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First record and otolith morphometric description of an adult lightfish, *Ichthyococcus ovatus* (Actinopterygii: Stomiiformes: Phosichthyidae), caught in the Strait of Sicily (central Mediterranean Sea)

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Abstract

On July 2018, one specimen of *Ichthyococcus ovatus* (Cocco, 1838) was caught in the Strait of Sicily during the International Bottom Trawl Survey in the Mediterranean (MEDITS). The adult *I. ovatus* measured 49 mm in total length and weighed 1.44 g. In this context, the presently reported study constitutes the first and deepest record of an adult of *I. ovatus* as well as the morphometric description of its sagittal otoliths. In addition, we provide an age estimation as well as an update of the geographical distribution of this bathypelagic species around the Mediterranean Sea. Based on the growth increments of sagittal otoliths, the estimated age was five years. Specifically, the otolith from the presently reported specimen of *I. ovatus* tended to be elliptic in shape related to aspect ratio and high rectangularity while circularity showed high complexity of otolith contour complexity. The absence of economic value of rarely reported species may underestimate their abundance. Therefore, more studies and research surveys would be necessary to fill the information gap on the biology of these deep-water species.

Keywords

Mediterranean deep sea, otolith, rare species, MEDITS, Strait of Sicily, trawl survey

Introduction

The family Phosichthyidae of the order Stomiiformes (Froese and Pauly 2022) comprises lightfishes that produce bioluminescence by ventrally located photophores (Schaefer et al. 1986). Specifically, this family constitutes a monophyletic group characterized by members with the advanced characters of three pectoral fin radials, which are further reduced in some genera with extremely small pectoral fins, and type gamma photophores having a lumen and duct (Weitzman 1974). Actually, earlier workers believed Phosichthyidae performed active diel vertical migration (Clarke 1971), which recent workers considered to range from the mesopelagic to epipelagic zones (Goçalo et al. 2011). However, only a few species of Phosichthyidae such as *Vinciguerria poweriae* (Cocco, 1838), *Vinciguerria attenuata* (Cocco, 1838), and *Pollichthys mauli* (Poll, 1953) have shown active diel migration (Badcock, 1984). Furthermore, fishes belonging to this family perform pelagic spawning, which allows them to deliver planktonic eggs and larvae (Ahlstrom and Ball 1954). However, not all genera of the family Phosichthyidae have been well studied. In particular, the genus *Ichthyococcus* Bonaparte, 1840 appears more evolute than the other congeneric species that are relatively primitive (Weitzman 1974). The genus *Ichthyococcus* includes 8 species (Froese and Pauly 2022), wherein *Ichthyococcus ovatus* (Cocco, 1848) has been singled out as an almost cosmopolitan bathypelagic species, found across a wide range of waters from the North Eastern Atlantic to the western/central Mediterranean basin (Lin et al. 2018; GBIF 2022). Moreover, it is worth mentioning that *I. ovatus* appears to be the only species of the genus *Ichthyococcus* reported within the Mediterranean Basin (Lin et al. 2018; GBIF 2022).

In relation to the Mediterranean Sea, the authors herein could only find the study of Battaglia et al. (2010) who reported the otolith morphology relations between some mesopelagic and bathypelagic species from the Strait of Messina. Otoliths are calcified structures ($CaCO_3$) located in the inner ear of fish providing sensory information about balance as well as hearing (Campana and Thorrold 2001; Popper et al. 2005). In particular, otoliths are demonstrated to continuously grow throughout the life of the fish (Chilton and Beamish 1992) along with absence of resorption or short-time variation (Cadrin and Friedland 2005). Such characteristics make otolith a powerful tool for age determination, and this activity entails reading (i.e., counting) the growth bands laid down as zones of opaque and translucent material (Ross et al. 2005; Rodríguez Mendoza 2006). Notably, the appearance, as well as shape of otolith (most often, the sagitta) in fish specimens remain species specific and can differ between populations of the same species in different locations (Lombarte et al. 2006; Ozpicak et al. 2018). This makes the otolith morphometry/shape a valuable tool for the identification of fish species. Additionally, the interspecific variations of otolith are considered useful for the identification of the stock as well as assessment of environmentally induced variation (Campana 2005; Rodríguez Mendoza 2006). More so, the form factor, roundness, and rectangularity are among such parameters that characterize the shape of the otolith's parts (Russ 1990).

