Relationships between otolith size and fish size in some mesopelagic and bathypelagic species from the Mediterranean Sea (Strait of Messina, Italy)

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SUMMARY: The length-weight relationships and the regressions between otolith size (length and width) and fish length of some mesopelagic and bathypelagic fishes living in the central Mediterranean Sea were provided. Images and morphological description of otoliths (sagittae) from 16 species belonging to the families of Gonostomatidae (1), Microstomatidae (2), Myctophidae (8), Phosichthyidae (2), Sternoptychidae (2) and Stomiidae (1) were given. The length-weight relationship showed an isometric growth in 13 species. No differences between right and left otolith sizes were detected by t-test, so a single linear regression was plotted against standard length (SL) for otolith length (OL) and otolith width (OW). Data fitted well to the regression model for both OL and OW to SL, for each species ($R^2>0.8$). These relationships offer a helpful tool in feeding studies and also provide support to palaeontologists in their research on fish fossils.

Keywords: mesopelagic fishes, bathypelagic fishes, otolith, fish-otolith sizes, length-weight relationship, Mediterranean Sea.

RESUMEN: RELACIONES ENTRE TALLA DEL OTOLITO Y TALLA DEL PEZ EN ALGUNOS PECES MESOPELÁGICOS Y BATIPELÁGICOS DEL MEDITERRÁNEO (ESTRECHO DE MESSINA, ITALIA). – En este trabajo se presentan las relaciones talla-peso y las regresiones entre la talla del otolito (longitud y anchura) y la talla del pez (SL) para algunos peces meso y batipelágicos que viven en el Mediterráneo central. Se incluyen imágenes y descripciones morfológicas de los otolitos (*sagittae*) de 16 especies de las familias Gonostomatidae (1), Microstomatidae (2), Myctophidae (8), Phosichthyidae (2), Sternoptychidae (2) y Stomiidae (1). La relación talla-peso muestra un crecimiento isométrico en 13 especies. No se encontraron diferencias relevantes (t-test) entre la talla del otolito derecho e izquierdo, por lo que se representó una sola regresión lineal entre la longitud estándar y los siguientes parámetros: longitud de otolite (OL) y la anchura (OW). Los datos se ajustaron bien al modelo de regresión lineal para OL y OW, para todas las especies ($R^2>0.8$). Las relaciones obtenidas puede ser utilizadas como instrumento en estudios de alimentación y para sustentar estudios de paleontología sobre peces fósiles.

Palabras clave: peces mesopelágicos, peces batipelágicos, otolito, pez-otolito, relación talla-peso, Mediterráneo.

INTRODUCTION

Mesopelagic and bathypelagic fishes are species usually living in mid-water masses (Salvanes and Kristoffersen, 2001), having a large vertical distribution (Gjøsaeter and Kawaguchi, 1980) and playing an important ecological role in the energy transfer from epipelagic waters to deep environments. In fact, they carry out large diel vertical migrations, moving to-wards the upper layers at night to feed on plankton or micronekton and coming back to deeper waters during the daytime to avoid predation (Marshall, 1960).

Mid-water fishes are a key component of the pelagic nekton and form a large fraction of the deep-scattering layer (DSL) (Benoit-Bird and Au, 2003). The high biomass of mesopelagic and bathypelagic fish communities in all oceans, especially in subtropical and tropical seas (Gjøsaeter and Kawaguchi, 1980; Mann, 1984;

Lam and Pauly, 2005), is an important food resource in the marine trophic web.

Studies on feeding behaviour have confirmed the mid-water species to be a primary trophic source for commercially important pelagic fishes such as tunas, mackerels and billfishes (Alverson, 1963; Abrams *et al.*, 1996; Hassani *et al.*, 1997; Lebourges-Dhaussy *et al.*, 2000; Moteki *et al.*, 2001; Consoli *et al.*, 2008). Moreover, several other predators, such as marine mammals (Hassani *et al.*, 1997; Pauly *et al.*, 1998; Springer *et al.*, 1999; Dolar *et al.*, 2003; Ohizumi *et al.*, 2003), seabirds (Springer *et al.*, 1999) and cephalopods (Marabello *et al.*, 1996; Watanabe *et al.*, 2004), rely on these food resources.

