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Otolith Morphology and Body Size Relationships for Selected Fishes in Suez Canal and Gulf of Suez

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ABSTRACT

The morphology of the sacular otolith (sagitta) was studied by means of image analysis of 28 extant species from Suez Canal and Gulf of Suez. The shape, margins and rostrum of sagittal otoliths for all species were analyzed. No difference was detected between left and right otolith length for any of the otolith pairs (paired t-tests, all p > 0.20). The largest otolith was recorded in *Morone saxatilis* and *Argyrosomus regius*; while the smallest otolith was recorded in *Myripristis botche*. Also, otolith weight or mass was varying between studied fishes, where the heaviest otolith was recorded in *Plectropomus leopardus*. Morphological characteristics of fish otoliths were highly variable between species, ranging from the relatively simple disc shape (*Terapon puta*, Terapontidae) to the irregular shape in *Myripristis botche* (Holocentridae). The shapes of the otolith of studied species were varying from oblong, ovate, fusiform, elliptic, rhomboidal and triangular. The margin sculpturing of these otoliths have four characters: irregular, lobed, entire and dentate. The relationships between otolith and fish size which examined by plotting the value of the otolith length and weight against the length and weight for each fish.

Key words: Otolith, morphology, Suez Canal, Gulf of Suez, Egypt.

INTRODUCTION

A great variation exists in the relative size of the three pairs of otoliths, but in most species the saccular otolith (sagitta) is bigger than the other otoliths (Nolf, 1985). The otoliths are calcium carbonate located in the inner ear of fish, which act as sound transducers and play an important role in fish hearing and balancing (Gauldie, 1988). Because of their accretionary growth and species (sometimes population) specific shape, they can be used as tools in fish aging (Gauldie, 1994; Karlou-Riga, 2000) determination of stock relationships and stock identification (Messieh *et al.*, 1989; Castonguay *et al.*, 1991; Campana and Casselman, 1993; DeVries *et al.*, 2002; Cardinale *et al.*, 2004), ecomorphological studies (Lombarte and Fortuno, 1992; Aguirre and Lombarte, 1999; Paxton, 2000; Lombarte *et al.*, 2003; Cardinale *et al.*, 2004), and identification of fish species in archaeological, fossil samples (Carpenter *et al.*, 2003) or in the stomach content samples of predators for dietary item identification (Cottrell *et al.*, 1996). The otolith size and shape is species specific and their phylogenetic patterns can be reflected in their morphology (Gaemers, 1984; Nolf, 1985; Nolf and Sterbaut, 1989).

External morphology and macrostructure of fish otoliths provide a great deal of biological information, for instance on age, growth and environmental conditions. Many studies have identified population structure using otolith morphometry (Iizuka, 2004). Otolith shape analysis is a way providing information on species (Nolf, 1985), their ecobiological parameters (Morales-Nin, 2000) and geographic origin (Castonguay *et al.*, 1991; Campana and Casselman, 1993). The otolith shape variability has been related to environmental factors, such as depth, water temperature and substrate type (Lombarte *et al.*, 2003; Monteiro *et al.*, 2004). Therefore, it is possible to conclude that an automatic system, able to describe and identify otolith shapes, which can be of general use for many ecological and biological studies.

The shape of the otoliths has specific value, which allows species to be identified and taxonomic relationships to be evaluated (Gaemers, 1984; Nolf and Steurbaut, 1989). Morphological characteristics of fish otoliths are highly variable between species, ranging from the relatively simple disc shape of some flatfish (Pleuronectidae) to the irregular shape of others such as redfish (Sebastes sp.). Otolith growth is related to increase in size of the fish and generally follows an allometric increase in dimensions (Chilton and Beamish, 1982).

The shapes of the otolith of different fish species are vary from oblong, oval, ovate, fusiform, elliptic, rhomboidal, triangle to triangular. The margin sculpturing of these otoliths have four characters: irregular, lobe, entire and dentate. Other morphologies of sagittal otoliths e.g. rostrum, antirostrum, ostium, cauda, dorasal area and ventral are also species specific (Smale *et al.*, 1995). The present research is a pioneer study, which tries to investigate otoliths morphology of some fishes from Suez Canal and Gulf of Suez. The main objective of the present study was to find otolith characteristics that may help in differentiation between fish species, based on variations in otolith morphology.

MATERIALS AND METHODS

Samples collection and Identification

Otolith pairs for 28 selected fish species were examined to obtain mean otolith shape and dimensions. Samples were collected during July 2007 to May 2008 from Suez Canal, Gulf of Suez and inland water in Suez

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Canal region. Also some samples were collected from fish markets along Suez Canal. Species identification was based on Randall (1983).

