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Morphological study of otoliths of *Antimora microlepis* and *Antimora rostrata* (Actinopterygii: Gadiformes: Moridae)

Laith A. Jawad, Ilya I. Gordeev, Rafael Bañón, Peter H. Frey & Alexei M. Orlov

Abstract

A comparative morphological investigation of otoliths from two species of *Antimora*, *A. microlepis* and *A. rostrata* was conducted to identify distinguishing species-specific characteristics. Some of the identified characters were shared between the two species studied. Ontogenetic changes in otolith morphology of the two morids studied were evident between small and larger specimens. Otoliths of small-sized individuals have shown the same degree of similarity with the large-sized individuals.

Keywords: Morphology, otoliths, SEM, Moridae, *Antimora*, ontogeny.

Zusammenfassung

Eine vergleichend-morphologische Untersuchung der Otolithen zweier Arten von *Antimora*, *A. microlepis* und *A. rostrata*, wurde durchgeführt, um artspezifische Merkmale zu identifizieren. Manche der identifizierten Merkmale wurden von den beiden untersuchten Arten geteilt. Zwischen kleinen und großen Exemplaren der beiden untersuchten Arten wurden ontogenetische Veränderungen in der Morphologie der Otolithen evident. Otolithen von kleinen Individuen zeigten den gleichen Grad an Ähnlichkeit mit denen großer Individuen.

Contents

1 Introduction

The morphology of hard structures such as otoliths, scales, and bones, can reveal useful taxonomic information about fishes and may be less costly than other methods such as molecular or genetic techniques (L'Abée-Lund & Jensen 1993, Aguirre & Lombarte 1999, Assis 2003, Tuset et al. 2003a, b, 2006, Ponton 2006, Jawad et al. 2008). In most teleost fishes, the sagittal otoliths are the largest of three pairs that also include the lapillus and asteriscus otoliths (Paxton 2000). Sagittal otoliths are often used for taxonomic and biological (e.g. age and growth) studies in non-ostariophysan teleosts because of their large size, relative ease of access, opaque and translucent seasonal markings, morphological variation, and resistance to digestion in the alimentary canals of predators (Platt & Popper 1981, Nolf 1985, L'Abée-Lund 1988, Tuset et al. 2003a).

While early illustrations and descriptions date back to the nineteenth century (Vaillant in 1888), Schmidt (1968) was among the first to note the unique shape of otoliths in members of the family Moridae. The diagnostic characters that make the morid Sagitta so different from that of other teleosts is the deeply channelled bifurcate cauda (posterior portion of the sulcus, or groove, on the inner face of an otolith). In his paper, Frost (1924) specified this character with the statement "In no other species that has passed through my hands is a double cauda to be seen," but he seemingly had not seen sufficient comparative material to recognize it as being diagnostic of the family. In an exceptional study on morid otoliths, Karrer (1971) indicated that the thin bladelike ridge (crista) which divides the deeply channelled cauda longitudinally is actually the posterior coIliculum. Accordingly, she concluded that three natural groups of living morids can be identified: the *Mora-group* comprising *Mora, Halargyreus, Antimora,* and *Lepidion;* the *Physiculus* group comprising *Physiculus, Gadella, Tripterophycis, Brosmiculus, Laemanema,* and *Salilata;* and the *Pseudophycis*-group comprising *Pseudaphycis* and *Auchenoceros.*

Members of the family Moridae were recognised only until Svetovidov (1948) showed for the third time the exceptionality of the swim bladder connection with the auditory capsule, a character that was reliable for marking morids from other gadoids. In a subsequent study, Svetovidov (1967) recognised additional morid genera and further established the validity of the "swim bladder and fontanelle" character, while other workers revealed equally valid characters in the morid caudal complex (Rosen & Patterson 1969) and the sagittal otoliths (Schmidt 1968, Karrer 1971).

Literature on otolith morphology of morid fish species are not extensive given the low commercial importance of this group and the deep waters they frequently inhabit (Orlov et al. 2020, Korostelev et al. 2020). Several authors have described the otolith of the members of the family Moridae either a single or multiple species (Karrer 1971, Paulin 1985, 1989, Smale et al., 1995, Paulin & Roberts 1997, Lin & Chang 2012, Lin 2016). Those studies that have described specific morid species are not many. Veen & Hoedemakers (2005) have described the otolith of *Physiculus huloti*, Lowery (2011) supply photos of *Physiculus rastrelliger*, Rossi-Wongtschowski et al. (2014) have described different species of the genera *Gadella imberbis* and *Laemonema goodebeanorum*, and Schwarzhans et al. (2017) described in details the morphology of *Tripterophyscis immutatus*.

As far as the authors are concerned, there are only limited studies that described the otolith of *Antimora rostrata* (Hecht 1978, Tuset et al. 2008) and Campana (2004) provide photo only. As to *A. microlepis*, the only available description is that of Fitch & Barker (1972). Schwarzhans (2019) studied the morphology of the otoliths of the family Moridae and confirmed their practicality for taxonomic drives at different taxonomic levels. In this study, Schwarzhans (2019) reviewed and refined the status of different taxonomic groups within the family Moridae and recognised the members of the genus are located within the *Mora* group.

The present study aims to, (1) describe the surface morphology of the otoliths of two morid species, *A. microlepis* and *A. rostrata,* (2) note developmental changes in the shape of otoliths obtained from fish specimens of different sizes, and (3) identify additional distinguishing features to those previously described for the two species in question. This study will contribute to *Antimora* taxonomy and paleoichthyology in general.

Acknowledgements

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2 Material and methods

Forty-two otoliths from *Antimora microlepis* and *A. rostrata* across various size groups were examined for the present study. Samples of *Antimora microlepis* were taken from fish caught in 2007, 2010, and 2015 on the West Coast Groundfish Bottom Trawl Survey conducted by the Northwest Fisheries Science Center along the United States west coast from 32° 00′ – 47° 48′ N, 117° 44′ – 125° 42′ W at depths of 467–1256 m. Samples of *Antimora rostrata* otoliths were taken from fish caught between February 1 and 17, 2016, just outside of Canada's Exclusive Economic Zone on the continental slope of Newfoundland in the northwestern Atlantic (46° 50′ – 43° 30′ N 49°01′ – 46° 40′ W) at depths of 809 to 2089 m.

In the laboratory, the top of the cranium was sliced exposing the brain. The otic capsules were detached and the otoliths slightly detached with a pair of fine forceps. Later, the otoliths were cleaned with 70% ethanol and stored dry. In order to observe ontogenic changes in the shape of the otoliths, otolith specimens were separated into groups according to their total length. Specimens of *A. microlepis* were placed in three groups (Group I, 200–299 mm TL; Group II, 300–399 mm TL; and Group III, 400–499 mm TL). Specimens of A. rostrata were placed in five groups (Group I, 100–199 mm TL; Group II, 200–299 mm TL; Group III, 300–399 mm TL; Group IV, 400–499 TL; and Group V, 600–699 TL). Specimens from each size class of both species were subjected to examination by Scanning Electron Microscopy (SEM). SEM allowed us to record morphological characteristics on the mesial and lateral faces of the otoliths. The morphological terms of the otolith adopted after Smale et al. (1995) (Fig. 1). The SEM imaging was performed by the D.S. Korzhinsky Institute of Experimental mineralogy of the Russian Academy of Sciences (IEM RAS) in the laboratory of physical research in a group of raster electron microscopy and X-ray spectral local microanalysis. In preparation for SEM analysis, otoliths were air cleaned and mounted on an aluminium stub using double-sided carbon tape. A digital scanning microscope Tescan Vega II XMU (S.R.O. Tescan, Brno, Czech Republic) with an energy-dispersive spectrometer INCA Energy 450 was used. Stubs were sputter coated with a 5 nm thick layer of gold in a vacuum EMITECH K550X (Quorum Technologies Ltd, United Kingdom) using the magnetron sputtering method.

