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Morphology study of the otoliths of the parrotfish, *Chlorurus sordidus* (Forsskål, 1775) and *Hipposcarus harid* (Forsskål, 1775) from the Red Sea coast of Egypt (Family: Scaridae)

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In the present study a comparison of the otolith morphology of two species of parrotfish, family Scaridae, collected from the Red Sea coast of Egypt, is conducted to identify the most appropriate taxonomic characters that separate these species. Ontogenetic changes in the otoliths of the two scarid fishes become evident. In the otoliths of Chlorurus sordidus*, the following characters are comparable in small-sized adult fishes: otolith width, otolith depth, mesial surface shape, lateral surface shape, shape of sulcus acusticus, column, rostrum and size of rostrum. The otoliths of young adults (GI)* C. sordidus *differ from the adult ones in 14 out of the 22 characteristics studied. In the otoliths of* Hipposcarus harid*, the following characters are comparable in small and large fish: otolith width, otolith depth, mesial and lateral surface shapes, shape of sulcus acusticus, rostrum and size of rostrum.*

Keywords: morphology, otoliths, SEM, parrotfish, Scaridae, Egypt, Red Sea

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INTRODUCTION

Chlorurus sordidus is a marine species that sometimes enters brackish water and lives in association with coral reefs (Riede, 2004) at depths from the surface down to 50 m (Fischer *et al*., 1990). It reaches maturity at total length 150 mm (Randall *et al*., 1990). Similarly, *Hipposcarus harid* has the same mode of life, but lives at a depth range of 1–25 m (Lieske & Myers, 1994). It reaches maturity at 750 mm total length (Randall, 1986).

Otolith morphology has proven useful in phylogenetics and palaeoecology, yet such studies for the family Scaridae are scarce. Prominent studies have been conducted in the Indo-Pacific region, North America, China and the Red Sea. Nolf (1985) provided a diagram of the sagittal otolith of *Scarus croicensis* (= *S. iseri*) (Bloch, 1789). Weisler (1993) commented on the importance of the otoliths of *Scarus perspicillatus* (Steindachner, 1879) for archaeological studies, indicating their significance in determining their communities during prehistoric periods. Smale *et al.* (1995) described six species of the genus Scarus and of the species *Calostomus spinidens, Leptoscarus vaigiensis* and *Hipposcarus harid*, demonstrating the use of otoliths in phylogeny. Rivaton & Bourret (1999) published images of otoliths of nine species of the genus Scarus and two species of the genus *Cetoscarus* from the Indo-Pacific region, showing an innovative technique for otolith morphological studies. Tuset *et al.* (2008) briefly described the otolith of *Saprisoma cretense* (Linnaeus, 1758) and *S. rubripinne* (Valenciennes, 1840), showing their superiority in phylogenetic studies compared with genetic studies. Baremore & Bethea (2010) used otoliths of *Nicholsina usta* (Valenciennes, 1840) from the Gulf of Mexico. Lin & Chang (2012) described the otoliths of seven species of the genus Scarus and species of the genera *Calotomus, Chlorurus, Hipposcarus* and *Leptoscarus* from Taiwan, confirming their phylogenetic relations, and Sadighzadeh *et al.* (2012) gave short descriptions of two Scarus species using otoliths morphology. Nolf (2013) produced otolith diagrams of *Nicholsina usta* (Valenciennes, 1840) and *Scarus croicensis* Bloch, 1790, showing their phylogenetic relationships. Except for the description of the otolith of H. harid from the Red Sea by Smale *et al.* (1995), there is a gap in information on the morphology of scarid otoliths from the Red Sea.

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Distinguishing between *C. sordidus* and *H. harid* using external morphological traits is a challenge. Using otolith morphology, however, may prove reliable in making such a distinction. Additionally, otolith morphology may prove a useful supporting tool for archaeology, and palaeoichthyology (Nolf, 1985). The objective of this study is to describe otoliths of juveniles and adults of fish of the family Scaridae. Collections were from the Red Sea, due to the high importance of this species in the region. This work will help resolve the taxonomy among the members of the family Scaridae.

MATERIALS AND METHODS

The vicinity of Hurghada was chosen as it represents one of the main fishing grounds for the two study species. Understanding the asymmetry of the two species is important to show the effect of this phenomenon on the settlement of their larvae in this important fishing ground, as has been shown for other fish species (Battaglia *et al.*, 2010). Specimens of parrotfish were obtained during the fishing season 2012–2013 through monthly sampling from the commercial landings. The fish were caught using gill nets of 60–100 m long with mesh size of 2 (0.25 cm). Standard length (TL) was measured to the nearest 0.1 cm using a digital caliper. The specimens of *C. sordidus* range from 161 to 250 mm in total length (N = 123). They were placed in seven groups according to their total length: Group I, 161–170 mm, N = 10; Group II, 171–180 mm, N = 15; Group III, 181–190 mm, N = 20; Group IV, 201– 210 mm, N = 15; Group V, 211– 220 mm, N = 25; Group VI, 231–240 mm, N = 15; and VII, 241–250 mm, N = 15. The specimens of *H. harid*, which range from 140 to 310 mm in total length (N = 115). Otoliths with obvious evidence of calcite crystallization or other abnormal formations were not considered in this study.