Apart from the geographical distribution and nictemeral migration, the biological information about lightfishes appears limited. Furthermore, relevant information regarding the otoliths of *I. ovatus* specific to the Strait of Sicily (central Mediterranean Sea), to our best knowledge, is not available. Therefore, to supplement existing information, the presently reported study presents the first record and otolith morphometric description of an adult lightfish, *I. ovatus*, caught in the Strait of Sicily. In addition, we provide an age estimation as well as an update of the geographical distribution of this bathypelagic species around the Mediterranean Sea.

Materials and methods

Sample collection, identification, and biometrics. On July 2018, one specimen of *Ichthyococcus ovatus* (trawl haul points: 36°36.89′N, 013°21.24′E) was caught, at a depth of about 547 m, during the International Bottom Trawl Survey in the Mediterranean (MEDITS) (Bertrand et al. 2002) in the Strait of Sicily. The sample was transported to the laboratory of CNR-IRBIM of Mazara del Vallo. The identification of the specimen was conducted following descriptions of Badcock (1984). The biometric data involved total length (TL), standard length (SL), head length, eye diameter, total weight, as well as dorsal, pectoral, ventral, and anal fin lengths. In addition to weight with an accuracy of 0.01 g, the length measurement was conducted to the nearest 0.1 mm using a vernier caliper. In particular, photophores were counted as follows:

- entire ventral photophores row extending from anterior end of isthmus to posterior termination of this row on caudal peduncle (IC);
- ventral series of pelvic and anal photophores, part of IC extending between a vertical line at insertion of posterior pelvic fin ray and anal fin origin or to end of row (VAV + AC);
- entire lateral series photophores on body side (OA).

Age estimation and otolith morphometry. The otoliths' extraction was performed based on the procedures recommended by Secor et al. (1992), which entailed the cleaning of the blood, otic sac, and other membranes using distilled water, subsequently stored in labelled vials and thereafter, allowed to air-dry for 48 h. More so, the weight of each otolith was measured to 0.0001 mg using an analytical balance (Entris® II Advanced Line; Sartorius AG, Göttingen, Germany). Whole otoliths were placed in a dish with tap water and a black background and viewed under reflected light through a stereomicroscope (Leica Wild Mz12.5; Leica Microsystems GmbH, Wetzlar, Germany) at 1.0× magnification. The contrast between opaque and translucent zones was enhanced by Adobe Photoshop software (v. 22.0, Adobe, San Jose, USA). The examination of whole otoliths required viewing the distal surface as shown in Fig. 1A. The age estimation was assigned independently by two readers using the views of whole otoliths and without additional information. Importantly, the growth zones of the otoliths were visible across the height (dorsal–ventral) as well as the length (anterior–posterior) surfaces, whereas the presumptive annuli were identified and counted from the core to margin along the longest axis of otoliths (Fig. 1B). Additionally, the opaque zones were counted.

The morphometric data of the otoliths were collected, which included area (A_o), perimeter (P_o), length (L_o, maximal distance from the anterior tip to the posterior edge, parallel to the sulcus (Harvey et al. 2000)) and width (W_o, maximal distance from the dorsal otolith edge to the ventral one, perpendicular to the sulcus). The morphometric parameters were measured using the ImageJ v.1.53f51