3 Results

Between small and large otoliths of *A. microlepis*, the following characters were shown to be similar: otolith shape, width, depth, mesial and lateral surface, ventral margin, sulcus acusticus, absence of ostio-caudal differentiation, developed crista superior and inferior, sloping posteriorly dorsal depression, absence of ventral depression, produced, medium sized, thick rostrum and column

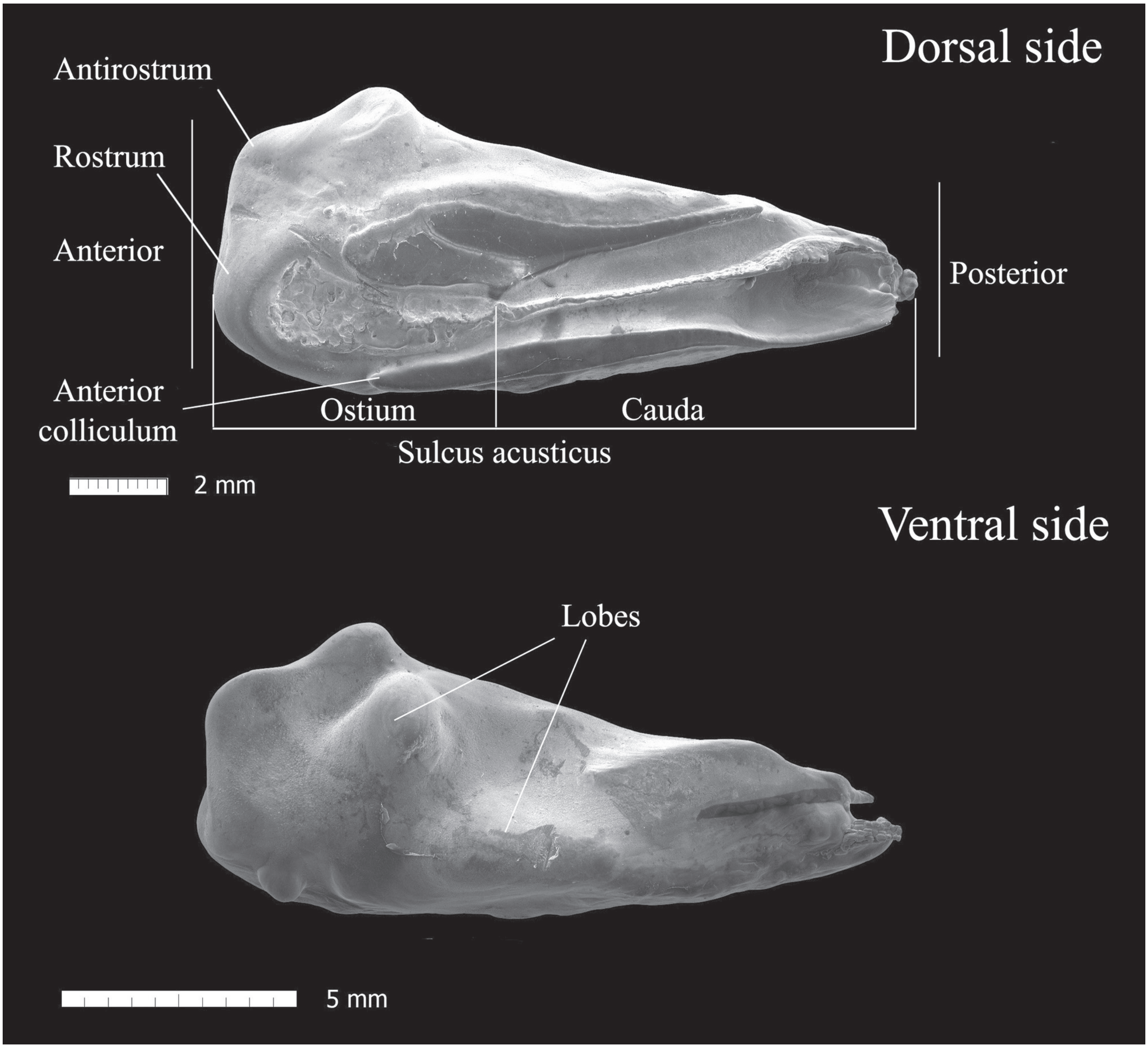

Figure 1. A, Diagram of the mesial surface of the left otolith of *Antimora rostrata*, 496 mm TL, illustrating various features which may be found on the otolith and which are described in the text; B, Diagram of the lateral surface of the otolith of *Antimora rostrata*, 496 mm TL, illustrating surface topography.

absent. For the otolith of *A. rostrata*, the following characters appeared to be the same in the small and large fish specimens: otolith shape and width, shape of the mesial and lateral surface, shape of sulcus acusticus and cauda, absence of ostio-caudal differentiation, shape of both crista superior and inferior and dorsal depression, absence of ventral depression, antirostrum, column and excisura (Table 1 and 2).

In the otolith of *A. microlepis* (Figs. 2 and 3), the dorsal margin of the otolith of GI group is either straight or convex, while it is slightly curved in members of GII and coarsely waved in GIII. Variations were observed in the shape of the posterior margin. This margin was found to be broadly pointed in GI, fine to broadly pointed and notched in GII and blunt in members of GIII. The ostium also displayed variations in the shape and depth. It is flared and narrow posteriorly, deep with colliculum raised in GI, flared and tapering posteriorly in GII and finally narrow and deep in GIII. The cauda was either narrowing posteriorly, deep with colliculum raised in GI or elongated, or shallow with similar width in GII and GIII. Although the general shape of crista superior is the same in the three

Table 1. Otolith characteristics of three size classes of *Antimora microlepis* (Figure 2 and 3). G, fish length group based on fish total length TL

Characters	**GI (TL 200-299 mm)**	**GII (TL 300–399 mm)**	**GIII (TL 400–499 mm)**
Otolith shape	Pyriform	Pyriform	Pyriform
Otolith width	Thick	Thick	Thick
Mesial surface	Flat posteriorly and concave anteriorly	Flat posteriorly and concave anteriorly	Flat posteriorly and concave anteriorly
Lateral surface	Convex	Convex	Convex
Dorsal margin	Straight or convex	Straight, slightly curved	Coarsely waved
Ventral margin	Flat	Flat	Flat
Posterior margin	Broadly pointed	Fine to broadly pointed, with notch	Blunt
Sulcus acusticus	Heterosulcoid, caudal	Heterosulcoid, caudal	Heterosulcoid, caudal
Ostium	Flared anteriorly and narrow posteriorly, colliculum raised, shallow	Flared tapering posteriorly, deep	Narrow, deep
Cauda	Narrowing posteriorly, deep	Elongated, shallow, with similar width along its length	Elongated, shallow, with similar width along its length
Ostio-caudal differentiation	Absent	Absent	Absent
Crista superior	Developed, with depression over ostium and ridges posteriorly	Poorly developed	Developed
Crista inferior	Well-developed under ostium, ridge-like posteriorly	Well-developed, with conspicuous edge under cauda	Well-developed, with conspicuous edge under cauda
Dorsal depression	Slightly slopping posteriorly	Slightly slopping posteriorly	Slightly slopping posteriorly
Ventral depression	Absent	Absent	Absent
Rostrum shape	Produced	Produced	Produced, rounded
Rostrum size	Medium	Medium	Medium
Rostrum thickness	Thick	Thick	Thick
Antirostrum	Developed	Presence or absent	Presence or absent
Collum	Absent	Absent	Absent
Excisura	Present	Presence or absent	Absent

length groups, the former showed to be poorly developed in the members of GII. The antirostrum is developed in members of GI, but it is either poorly developed or absent in the remaining length groups GII and GIII.

