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Distribution of *Sabellaria alveolata* (Polychaeta Sabellariidae) in the Mediterranean Sea: update and new findings

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Abstract

An update of the geographical distribution of the sabellariid polychaete *Sabellaria alveolata* (Linnaeus, 1767) within the Mediterranean Sea is provided after checking the known literature. This shallow-water, reef-forming species is first recorded from new sites in southeastern Sicily, both along the Sicily Straits and the Ionian Sea, from where *S. alveolata* was so far unknown.

These new collections also provided material for a detailed description and SEM documentation of morphological features of the operculum and the body.

Introduction

The so-called sandcastle worms of the genus *Sabellaria* (Polychaeta, Sabellariidae) are currently known from the Mediterranean Sea with three species, all living at very shallow depths: *S. alveolata* (Linnaeus, 1767), *S. spinulosa* (Leuckart, 1849) and *S. alcocki* Gravier, 1906 (Castelli *et al.* 2008). The last two species, first described from the North Sea and the Indian Ocean, respectively, have still uncertain geographical ranges owing to some possibly erroneous identifications. Indeed, they can be distinguished from each other only at worm adult stage, when the operculum is fully developed (Lezzi *et al.* 2015). Both *S. spinulosa* and *S. alcocki* usually occur with single specimens or small aggregates that form thin crusts and clumps (Linke 1951; Wilson 1971). These species are particularly sensitive to natural and anthropic disturbances that may cause critical damage, extension reduction or even total dismantling of their structures (Vorberg 2000; Pearce *et al.* 2014; Plicanti *et al.* 2016). By contrast, *S. alveolata*, originally described from British waters, is widespread all throughout the western Mediterranean (Porras *et al.* 1996; Nicoletti *et al.* 2001; Delbono *et al.* 2003; La Porta & Nicoletti 2009; Schimmenti *et al.* 2016; Bertocci *et al.* 2017; Sanfilippo *et al.* 2019, *inter alias*). In this basin, it forms aggregates that are larger and more persistent than those produced by the two congeners. *S. alveolata* bioconstructions consist of tube aggregates forming pillows or hummocks often coalescing into reefs, up to one meter in height and several tens square meters in extension (Delbono *et al*. 2003; Bertocci *et al.* 2017). Reef accretion happens on both hard and soft bottoms and relays on the worm's ability to catch sand grains and cement them to build the walls of the aggregated tubes (Vovelle 1965; Gruet *et al*. 1987; Dubois *et al.* 2005; Sanfilippo *et al.* 2019; Lisco *et al.* 2020).

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The building and habitat forming capabilities of *S. alveolata* depend upon suitable environmental conditions, including high hydrodynamic energy constantly re-suspending sediment particles needed for tube accretion (Kirtley 1994). However, reefs are somewhat ephemeral because they undergo seasonal/plurennial perturbations related to natural events, like extreme storms, and human activities, which may cause erosion, fragmentation and areal reduction of bioconstructions (Wilson 1971; Gruet 1972, 1982, 1986; Dubois *et al*. 2002, 2006, 2007; Plicanti *et al.* 2016; Curd *et al.* 2019).

S. alveolata reefs have relevant ecological significance in providing available substrates and microhabitats where several organisms can live on, feed, refuge and nurse (Holt *et al.* 1998; Cocito 2004; Desroy *et. al.* 2011; Plicanti *et al.* 2017). Because of their key role in promoting the biodiversity in coastal environments (Cole & Chapman 2007; Dubois *et al.* 2002, 2006), and owing to their vulnerability to coastal hazards, *Sabellaria* "reefs" must to be considered for protection by the European Union legislation, including the Habitats Directive (Directive 92/43/EEC) and the Marine Strategy Framework Directive (Directive, 2008/56/EC). Despite this, the status and extension of these reefs in the Mediterranean, as well as in the Atlantic, are still largely unknown, and consequently, they have been included as 'Data Deficient' in the European Red List of Habitats (Gubbay *et al.* 2016).