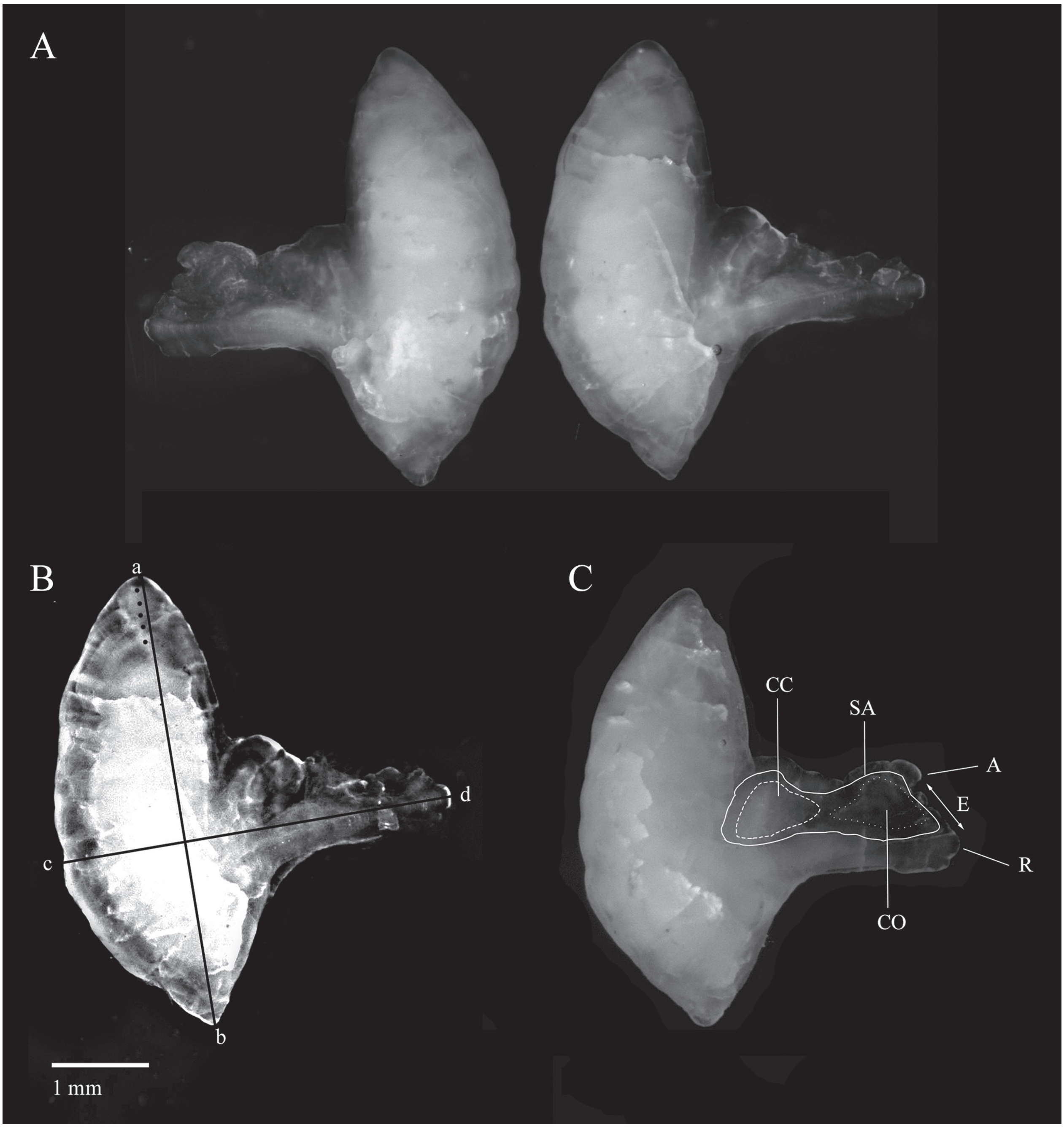

Figure 1. (**A**) Distal surface of the sagittal otoliths from *Ichthyococcus ovatus.* (**B**) Enhanced image of the right otolith used to count presumptive annuli for age estimation. Black dots represent the growth rings; the distance between a and b is the otolith width while the distance between c and d is the otolith length; (**C**), proximal surface of the left otolith showing *rostrum* (R), *antirostrum* (A), *excisura ostii* (E), *sulcus acusticus* (SA, continuous line), *colliculum ostii* (CO, dotted line), *colliculum caudii* (CC, dashed line).

software (Wayne Rasband (NIH), Bethesda, USA), which cumulatively enabled such dimensionless shape indices like otolith relative length ($100(L_o/\mathrm{TL})$, $100(L_o/\mathrm{SL})$), otolith relative size ($1000(A_o/\mathrm{TL}^2)$), aspect ratio (Ar, shape tendency of otolith, L_o/W_o), form factor (Ff, its values range from 0 to 1 where a value of 1 corresponding to a perfect circle, $4\Pi A_o/\mathrm{P}^2$ where Π is the pi, i.e. about 3.14), ellipticity (El, values close to 0 indicating a tendency towards circularity, $(L_o - W_o)/(L_o + W_o)$), roundness (Ro, the larger it is the more the otolith shape approximates that of a disk, $4A_o/\Pi L_o^2$), rectangularity (Re, a value of 1 indicating a perfect rectangle or square, $A_o/(L_o \times W_o)$) and circularity (Ci, complexity of otolith contour, P^2/A_o) (Russ 1990; Tuset et al. 2003; Pavlov 2016). In addition, a pictorial comparison with the extant literature was performed.