In *A. rostrata* otoliths (Figs. 4–7), the dorsal margin was shown to be either emarginated through all its length (GI), straight posteriorly (GII), emarginated posteriorly (GIII), or slightly emarginated (GIV and GV). The dorsal margin either had no notch (GI and GIV), a notch anteriorly (GII), a shallow notch (GIII), or a conspicuous curved notch in GV. The ventral margin was either emarginate and curved as in members of GI or uneven and flat as in the remaining length groups. The posterior margin also showed variation between the 5 length groups studied. It was blunt, bifurcated and lobed in GI, broadly or finely pointed in GII, finely pointed in GIII, broad and bifurcated in GIV and finally blunt in GV.

The ostium appeared flared, shallow and oblong in GI, while it was narrow, and shallow, or deep in the remaining length groups. The rostrum was either broad as in GI and GII, pointed or absent as in GIII, absent in GIV or developing in GV. The rostrum was medium or large in groups GI and GII but was small or absent from the other groups. Similarly, the antirostrum is thick in GI and GII and narrow or absent in the remaining length groups.

Table 2. Otolith characteristics of five size classes of *Antimora rostrata* (Figure 4–7). G, fish length group based on fish total length LT

Characters	**GI (TL 100–199 mm)**	**GII (TL 200–299 mm)**	**GIII (TL 300–399 mm)**	**GIV (TL 400–499 mm)**	**GV (TL 600–699 mm)**
Otolith shape	Pyriform, high anteriorly	Pyriform, high anteriorly	Pyriform, high anteriorly	Pyriform, high anteriorly	Pyriform, high anteriorly
Otolith width	Thick	Thick	Thick	Thick	Thick
Mesial surface	Flat posteriorly, with lobes anteriorly	Flat posteriorly, with lobes anteriorly	Flat posteriorly, with lobes anteriorly	Flat posteriorly, with lobes anteriorly	Flat posteriorly, with lobes anteriorly
Lateral surface	Convex	Convex	Convex	Convex	Convex
Dorsal margin	Emarginate	Straight posteriorly, high with notch anteriorly	Emarginate posteriorly, high with notch anteriorly	Slightly emarginated, low anteriorly	Curved over ostium
Ventral margin	Emarginate, curved, flat	Uneven	Flat	Flat	Flat
Posterior margin	Blunt, bifurcated	Broad or finely pointed	Finely pointed	Bifurcated, broad	Blunt
Sulcus acusticus	Heterosulcoid, caudal	Heterosulcoid, caudal	Heterosulcoid, caudal	Heterosulcoid, caudal	Heterosulcoid, caudal
Ostium	Flared, oblong, shallow	Narrow, shallow or deep	Narrow, shallow or deep	Narrow, shallow or deep	Narrow, shallow or deep
Cauda	Elongated, similar in width or narrow, deep	Elongated, similar in width or narrow, deep	Elongated, similar in width or narrow, deep	Elongated, similar in width or narrow, deep	Elongated, similar in width or narrow, deep
Ostio-caudal differentiation	Absent	Absent	Absent	Absent	Absent
Crista superior	Well-developed	Well-developed	Well-developed	Well-developed	Well-developed
Crista inferior	Well-developed forming shelve	Well-developed forming shelve	Well-developed forming shelve	Well-developed forming shelve	Well-developed forming shelve
Dorsal depression	Slopping posteriorly	Slopping posteriorly	Slopping posteriorly	Slopping posteriorly	Slopping posteriorly
Ventral depression	Absent	Absent	Absent	Absent	Absent
Rostrum shape	Broad, rounded, bi-lobed	Broad, bi-lobed, blunt	Pointed or absent	Absent	Developing
Rostrum size	Large to medium	Large	Small	Absent	Small
Rostrum thickness	Thick	Thick	Thick	Thick	Thick
Antirostrum	Absent	Absent	Absent	Absent	Absent
Collum	Absent	Absent	Absent	Absent	Absent
Excisura	Absent	Absent	Absent	Absent	Absent

4 Discussion

Several morphological features of the sagittal otolith can inform taxonomic studies (Fig. 1). Such characteristics have been identified in the works of several authors since the early twentieth century (e.g. Chaine & Duvergier 1934, Nolf 1985, 2013). Because of their large size and degree of inter-specific variation, the teleost sagittal otolith is the most widely used anatomical feature in comparative taxonomic studies (Jawad 2007; Jawad et al. 2008). In this study we examined a wide range of otolith features, however, only a few emerged to be taxonomically important for future systematic studies.

We identified two broad types of distinguishing otolith features in this study: (1) characteristics that are constant in the otoliths of fish from different length groups, which