Fish otoliths are located on the two sides of the basioccipital bone and separated by a thin septum arising from the mid-ventral ridge of the occipital (Ruck, 1976; Jawad *et al.*, 2007; Jawad, 2008). Otoliths were removed by slicing open the top of the cranium and exposing the brain. After removal of the brain with a sharp scalpel, the otic capsules were separated and the otoliths gently removed with a pair of fine tweezers. Later, the otoliths were cleaned with 70% ethanol and stored dry in a small glass tube. Scanning electron microscopy was used to record the morphological characteristics on the inner face of the saccular otolith (sagitta). The terminology of otolith morphology follows Smale *et al.* (1995) (Figure 1). The otoliths to be used for SEM were air dried and mounted on an aluminium stub using double-sided carbon tape. Otolith left sagitta were viewed in an ESEM Fei Quanta 200 at 10.0–20.0 KV.

Otolith morphometry

According to the terminology of Avigliano *et al.* (2014, 2015), a number of otolith measurements were recorded. These were otolith length (OL, mm), otolith width (OW, mm), otolith perimeter (OP, mm), otolith surface (OS, mm^2), sulcus perimeter (SP, mm), sulcus surface (SS, mm^2), sulcus length (SL, mm), cauda length (CL, mm), ostium length (OSL, mm), rostrum width (RW, mm) and rostrum length (RL, mm) (Figure 2). These measurements were taken for all the otoliths

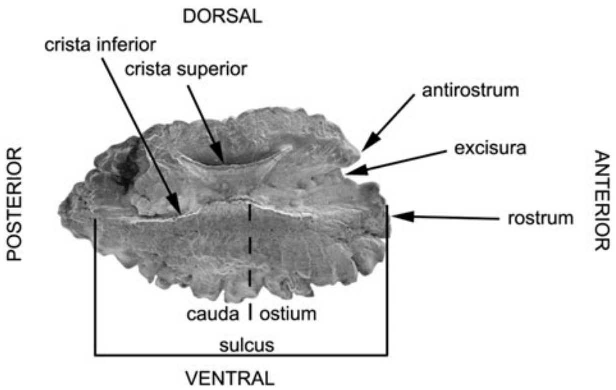

Fig. 1. Diagram of the mesial surface of the left otolith of *Hipposcarus harid* illustrating various features of the otolith, which are described in the text.

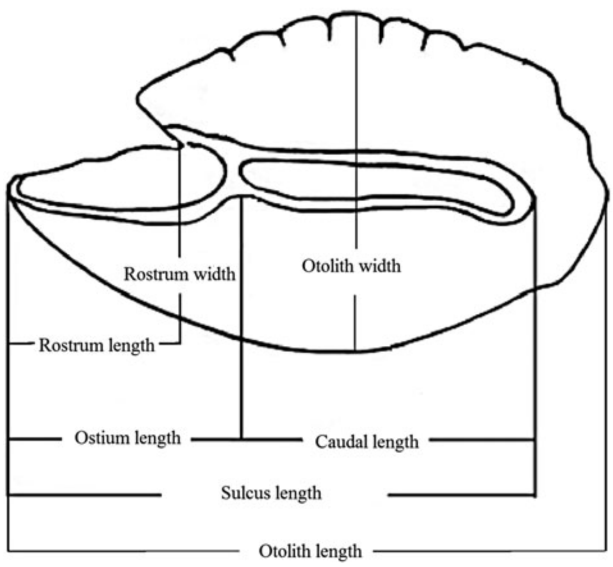

Fig. 2. Generalized scheme of the inner surface of saccular otoliths of a parrotfish illustrating otolith measurements, described in the text.

using image-processing systems (image analysis software TpsDig2; Rohlf, 2006). Subsequently, the following otolith shape indices were calculated: aspect ratio (OW/OL, %), percentage of the otolith surface occupied by the sulcus (SS/OS, %), percentage of the sulcus length occupied by the cauda length (CL/SL, %), percentage of the sulcus length occupied by the ostium length (OSL/SL, %), rostrum aspect ratio (RW/RL, %), and percentage of the rostrum length occupied by the otolith length (RL/OL, %). CL/SL and OSL/SL indices were used for the first time in this work.

RESULTS

There were ontogenetic changes in the otoliths of the two scarid fish species. In the otoliths of *C. sordidus* (Figure 3), otolith width, otolith depth, mesial surface shape, lateral surface shape, shape of sulcus acusticus, column, rostrum, and size of rostrum were similar. The otoliths of the small adults (GI) *C. sordidus* differed from the large adult ones in 14 out of the 22 characteristics studied. Detailed descriptions of the otoliths in seven size classes of fish are shown in Table 1.