Geographical distribution and mapping. The geographical distribution of this lightfish species has been prepared by compiling all existing scientific literature concerning reported records of *I. ovatus* with particular reference to the Mediterranean Sea. Every published article we found that contained reports of *I. ovatus* in the Mediterranean Sea was scrutinized in order to extract the spatial data. In addition, the Mediterranean

Table 1. Comparison of biometric and meristic characters of the presently reported *Ichthyococcus ovatus* from the Strait of Sicily with those provided by selected literature sources.

Character	This paper				Lombarte et al. 2006	Battaglia et al. 2010	
	n = 1				*n* = 1	*n* = 40	
	Absolute		Relative	Meristic	Absolute	Absolute	
	[mm]	[g]	[%SL]		mm	mm	[g]
Total length	59				45		
Standard length	49					16.9–38.1	
Head length	14		28.6				
Eye diameter	4		8.2				
Total weight		1.44					0.11–1.27
Dorsal fin length	9		18.4				
Pectoral fin length	7		14.3				
Ventral fin length	4		8.2				
Anal fin length	7		14.3				
Dorsal fin rays				11			
Pectoral fin rays				8			
Ventral fin rays				7			
Anal fin rays				16			
Vertebrae				42			
IC				46			
VAV + AC				21			
OA				23			

%SL = percentage of the standard length; IC = Summary of photophores of the ventral series (isthmus to caudal fin base), VAV = Ventral series photophores (pelvic fin base to the caudal fin base), AC = posterior part of IC series, OA = entire lateral series photophores on body side (OA).

records of this species lacking in the literature were found using the Global Biodiversity Information Facility (GBIF 2022). In particular, all the records not verified in GBIF were excluded. Lastly, the records of *I. ovatus* were mapped via the help of Quantum GIS software (QGIS 2020).

Results

The photographic image of the *Ichthyococcus ovatus* specimen caught in the Strait of Sicily is shown in Fig. 2. The biometric and meristic measurements of individual *I. ovatus* specimen are showed in Table 1.

The examination of the whole otoliths by the distal surface as shown in Fig. 1. Considering the visibility of the growth zones (Fig. 1B), an age estimation and gross morphology of the otolith of the *I. ovatus* specimen appeared feasible. Thus, the putative age was estimated at five years. According to the terminology used by Smale et al. (1995) and Tuset et al. (2008), the gross morphology was described as follows: **Shape**: high and approximately triangular, entire to sinuate margins; **Thickness**: moderately thick; **Form**: Mesial slightly concave, Lateral very convex; ***Sulcus acusticus***: pseudo-ostial, median, dorsal and ventral area similar sized; crista superior absent; crista inferior with a low ridge-like along entire sulcus acusticus. **Ostium**: elliptic, confined to antero-dorsal part of rostrum. **Cauda**: round-oval. **Ostio-cauda differentiation**: slight ventral constriction. **Anterior region**: peaked to notched with irregular margin, extended rostrum, very short and round antirostrum, excisura narrow with a shallow notch. **Posterior region**: entire to sinuate margins (Fig. 1C). The shape parameters and indices mea-

Figure 2. *Ichthyococcus ovatus* specimen that was caught in the Strait of Sicily.

Table 2. Shape parameters and indices from otolith of *Ichthyococcus ovatus* from the Strait of Sicily, described in the presently reported study.