However, during feeding studies, the identification and quantification of these preys is frequently a difficult task: in most cases specimens are already partially or totally digested and the hard remains in stomachs, intestines, faeces and scats are the only diagnostic features that can be considered. In particular, otoliths are quite resistant to the digestion and they are an important tool for prey classification in several dietary studies (Granadeiro and Silva, 2000; Pierce and Boyle, 1991; Pierce *et al.*, 1991). Furthermore, the diet analysis of marine mammals and sea birds requires non-invasive methods, so the examination of *sagittae* from faeces and regurgitated digestive pellets is often the only way to recognize the preys (Pierce and Boyle, 1991; Pierce *et al.*, 1991; Duffy and Laurenson, 1983; Johnstone *et al.*, 1990). Their importance is also documented in stomach analysis of cephalopods that use their beaks to chop preys (e.g. Watanabe *et al.*, 2004), making them identifiable only by otolith determination.

For these reasons and thanks to their high interspecific variability, several keys and identification guides on fish otoliths have been published (Smale *et al.*, 1995; Campana, 2004; Lombarte *et al.*, 2006; Tuset *et al.*, 2008). To better understand the real role of fish preys' energy contribution to a predator diet, it is important to estimate their biomass and their numerical abundance. The rebuilding of body size and prey biomass from otolith measurement is possible by applying a back-calculation: a relationship between fish length and otolith size has been widely demonstrated in many fishes (Wyllie Echeverria, 1987; Gamboa, 1991; Granadeiro and Silva, 2000; Harvey *et al.* 2000; Waessle *et al.*, 2003).

Moreover, the resistance of otoliths to deterioration, due to their particular calcareous structure (a concretion of calcium carbonate and other salts deposited in a protein matrix), made it possible to use them in paleontological studies. Fossil otoliths are found in a wide spectrum of sedimentary environments and are common in many marine sediments (Nolf, 1995). By comparing them to recent reference collections, many authors have made an important contribution to knowledge of the taxonomic status of the ancient fauna of the planet and to the validity of otolith-based fossil fish species (e.g. Nolf, 1985, 1995; Girone *et al.*, 2006).
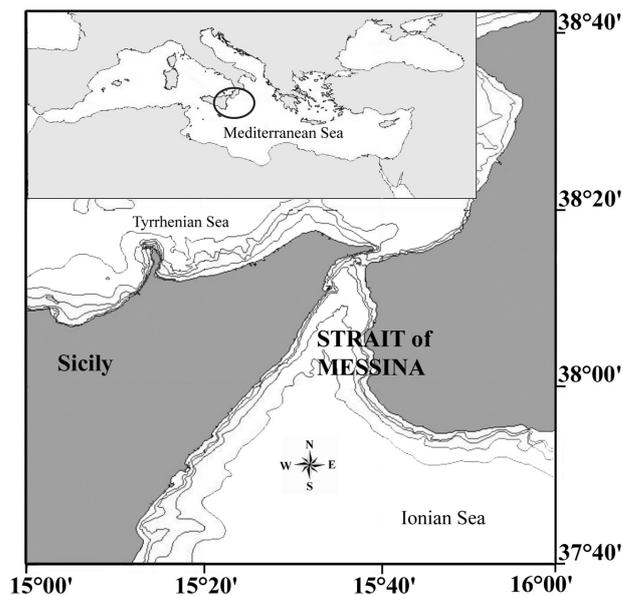
FIG. 1. – Map of the Mediterranean Sea showing the location of the study area in the Strait of Messina.

Though their reliability and scale are proportional to the availability of information on description of current otolith species, otolith data are widely used in the fields of paleoecology, paleobathymetry, paleoclimatology, paleobiogeography and biostratigraphy (Nolf, 1995).

The aim of this paper is to provide data about the relationship between otolith size (length and width) and fish length as well as between fish weight and fish length of some mesopelagic and bathypelagic fishes living in the central Mediterranean Sea. As little information is available on these fishes, in spite of their role in the food web, this paper fills an important gap. The data offer a helpful tool for feeding studies and also provide support to palaeontologists in their research on fossils. We also supply otolith images from these fishes, in order to improve and facilitate their identification. According to the terminology used by Tuset *et al.* (2008), we present a brief description of the sagittae for the species that were not reported in this last atlas, which offered the first major description of otoliths of recent Mediterranean fish species.

MATERIALS AND METHODS

Fishes stranded along the coasts of the Strait of Messina in the central Mediterranean Sea (Fig. 1) were collected in 2007-2009. The Strait of Messina joins the Tyrrhenian and the Ionian Basins together and its depth changes from about 2000 m off the southern Ionian part to about 80 m in the central part, while it reaches 300 m in the Tyrrhenian versant.

This area is known for its strong upwelling currents caused by different tidal phases of the two abovementioned basins and their intensity is regulated by lunar phases (Mazzarelli, 1909; Vercelli, 1925; De

TABLE 1. – List of the mesopelagic species sampled in the Strait of Messina. Number of individuals (n), ranges of fish lengths (SL) and weights (W) are given.