In this scenario, the present paper aims to: 1. report new findings from southeastern and eastern coasts of Sicily, respectively in the Sicily Straits and Ionian Sea; 2. summarize present knowledge about *S. alveolata* distribution in the Mediterranean; and 3. provide a detailed description and SEM documentation of morphological features of the operculum and the body from newly collected specimens.

Materials and methods

Existing literature was checked to produce an updated review of the geographical distribution of *S. alveolata* within the Mediterranean Sea (Tab. 1, Fig. 1), according to biogeographic sectors and subregions defined in Bianchi & Morri (2000) and UNEP-MAP-RAC/SPAB (2010). Only publications based on real findings/records of *S. alveolata* were selected and critically reviewed discarding mentions/listing based on records by previous authors.

TABLE 1. Mediterranean records and related references for *Sabellaria alveolata*.

Biogeographic sector			Site	Reference
A	**Alboran Sea**		none	
B	**Southern Spain and northern Tunisian coasts**	1	Bizerte (Tunisia)	Rabaoui *et al.* (2009)
C	**Balearic Sea**	2	Gulf of Valencia (Spain)	Ibáñez Genis (1973), Campoy (1982), Porras *et al.* (1996)
D	**Gulf of Lyon and Ligurian Sea**	3	Marseilles (France)	Bellan (1964)
		4	Quarto (Genoa - Liguria)	Issel (1918)
		5	Chiavari, Gulf of Tigullio, Lavagna (Liguria)	Delbono *et al.* (2003)
		6	Sestri Levante (Liguria)	Delbono *et al.* (2003)
E	**Tyrrhenian Sea**	7	Punta delle Quaglie (Viterbo - Lazio)	La Porta *et al.* (2006), Nicoletti *et al.* (2001), La Porta & Nicoletti (2009)
		8	Civitavecchia (Lazio)	Giordani-Soika (1956), Somaschini (1988)
		9	Ostia Lido (Roma - Lazio)	Bonifazi *et al.* (2019), Casoli *et al.* (2019), Lisco *et al.* (2020)
		10	Tor Caldara (Latina - Lazio)	Taramelli-Rivosecchi (1961), Nicoletti *et al.* (2001), La Porta *et al.* (2006), La Porta & Nicoletti (2009)
		11	Lavinio (Anzio - Lazio)	Taramelli-Rivosecchi (1961), Gambi *et al.* (1996), Nicoletti *et al.* (2001)

...Continued on the next page

TABLE 1. (Continued)

Biogeographic sector			Site	Reference
		12	Torre Paola (Latina - Lazio)	La Porta *et al.* (2006), La Porta & Nicoletti (2009)
		13	Circeo (Latina - Lazio)	Chimenz Gusso *et al.* (1995), Nicoletti *et al.* (2001)
		14	Gulf of Naples (Campania)	Lo Bianco (1888, 1893), Giordani-Soika (1956)
		15	Salerno, Policastro (Campania)	Giordani-Soika (1956)
		16	Castellammare del Golfo (Trapani - Sicilia)	Sparla *et al.* (1992)
F	**Adriatic Sea**		none	
G	**Ionian Sea**	17	Simeto River mouth (Catania - Sicily)	Sanfilippo *et al.* (this paper)
H	**Sicily Straits, Tunisian Plaetau and Gulf of Sirte**	18	Triscina (Trapani - Sicily)	Iaciofano *et al.* (2015), Schimmenti *et al.* (2016), Bertocci *et al.* (2017)
		19	Eraclea Minoa (Agrigento - Sicily)	Iaciofano *et al.* (2015), Schimmenti *et al.* (2016), Bertocci *et al.* (2017)
		20	Agrigento (Sicily)	Giordani-Soika (1956)
		21	San Leone River mouth (Agrigento - Sicily)	Molinier & Picard (1953)
		22	Scoglitti (Ragusa- Sicily)	Sanfilippo *et al.* (this paper)
		23	Donnalucata (Ragusa - Sicily)	Iaciofano *et al.* (2015), Schimmenti *et al.* (2016), Bertocci *et al.* (2017)
		24	Sampieri (Ragusa - Sicily)	Sanfilippo *et al.* (2019, this paper)
		25	Portopalo (Siracuse - Sicily)	Sanfilippo *et al.* (this paper)
		26	Monastir (Tunisia)	Rabaoui *et al.* (2009)
		27	Gulf of Gabès (Tunisia)	Ayari *et al.* (2009)
		28	Djerba (Tunisia)	Wesenberg-Lund (1939), Ayari *et al.* (2009)
		29	Bahiret el Bibane (Tunisia)	Wesenberg-Lund (1939), Ayari *et al.* (2009)