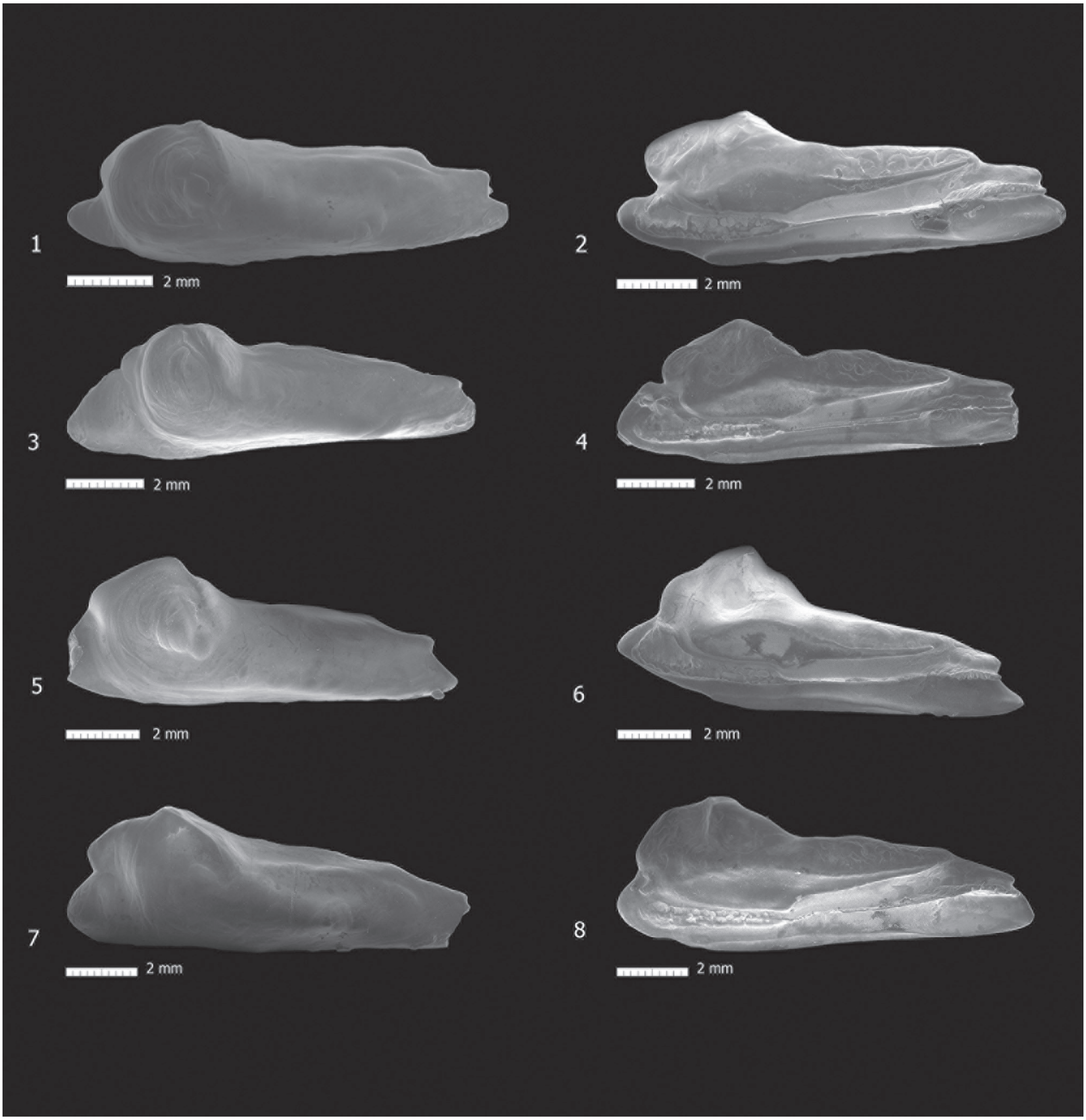

Figure 2. Scanning Electron Micrograph of *Antimora microlepis*, 270 mm TL; 1, lateral surface; 2, mesial surface; 290 mm TL; 3, lateral surface; 4, mesial surface; 310 mm TL; 5, lateral surface; 6, mesial surface; 330 mm TL; 7, lateral surface; 8, mesial surface.

can be used to identify individual species; and (2) traits that vary due to ontogenetic changes, but may be useful to define certain developmental stages.

Karrer (1971), supported by Fitch & Barker (1972), described the unique morphology of Moridae otoliths, which differ extensively from the general shape of gadiform otoliths. Schwarzhans (2019) distinguished the otolith of the family Moridae and located them within *Mora* group that has been established by Karrer (1971). The Mora group contains the following species and showed similarities in the morphology of their otolith. *Antimora microlepis* Bean, 1890, *Antimora rostrata* (Günther,

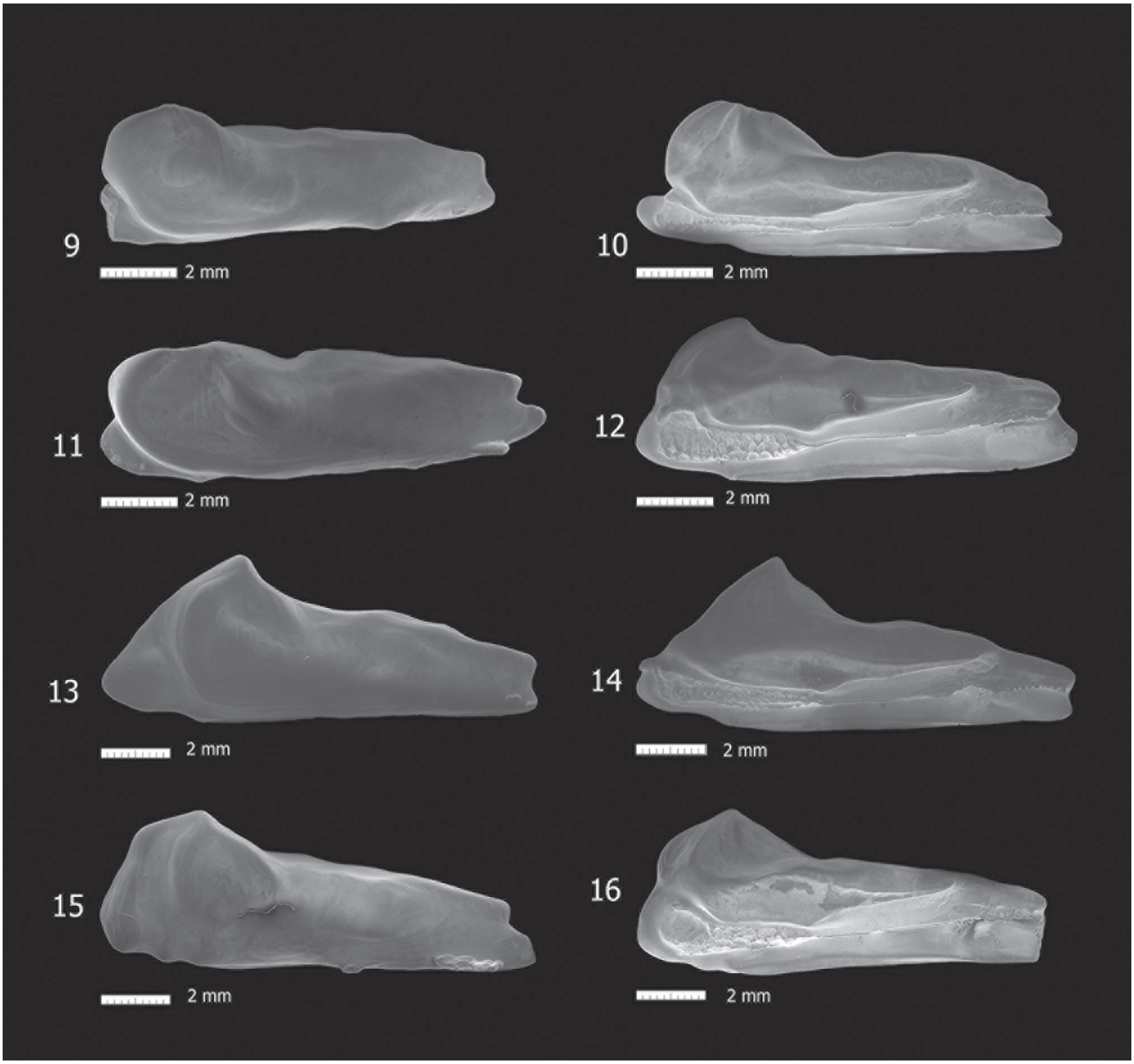

Figure 3. Scanning Electron Micrograph of *Antimora microlepis*, 350 mm TL; 9, lateral surface; 10, mesial surface; 390 mm TL; 11, lateral surface; 12, mesial surface; 400 mm TL; 13, lateral surface; 14, mesial surface; 410 mm TL; 15, lateral surface; 16, mesial surface.

1878), *Halargyreus johnsonii* Günther, 1862, *Mora moro* (Risso, 1810), *Lepidion capensis* Gilchrist, 1922, *Lepidion ensiferus* (Günther, 1887), *Lepidion eques* (Günther, 1887), *Lepidion lepidion* (Risso, 1810), *Lepidion guentheri* (Giglioli, 1880), *Lepidion microcephalus* Cowper, 1956.