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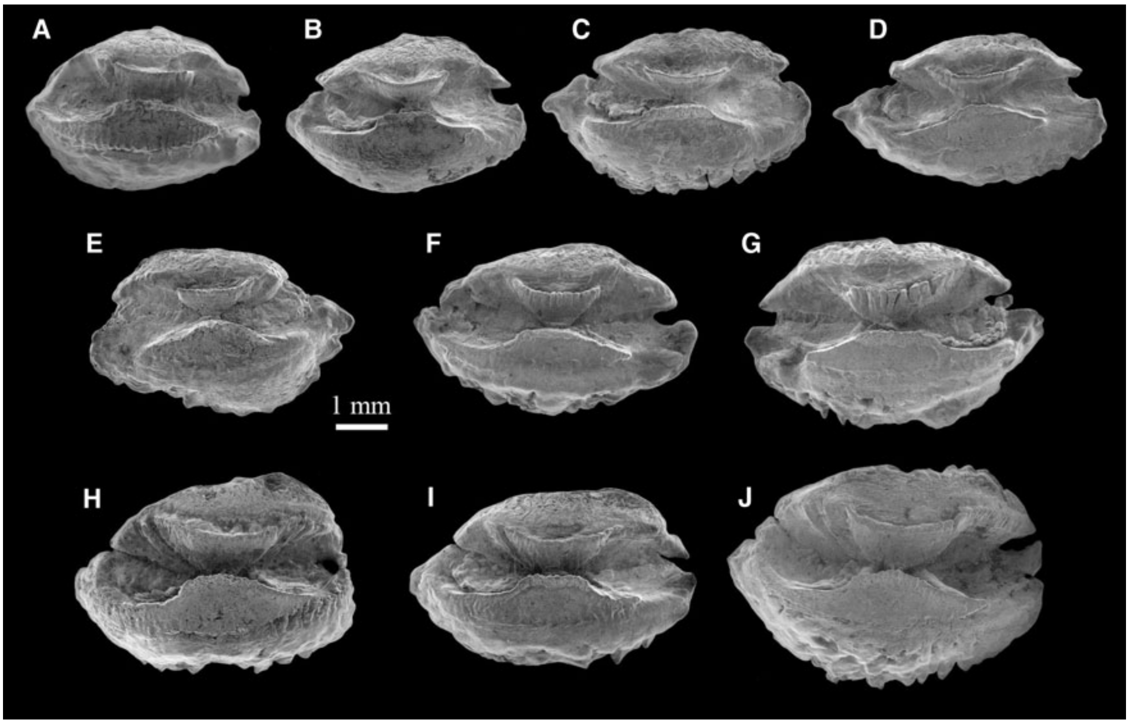

Fig. 3. (A–J) Otoliths of *Chlorurus sordidus*. (A) 161 mm TL; (B) 175 mm TL; (C) 183 mm TL; (D) 184 mm TL; (E) 204 mm TL; (F) 210 mm TL; (G) 215 mm TL; (H) 220 mm TL; (I) 240 mm TL; (J) 248 mm TL.

In the otoliths of *H. harid*, otolith width, otolith depth, mesial (inner) and lateral surface shapes, shape of sulcus acusticus, rostrum and size of rostrum were similar. The otoliths of the very small (GI) *H. harid* differ from the large-sized ones in 13 out of the 22 characteristics studied. In the otoliths of *H. harid*, the following characters were shown to be not different among young individuals studied: otolith shape, width and depth, mesial surface shape, lateral surface shape, shape of sulcus acusticus, rostrum, ventral depression and size of rostrum. Detailed descriptions of the otoliths in the seven size classes of fish are shown in Figure 4 and Table 2.

The shape of the otoliths of *C. sordidus* can be either oval or oblong, while they are oblong in *H. harid* (Tables 1 & 2, Figures 3 & 4).

The mesial surface, however, provided a wide range of ornamental sculptures that in most cases helped to differentiate taxa.

The shape of the dorsal margin of the otolith of *C. sordidus* is mainly rounded with lobes in GI to GIII and becomes flat in GIV to GVII. In the otoliths of *H. harid*, it varies between lobed, curved and emarginate in GI to GV and becomes approximately flat in GVI and GVII. Lobes and irregularities are present on the dorsal margin in fish groups I to V, which becomes smooth or nearly smooth in GVI and GVII.

The ventral margin in the otoliths of *C. sordidus* was generally rounded in GII and GI and became lobed or irregular in adult fish groups. On the other hand, in *H. harid*, it was generally lobed in otoliths of young and adult with slight variations in the size of the lobes in the different length groups.

The posterior margin in otoliths of *C. sordidus* were usually rounded in groups of smaller length and always rounded in the groups of larger length. The presence of a notch was a persistent feature of this margin. It was shallow in the otoliths of small adult fish and deep in large adult fish. Two notches were observed in otoliths of GVII. Presence of lobes and a deep notch were two features of the otoliths of GI–GIV of *H. harid*. This margin became rounded and broadly rounded with a shallow notch in otoliths of large-sized young fish (GV to GVII).

The ostium in otoliths of *C. sordidus* of all length groups studied was characterized to be flared and its floor covered with lumps. The depth of the ostium changed from shallow in GI and GIII to deep in the otoliths of the large-sized young fish (GIV–GVII). In otoliths of *H. harid*, the ostium was also flared in all length groups studied. Features of otoliths of GI–GV were the deep sulcus, with its lower side covered by lumps and sometimes with ridges. The sulcus became shallow and its floor smooth in large-sized young fish groups (GVI–GVII).

The cauda in otoliths of all length groups of both *C. sordidus* and *H. harid* was flared and deep, its lower side was mainly smooth and sometimes covered by lumps or ridges. The column was often well developed in otoliths of the large-sized fish groups in both species.