Shape parameters	Value
Area (A_o) [mm^2]	8.89
Perimeter (P_o) [mm]	17.01
Mass (M_o) [mg]	0.0154
Length (L_o) [mm]	3.99
Width (W_o) [mm]	4.68
Shape indices	
Otolith relative length (TL)	6.76
Otolith relative length (SL)	8.14
Otolith relative size	2.55
Aspect ratio (Ar)	0.85
Form factor (Ff)	0.39
Ellipticity (El)	0.07
Roundness (Ro)	0.71
Rectangularity (Re)	0.48
Circularity (Ci)	32.54

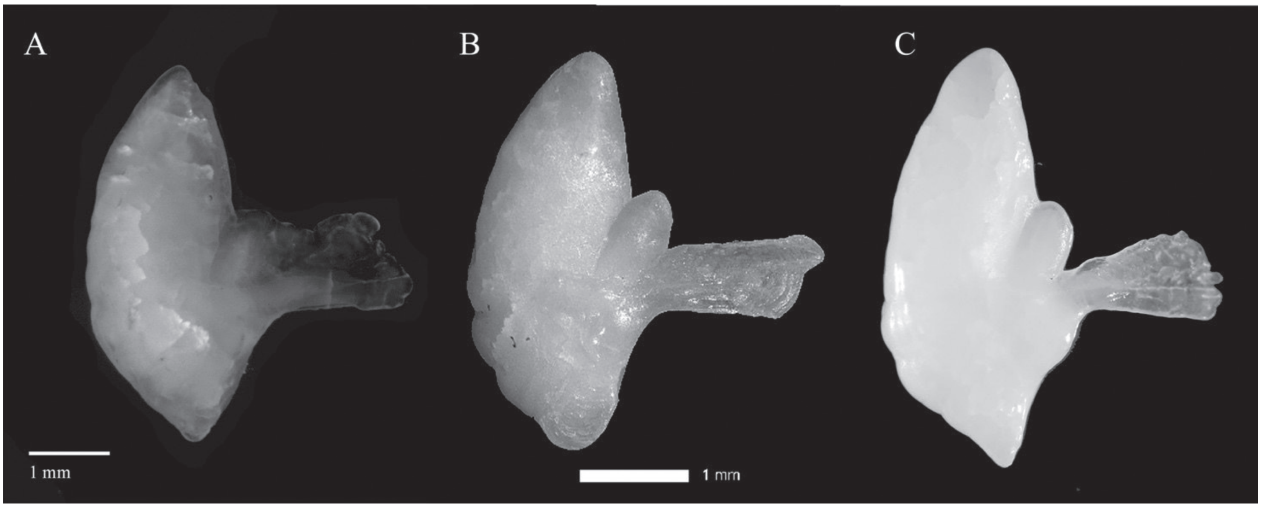

Figure 3. *Ichthyococcus ovatus* otolith (**A**) proximal view of the left sagitta from the Strait of Sicily, (**B**) otolith from the Canary Islands, (**C**) otolith from the Strait of Messina.