In general, the otoliths of the morids are generally large and thick, most likely to adapt to the deep sea environment (Morales-Nin & Panfili 2005). The large otolith size was clearly noted in the two *Antimora* species studied, illustrating the relationship of ecology and otolith size. Relationships between otolith size, habitat and behavior are also seen in other groups such as some notothenioids (Klingenberg & Ekau 1996, Lombarte et al. 2003).

Sadighzadeh et al. (2014) found a relationship between the variations in the antero-dorsal area of the sagittal otolith of snappers and certain behaviors. An extensive development of the antero-dorsal area was found in *Lutjanus argentimaculatus*, a species that is active at night

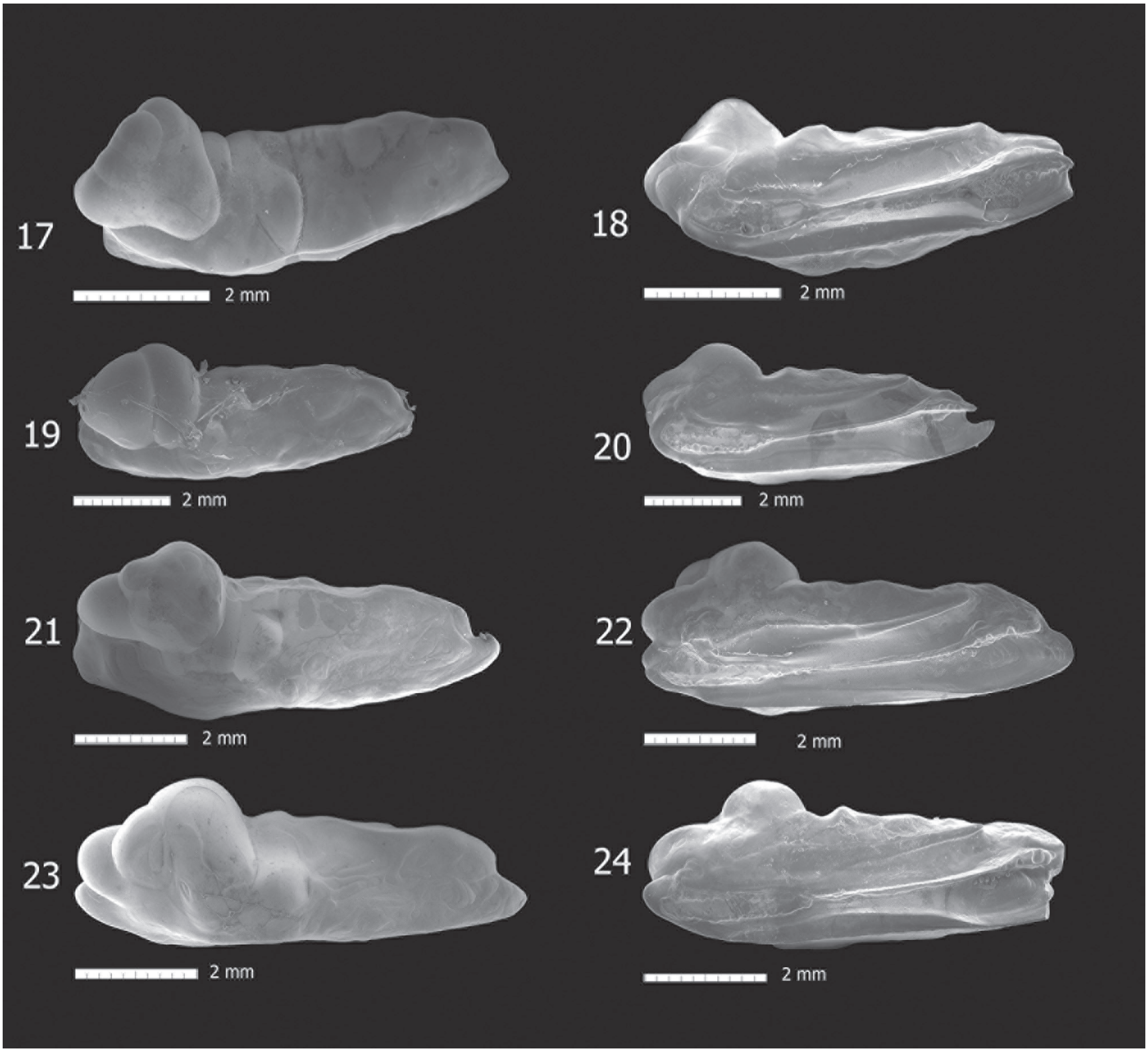

Figure 4. Scanning Electron Micrograph of *Antimora rostrata*, 112 mm TL; 17, lateral surface; 18, mesial surface; 146 mm TL; 19, lateral surface; 20, mesial surface; 156 mm TL; 21, lateral surface; 22, mesial surface; 171 mm TL; 23, lateral surface; 24, mesial surface.

(Martínez-Andrade 2003). Results from this study does not support this finding as the anterior-dorsal area of the two *Antimora* species studied were shown to have lobes and all of these species are daily feeders (Carrassón et al. 1997).

This study has also shown that the overall morphology of otolith remains changeable from small to larger individuals. Out of 21 characters studied, *A. microlepis* and *A. rostrata* were shown to have 8 and 7 characters that differed between small and larger invididuals respectively. Both species have nearly the same number of characters that they smaller individuals differ from the larger in. In general, and in the otolith of *A. microlepis*, the present study has shown a presence of ontogenetic changes such as: the changes in the shape of the dorsal margin from straight or convex to coarsely waved, absence of antirostrum and excisura. On the other hand and in the otolith of *A. rostrata*, a tendency in the shape of the dorsal margin from emarginate to slightly curved, emarginated ventral margin to flat or even, flared to narrow ostium, large and thick to small sized and narrow rostrum.