The crista superior of the ostium and the cauda was generally poorly developed, but usually well developed over the neck in otoliths of *C. sordidus*, where it became a high ridge, bordering a dorsal depression. The same applied to the crista superior in otoliths of *H. harid* (GIV–GVII), where it was generally less developed in otoliths of small-sized adult fishes (GI and GIII).

The crista inferior was less defined in the otoliths of small-sized adult fishes of *C. sordidus* (GI); it became well developed in GII–GVII. On the contrary, the crista inferior in *H. harid* was better developed in otolith of small-sized young fishes (GI) and showed some variation in groups II–VII.

The dorsal depression in both species varied between shallow or deep and elongated or wide in otoliths of young fish (GI–GIV). It was very pronounced in otoliths of large-sized young fish (GV–GVII), accentuated by the high crista superior on its ventral side. There was no ventral depression in either scarid species.

Table 1. Otolith characteristics of seven size classes of *Chlorurus sordidus* (Figure 3).

Characters	GI (161–170 mm) (N = 15)	GII (171–180 mm) (N = 14)	GIII (181–190 mm) (N = 25)	GIV (201–210 mm) (N = 24)	GV (211–220 mm) (N = 23)	GVI (231–240 mm) (N = 10)	GVII (241–250 mm) (N = 12)
Otolith shape	Oval	Oval	Oblong	Oblong	Oblong	Oblong	Oblong
Otolith width	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Otolith depth	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Mesial surface	Convex	Convex	Convex	Convex	Convex	Convex	Convex
Lateral surface	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Dorsal margin	Rounded with single lobe at centre	Rounded with single lobe at centre	Curved, slightly lobed, raised over cauda	Flat , raised slightly over cauda	Flat or approximately flat, irregular overneck, raised over cauda	Flat, smooth	Flat, irregular over cauda
Ventral margin	Rounded, slightly emarginate	Rounded, slightly emarginate	Lobed or slightly lobed	Crenate	Irregular with notch uder neck	Slightly irregular	Curved, irregular
Posterior margin	Rounded with shallow notch	Rounded with deep notch	Rounded with narrow or deep notch	Broadly pointed, curved with deep notch	Approximately straight with deep notch	Rounded with deep notch	Curved with two notch, dorsal deep, ventral shallow
Sulcus acusticus	Ostial	Ostial	Ostial	Ostial	Ostial	Ostial	Ostial
Ostium	Flared, shallow, floor with lumps	Flared, shallow, floor with ridges	Flared, shallow, floor with lumps	Flared, deep, floor with lumps	Flared, deep, floor with lumps or ridges	Flared, deep, floor with lumps	Flared, deep, floor smooth
Cauda	Flared, deep, floor smooth	Flared, deep, floor smooth	Flared, shallow, floor smooth	Flared, shallow or deep, floor smooth	Flared, shallow or deep, floor smooth or with ridges	Flared, shallow, floor with lumps	Flared, shallow, floor smooth
Ostio-caudal differentiation	Well developed	Well developed	Well developed	Well developed	Well developed	Well developed	Well developed
Crista superior	Partly developed over neck, otherwise poorly developed	Well developed over neck	Well developed over neck	Well developed over neck	Well or poorly developed	Well developed over neck otherwise poorly developed	Poorly developed
Crista inferior	Poorly developed	Well developed	Well or poorly developed	Well developed	Well developed	Poorly developed	Poorly developed
Dorsal depression	Shallow, elongated	Deep, narrow	Shallow, elongated	Deep, elongated	Shallow, wide or elongated	Shallow, elongated	Shallow, elongated
Ventral depression	Deep, wide	Shallow	Shallow or absent	Shallow, wide	Absent	Absent	Absent
Rostrum shape	Broadly pointed	Broadly pointed, produced	Pointed	Broadly pointed	Broadly pointed	Broadly pointed	Broadly pointed
Rostrum size	Large	Large	Large	Large	Large	Large	Large
Rostrum thickness	Broad	Broad	Broad	Broad	Broad	Broad	Broad
Antirostrum	Absent	Short, pointed	Short or long broad	Short, broad	Broad, long or short	Broad, short	Broad, short
Collum	Low	Low	Low	Low	Low	Low	Low
Excisura	Absent	Shallow, notch shallow, angle acute	Shallow or deep notch shallow or deep, angle acute or wide	Absent	Absent or deep, notch deep, angle acute	Absent	Absent

Number of otoliths (N) examined in parantheses.