Otolith removal, measurement and description

Otolith removal was conducted under a dissecting microscope. The head of the fish was cut using scissors, and a forceps was used to remove the otoliths from each side of the skull. Otoliths from the left and the right side of the skull were separated. Otoliths were cleaned in distilled water and left to dry at room temperature for 15 min and then mounted on a labeled glass slide. Each otolith was immersed in 70% ethanol solution in a glass dish. The otoliths were photographed under reflected light at 100 magnification under a dissecting microscope with an Olympus C3030 digital camera (Olympus Corporation, Tokyo, Japan) connected to a computer with analysis software version 3.1 (SIS GmbH, Hamburg, Germany). Otolith length (OL), height (OH), weight (OM) and width (OW) were measured, and described using the terminology of Smale *et al*. (1995). All fish body lengths and weights were measured. The shape, margins and rostrum of otoliths for all species were analyzed. LR (length of the rostrum) in millimeters, with an error less than 0.01 mm. Two indexes, *E* and *R*, were calculated from the otoliths of 28 species. The *E* value (E = OW/OL %) expresses the tendency in the shape of the otoliths (circular or elongate). The *R* value (R = LR/OL %) expresses the percentage in the TL of the otoliths that corresponds to the rostrum.

Relationships between fish and otolith

The relationships between otolith length OL (mm), otolith width OW (mm) and otolith weight OM (g) and fish total length TL (cm) and total weight TW (g) were investigated. Fish and otolith weights were log-transformed to linearise data for the calculation of 95% confidence limits of regressions and associated predictions. Data were subsequently back-transformed to natural units.

Data analysis

The data were analyzed statistically using the software packages SPSS (V 15.0). This software was used for all statistical procedures. Before any application of ANOVA, the homogeneity of variances was examined using the Bartlett's test (Zar, 1984). All of the statistical inferences were based on the 0.05 significance level.

RESULTS

Otolith description and morphology

There is no significant differences between left and right otolith length for any of the otolith pairs (paired t-tests, all $p > 0.20$). Regression of the difference between left and right otolith on fish length indicated slopes not significantly different from zero with low correlation for length, weight and width. The shapes and margin of the otoliths of the studies species were vary widely between different species. The largest otolith was recorded in *Morone saxatilis* (11.6±1.9 OL – 5.8±1.1 OW) and *Argyrosomus regius* (11.5±0.4 OL – 6.8±0.2 OW); While the smallest otolith was recorded in *Myripristis botche* (1.9±0.3 OL – 1.4±0.1 OW), as shown in Table (1). Otolith weight (OM) was also vary between the studied fishes, where the heaviest otolith was recorded in *Plectropomus leopardus* (OW 0.40 g, with TL 19.4 cm), which represent half length of the largest fish, *A. regius* (TL 41.3 cm). This confirm that the thickness of otolith vary between different species (the weight of the otolith not only related with length of otolith, but also with thickness).

Morphological characteristics of fish otoliths were highly variable between different fish species Figs. (1-4), ranging from the relatively simple disc shape of *Terapon puta* (Terapontidae) to the irregular shape of others such as *Myripristis botche* (Holocentridae),. Table (2) shows the morphometrics description of the otoliths of all examined species. The shapes of the otolith of studies species were vary from oblong, ovate, fusiform, elliptic, rhomboidal and triangular, (Table 2). The margin sculpturing of these otoliths have four characters: irregular, lobe, entire and dentate. Some otoliths were very thin (laterally compressed; thickness = 0.2 mm), such as *Sardinella aurita*, *Myripristis botche* and *Siganus rivulatus*. The others were thick such as *Lethrinus lentjan* and *Argyrosomus regius* (thickness > 1.9 mm), (Table 2).

Otoliths of group 1 (including 7 species) showed a circular or polygonal shape and rounded borders, where *R* value equal zero. The rostrum was absent in the otoliths of *Lethrinus lentjan*, *Terapon puta*, *Tilapia zillii*, *Rhabdosargus haffara* and *Scarus ferrugineus* (Figs. 1 B, D, E, F and H). The rostrum was present but less evident in the otoliths of *Mugil cephalus* and *Argyrosomus regius* (Fig. 2 B and C). The mean values of the *E* index for group 1 were ranged between 5.0 and 9.4, but the *R* indices were ranged between 0 to 0.5, Table 2. The otoliths of group 2 (including 9 species) showed an elongated shape and ornamented margins. In all the otoliths of this group, the rostrum was present with different degrees of development. The most developed rostrum was found in *Scomberoides lysan, Caranx crysos, Sardinella aurita, Barbonymus schwanenfeldii, Synodontis schall, Dicentratrachus punctatus, Scomber japonicus, Plectropomus leopardus* and *Siganus rivulatus* (Figs. 1-4). The mean values of the *E* index for group 2 were ranged between 3.3 and 9.6, and the *R* indices were ranged between 4.0 to 11.2. The otoliths of group 3 include the other studied species, where the *R* index was ranged between 0.6 to 4.0.

Table (1): The average (means ± SD) for the standardized morphometries of otolith and fish length and weight for all examined species.