Species	Common name	Family	n	SL range (mm)	W range (g)
Argyropelecus hemigymnus Cocco, 1829	Half-naked hatchetfish	Sternoptychidae	138	8.3-41.0	0.01-1.75
Ceratoscopelus maderensis (Lowe, 1839)	Madeira lantern fish	Myctophidae	15	14.5-68.7	0.04-4.97
Chauliodus sloani Bloch & Schneider, 1810	Sloane's viperfish	Stomiidae	83	68.0-203.0	0.60-116.20
Diaphus holti Tåning, 1918	Small lantern fish	Myctophidae	23	13.5-53.0	0.06-2.66
Electrona risso (Cocco, 1829)	Chubby flashlight fish	Myctophidae	233	9.6-50.0	0.01-3.95
Gonostoma denudatum Rafinesque, 1810		Gonostomatidae	65	26.5-131.2	0.12-15.90
Gonychthys cocco (Cocco, 1829)		Myctophidae	16	23.5-47.7	0.14-1.17
Hygophum benoiti (Cocco, 1838)	Benoit's lanternfish	Myctophidae	288	16.0-58.0	0.04-3.37
Hygophum hygomii (Lütken, 1892)	Bermuda lantern fish	Myctophidae	45	16.8-30.2	0.05-0.47
Ichthyococcus ovatus Cocco, 1838	Lightfish	Phosichthyidae	40	16.9-38.1	0.11-1.27
Lampanyctus pusillus (Johnson, 1890)	Pygmy lanternfish	Myctophidae	27	7.8-41.1	0.01-0.82
Maurolicus muelleri (Gmelin, 1789)	Pearlsides	Sternoptychidae	93	12.0-50.0	0.02-2.10
Microstoma microstoma Risso, 1810	Slender argentine	Microstomatidae	49	18.3-186.3	0.03-27.40
Myctophum punctatum Rafinesque, 1810	Spotted lanternfish	Myctophidae	82	20.3-73.7	0.06-5.72
Nansenia oblita (Facciolà, 1887)		Microstomatidae	80	15.3-78.0	0.04-4.66
Vinciguerria attenuata (Cocco, 1838)	Slender lightfish	Phosichthyidae	136	15.3-36.5	0.03-0.65

Domenico, 1987). The strong hydrodynamism and the particular meteorological conditions (strong wind from the SE) are the main causes of mesopelagic and deep fauna stranding in this area (Mazzarelli, 1909; Genovese *et al.*, 1971; Berdar *et al.,* 1977; Spalletta *et al.,* 1995).

The biological material was collected along the Sicilian coast of the Strait of Messina before the sunrise, in order to avoid the competition of seabirds, ants and wasps and the sun's drying effect.

Specimens were identified following Whitehead *et al.* (1984-1986), photographed with a camera, measured by calliper to the nearest 0.1 mm (following Tortonese, 1970) and weighed to the nearest 0.01 g. In most cases the caudal fin was damaged, so the standard length (SL) in place of the total length (TL) was considered. Sagittal otoliths were removed, cleaned and stored dry with a code number.

Lengths of sagittae (OL) were determined by an ocular micrometer mounted on a Zeiss Stemi 2000-C stereomicroscope and were recorded as the greatest distance measured from the anterior tip to the posterior edge, parallel to the sulcus (Harvey *et al.*, 2000). The width of every sagitta (OW) was determined by considering the greatest distance from the dorsal otolith edge to the ventral one, perpendicular to the sulcus.

Length-weight relationship for every species was also described using the potential function:

$$W = a * SL^b$$

where W is the total weight, SL the standard length, *a* the intercept of the regression line and *b* the regression coefficient, indicating the isometric growth when equal to 3 (Anderson and Neumann, 1996). Parameters *a* and *b* were estimated by transforming (ln) the equation by linear regression. To check the theoretical isometric (*b* = 3) or allometric growth (*b* ≠ 3), Student's *t*-test (Snedecor and Cochran, 1967) was employed.

The relationships between otolith and fish sizes were determined using a least-squares linear regression for the following parameters: otolith length (OL) – fish length (SL) and otolith width (OW) – fish length (SL). These equations were first calculated for both left and right otoliths and the *t*-test was used to check any difference between regressions. The regression coefficients were compared and when significant differences ($p<0.05$) were not found, the H_0 hypothesis ($b_{rigth} = b_{left}$) was accepted. When the equations did not differ statistically, a single linear regression was reported for each parameter (OL; OW) and species, by choosing randomly one right or left otolith from each specimen. The significance of the linear regressions was verified using the *F*-test.