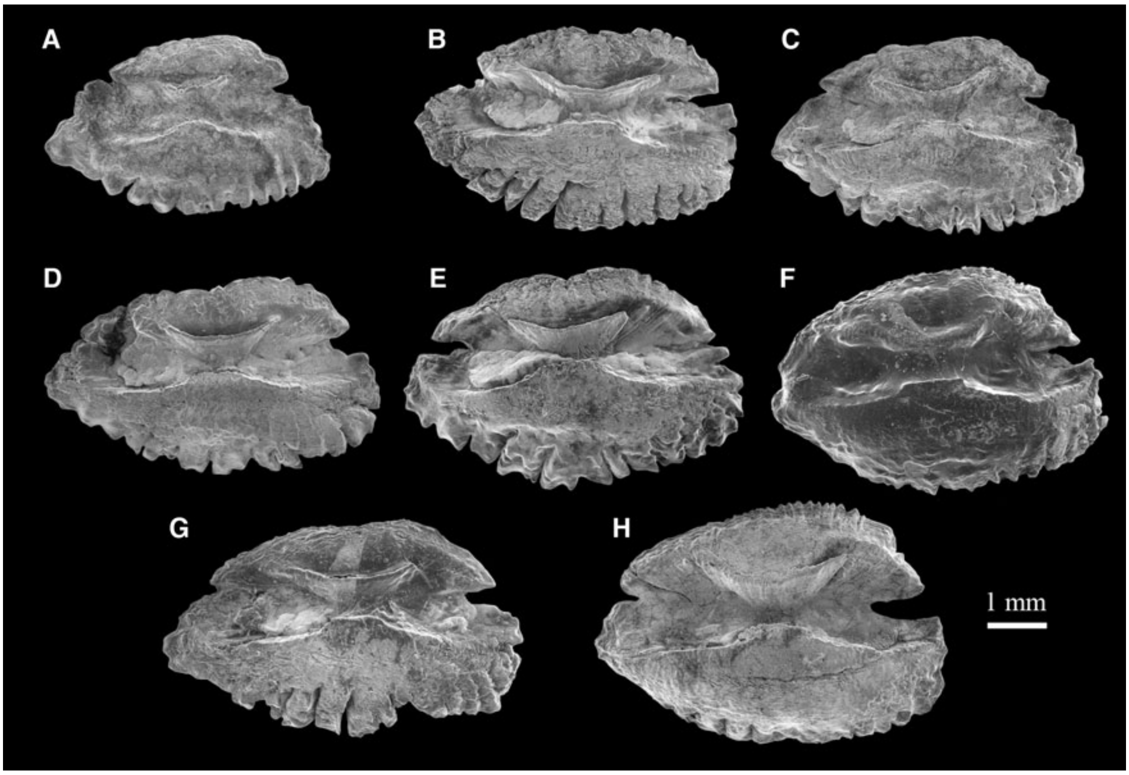

Fig. 4. (A–H) Otoliths of *Hipposcarus harid*. (A) 140 mm TL; (B) 160 mm TL; (C) 222 mm TL; (D) 245 mm TL; (E) 263 mm TL; (F) 270 mm TL; (G) 288 mm TL; (H) 306 mm TL.

The anterior rim was rounded or straight, with a distinct rostrum and excisura in most specimens of both species, although sometimes less distinct in *C. sordidus*. The shape of the rostrum (broadly pointed, blunt, rounded) was characteristic in otoliths of the small-sized adult fishes of both *C. sordidus* and large-sized young fishes of *H. harid*, but it became broadly pointed and rounded in larger fish sizes of *C. sordidus* and *H. harid* respectively. The antirostrum varied in shape between complete absence or short or broad in otoliths of small-sized adult fishes of *C. sordidus* (GI–GV), but remained broad and short in large-sized fish groups (GVI and GVII). However, it was short and broad in otolith of the small-sized young fishes of *H. harid* (GI–GV), but became long and pointed in the two length groups of larger young fishes (GVI and GVII). The antirostrum was, however, always shorter than the rostrum. Slight variations (absence, shallow, deep, notch deep or shallow, angle acute) were noticed in the excisura of the otoliths of small adult fishes of *C. sordidus* (GI–GIV), it was sometimes absent in the two large adult fish groups (GVI and GVII). Variations in the shape (absence, shallow, deep, notch wide, shallow, angle acute) of the excisura of the otoliths of *H. harid* remained consistent throughout the different fish length groups studied.

Lower proportions were found in CL and RL for *C. sordidus* and *H. harid* respectively, while higher proportions were observed in OL and OP for *C. sordidus* and *H. harid* respectively. As for the percentage indices, the lowest values were shown in CL/SL and RW/RL and the highest were for CL/SL in both species studied (Table 3).

For *C. sordidus*, the non-linear power function coefficient 'b' of otolith length (Y) on different otolith variables (X) was highest for OL/OP, where the values were 4.370. For *H. harid*, the value of the coefficient 'b' was 6.698 for OL/SP. The lowest values for both species were 0.034 and 0.426 for OL/RL and OL/OSL for *C. sordidus* and *H. harid* respectively.

The highest correlations found of the otolith length with the different otolith indices is $r = 0.87$ and $r = 0.86$ for OL/SS and OL/OP for *C. sordidus* and *H. harid* respectively.

The growth of the different otolith morphometric characters relative to the otolith length of *C. sordidus* were shown to be negative for OL/OW and OL/OP. The other relationships were shown to have a positive allometric growth. For *H. harid*, the relationships OL/OW, OL/OP/OL/SP, and OL/RW had negative allometric growth and the remaining six relationships had positive allometric growth (Table 4).

DISCUSSION

Since the early 20th century, certain characters of the saccular otolith have been used to support taxonomic studies (e.g. Chaine & Duvergier, 1934) despite the degree of inter-specific variation (Jawad *et al.*, 2007). The present study of otolith morphology in two scarid species considered a wide range of otolith characteristics. However, only a few characteristics were taxonomically important for these species, and useful in systematics.