Field inspections were performed in subsequent times during several years (September 2013 to May and September 2019) at different localities along the southeastern coast of Sicily to localize sites hosting sabellariid bioconstructions. Four sites were identified (details are given in Fig. 2 and Tab. 2). Scuba divers documented the bioconstructions and neighboring environments through underwater cameras, and obtained photo documentation.

Non-invasive sampling was performed on each site, except for the Portopalo one, because of the poor state of this *S. alveolata* reef that, at survey time (September 2018) appeared rather reduced in extension compared to previous visual observations. Six small blocks (ca. 20x10x20 cm) were randomly sampled using a hammer and a putty knife in order to gain some specimens for taxonomic identification. They were preserved in separate bags in 70% ethanol for subsequent analyses. In the Palaeoecology laboratory of the University of Catania, all individuals of each *Sabellaria* reef were examined and identified under an Axioplan II stereomicroscope (Zeiss) using the morphological diagnostic characters of the animal, mainly paleae from the operculum (Fig. 3). Species identification is based on Fauvel (1927), Fauchald (1977), Kirtley (1994), Capa *et al.* (2012) and Nishi *et al*. (2015). Further observations and photo-documentation of the body features (setae and uncini from the body) and details from opercular crown were obtained using a Tescan Vega 2 LMU, Low Vacuum Scanning Electron Microscope, with backscattered electrons produced images at the Microscopy Laboratory of the University of Catania.