RESULTS

Overall 16 mesopelagic and bathypelagic species belonging to the families Gonostomatidae (1), Microstomatidae (2), Myctophidae (8), Phosichthyidae (2), Sternoptychidae (2) and Stomiidae (1) were studied (Table 1). In Table 1 the sample size (n), SL range (mm) and W range (g) for each species are also reported. The highest number of specimens was recorded for Benoit's lanternfish, *Hygophum benoiti* (n = 288), and the chubby flashlight fish, *Electrona risso* (n = 233).

Otoliths' morphology

Representative otoliths for each species are shown in Figures 2 and 3. A brief description is also provided for the species that were not reported in the atlas published by Tuset *et al.* (2008), according to the terminology used by these authors:

i) Microstomatidae. Lanceolated anterior region and round to peaked posterior one. Broad and pointed rostrum. Lobed dorsal margin and lobed to irregular ventral margin. Median ostial sulcus acusticus, tubular ostium and tubular straight cauda. *Microstoma microstoma* (Fig. 2B), spindle-shaped otolith; *Nansenia oblita* (Fig. 2C), spindle-shaped to sagittiform otolith.

ii) Myctophidae. Discoidal otolith, with double-
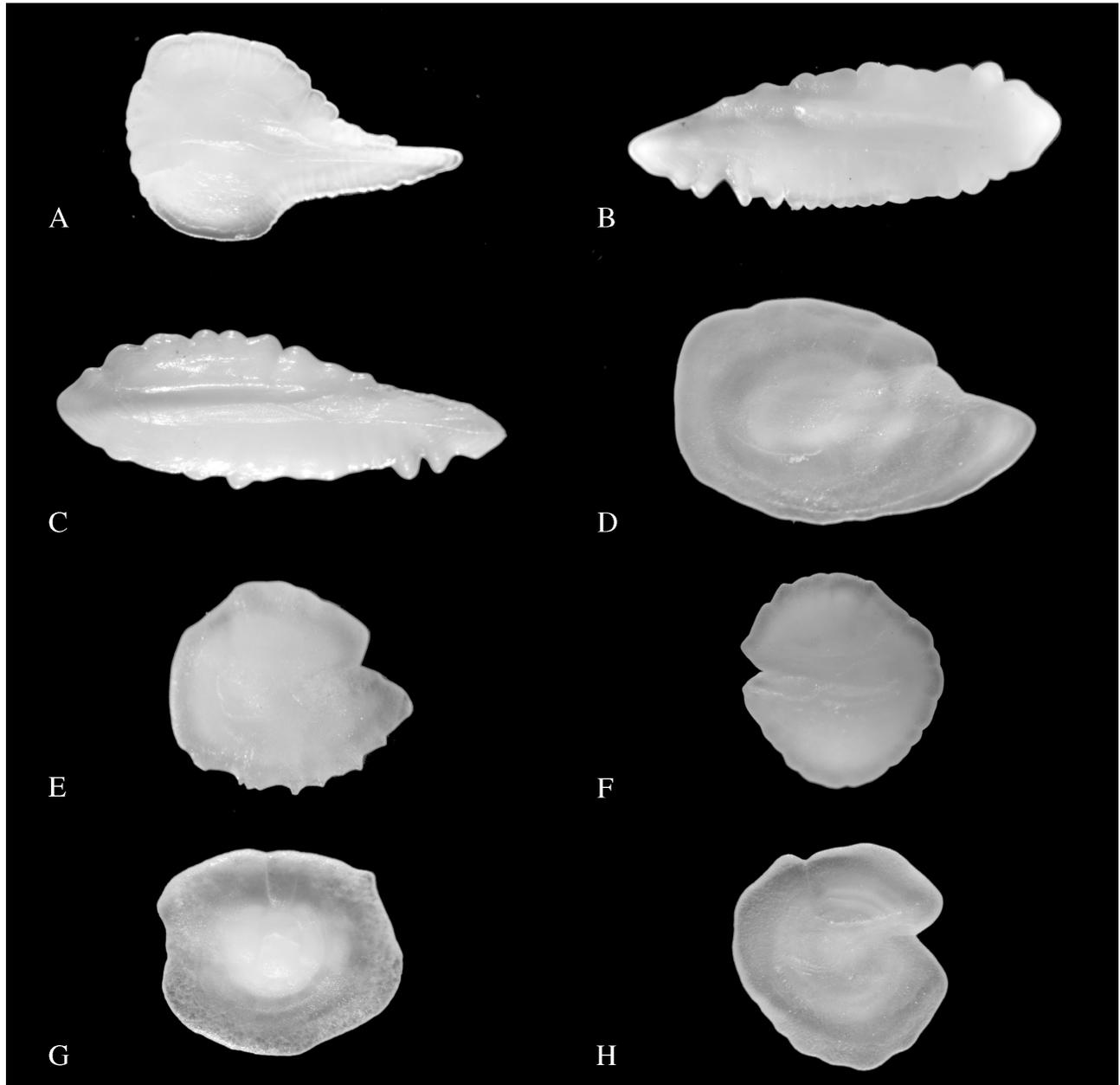
Fig. 2. – A, *Gonostoma denudatum* (SL = 118.2 mm; W = 8.10 g), left otolith (OL = 4.18 mm; OW = 2.59 mm); B, *Microstoma microstoma* (SL = 146.0 mm; W = 18.09 g), right otolith (OL = 5.37 mm; OW = 1.92 mm); C, *Nansenia oblita* (SL = 78.0 mm; W = 4.66 g), left otolith (OL = 4.01 mm; OW = 1.44 mm); D, *Ceratoscopelus maderensis* (SL = 62.5 mm; W = 2.95 g), left otolith (OL = 2.93 mm; OW = 1.70 mm); E, *Diaphus holti* (SL = 53.0 mm; W = 2.66 g), left otolith (OL = 3.09 mm; OW = 2.93 mm); F, *Electrona risso* (SL = 48.5 mm; W = 3.37 g), right otolith (OL = 3.29 mm; OW = 3.64 mm); G, *Gonichthys cocco* (SL = 45.5 mm; W = 1.10 g), right otolith (OL = 1.27 mm; OW = 1.09 mm); H, *Hygophum benoiti* (SL = 51.2 mm; W = 2.40 g), left otolith (OL = 1.86 mm; OW = 1.96 mm).