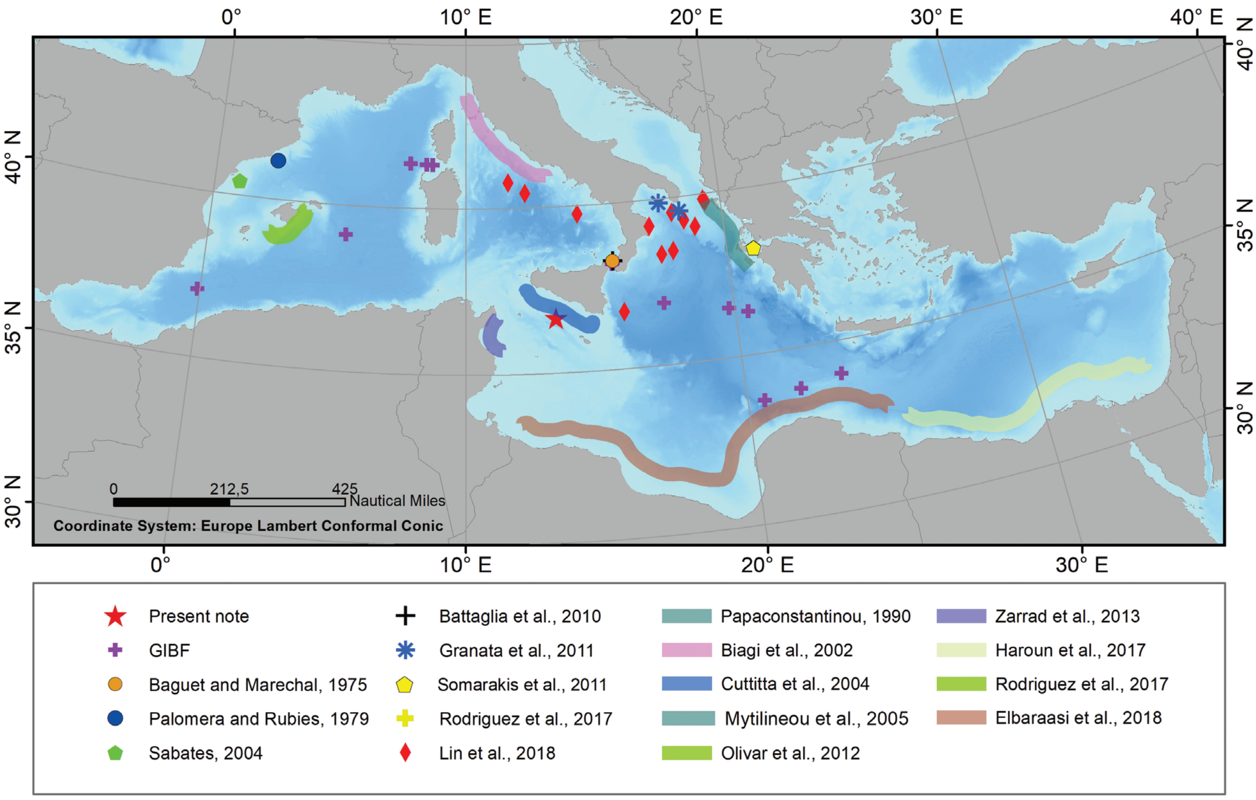

Figure 4. Map showing the geographical distribution of *Ichthyococcus ovatus* based on the previous and the presently reported study within the Mediterranean Basin. Specific records include: green, blue, violet, pink, stripes, and green pentagon as larvae; brown and light green stripes as the probable catch areas for specimens of Libyan, and Egyptian waters, respectively.

sured from the left sagittal otolith of *I. ovatus* caught in the Strait of Sicily can be seen in Table 2.

Overall, the otolith of the presently reported study tended to be elliptic in shape related to aspect ratio (Ar) and high rectangularity (Re) while circularity (Ci) showed high complexity of otolith contour (Table 2). Moreover, comparing the sagitta otoliths of this work (Fig. 3A) with those of published literature (Fig. 3B and 3C), there appears to be a somewhat but slight observable difference. Specifically, the otoliths of Canary Islands and Strait of Messina possess rather shallower notches between the rostrum and antirostrum. Further, the rostrum appear somewhat prominent, whereas much less so for the antirostrum, and with different shapes in the Canary Islands and Strait of Messina.

Map comparing the geographical distribution of *I. ovatus* of the presently reported study with those of other previous studies within the Mediterranean Basin is shown in Fig. 4, which suggests the widespread nature of this lightfish species.

Discussion

Consistent with the features described by Badcock (1984), this *Ichthyococcus ovatus* specimen physically appeared dark in the back, silvery-translucent to the flanks and with the fin rays speckled basally. The photophores, biometrics and meristic counts of the *I. ovatus* specimen appear consistent with information provided by Badcock (1984). Notably, the nature and patterns of photophores are of high importance for discrimination of *Ichthyococcus* spp. as well as identifying larvae and adults (Ahlstrom et al. 1984). In particular, symphyseal photophores were absent whereas photophores of the ventral series, from the pectoral fin base to the pelvic fin base and from the anal fin base to caudal fin base, were in a straight line when viewed from below and continuous, respectively. According to Badcock (1984), the photophores development complete at about 15–17 mm of SL. Thus, our specimen might be ascribed as an adult of *I. ovatus*. As we have considered the putative age of the *I. ovatus* specimen to be estimated at five years, it is feasible to treat the specimen as an adult. However, the periodicity in the formation of the rings would need to be established. In addition, age validation studies would be required if a more accurate age determination of this lightfish species is to be realized. Additionally, the pictorial comparison with the extant literature might show a possibility of differentiation between the population of *I. ovatus* in the Canary Islands (Atlantic Ocean), Strait of Sicily, and Strait of Messina.