Fish species	Fish length (cm)	Fish weight (gm)	Otolith (mm)		
			length	width	weight
Family: Carangidae					
Scomberoides lysan	28.8±7.4	156.9±67.2	4.6±0.7	1.7±0.3	0.004±0.001
Caranx crysos	16.5±1.0	36.7±21.7	4.5±1.1	2.5±0.6	0.010±0.007
Family: Clupeidae					
Sardinella aurita	10.6±1.6	11.5±6.5	2.0±0.3	1.0±0.2	0.002±0.003
Family: Cyprinidae					
Barbonymus schwanenfeldii	28.8±4.1	228.9±215.1	3.7±0.4	2.8±0.3	0.008±0.002
Family: Holocentridae					
Myripristis botche	16.4±3.4	90.9±41.8	1.9±0.3	1.4±0.1	0.022±0.002
Family: Lethrinidae					
Lethrinus lentjan	28.5±6.1	427.0±228.5	9.7±1.4	6.8±1.1	0.17±0.07
Family: Mochokidae					
Synodontis schall	17.3±3.0	63.4±32.9	5.1±1.2	2.8±0.6	0.003±0.002
Family: Moronidae					
Dicentratrachus punctatus	25.3±3.4	199.9±88.1	8.5±0.7	4.3±0.03	0.05±0.02
Morone saxatilis	35.7±7.5	682.3±417.1	11.6±1.9	5.8±1.1	0.10±0.05
Family: Mugilidae					
Liza carinata	13.1±3.2	25.3±8.0	4.3±0.5	1.8±0.2	0.006±0.001
L. ramada	25.7±1.9	141.9±33.5	7.6±0.3	3.5±0.4	0.032±0.004
Mugil cephalus	28.2±3.0	234.4±93.4	7.0±0.5	3.3±0.4	0.060±0.06
Family: Mullidae					
Parupeneus porphyreus	14.1±4.5	38.6±43.5	2.7±0.4	1.7±0.3	0.004±0.001
Family: Cichlidae					
Oreochromis niloticus	19.0±3.7	152.4±68.2	6.8±0.9	4.3±0.4	0.09±0.01
Tilapia zillii	15.1±1.7	69.9±21.2	5.2±0.5	3.7±0.4	0.03±0.01
Family : Platycephalidae					
Platycephalus indicus	25.3±3.9	111.9±55.2	6.1±0.05	2.0±0.4	0.013±0.005
Family: Scaridae					
Scarus ferrugineus	19.3±1.1	148.8±26.1	4.2±0.3	2.6±0.3	0.07±0.04
Family: Sciaenidae					
Argyrosomus regius	41.3±7.06	643.9±131.8	11.5±0.4	6.8±0.2	0.33±0.03
Family: Scombridae					
Scomber japonicus	22.4±1.1	120.9±18.6	4.3±0.4	1.8±0.1	0.005±0.001
Family: Serranidae					
Acanthistius ocellatus	20.8±6.3	144.5±145.6	8.6±2.2	4.1±0.9	0.3±0.005
Epinephelus fasciatus	20.1±1.3	117.0±46.2	6.7±0.4	3.3±0.3	0.3±0.1
Plectropomus leopardus	19.4±1.6	139.0±38.7	8.0±0.1	3.9±0.3	0.4±0.1
Family: Siganidae					
Siganus rivulatus	14.7±1.6	33.0±10.8	2.2±0.3	1.3±0.2	0.002±0.0004
Family: Sparidae					
Pagellus erythrinus	18.3±2.2	79.5±34.8	7.4±1.3	4.8±0.8	0.05±0.03
Rhabdosargus haffara	22.4±2.0	154.7±52.2	6.5±0.3	3.9±0.1	0.029±0.003
Family: Synodontidae					
Trachinocephalus myops	18.9±1.1	42.5±7.4	5.7±0.3	1.9±0.2	0.011±0.002
Family: Terapontidae					
Terapon jarbua	11.6±0.5	19.4±2.5	3.7±1.3	1.5±0.2	0.005±0.004
T. puta	10.7±0.7	20.8±4.2	4.9±0.4	3.3±0.3	0.022±0.002

Relationships between fish and otolith

Regression analyses of otolith length against fish length indicate simple relationships between variables with otolith length increasing with increasing body size. The data are reasonably well fitted with simple linear regressions. Similar results were obtained from scatter plots of otolith weight against fish weight. The relation between otolith size and fish size is examined by plotting the value of the otolith length and weight against the length and weight of each fish (Fig. 5). Scatter plots of otolith size of four studied species were shown strong relationships (*Tilapia zillii*: r^2 0.972 for length and r^2 0.983 for weight; *Lethrinus lentjan*: r^2 0.958 for length and r^2 0.973 for weight; *Liza carinata*: r^2 0.836 for length and r^2 0.892 for weight; *Mugil cephalus*: r^2 0.920 for length and r^2 0.796 for weight). Generally, the relationships between fish length and otolith length were linear, and most of the variability was explained by the regression ($r^2 > 0.7$ in all cases, Fig. 5). All relationships were significant ($p < 0.05$). Higher r^2 values compared to those obtained from otolith linear dimensions, suggested that otolith mass or weight can provide more useful predictor of fish size than otolith length measurements.