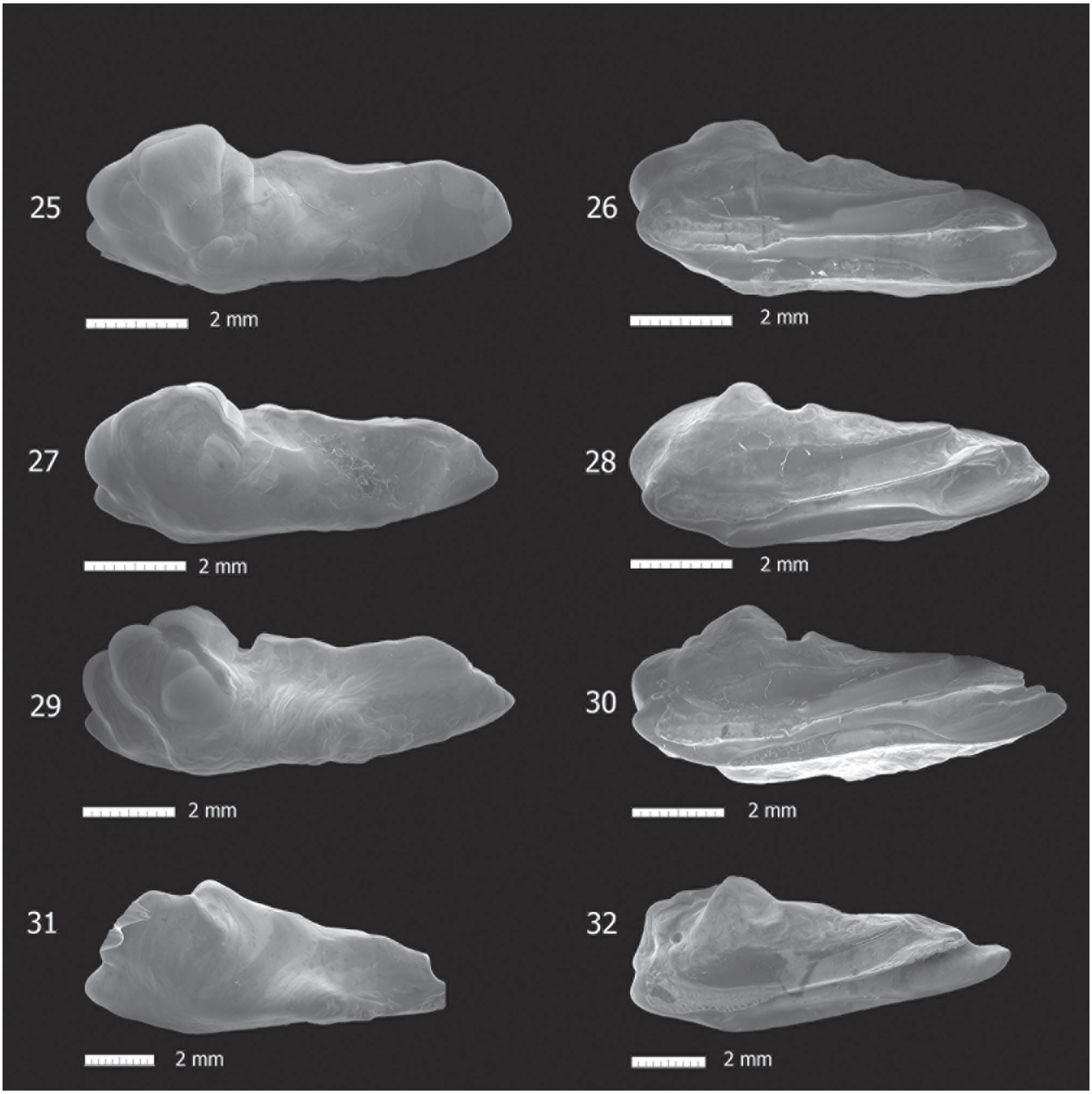

Figure 5. Scanning Electron Micrograph of *Antimora rostrata*, 181 mm TL; 25, lateral surface; 26, mesial surface; 192 mm TL; 27, lateral surface; 28, mesial surface; 223 mm TL; 29, lateral surface; 30, mesial surface; 298 mm TL; 31, lateral surface; 32, mesial surface.

The two *Antimora* species studied displayed shared consistent characters from smaller to larger individuals (Tables 1 and 2). Nevertheless, these characters cannot be used as a tool to separate individual species from other members of the family Moridae. The characters such as the shape of the sulcus acusticus, the deep ostium, the ridge-like crista superior and inferior, slopping dorsal depression, and the tendency for the absence of rostrum and antirostrum have shared by members of the genus *Gadella* (Paulin & Roberts 1997, Tuset et al. 2008; Lin & Chang 2012; Rossi-Wongtschowski et al. 2014), the genus *Laemonema* (Fitch & Barker 1972, Smale et al. 1995, Paulin & Roberts 1997, Paulin & Roberts 1997, Tuset et al. 2008, Lin & Chang 2012, Rossi-Wongtschowski et al. 2014), the

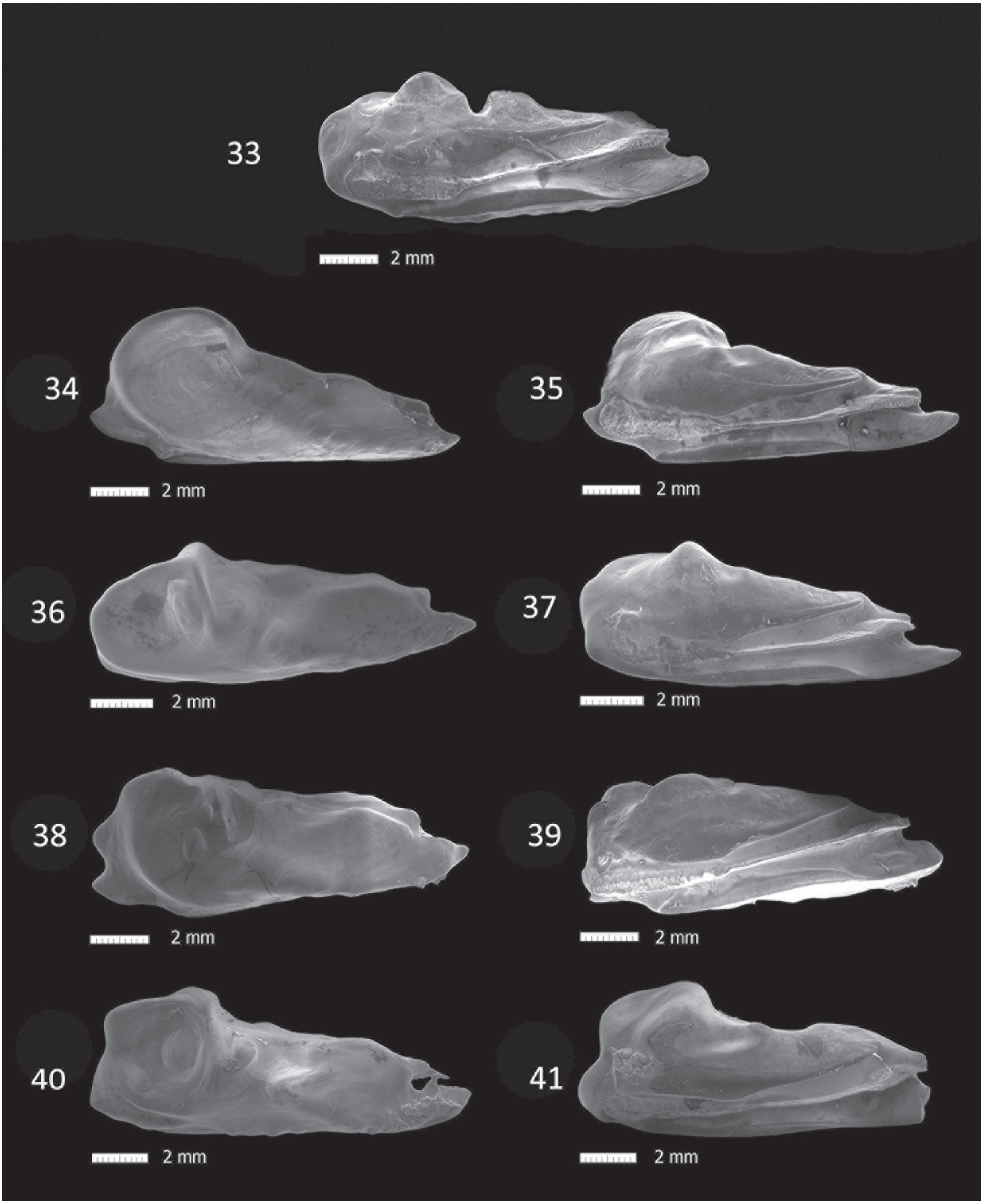

Figure 6. Scanning Electron Micrograph of *Antimora rostrata*, 319 mm TL; 33, lateral surface; 391 mm TL; 34, lateral surface; 35, mesial surface; 395 mm TL; 36, lateral surface; 37, mesial surface; 402 mm TL; 38, lateral surface; 39, mesial surface.