The results of the present study showed two groups of characteristics: (1) characteristics that are consistent in the otoliths of fish from different length groups, which are thus valuable to identify the species and (2) characteristics that vary due to ontogenetic changes, but that may be useful to define developmental stages.

Morphology and external colouration are used to recognize several species of parrotfish. Such groupings are consistent with the phylogenetic evolution in their family (Bellwood,

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Table 2. Otolith characteristics of seven size classes of *Hiposarcus harid* (Figure 4).

Characters	GI (140–150 mm) (N = 10)	GII (151–160 mm) (N = 15)	GIII (221–230 mm) (N = 20)	GIV (241–230 mm) (N = 15)	GV (261–270 mm) (N = 25)	GVI (281–290 mm) (N = 15)	GVII (301–310 mm) (N = 15)
Otolith shape	Oblong	Oblong	Oblong	Oblong	Oblong	Oblong	Oblong
Otolith width	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Otolith depth	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Mesial surface	Convex	Convex	Convex	Convex	Convex	Convex	Convex
Lateral surface	Flat	Flat	Flat	Flat	Flat	Flat	Flat
Dorsal margin	Lobed, flattened	Curved	Emarginate	Slightly lobed	Rounded, finely crenate, curved over neck	Approximately flat and smooth	Approximately flat with fine lobes
Ventral margin	Lobed	Crenate	Crenate	Lobed	Coarsly lobed	Finely lobed	Finely lobed
Posterior margin	Straight, lobed	Lobed with shallow notch	Lobed, with deep notch	Lobed with deep and wide notch	Rounded, coarsely lobed with deep notch	Broadly rounded	Broadly rounded with small notch
Sulcus acusticus	Ostio-caudal, homosulcoid	Ostio-caudal, homosulcoid	Ostio-caudal, homosulcoid	Ostio-caudal, homosulcoid	Ostio-caudal, homosulcoid	Ostio-caudal, homosulcoid	Ostio-caudal, homosulcoid
Ostium	Flared, deep, floor with ridges	Flared, shallow, floor smooth	Flared, shallow, floor smooth	Flared, deep, floor with lumps	Flared, deep, floor with ridges	Flared, shallow, floor smooth	Flared, shallow, floor smooth
Cauda	Flared, deep, floor with lumps	Flared, shallow, floor smooth	Flared, shallow, floor smooth	Flared, deep, floor with lumps	Flared, deep or shallow, floor smooth or with ridges	Flared, shallow, floor smooth	Flared, shallow, floor smooth
Ostio-caudal differentiation	Well developed	Absent	Absent	Poorly developed	Well developed	Well developed	Well developed
Crista superior	Ridge-like, poorly developed over neck	Absent	Absent	Well developed over nick, otherwise poorly developed	Well developed over nick, otherwise poorly developed	Well developed over nick, otherwise poorly developed	Well developed over nick, otherwise poorly developed
Crista inferior	Well developed	Poorly developed	Absent	Well developed	Poorly developed	Poorly developed	Poorly developed
Dorsal depression	Deep, elongated	Shallow	Shallow	Deep, elongated	Poorly developed	Poorly developed	Poorly developed
Ventral depression	Absent	Absent	Absent	Absent	Absent	Absent	Absent
Rostrum shape	Rounded	Broadly pointed	Broadly pointed	Broadly pointed	Blunt or rounded	Rounded	Blunt
Rostrum size	Large	Large	Large	Large	Large	Large	Large
Rostrum thickness	Broad	Broad	Broad	Broad	Broad	Broad	Broad
Antirostrum	Short, broad	Short, broad	Short, broad	Short, broad	Long, broad or poorly developed	Long, pointed	Long, pointed
Collum	Solid-bridge	Absent	Absent	Solid-bridge	Solid-bridge	Solid-bridge	Solid-bridge
Excisura	Moderate, notch shallow. Angle acute	Narrow, notch shallow, angle acute	Absent	Absent	Deep, notch deep, angle acute or absent	Shallow, notch shallow, angle acute	Deep, notch deep, angle acute

Number of otolith (*n*) examined in parantheses.

Table 3. Mean and standard deviation and range (minimum–maximum) of the morphological indices of *Chlorurus sordidus* and *Hipposcarus harid*.