DISCUSSION

Many of the published regressions of fish length to otolith length were developed for species common in food habits studies of marine mammals (Frost and Lowry, 1981; Brown and Mate, 1983) or species that were commercially important (Spratt, 1975; Boehlert and Yoklavich, 1984). In the present study, the most studied species were commercially important. The relationships of otolith length, weight and width with

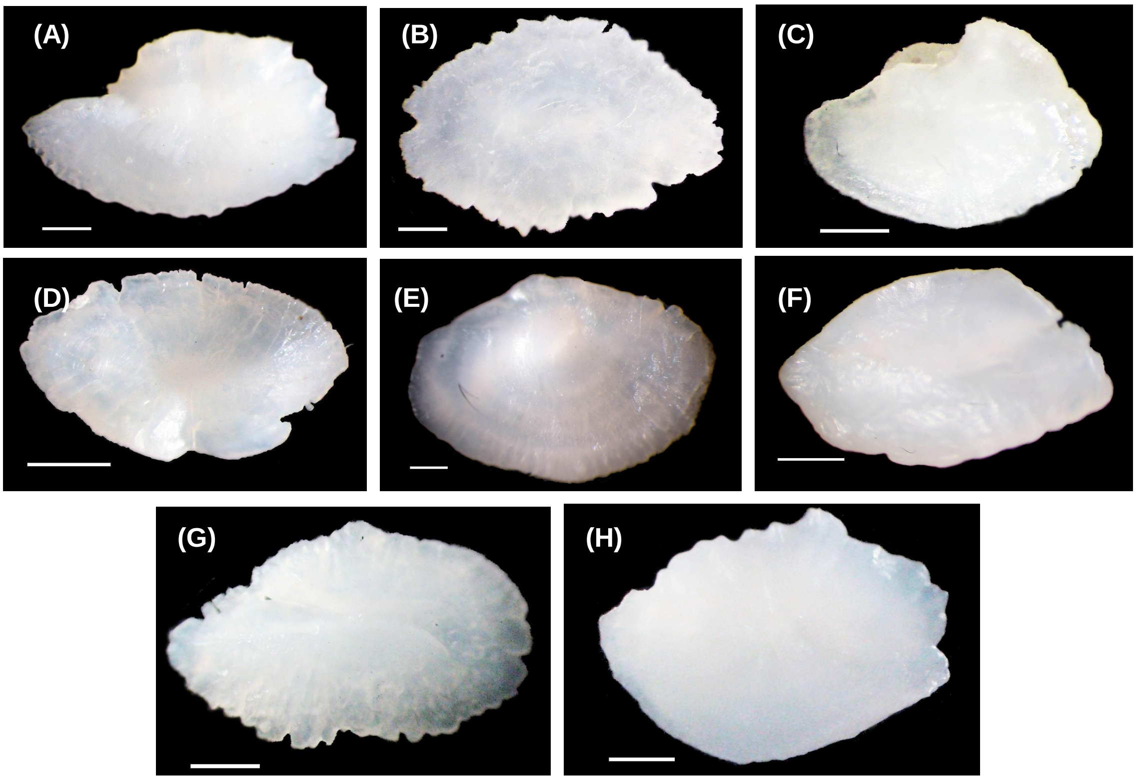

Figure (1): Morphology of otolith of selected fish. A: *Caranx crysos*, B: *Tilapia zillii*, C: *Synodontis schall*, D: *Rhabdosargus haffara*, E: *Terapon puta*, F: *Scarus ferrugineus*, G: *Oreochromis niloticus*, H: *Lethrinus lentjan*. Scale: 1 mm.