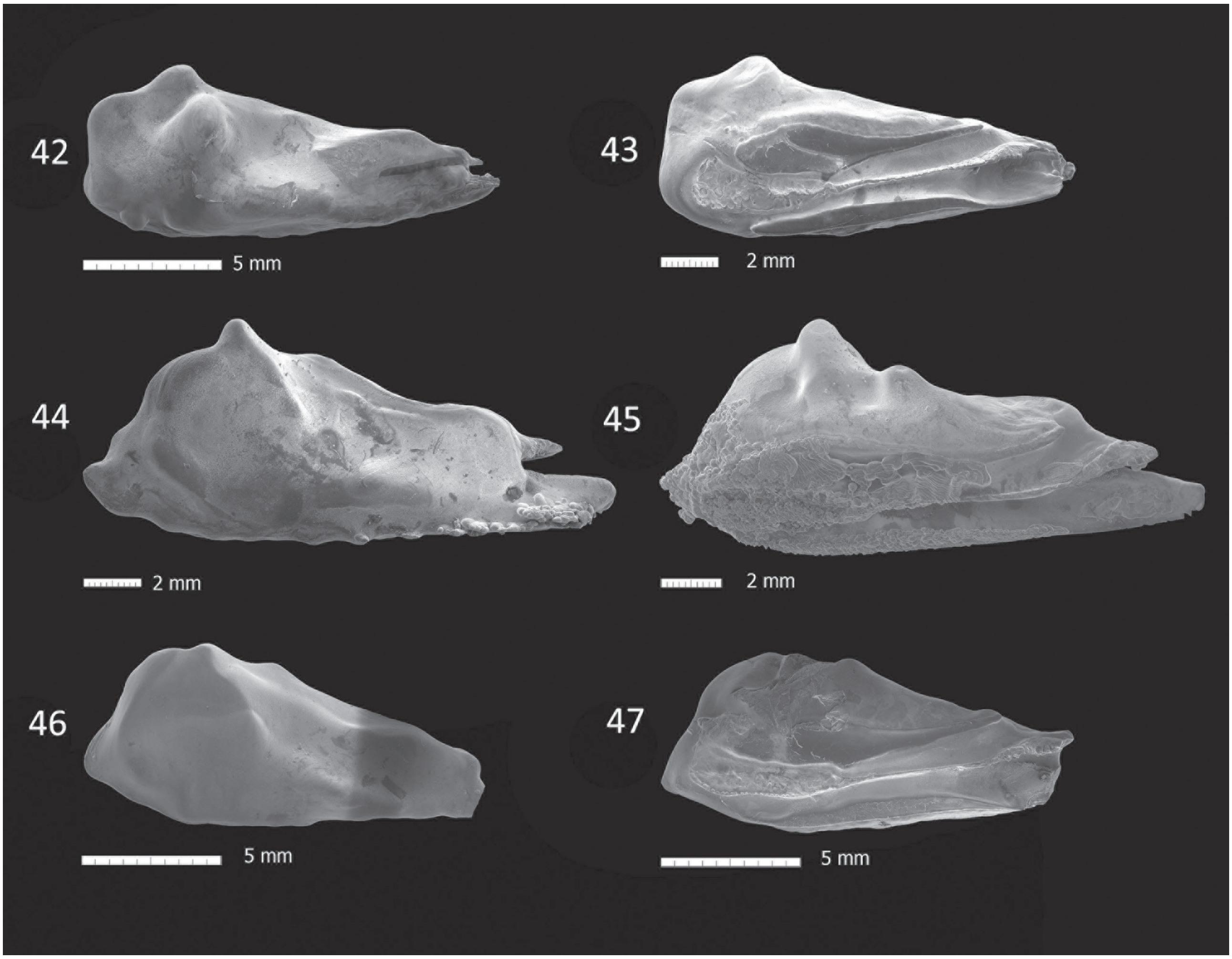

Figure 7. Scanning Electron Micrograph of *Antimora rostrata*, 447 mm TL; 40, lateral surface, 41, mesial surface; 496 mm TL; 42, lateral surface; 43, mesial surface; 660 mm TL; 44, lateral surface; 45, mesial surface; 680 mm TL; 46, lateral surface; 47, mesial surface.

genus *Physiculus* (Paulin 1983, Fitch & Barker 1972, Hecht 1987, Smale et al. 1995, Paulin & Roberts 1997, Veen & Hoedemakers 2005, Tuset et al. 2008, Lowry 2011, Lin & Chang 2012), the genus *Tripterophycis* (Fitch & Barker 1972, Smale et al. 1995, Schwarzhans et al. 2017), the genus *Lepidion* (Smale et al. 1995, Paulin & Roberts 1997; Tuset et al. 2008) and the genus *Mora* (Tuset et al. 2008).

Fitch & Barker (1972) examined and illustrated otolith of *A. microlepis* (10.4 mm TL) obtained from fish specimen collected from the eastern north Atlantic. In this otolith, the posterior most end is extended, the anterior end bulge slightly dorsally. Comparing this otolith with the nearest size (10.5 mm long) otolith obtained in the present study (Fig. 2.2), it is clear that our specimen has a flat dorsal and ventral margins v wavy margin; blunt posterior margin v bifurcated; anterior margin with conspicuous notch v slight curved; and anterior-dorsal part high v low. As far as the author concerned, no description other than that of Fitch & Barker (1972) is available for *A. microlepis*.

Hecht (1987) examined and described 15 otolith specimens of *A. rostrata* of unknown fish length, otolith length and locality. The description and the diagram given by Hecht (1987) agree well with that of the present study for this species. Comparing the otolith diagram given by Hecht (1987) and with those obtained for *A. rostrata* in the present study, the nearest otolith obtained from fish total length 391 mm looks like that of Hecht (1987) in plate 9, Fig. (40).

Smale et al. (1995) describe and made available images of 3 otolith of *A. rostrata* obtained from fish specimens of

173, 227 and 405 mm TL. These otoliths fall in the length groups of GI, GII and GIV of *A. rostrata* given in the present study. The three otoliths of Smale et al. (1995) having similar shape of ostium and cauda found in the comparable otolith of the present study. In addition, otolith from 173 mm TL of Smale et al. (1995) has similar dorsal and posterior margin to otolith obtained from 171 and 181 mm TL of the present study (Fig. 4, 24). On the other hand, it differs from our specimens in the shape of the anterior and the ventral margin. The otolith obtained from 227 mm TL of Smale et al. (1995) is comparable to the otolith extracted from fish specimens of 223 and 298 mm TL. In this case, the otolith of Smale et al. (1995) is similar in the shape of the anterior, ventral and posterior margin of our otoliths (223 and 298 mmm TL) and differs in the shape of the dorsal margin (Figs. 5, 30–31). The 3rd otolith of Smale et al. (1995) (405 mm TL) is analogous to our otolith gained from fish with 402 mm TL. It is similar to our otolith in having the same shape of the anterior, and ventral margin and differs in the shape of the dorsal and the posterior margin (Fig. 6, 39).

Campana (2004) in his photographic atlas of the otolith of the fishes of the North Atlantic Ocean, gave a photo of otolith of *A. rostrata* with 230 mm FL. This otolith is equivalent to our otolith acquired from fish specimen of 223 mm TL. The features of the surface morphology of Campana (2004) otolith look exactly similar to our otolith except for slight variation in the shape of the ventral margin, which could be an individual variation (Fig. 5, 30).