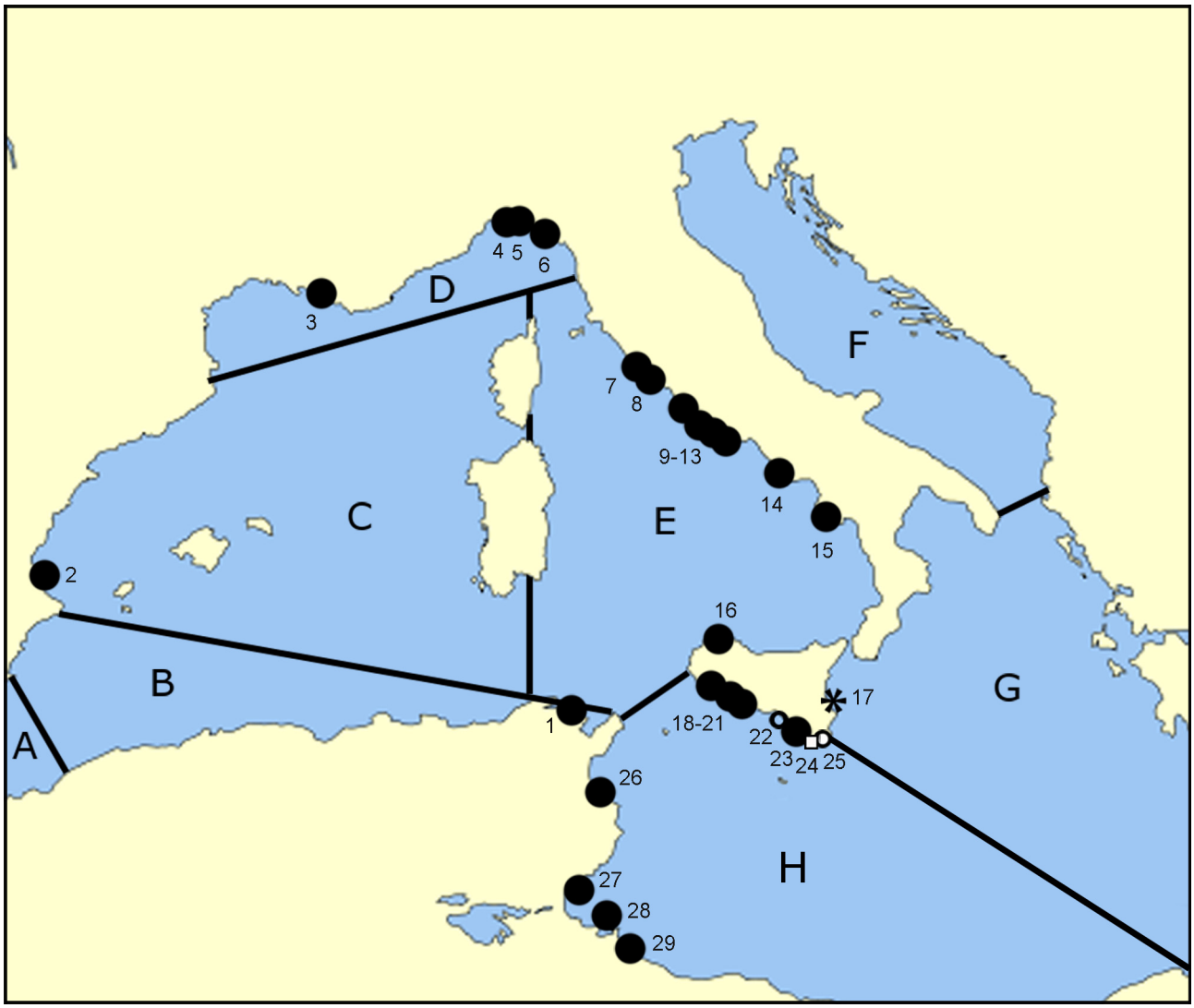

FIGURE 1. Geographic distribution of *S. alveolata* in the Mediterranean Sea. Letters indicate the different biogeographic sectors: A. Alboran Sea; B. Southern Spain and northern Tunisian coasts; C. Balearic Sea; D. Gulf of Lyon and Ligurian Sea; E. Tyrrhenian Sea; F. Adriatic Sea; G. Ionian Sea; H. Sicily Straits, Tunisian Plateau and Gulf of Sirte.
Black dots represent literature records. New findings are indicated with small circle (Scoglitti), small white square (Sampieri), small white dot (Portopalo) and asterisk (Simeto). Numbers indicate the locality names reported in Table 2.

The sampled frames and the extracted worm specimens were deposited in the invertebrate section of the Museum of Palaeontology, Department of Biological, Geological and Environmental Sciences of the University of Catania in the Sanfilippo Collection, under the code number PMC.S.I.HPol-1b.

Results

Check of literature data revealed that all Mediterranean records of *S. alveolata* refer to bioconstructions of limited extension, which are discontinuous and unevenly distributed. They are widespread in the western Mediterranean basin and particularly in the Tyrrhenian Sea and Sicily Straits (Fig. 1) while seem to be absent from the Balearic Sea, the Sardinia and Corsica waters, as well as the Adriatic and Ionian seas. The occurrence of *S. alveolata* reefs in Italian Tyrrhenian coasts (except for the eastern Sardinian side) is long lasting. They were known since the nineteenth century from Civitavecchia and subsequent findings demonstrated they are extensively widespread not only in Lazio but also along the Campania and Tuscany coasts towards South and

North, respectively. In addition, findings from the Gulf of Gabes and other Tunisian coastal areas are known since long time, while records from the southern Sicilian coast mostly date back to the last few years (see Tab. 1 for author references).