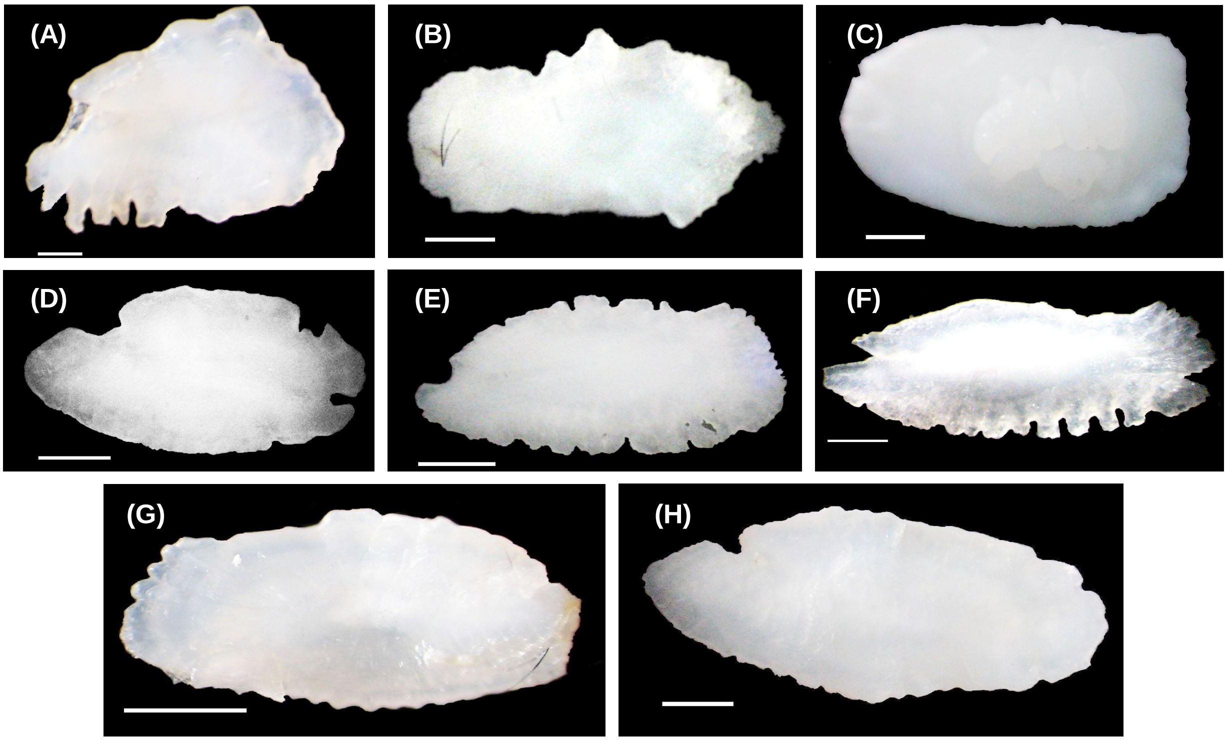

Figure (2): Morphology of otolith. A: *Parupeneus porphyreusr*, B: *Mugil cephalus*, C: *Argyrosomus regius*, D: *Plectropomus leopardus*, E: *Liza ramada*, F: *Liza carinata*, G: *Epinephelus fasciatus*, H: *Acanthistius ocellatus*. Scale: 1 mm.

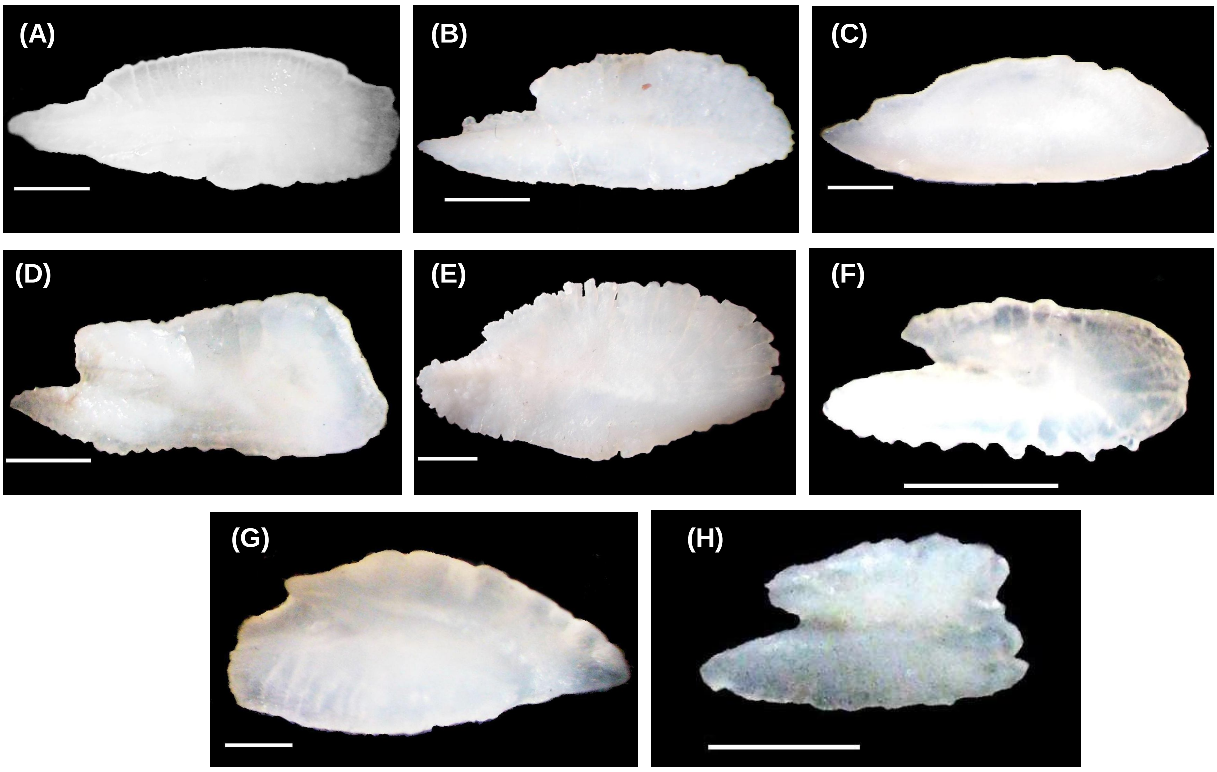

Figure (3): Morphology of otolith. A: *Trachinocephalus myops*, B: *Scomberoides lysan*, C: *Platycephalus indicus*, D: *Scomber japonicus*, E: *Morone saxatilis*, F: *Saradinella aurita*, G: *Terapon jurabon*, H: *Siganus rivulatus*. Scale: 1 mm.