Otolith morphological characters	*Chlorurus sordidus*		*Hipposcarus harid*	
	Mean and standard	minimum–maximum	Mean and standard	minimum–maximum
OL	21.39 + 4.54	4.54–6.15	5.44 + 4.21	4.69–6.02
OW	3.25 + 3.54	2.89–4.22	3.34 + 3.76	2.81–3.9
OP	16.47 + 7.54	13.51–22.7	18.84 + 5.34	17.0–21.08
OS	12.74 + 6.65	10.25–20.16	14.01 + 4.63	12.48–17.91
SP	13.84 + 5.43	11.21–20.16	13.09 + 4.35	11.80–14.31
SS	4.24 + 3.15	3.17–6.08	3.62 + 3.76	2.91–4.74
SL	4.78 + 3.42	4.03–5.58	4.58 + 3.65	4.11–5.68
CL	2.2 + 2.21	1.72–2.79	2.45 + 2.51	1.96–2.95
OSL	2.48 + 2.43	2.12–2.97	2.42 + 2.13	2.07–2.69
RW	1.44 + 1.41	1.07–1.98	1.94 + 1.23	1.72–2.16
RL	0.68 + 0.08	0.42–1.07	0.93 + 0.71	0.79–1.18
OP2/OS (CI)	21.39 + 2.17	17.1–25.7	25.34 + 2.28	23.2–28.8
OS/(OL*OW) (RE)	0.73 + 0.04	0.6–0.8	0.77 + 0.03	0.7–0.8
OW/OL, %	61.03 + 5.29	53.6–68.8	61.41 + 3.88	56.2–68.0
SS/OS, %	33.18 + 4.89	26.1–45.4	25.84 + 3.59	20.9–34.5
CL/SL, %	46.37 + 3.71	40.0–54.7	50.51 + 3.37	46.2–57.4
OL/SL, %	52.42 + 3.29	45.4–58.8	49.98 + 2.90	45.3–53.9
RW/RL, %	221.08 + 46.02	164.317.4	206.21 + 28.09	171.9–255.3
RL/OL, %	27.16 + 5.38	17.7–33.8	39.59 + 5.89	29.9–47.7
CL/SL	0.46 + 0.04	0.4–0.5	0.51 + 0.03	0.5
OL/SL	0.52 + 0.03	0.5–0.6	0.50 + 0.03	0.5

OL, otolith length; OW, otolith width; OP, otolith perimeter; OS, otolith surface; SP, sulcus perimeter; SS, sulcus surface, SL, sulcus length; CL, cauda length; OSL, ostium length; RW, rostrum width; RL, rostrum length; CI, circularity; RE, rectangularity.

1994). Larger eyes and bright colours are characteristics of species living in shallow waters. Such criteria assist the fish in visual communication. The otoliths of these species are usually small so they can avoid background noise produced by rough seas (Lombarte *et al*., 2010). On the contrary, a darker colouration is characteristic of species inhabiting deeper or dimly illuminated waters in which they possess larger otoliths (Lombarte *et al*., 2010). This pattern was clearly noted in the two scarid species studied, illustrating the relationship of morphology, external colouration and otolith size. The two species studied are pelagic, live in water depths ranging from the surface down to 50 m (Froese & Pauly, 2016) and have small otoliths. These observations are in agreement with those of snappers from the Persian Gulf (Sadighzadeh *et al*., 2014). Differences in colour are also important in sympatric, brightly coloured species as it is an essential component of sexual selection. Notothenoid species have similar relationships between otolith size, habitat and behaviour (Klingenberg & Ekau, 1996; Lombarte *et al*., 2003). The development of the antero-dorsal area of the sagittal otolith can be related to the behaviour of the fish.

Table 4. Statistical relationship of morphometric traits of *Chlorurus sordidus* and *Hipposcarus harid*.

$Y = b\,X^a$	R^2
Chlorurus sordidus	
$OL = 1.207\ OW^{0.590}$	0.28
$OL = 4.370\ OP^{6.857}$	0.79
$OL = 0.594\ OS^{1.825}$	0.79
$OL = 0.652\ SP^{1.819}$	0.77
$OL = 0.044\ SS^{2.722}$	0.87
$OL = 0.626\ SL^{1.210}$	0.86
$OL = 0.368\ CL^{1.066}$	0.43
$OL = 0.484\ OSL^{0.975}$	0.76
$OL = 0.480\ RW^{0.652}$	0.14
$OL = 0.034\ RL^{1.766}$	0.38
Hipposcarus harid	
$OL = 1.066\ OW^{0.673}$	0.43
$OL = 2.543\ OP^{1.180}$	0.86
$OL = 0.523\ OS^{1.939}$	0.85
$OL = 6.698\ SP^{0.393}$	0.09
$OL = 0.169\ SS^{1.801}$	0.61
$OL = 0.753\ SL^{1.099}$	0.79
$OL = 0.248\ CL^{1.351}$	0.72
$OL = 0.426\ OSL^{1.024}$	0.63
$OL = 1.028\ RW^{0.374}$	0.19
$OL = 0.564\ RL^{0.564}$	0.10

OL, otolith length; OW, otolith width; OP, otolith perimeter; OS, otolith surface; SP, sulcus perimeter; SS, sulcus surface, SL, sulcus length; CL, cauda length; OSL, ostium length; RW, rostrum width; RL, rostrum length; R^2, correlation coefficient.

Sadighzadeh *et al*. (2014) found such a relationship in the variations of snapper otolith.

The results of the present study show that there are variations in the overall morphology of the otoliths from small-sized adult individuals of *C. sordidus* and small-sized young fishes of *H. harid*. Out of 22 otolith characters examined, *C. sordidus* and *H. harid* have 13 and 14, respectively, which are similar between young and adult. Such variation may be related to the organic matrix and the way in which $CaCO_3$ is deposited during sagittal development (Volpedo & Echevarria, 2003). In the species studied here, calcium is not uniformly deposited as the otolith grows, judging from the inconsistency of shape throughout the ontogenetic development of the two species. This result agrees with the work of Smale *et al*. (1995) on *H. harid* of 325 and 424 mm, and with the descriptions of other scarid species (Rivaton & Bourret, 1999, on *S. rivulatus* of 291 mm; Lin & Chang, 2012, on *H. longiceps* of 203 mm; Sadighzadeh *et al*., 2012, on *S. ghobban* of 191 mm).