Environmental factors are believed to influence the otolith shape such as the depth, temperature, substrate type, salinity, and feeding conditions (Lombarte and Lleonart 1993; Torres et al. 2000). Besides, the different variations in otolith shape would at times be interpreted to result from habitat differentiation (Morat et al. 2012). For instance, Vignon and Morat (2010) showed that contrasting environmental factors induce an overall change in otolith shape, but genetically induced changes locally affect the otolith shape in the area of the rostrum and antirostrum for bluestripe snapper *Lutjanus kasmira* (Forsskål, 1775). However, to clearly establish the specific details, it is necessary that a proper shape analysis (and more otoliths) be performed. Indeed, the literature on the biology and distribution of deep-water species is scarce. In addition, relevant information concerning the size at maturity, feeding strategy, sexual dimorphism, and growth of *I. ovatus* appears scanty.

The widespread nature of this lightfish species is demonstrated by its geographical distribution within the Mediterranean Sea. The records in the waters off Libya (Elbaraasi et al. 2019; GBIF 2022) and western coasts of Egypt (Akel and Karachle 2017; GBIF 2022) suggest that the geographical range of *I. ovatus* can extend to the Levantine basin of the Mediterranean Sea. Other workers found it as reported at different areas, for example, the Western and Central basin such as the Catalan Sea, Balearic Sea, Corsican Sea, Tyrrhenian Sea, Ionian Sea, Gulf of Hammamet, and Strait of Messina (Palomera and Rubies 1979; Papaconstantinou 1990; Biagi et al. 2002; Sabatés 2004; Mytilineou et al. 2005; Battaglia et al. 2010; Somarakis et al. 2011; Olivar et al. 2012; Rodríguez et al. 2013; Zarrad et al. 2013; Lin et al. 2018; GBIF 2022). Further, the occurrence of *I. ovatus* within the Mediterranean Sea would reach depths, ranging from 40 up to 1100 m (Granata et al. 2011; Olivar et al. 2012; Rodríguez et al. 2013; Zarrad et al. 2013). In particular, the records up to a depth of 200 m were ascribed as fish larvae (Sabatés 2004; Cuttitta et al. 2004; Somarakis et al. 2011; Zarrad et al. 2013). According to Watanabe et al. (1999), diel vertical migration is known to occur in several groups of fish and their larvae, especially in species with light organs. Further, *I. ovatus* vary in bathymetric range from the mesopelagic zone at a depth of about 200–500 m (Schaefer et al. 1986) to the deeper waters of the bathypelagic zone (Yang et al. 1996). It is important to mention here that the first record of *I. ovatus*, specifically at its larval stage, in the Strait of Sicily, was reported by Cuttitta et al. (2004) and since then, there appears to have been no other published report. Therefore, this presently reported study shows the first occurrence of an adult *I. ovatus* specimen in the Strait of Sicily. Besides, the *I. ovatus* specimens in the presently reported study represented the deepest record of this species in the Strait of Sicily.

Conclusions

The first record and morphometric description of sagittae otoliths in an adult *Ichthyococcus ovatus* specific to the Strait of Sicily has been presented in this communication. It also included an updated geographical distribution of this deep-water species around the Mediterranean Sea. As we have considered the putative age of the *I. ovatus* specimen estimated at five years, the periodicity in the formation of the rings must be established and age validation studies are required for accurate age determination of this lightfish species. This presently reported study is preliminary and lays a baseline for the future study of this *I. ovatus* species, which are not commonly caught by trawling likely because of its bathymetric distribution. A more robust study involving age validation and shape analysis will require the collection of more *I. ovatus* species samples. Indeed, the absence of economic value of rarely reported species may actually underestimate their presence/abundance in the Mediterranean basin (Sardo et al. 2020). Besides improving the sampling design (Falsone et al. 2017; Geraci et al. 2019), more research surveys involving the collection of meso- and bathypelagic fish fauna would be necessary in order to fill the information gap on the biology of these Mediterranean deep-water species.

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