The present paper and Sanfilippo *et al.* (2019) contribute three new findings, still from the western Mediterranean, all from the Sicily Straits, in the sector H, which add to the known literature ones. Finally, bioconstruction found in the Ionian Sea represent the first ever record from the sector G (Tab.1, Fig. 1) pertaining to the western sector of the Eastern Mediterranean.

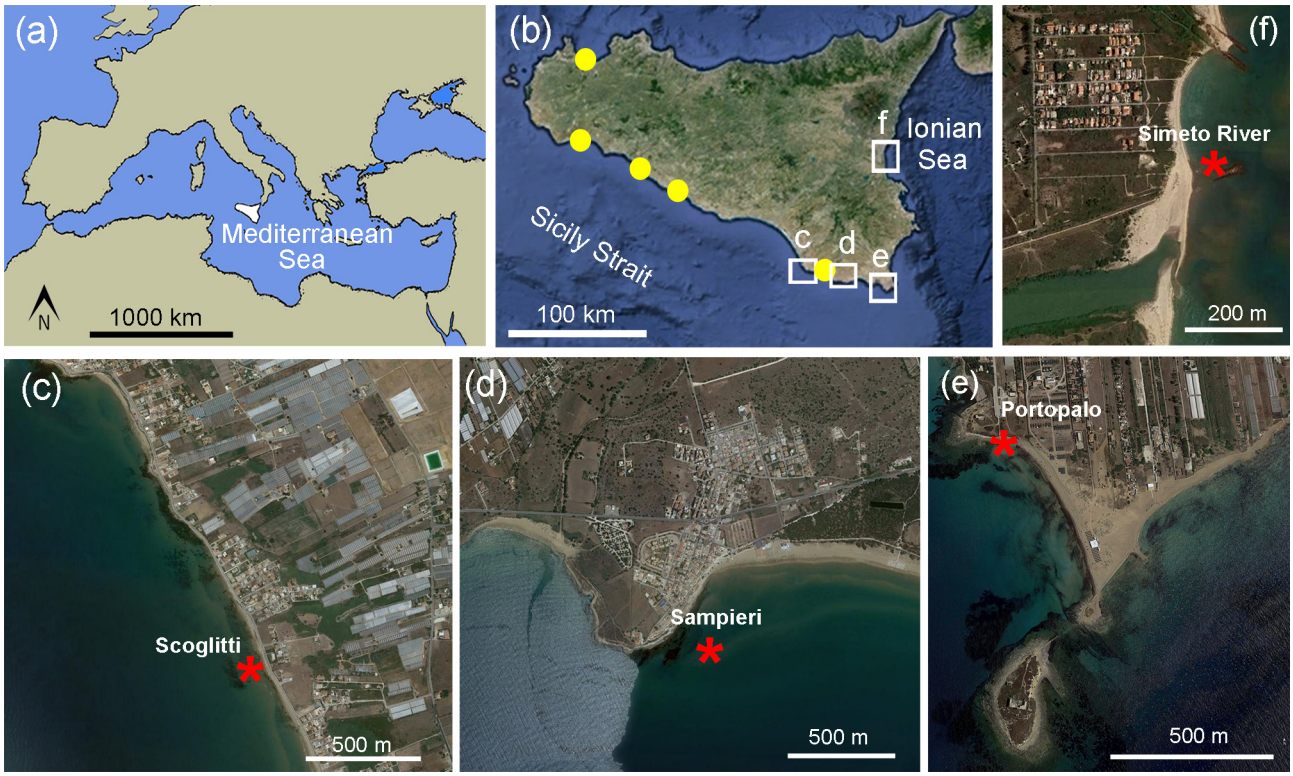

FIGURE 2. Location of the new findings within the Mediterranean (a) and the southern and eastern Sicilian coasts (b). Previous literature data are indicated with dots. New findings with squares; localities enlarged in (c) Scoglitti, (d) Sampieri, (e) Portopalo and (f) Simeto. Sampling sites are indicated with asterisks.