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The two scarid species studied shared similar patterns in otolith morphology from different fish length groups. These characters cannot be used as a tool to separate these species from other members of the family Scaridae as members of other scarid genera also share them.

The shape of the otolith varies between oval and oblong in *C. sordidus*, but is oblong in the otoliths of both small- and large-sized fishes of *H. harid*. In the case of *C. sordidus*, there are only two shapes and with such variation it is possible to separate the otoliths of the small-sized adult (GI and GII) from the large-sized adult. For *H. harid*, it is possible to determine a predictable shape for its otolith. Such consistency can be used as a trait for identifying this species. Such a result does not agree with that of Smale *et al.* (1995) on the same species.

Three margins of the otolith, dorsal, ventral and posterior, show a wide range of shape variation in the two scarid species studied. There are grades of lobation and irregularities in their shapes throughout the different length groups. This result is in agreement with those obtained for triplefin (*Enneapterygius* spp.) by Jawad (2008) and Jawad *et al.* (2007) on *Saurida tumbil*.

The shape of both cristae superior and inferior of the otoliths of the two scarid species cannot be considered as a criterion to separate the otoliths of fishes from different length groups. The shape and nucleus location result from the release of soluble Ca^{2+} on the proximal side (Ibsch *et al.*, 2004), which in turn 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, the growth of the crista superior and crista inferior is privileged and there is a more important development of the sulcal side. The macula is elongated and narrow in teleosts, and the cristae superior and inferior are proportionally more important than the colliculum (Ladich & Popper, 2001). The macula faces the column, and prevents otolith growth at this level (Pannella, 1980; Popper & Hoxter, 1981). This is clear in some species where the column is either poorly developed or absent. Lombarte *et al.* (2003) showed the variability in the shape of the sagitta in *Merluccius* as a relation to genetic, ontogenetic and environmental factors. Many previous studies on otoliths from fossil and extant fish have demonstrated that the sulcus morphology usually is consistent among the species of a single genus (Nolf, 1985), and thus this feature is probably controlled genetically (Gauldie, 1988).

However, sulcus variation has been shown to be related with specialization in hearing abilities, and thus interspecific sulcus variation may result from ecomorphological adaptations (Ramcharitar *et al.*, 2004; Popper *et al.*, 2005).

Apart from sulcus morphology, a correlation between particular otolith features (e.g. rostrum, antirostrum proportions) and biological functions such as swimming ability, feeding or other activities has not yet been established (Popper *et al.*, 2005). Considering the great diversity of teleost fishes there might be some correlation between the otolith rostrum length and swimming ability (Volpedo & Echevarria, 2003), but this has not been shown to be significant in the discrimination of closely related species (Reichenbacher *et al.*, 2007). In the present study, the general morphology of the rostrum is broad, long and pointed in *C. sordidus*, and large, broad, rounded or blunt in *H. harid*. Such consistency in these features agrees with the finding of Reichenbacher *et al.* (2007).

The shape of the excisura in the otoliths of fish of different length groups of both *C. sordidus* and *H. harid* is not considered to be a good taxonomic character to separate the two species from their congeners.

Significant variations in the morphology of the otoliths of *C. sordidus* and *H. harid* were observed. These variations exist in specimens taken from close geographic regions. Smale *et al.* (1995) described the morphology of *C. sordidus* from Dahab, Sinai, Red Sea, and *H. harid* from the Red Sea. Their descriptions cover different aspects of the otolith morphology and are not restricted to certain criteria. Changes in physical and chemical parameters may be responsible for differences in calcareous concrescence formation in fishes (Kumar *et al.*, 2012). The presence of a cauda and an ostium with different textures, where the cauda curves to the ventral margin and is much deeper than the ostium have also been reported (Correa & Vianna, 1993). Baldas *et al.* (1997) have reported a similar calcareous concrescence and a dorsal depression in the inner face. The selective pressures act on sagittae so that their morphology meets specific auditory needs (Platt & Popper, 1981; Popper & Coombs, 1982; Gauldie, 1988). Some otolith size differences are related to fish growth, but otoliths in very large species can be much smaller than those of small species and vice versa (Campana, 2004). A limited comparison made by Friedland & Reddin (1994) suggested greater genetic influences on otolith shape.

The geographic variations observed in the morphology of the otoliths of *C. sordidus* are in agreement with the findings herein. Rivaton & Bourret (1999) showed an image of an otolith of a specimen of *C. sordidus* (235 mm) with the following set of characters. These characters were compared with those of the otoliths obtained from fish of the same length group in our sample. The characters were: the dorsal margin is lobed *vs* flat and smooth, ventral margin lobed *vs* slightly irregular, posterior margin straight with notch *vs* rounded, cauda deep *vs* shallow and excisura shallow, notch wide and angle acute *vs* absent. The descriptions of the otolith in Rivaton & Bourret (1999) and of those in the present paper provide an integrated description of the otolith of this species.

The results from our analysis also demonstrate intraspecific variations in otolith shape for each species. This suggests that a genetic flow within populations of both species. The overall data collected in this study indicate that variability in otolith shape can be added to the traits describing each species. Bani *et al.* (2013) reached a similar conclusion in their study on gobiids from the Caspian Sea. 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 species.

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