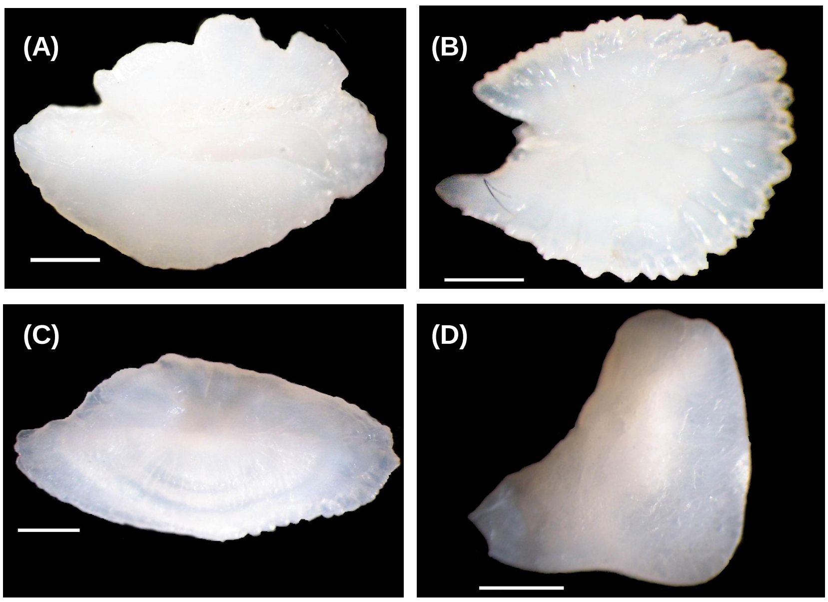

Figure (4): Morphology of otolith. A: *Pagellus erythrinus*, B: *Barbonymus schwanenfeldii*, C: *Dicentrarchus punctatus*, D: *Myripristis botche*. Scale: 1 mm.

Table (2): List of fish species and the morphometrics description of the otolith for all examined species, *E* = OW/OL %, *N* = total number of otolith samples; *R* = LR/OL %.

	Shape	Margin	Thickness	*N*	*E*	*R*
Family: Carangidae						
Scomberoides lysan	Triangular	Lobed	0.3	22	3.3	11.2
Caranx crysos	Ovate	Irregular	0.4	13	4.1	4.0
Family: Clupeidae						
Sardinella aurita	Rhomboidal	Dentate	0.2	36	4.8	9.8
Family: Cyprinidae						
Barbonymus schwanenfeldii	Rhomboidal	Dentate	0.4	11	9.6	4.0
Family: Holocentridae						
Myripristis botche	Trilobite	Entire	0.2	9	14.3	2.7
Family: Lethrinidae						
Lethrinus lentjan	Ovate	Irregular	1.9	31	8.5	0
Family: Mochokidae						
Synodontis schall	Ovate	Entire	0.7	12	8.6	6.3
Family: Moronidae						
Dicentratrachus punctatus	Ovate	Dentate	1.0	29	5.4	4.9
Morone saxatilis	Fusiform	Dentate	1.1	24	5.6	2.8
Family: Mugilidae						
Liza carinata	Rhomboidal	Irregular	0.3	25	4.4	2.0
L. ramada	Pyriform	Dentate	0.7	21	5.1	1.0
Mugil cephalus	Oblong	Irregular	0.6	19	6.2	0.5
Family: Mullidae						
Parupeneus porphyreus	Ovate	Irregular	0.3	24	6.9	0.8
Family: Cichlidae						
Oreochromis niloticus	Pyriform	Dentate	0.5	21	6.1	1.6
Tilapia zillii	Pyriform	Dentate	0.7	28	9.4	0
Family : Platycephalidae						
Platycephalus indicus	Rhomboidal	Entire	0.5	9	3.4	1.2
Family: Scaridae						
Scarus ferrugineus	Rhomboidal	Entire	0.7	11	7.6	0
Family: Sciaenidae						
Argyrosomus regius	Oblong	Entire	2.8	12	6.9	0.5
Family: Scombridae						
Scomber japonicus	Triangular	Entire	0.4	15	4.7	4.0
Family: Serranidae						
Acanthistius ocellatus	Ovate	Dentate	0.9	15	4.9	2.8
Epinephelus fasciatus	Oblong	Entire	0.6	16	5.8	0.5
Plectropomus leopardus	Ovate	Lobed	0.9	11	5.0	4.1
Family: Siganidae						
Siganus rivulatus	Triangular	Lobed	0.2	23	9.5	7.3
Family: Sparidae						
Pagellus erythrinus	Ovate	Irregular	1.2	19	8.9	2.7
Rhabdosargus haffara	Ovate	Irregular	0.7	24	6.8	0
Family: Synodontidae						
Trachinocephalus myops	Triangular	Irregular	0.4	23	3.5	2.8
Family: Terapontidae						
Terapon jarbua	Elliptic	Irregular	0.8	9	8.0	1.2
T. puta	Ovate	Entire	0.5	8	5.0	0