Tuset *et al*. (2008) described and made available photo of an otolith of *A. rostrata* obtained from unknown fish length in the western Mediterranean Sea. The shape of this otolith looks unfamiliar to that of the otolith of *A. rostrata* already published or those obtained in the present study. The posterior end is strongly pointed and the dorsal margin is very high with a dome-shape. Also, the anterior margin is also produced. The shape of this otolith is comparable to two otoliths obtained from fish specimens of 395 and 402 mm TL (Figs. 6, 37 and 39), with differences in the major aspects of the shape of the otolith. The summary of this comparison is given in Table 3.

The features of the otoliths of both *A. microlepis* and *A. rostrata* described by different authors from different localities (Fitch & Barker 1972; Hecht 1987; Smale et al. 1995; Campana 2004; Tuset et al. 2008) have shown consistency although the fish specimens were collected from different localities. For example on such characters are the general shape of the sulcus acusticus, ostium, cauda, crista superior, and inferior. This result is on contrary to that obtained for other fish groups such as parrotfish. Smale et al. (1995) have described the sulcus acusticus, for example of some species of parrotfish. Sadighzadeh et al. (2012) have described the same structure of the same species, but from different locality. They reached to different conclusion in the shape of the sulcus acusticus.

Unlike other fish groups such as Scaridae, the shape of the otolith showed no variation between small and large groups and being consistent in having pyriform shape. Such consistency in the shape is in agreement to the finding of Schmidt (1968) in which he suggested the term "morid type" due to the uniformity in the shape of the otolith of the family Moridae.

The anterior margin has an antero-dorsal angle, which is high and bulbous in the morid in general and the two species of *Antimora* in particular. The anterior margin did not described as one unit as the other margins, instead its different components, rostrum, excisura and antirostrum were described separately. The three margins of the otolith, dorsal, ventral and posterior, showed narrow range in shape variation in the species studied. There were grades of lobation and irregularities in shapes shown through the different length groups. These finding concurs with data obtained for triplefin species by Jawad (2007), Jawad et al. (2008) on greater lizardfish *Saurida tumbil* and by Jawad et al. (2018) on two species of parrotfishes from the Red Sea.

The shape of the ostium in the two *Antimora* species studied shared the flared shape and the narrow and straight for the cauda. Ostium is mainly shallow and its floor is covered with either lumps of different sizes or ridges, while caudal is deep and with smooth floor. These similarities were also reflected in the shape of the sulcus acusticus and both the crista superior and crista inferior of the species studied. On the proximal part of the otolith, shape and nucleus location will be affected by the release of soluble Ca_{2+} (Ibsch et al., 2004), which later on precipitates as $CaCO_3$ crystals due to an increasing alkaline gradient, from the sulcal area towards the otolith edge (Gauldie & Nelson 1990). As a result, both cristae will grow and there is a more important development on the mesial side. The macula is elongated and narrow in teleosts, and the crista superior and inferior are proportionally more important than the colliculum (Popper & Hoxter 1981, Lombarte & Fortuno 1992, Ladich & Popper 2001). The macula faces the collum, and prevents otolith growth at this level (Pannella 1980, Popper & Hoxter 1981, Lombarte & Fortuno 1992). This is clear in the two species of *Antimora* where the collum is absent. Lombarte et al. (2003) have suggested that in *Merluccius* the sagittal otolith shape inconsistency is related to genetic, ontogenetic and environmental factors. Preceding studies on fossil and extant otoliths have proven that the sulcus morphology usually is steady among the species of a single genus (e.g. Nolf 1985), and therefore this feature is probable genetically controlled (Gauldie 1988).

Relationship between particular otolith features (e.g. rostrum and antirostrum proportions) and biological functions such as swimming ability, feeding, or other activities

Table 3. Comparative morphology of the otolith of *A. rostrata* obtained by different studies from different fish sizes.

Studies	**Hecht (1987)**		**Smale et al. (1995)**						**Campana (2004)**		**Tuset et al. (2008)**	
	No size available		173 mm TL		227 mm TL		405 mm TL		230 mm FL		No size available	
	Similarity	Differences	Similarity	Differences	Similarity	Differences	Similarity	Differences	Similarity	Differences	Similarity	Differences
Present study	Similar	NIL	Similar to GI, shape of ostium and cauda, dorsal and posterior margins	Shape of anterior, ventral margins	Similar to GII, shape of the anterior, ventral and posterior margins	Shape of the dorsal margin	Similar to GIV, shape of the anterior and ventral margins	Shape of dorsal and posterior margins	Similar	Slight variation in ventral margin	Ostium, cauda, crista superior and inferior	Anterior, dorsal and posterior margins
Hecht (1987)	*	*	Similar	Slight variation in anterior margin	–	–	–	–	Slight	Anterior and posterior margins	Ostium, cauda, crista superior and inferior	Shape of all margins
Smale et al. (1995)	*	*	*	*	*	*	*	*	Otolith shape, posterior and ventral margins, ostium, cauda	Anterior and dorsal margins	Ostium, cauda, crista superior and inferior	Shape of all margins
Campana (2004)	*	*	*	*	*	*	*	*	*	*	Ostium, cauda, crista superior and inferior	Shape of all margins

have not yet been established (Popper et al. 2005). Bearing in mind the variety of teleost fishes there may be some correlation between the otolith rostrum length and swimming ability (Nolf 1985, Volpedo & Echeverria 2003), but this feature has not been shown to be significant in the discrimination of closely related species (Reichenbacher et al. 2007). In this study, the general morphology of the rostrum in the two *Antimora* species examined was either weakly developed or absent such consistency in these features agrees with (Reichenbacher et al. 2007).

Certain pressures can sometimes affect sagittae so that their morphology meets specific auditory needs (Platt & Popper 1981, Popper & Coombs 1982, Gauldie 1988). Limitations in terms of physical packing of sagittae within the skull have also been cited in several studies, particularly those exploratory closely related species with large sagittae (Gaemers 1984, Smith 1992, Arellano et al. 1995). It has been known that otolith growth have a positive relationship to fish age (e.g. Sabetian et al. 2015), but otoliths in very large fishes can be much smaller than small fish and vice versa (Campana, 2004). A restricted comparison made by Friedland & Reddin (1994) recommends that otolith shape is also influenced by genetics.

The results of this study have highlighted enough variability to distinguish small and large individuals of the two Antimora species studied. Further investigation is required, including a comparative study of the shape and geometry of the sagittal otolith, to add further taxonomic characters for the identification of these two species.

Since morid otoliths are likely to be encountered in food habit studies, fossil deposits, and bottom sediments, and could be useful in a taxonomic revision of the family, we have created a key for identifying to genus the sagittae we have seen. Although obviously incomplete, this key can be expanded when otoliths of other genera becomes available.

5 Key to the species of *Antimora* based on otolith morphology

Lateral surface concave to flat, rostrum produced, anterior margin not bulbous, no bony shelve under cauda, cauda straight posteriorly, anterior-dorsal area flat or pointed .... ***Antimora microlepis***

– Lateral surface highly lobate, rostrum poorly developed or absent, anterior margin bulbous, presence of bony shelve under cauda, cauda flared posteriorly, anterior-dorsal area lobate .... ***Antimora rostrata***

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