TABLE 2. New records of *S. alveolata* bioconstructions, with indications about sampling and observation time and habitat.

SITES	COORDINATES	DEPTH	SAMPLING DATE	BOTTOM NATURE	SAMPLED MATERIAL
Sicily Straits					
Scoglitti	36.90856 N, 14.417814 E	1.5–2 m	October 2018	Artificial rocky habitat with sands	2 reef portions, 10 individuals inside
Sampieri	36.719167 N, 14.737222 E	1–1.5 m	September 2013	Artificial hard substrates (breakwater)	2 reef portion, 3 dried individual inside
Portopalo	36.651103 N, 15.077389 E	0.5 m	September 2018	Sands and muds	none
Ionian Sea					
Simeto	37.403332 N, 15.091758 E	2 m	February 2018, May 2019	Bedrock with shell gravel	3 reef portions, 3 individuals inside

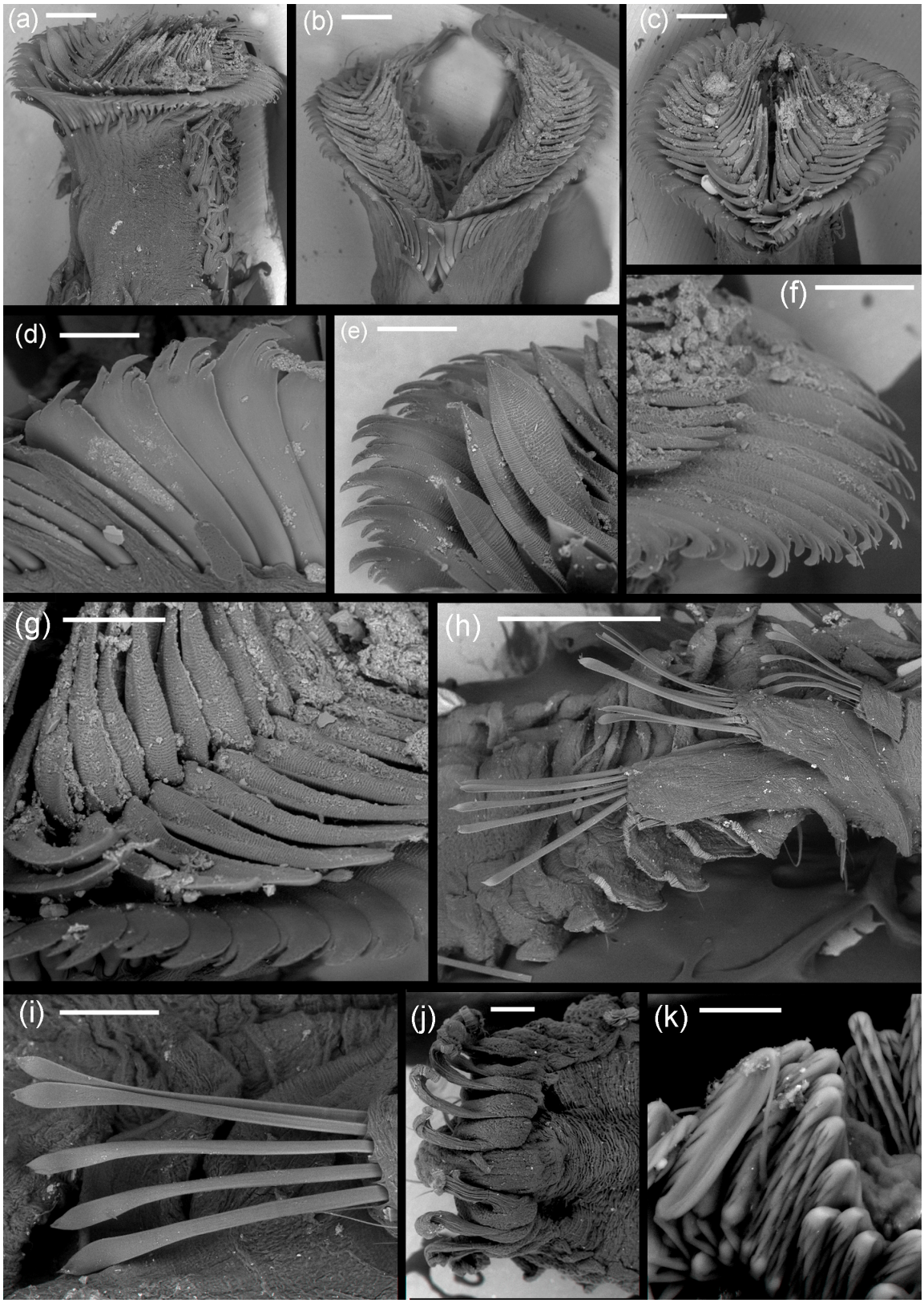

FIGURE 3. *Sabellaria alveolata* (Linnaeus, 1786). Anterior end in lateral view (a). Opercular crown in dorsal view (b) and upper view (c). Outer paleae of the operculum (d). Two different views of outer and middle rows of paleae (e, f). Arrangement of inner and middle paleae with cross-interlocking joints (g). Parathoracic segments and thori (h). Oar-shaped notochaeta and capillary setae from the third parathoracic segment (i). Posterior end (j). Abdominal uncini from the posterior end (k). Scale bars: a, b, c = 500 microns; d, e, f, g, i, j = 200 microns; h = 1 mm; k = 20 microns. Specimens from: Scoglitti (a, c, e-k); Simeto (b, d).

Findings from the Sicily Straits are from the coasts of Scoglitti, Sampieri and Portopalo (Fig. 2c–e), that from the Ionian Sea is located in the Natural Oriented Reserve of the Simeto River, in front of the river mouth (Fig. 2f).

Bioconstructions occur on sandy bottoms in the neighborhood of *P. oceanica* meadows at Scoglitti and Portopalo; they are located at the base of a rocky breakwater at the Sampieri beach. Sediments from agglutinate tubes of these bioconstructions are sandy and mostly biogenic, being largely composed by mollusc shell fragments. The Simeto bioconstructions occur in an open embayment, 150 m offshore, and north of the river mouth. Agglutinate tubes consist of sandy sediments mainly quartz-feldspathic in composition. The