peaked anterior region and round posterior one. Short and broad rostrum. Median ostial sulcus acusticus. *Diaphus holti* (Fig. 2E), serrate ventral margin and sinuate dorsal one; Funnel-like ostium and round-oval cauda. *Electrona risso* (Fig. 2F), sinuate to crenate margins; oval ostium and round-oval cauda. *Hygophum benoiti* (Fig. 2H), sinuate margins; funnel-like ostium and round-oval cauda. *Hygophum hygomii* (Fig. 3A), lobed margins; funnel-like ostium and slightly curved tubular cauda. *Lampanyctus pusillus* (Fig. 3B), the anterior re-

gion is not double-peaked but approximately flattened; entire margins and very short rostrum; rectangular ostium and a round-oval cauda.

iii) Phosichthyidae. *Ichthyococcus ovatus* (Fig. 3D), tall and pseudo-triangular otolith, notched anterior region with lobate margin, round posterior region with entire to sinuate margins; rostrum is elongated; median pseudo-ostial sulcus acusticus, elliptic ostium and round-oval cauda. *Vinciguerria attenuata* (Fig. 3E), pyriform otolith with peaked anterior region and round posterior
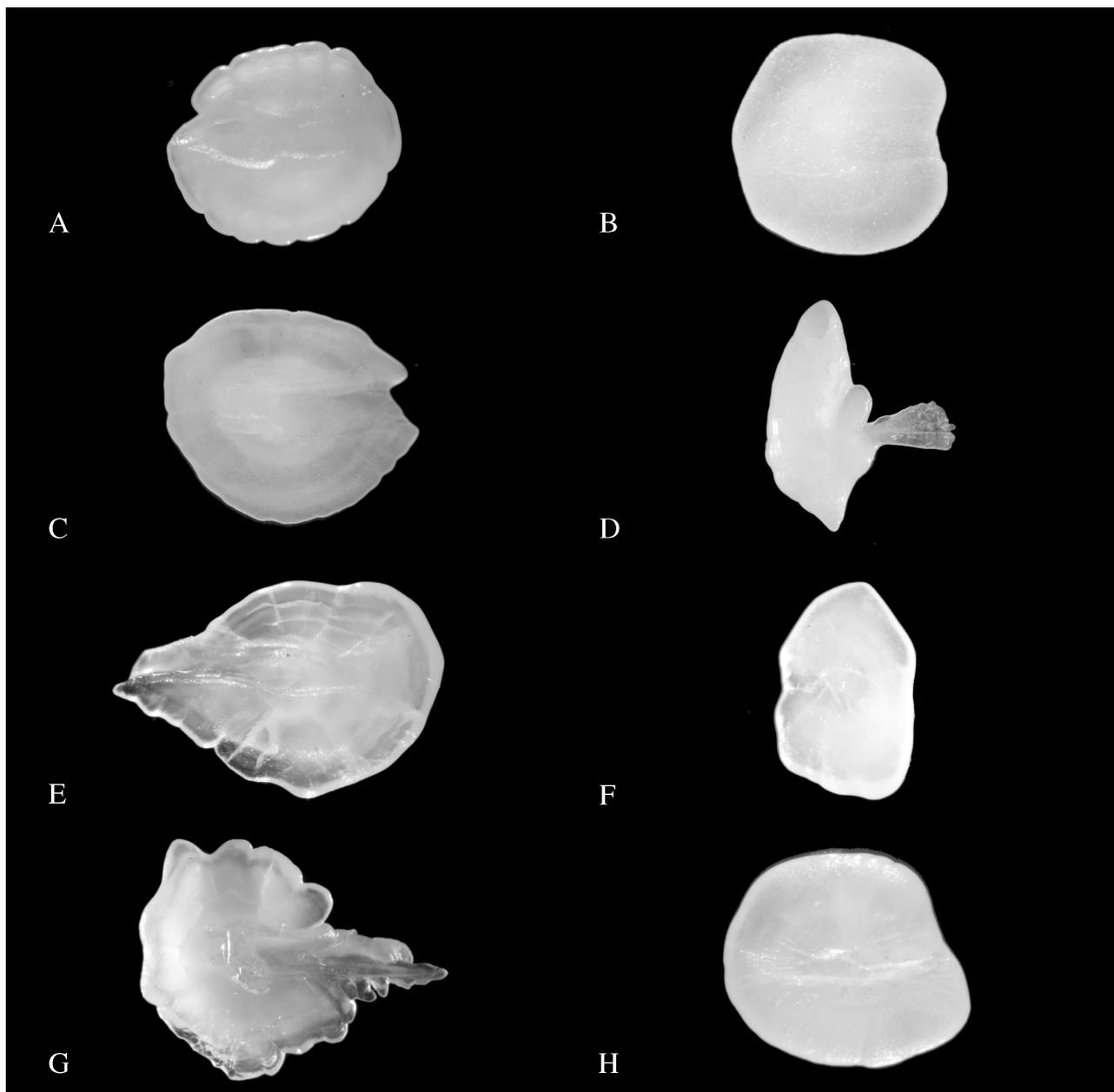
Fɪɢ. 3. – A, *Hygophum hygomii* (SL = 28.7 mm; W = 0.37 g), right otolith (OL = 1.69 mm; OW = 1.48 mm); B, *Lampanyctus pusillus* (SL = 37.4 mm; W = 0.51 g), left otolith (OL = 1.05 mm; OW = 1.05 mm); C, *Myctophum punctatum* (SL = 73.7 mm; W = 5.72 g), left otolith (OL = 3.29 mm; OW = 2.69 