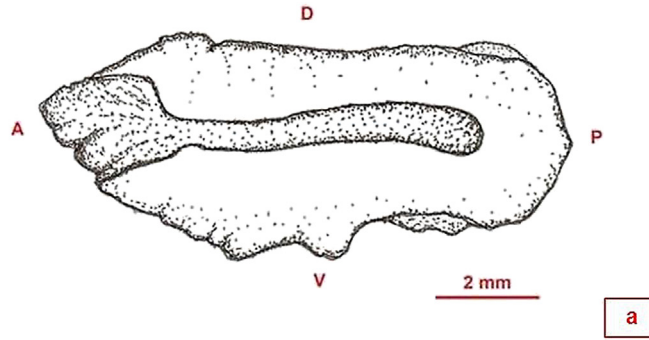


Fig. 6. Right sagitta of *Mugil cephalus* (36.4 cm TL). a–b. Internal view; c. External view; d. Dorsal view; e. Ventral.

3.3. Saccular otolith morphology key to the Northeastern Atlantic Ocean and Mediterranean Sea well-established species of Mugilidae family

- 1 Tubular and sinuous cauda bent towards the ventral region.....2
- 1' Tubular cauda straight or slightly curved.....*Mugil cephalus*
- 2 Cauda strongly bent (30–60°) towards the ventral region.....3

- 2' Cauda markedly bent (60–100°) towards the ventral region.....5
- 3 Sagitta with presence of a plateau in its proximal face.....*Chelon labrosus*
- 3' Sagitta without a plateau in its proximal face.....4
- 4 Sagitta with sulcus centrality index (SC) always inferior to 0.20..... *Liza aurata*
- 4' Sagitta with sulcus centrality index (SC) equal or superior to 0.20..... *Liza carinata*
- 5 Sagitta with a ventral areal depression, parallel to the straight portion of the cauda.....
.....*Liza saliens*
- 5' Sagitta without a ventral areal depression.....6
- 6 Posterior region round to angled.....*Liza ramada*
- 6' Posterior region flattened to irregular..... *Oedalechilus labeo*

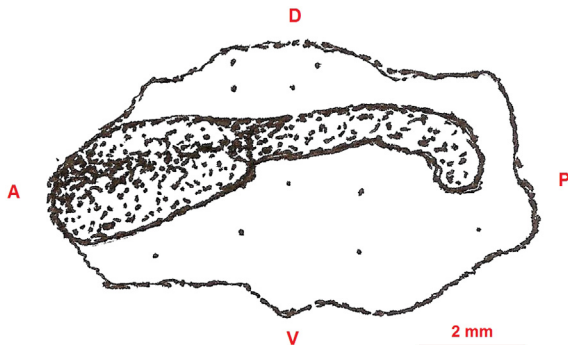


Fig. 7. *Oedalechilus labeo* sagitta otolith (45.3 cm TL). Medial view.

4. Discussion

The species of Mugilidae family in Northeastern Atlantic Ocean and the Mediterranean Sea could be identified by the morphology of their sagitta otolith. A general pattern of the saccular otoliths for

this family could be identified analyzing the shape, the presence of an ostial *sulcus acusticus*, the type of ostium and cauda and the characteristics of the dorsal and ventral margins. These features could also be recognized in adult specimens of *Mugil liza* and *Mugil curema* obtained in the west coast of Southwestern Atlantic Ocean. Although, the description of mugilid otoliths in the present study is comparable to previous ones done by other authors (Bauzá-Rullán, 1960; Assis, 2004; Tuset et al., 2008); a key for identifying all well-established Mediterranean and Northeastern Atlantic mullets was developed for the first time. The distinctive features between the species are the position of the sulcus, the curvature of the cauda, the presence of areal depositions and plateaus, and the type of anterior and posterior regions.

These type of studies are particularly relevant for trophic ecology where otoliths present in stomach contents and feces of ichthyophagous could be eroded (García Rodríguez and De La Cruz Agüero, 2011; Bustos et al., 2012; Veen et al., 2012; Riet-Sapriza et al., 2013). By the use of otolith morphology it is possible to recognize not only the species on the diet but also to determine prey size (Barret et al., 2007). Furthermore, there is relevance in paleoecology where it is possible to recognize and identify fish families and species from the morphology of fossil otoliths (Jost et al., 2006; Reichenbacher et al., 2007; Gierl et al., 2013). In this matter it is also possible, by the use of otolith morphology, to formulate hypothesis on phylogenetic relationships among fish taxa of current and fossil species (Assis, 2004).

The identification key developed in this study is the first publication for the recognition, thru otolith morphology, of the Mugilidae family species present in the Mediterranean Sea and the Northeastern Atlantic Ocean.

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