bottom where *S. alveolata* bioconstructions develop is sandy-muddy, and turbidity in the area is recurrent (GC, personal observations in the period January–September 2019) due to the river discharge of pelitic fraction. *S. alveolata* aggregates form crusts or "veneer" *sensu* Gruet (1982) at Portopalo, and dm-sized hummock structures that can coalesce to form small reefs up to 30 cm high at the other three sites.

In all sites, agglutinated sediment falls within medium and coarse sands, with subordinate fine sands and granules. Shape of particles varies according to their compositional nature.

The structure of individual tubes, the particle sizes and shapes used in the tube construction, as well as the nature of the biocement of the bioconstruction have been analysed by Sanfilippo *et al.* (2019).

Living animals found inside tubes demonstrated they belong to the species *S. alveolata,* according to the shape of the outer opercular paleae, their dentition pattern and the absence of nucal spines, all characters which allow the distinction from *S. spinulosa* and *S. alcocki*. The operculum is divided into two symmetrical lobes bearing three rows of paleae arranged in two concentric semicircles (Fig. 3a–c). Outer paleae are slightly arcuated blades, with smooth surface and lateral margins and serrated distal tips with four curved spines anteriorly directed (Fig. 3b, d–f). These latter may be more numerous and frayed (Fig. 3e). Two pairs of middle and inner paleae consisting of slender concave blades, are arranged with cross-interlocking joints (Fig. 3g), both pointing towards the outer edge and inwards, to the center of the operculum. Each blade has a pinnate aspect produced by an asymmetrical median carina separating two wrinkled lobes. The three parathoracic chaetigers and segments with notochaetal uncini, typical of the species, have been recognised (Fig. 3h). Chetigers bear stout oar-shaped lanceolate chaetae and many thin short capillaries (Fig. 3h–i). The posterior region bears thori with bi-pectinate notopodial uncini with 5–7 rows of superimposed teeth (Fig. 3j–k), as in the other segments.