fish length were species-specific, and even within closely related species, considerable differences occurred. Strong relationships between otolith size and fish size have been observed for many species of fishes found in other parts of the world (Waessle *et al.*, 2003).

Fish size-otolith size relationships will be useful for researchers examining food habits of piscivores and size of fish in archaeological samples. Many more species and sizes of fish should be sampled to cover the full range of fishes involved in these studies. Otoliths have been used to identify fish species eaten by marine predators (Brown and Mate, 1983; Harvey, 1987). Specific guides or keys to fish otoliths also have been published (Hecht, 1987; Smale *et al*., 1995). Generally, standard length of fishes is linearly related to otolith length. Predicting size of fishes (length and weight) can be accomplished with fair reliability on the basis of otolith length. This relationship, however, is not always reliable. Otolith length typically is linearly related to length of the fish until the fish reaches its maximum size; thereafter, the otolith increases only in thickness (Blacker, 1974). One difficulty is that otoliths may erode during digestion and that the degree of erosion is species-specific (Bowen, 2000). Degradation due to digestion may result in biases when otoliths are used to identify diet composition in higher predators.

The otoliths showed different morphological patterns in the different ecological studied groups. The otoliths of fish associated with the bottom presented differences in their borders and topography, the common feature of the morphology was rounded. The rostrum of the otoliths was absent or insinuated in fishes related to soft bottoms, the rostrum of fishes related to hard substrates was short and not prominent. In the present study, the otoliths of group 1 (including 7 species) showed a circular or polygonal shape and rounded borders, where