mm); D, *Ichthyococcus ovatus* (SL = 35.7 mm; W = 1.06 g), left otolith (OL = 3.16 mm; OW = 3.88 mm); E, *Vinciguerria attenuata* (SL = 35.8 mm; W = 0.42 g), rigth otolith (OL = 1.39 mm; OW = 0.94 mm); F, *Argyropelecus hemigymnus* (SL = 34.0 mm; W = 0.87 g), rigth otolith (OL = 0.60 mm; OW = 0.90 mm); G, *Maurolicus muelleri* (SL = 45.0 mm; W = 1.33 g), left otolith (OL = 2.05 mm; OW = 1.61 mm); H, *Chauliodus sloani* (SL = 201.9 mm; W = 18.50 g), left otolith (OL = 0.99 mm; OW = 0.89 mm).

one; elongated and pointed rostrum: sagitta has irregular margins, a median ostial sulcus acusticus, a funnel-like ostium and a tubular straight cauda.

Data analysis

Length-weight relationships and linear regression of otolith length and width against fish length for every species are given in Table 2. Of a total of 16 species, 13 showed an isometric growth since the regression coefficient b did not differ significantly from the theoretical value of 3. Statistical analysis (t-test) revealed significant differences only for three species, indicating an allometric growth: *Hygophum benoiti* (n = 288, df = 286, p<0.01), *H. hygomii* (n = 45, df = 43, p<0.001), and *Vinciguerria attenuata* (n = 136, df = 134, p<0.001). High correlation coefficients (R^2>0.93) calculated for the SL-W relationship were obtained in 15 species, with the exception of *Chauliodus sloani*, which showed a lower value (R^2 = 0.833).