Discussion and conclusion

The presence of *S. alveolata* bioconstructions in Mediterranean coastal areas is discontinuous and dimensionally variable probably because the species is sensitive to particular stressors, namely some hydrodynamic/environmental conditions (see Introduction) and human activities and their effects, mostly trampling and organic pollution (Dubois *et al*. 2002, 2006, 2007; Plicanti *et al.* 2016). For this reason, it is difficult to gain an updated and permanent distribution of these reefs in Mediterranean bottoms where they occur, in order to distinguish temporary from persistent reefs.

Some papers checked for Mediterranean records, and mostly the oldest ones, are not exhaustive because they merely list *S. alveolata*; some others omit any information about the presence of isolated individuals rather than of reefs, or do not give accurate descriptions of the morphology and extension of the bioconstructions, when mentioned.

The new findings of *S. alveolata* from southern Sicily coasts partly overlap and integrate the currently known Mediterranean geographical range (Tab. 1, Fig. 1) of the species. The greatest number of findings and the largest bioconstructions have so far been reported from the Lazio coasts (Casoli *et al.* 2019). However, the Simeto record extends the occurrence of the species in the Ionian Sea and represents the easternmost outpost of the species in the Mediterranean basin from where it was previously apparently absent. This is an area crucial in promoting, or rarely halting, species biogeographical diffusion, acting as a crossroad between the western and eastern basin. Consequently, after this first finding, research is needed to locate possible further sites where *S. alveolata* occurs, to demonstrate its actual scantiness or even its absence from other sectors of the Eastern Mediterranean basin. Instead, in this basin the other two congeners (i.e. *S. spinulosa* and *S. alcoki*) greatly

prevail (Nicoletti *et al.* 2001; Lezzi *et al.* 2015; Lisco *et al.* 2017; Gravina *et al.* 2018). Both these species are less noticeable than *S. alveolata* because worms grow isolated from each other, and even when they form frames, their dimensions are very small.

Owing to this size and strikingness differences, the potential co-occurrence of *S. spinulosa* and *S. alcoki* with *S. alveolata* in western Mediterranean must be also checked in sites where only *S. alveolata* has been previously reported.

Indeed, the dramatic increase in the number of records of *S. alveolata* bioconstructions (mostly localized in sectors E and H and particularly along the coasts of Italy and Sicily) in the very last years, points to incompleteness of existing data and to the need for further investigation in order to map present real distribution. But this also reflects an increase in the number of specialists (mostly Italians) working on this species and habitat, possibly also linked to a raise of interest about shallow water Mediterranean "reefs" produced by the European H2020 expectations and the Habitats Directive (Ingrosso *et al.* 2018).

Following the inclusion of *S. alveolata* reefs in the European Red List of Habitats, studies aiming at improving their knowledge must be promoted to produce a baseline of knowledge. Furthermore, periodical updated information would be required to verify the actual occurrence of the bioconstructions in the areas of their first discovery, especially for the smaller ones, as well as to monitor their long-term persistence and possible variations in extension and state in order to promote an appropriate management plan of these sensitive coastal habitats.

Author contributions

RS, ARo and AG designed the study. RS, CD, GC, ARe and GI contributed in reef detection, field investigation and sampling; RS wrote the first draft of the manuscript. CD contributed in laboratory work, check of literature records and drawing of some figures. RL helped in scuba sampling. All authors collaborated on interpreting data, writing and revising the final manuscript.

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