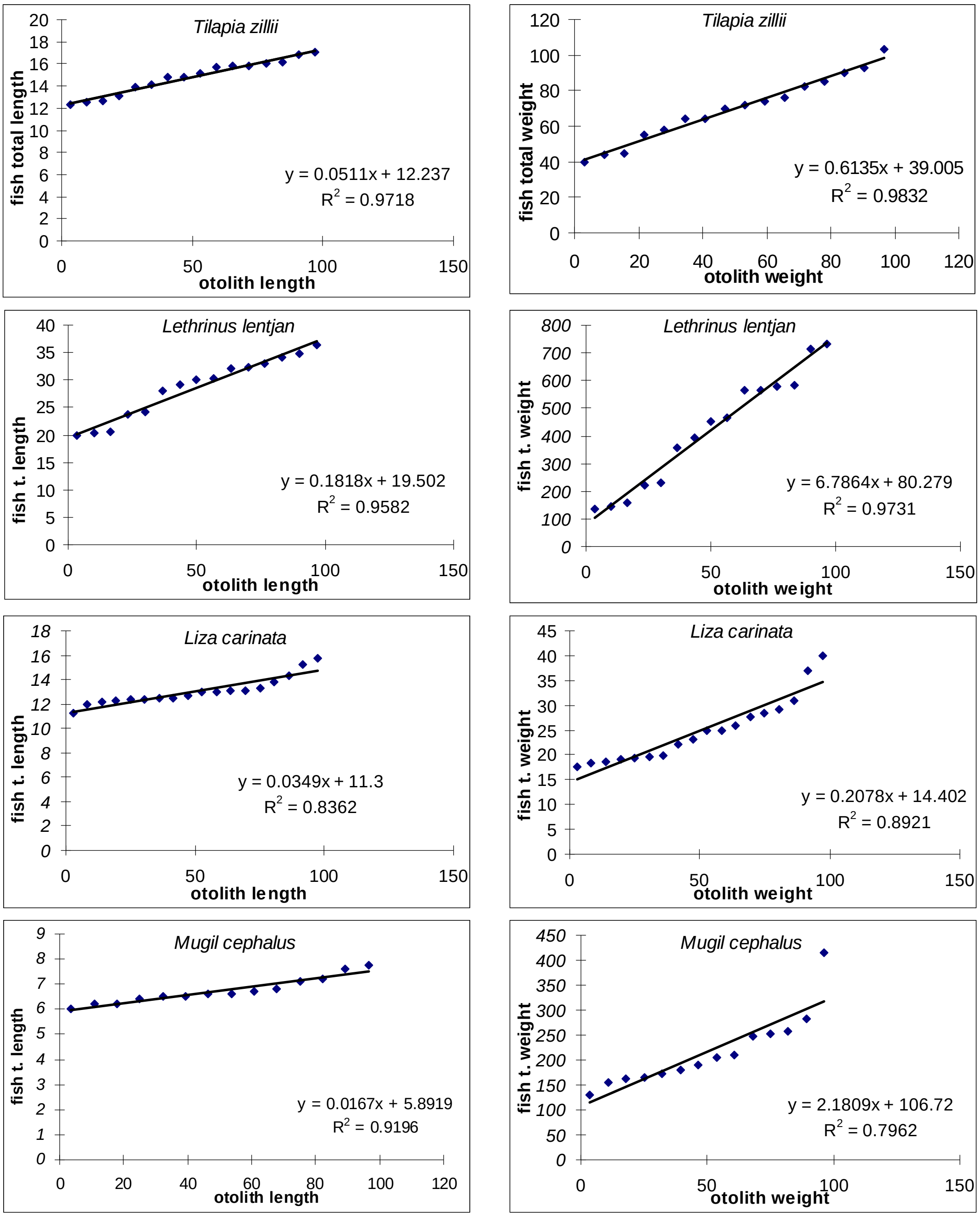

Figure (5): The relationships between otolith size and fish size for four species (*Tilapia zillii, Lethrinus lentjan, Liza carinata* and *Mugil cephalus*).

R value equal zero (no rostrum or very short). Most of these species lives in soft bottom habitats in Suez Canal and Gulf of Suez.

Otolith weight can be used to provide predictions of fish length or fish weight. However, we would not recommend estimating of fish weight directly from otolith weight measurements as this is likely to vary with spawning condition. Previous studies on otoliths have, however, found there to be no difference between the size of otoliths in males and females. Strong relationships between otolith size and fish size have been observed for many species of marine and freshwater fishes found in other parts of the world, including studies on Mediterranean species (Massuti *et al.*, 1995) and those found in South African waters (Smale *et al.*, 1995). In the present study, the otolith size was strongly correlated with fish size for many species, especially the four species (*Tilapia zillii*, *Lethrinus lentjan*, *Liza carinata* and *Mugil cephalus*) (Fig. 5).

Comparative ecomorphological studies with a larger number of species should be carried on to investigate this issue and to assess the relative importance of ecological factors in otolith shape determination. Our results will be useful for researchers studying food habitats of piscivorous fish, archaeology and fish ecology or fish taxonomy to identify fish family and species from recovered otoliths. Many more species of fish will be sampled to cover all Egyptian marine and freshwater fishes and a reference collection of otoliths will be established in the future. Based on the findings in this study we suggest that more work should be done to investigate the possibility of using otolith measurements to improve precision and accuracy in food determination of piscivorous fish.

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الشكل الظاهرى لحصوة الأذن وعلاقاتها بحجم الجسم لبعض الأسماك المختارة من قناة السويس وخليج السويس

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أجريت هذه الدراسة للتعرف على الشكل الظاهرى لحصوة الأذن (الساجتا) بتحليل الصور الملتقطة للحصوات لعدد 28 نوع من أسماك قناة السويس وخليج السويس. تم فحص ووصف الأشكال والحواف والبروزات للحصوات الأذنية لجميع الأنواع محل الدراسة. وقد وجد أنه لا توجد إختلافات معنوية بين طول الحصوات اليمنى واليسرى لجميع الأنواع المختارة. أكبر حصوة أذنية سجلت فى سمكة مورونى ساكستيلس وسمكة أرجروسوس رجيس، بينما تم تسجيل أصغر حصوة أذنية فى سمكة ميريبستس بوتش. أيضا إختلف وزن الحصوة ما بين الأنواع، حيث سجلت أثقل الحصوات فى النوع بلكتروبوس ليوباردس. كذلك وجد أن الخصائص والصفات الظاهرية للحصوة الأذنية للأسماك محل الدراسة متغيرة، حيث تتراوح بين المنتظمة ودائرية الشكل مثل سمكة تيرابون بوتا (عائلة تيرابونتيدى) الى الغير منتظمة الشكل مثل سمكة ميريبستس بوتش (عائلة الهولوسنتريدى). كما تنوعت أشكال حصوات بين الشكل المستطيلى والبيضاوى والإنسيابى والهلالى والمعينى والمثلثى. كذلك الحواف إختلفت فيما بينها، حيث أظهرت الدراسة أن الحواف تتميز أو تنحصر فى أربعة صفات: غير المنتظمة والمفصصة والكاملة والمسننة. أيضا تم دراسة العلاقة بين حجم الحصوة وحجم السمكة بتمثيلها بيانيا لطول وعرض الحصوة الأذنية فى مقابل طول وعرض كل سمكة. الرسم البيانى لحجم الحصوة الأذنية لأربعة أنواع من الأسماك محل الدراسة (تيلابيا زيلى ، لثرنس لوتجانس ، ليزا كاريناتا ، ميوجل سيفالس) أعطى علاقة قوية ما بين حجم الحصوة وحجم هذه الأنواع الأربعة.