TABLE 2. – Relationships of fish weight (W) in grams to standard length (SL) in millimetres, standard length to otolith length (OL) and to otolith width (OW) in millimetres. The number of specimens (n) and the coefficient of determination (R^2) are given for each equation.

Family	Species	n	fish length / fish weight Equation	R^2	otolith length / fish length Equation	R^2	otolith width / fish length Equation	R^2
Gonostomatidae	*Gonostoma denudatum*	65	W = 7.8E-05 SL$^{2.923}$	0.961	SL = 28.650 OL + 0.868	0.964	SL = 48.906 OW + 2.914	0.967
Microstomatidae	*Microstoma microstoma*	49	W = 1.2E-05 SL$^{2.841}$	0.994	SL = 27.816 OL – 9.621	0.965	SL = 81.380 OW – 8.916	0.985
	Nansenia oblita	80	W = 3.3E-05 SL$^{2.729}$	0.965	SL = 18.126 OL – 2.005	0.948	SL = 53.516 OW – 6.325	0.953
Myctophidae	*Ceratoscopelus maderensis*	15	W = 7.4E-06 SL$^{3.144}$	0.996	SL = 15.858 OL + 12.417	0.946	SL = 26.275 OW + 10.893	0.944
	Diaphus holti	23	W = 1.3E-05 SL$^{3.102}$	0.981	SL = 15.203 OL – 0.522	0.953	SL = 16.678 OW + 0.378	0.960
	Electrona risso	233	W = 1.7E-05 SL$^{3.156}$	0.990	SL = 13.438 OL + 2.181	0.987	SL = 12.538 OW + 1.846	0.989
	Gonychthys cocco	16	W = 7.5E-06 SL$^{3.105}$	0.988	SL = 40.193 OL – 5.554	0.946	SL = 49.028 OW – 8.055	0.943
	Hygophum benoiti	288	W = 5.8E-06 SL$^{3.306}$	0.978	SL = 29.128 OL – 4.550	0.913	SL = 26.641 OW – 3.417	0.927
	Hygophum hygomii	45	W = 1.7E-06 SL$^{3.676}$	0.962	SL = 15.941 OL + 1.774	0.957	SL = 17.913 OW + 1.940	0.919
	Lampanyctus pusillus	27	W = 0.00012 SL$^{2.296}$	0.935	SL = 36.396 OL + 1.445	0.990	SL = 37.634 OW + 0.923	0.992
	Myctophum punctatum	82	W = 1.4E-05 SL$^{2.971}$	0.963	SL = 22.842 OL – 2.739	0.950	SL = 27.335 OW – 1.463	0.944
Phosichthyidae	*Ichthyococcus ovatus*	40	W = 1.4E-05 SL$^{3.159}$	0.954	SL = 11.813 OL – 3.048	0.936	SL = 9.470 OW – 0.594	0.957
	Vinciguerria attenuata	136	W = 1.4E-06 SL$^{3.587}$	0.957	SL = 2.222 OL + 4.397	0.964	SL = 35.026 OW + 3.036	0.960
Sternoptychidae	*Argyropelecus hemigymnus*	138	W = 2.0E-05 SL$^{3.064}$	0.960	SL = 70.699 OL – 5.998	0.813	SL = 45.985 OW – 3.172	0.893
	Maurolicus muelleri	93	W = 1.6E-05 SL$^{2.946}$	0.979	SL = 24.768 OL – 2.493	0.978	SL = 30.470 OW – 1.832	0.982
Stomiidae	*Chauliodus sloani*	82	W = 2.7E-06 SL$^{2.984}$	0.833	SL = 223.830 OL – 21.103	0.869	SL = 265.180 OW – 33.160	0.920

In the analysis of morphometric parameters (otolith length and width) against SL, no considerable differences between right and left otoliths were detected by the *t*-test, so a single linear regression was plotted for each parameter. Data fitted well to the regression model for both OL and OW to SL for each species, as demonstrated by the high values of the coefficient of determination. Only the half-naked hatchetfish *Argyropelecus hemigymnus* showed a R^2 value that was considerably lower ($R^2 = 0.813$) than the others.

DISCUSSION

Otoliths are a powerful taxonomic feature for fish species identification because of their high inter-specific variability in shape. Though the classification of fish preys is facilitated by some reference works (Smale *et al.*, 1995; Campana, 2004; Lombarte *et al.*, 2006; Tuset *et al.*, 2008), only certain geographical areas are covered and the access to reference material remains essential (Santos *et al.*, 2001). Therefore, a fundamental objective of researchers studying the marine predators' feeding habits is to fill the gap of information on the fish otolith morphology and on the estimation of specific equations, which is useful to calculate the size and mass of preys.

The results of the present study respond to this need, providing SL-W, OL-SL and OW-SL relationships for several mesopelagic and bathypelagic species. Despite the importance of these fishes in top predators' diet, their biology and ecology had not been well investigated until today. In fact, owing to their null commercial value, they are not a target of fishing activities and they can only be sampled by organizing appropriate scientific cruises. The opportunity of collecting stranded specimens in the area of Strait of Messina allowed us to study these species at a low cost.

This study provides a useful tool for better understanding the trophic relationships in the Mediterranean food web. The rebuilding of prey biomass from otolith size may help to return the real importance to the Mediterranean mid-water fishes, shedding light on their role in the trophic structure, as pointed out by some feeding studies (Castriota *et al.*, 2007; Falautano *et al.*, 2007; Consoli *et al.*, 2008; Karakulak *et al.*, 2009). However, to this day, the lack of data in these area has not always permitted an appropriate quantification of their prey biomass and classification to species level in the diet of Mediterranean pelagic predators. In fact, quite a high percentage of unidentified mesopelagic fishes and otoliths in swordfish and tuna stomach contents have been recorded (Sinopoli *et al.*, 2004; Falautano *et al.*, 2007; Mostarda *et al.*, 2007; Romeo *et al.*, 2009).

In comparison with other similar studies on the relationship between fish and sagitta sizes (Wyllie Echeverria, 1987; Gamboa, 1991; Granadeiro and Silva, 2000; Harvey *et al.*, 2000; Waessle *et al.*, 2003), this paper supplies additional information by considering both the otolith width (OW) and length (OL). In most cases, the calculation of two equations (OL-SL and OW-SL) is more suitable, since the tip of the otolith rostrum may be damaged, making it impossible to measure the OL. Moreover, the coefficient of determination of the OW-SL linear regression attained a higher value than in the OL-SL one in the same species (Table 2).

The otoliths of the investigated species did not show significant differences in size between left and right sagittae, in contrast with the findings of Waessle *et al.* (2003) in two sciaenid fishes (*Micropogonias furnieri* and *Macrodon ancylodon*) and Harvey *et al.* (2000) in the teleost *Lycodes palearis* (Zoarcidae). However, Harvey *et al.* (2000) indicated the small size of the sample as the possible cause of this diversity.

Most published regressions of OL to SL (Wyllie Echeverria, 1987; Gamboa, 1991; Harvey *et al.*, 2000; Waessle *et al.*, 2003) or SL to W relationships (Harvey *et al.,* 2000; Valle *et al.*, 2003; İlkyaz *et al.*, 2008; Mata *et al.*, 2008) concern coastal or commercially important species. Very few data are available on mesopelagic and bathypelagic fishes. As regards the species considered in the present paper, the sternoptychid *Maurolicus muelleri* has been the most investigated and SL-W and OL-SL relationships for populations living in the Norwegian Sea have been calculated (Rasmussen and Giske, 1994; Salvanes and Stockley, 1996; Kristoffersen, 2007). SL-W relationships for *Argyropelecus hemigymnus* and *Hygophum benoiti* by specimens collected in the Strait of Messina were provided by Donato *et al.* (1993) and Potoschi *et al.* (2003) respectively.

Though all data fitted well with the linear regression (OL-SL and OW-SL) and the potential (SL-W) models, it is advisable to use these equations within the fish size range limits reported in Table 1. In fact, otoliths may slow down the increase in length, increasing only in thickness at the maximum fish size (Williams and Bedford, 1974) or may grow following a curvilinear model in juvenile fishes (Nishimura and Yamada, 1988). In particular, Linkowski (1991) described a change in the otolith growth pattern at a larval size of 12 mm in the myctophid *Ceratoscopelus maderensis* and then supplied two different OL-SL regressions for specimens smaller than 12 mm and for larger ones. Since the individuals of *C. maderensis* collected in the present paper belong to the 14.5–68.7 mm SL range, the single OL-SL regression reported in Table 2 can be accepted.

Finally, some limitations to the use of biomass reconstruction from otolith size should be taken into account. The growth of individuals belonging to the same species may show some variations for different areas and stocks (Campana and Casselman, 1993; Reichenbacher *et al.*, 2009) or between sexes (Wyllie Echeverria, 1987). Furthermore, otoliths are exposed to chemical and mechanical abrasion in the digestive track of predators (Jobling and Breiby 1986; Granadeiro and Silva, 2000) and their size may be underestimated.

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