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Alien Sipuncula species in the Mediterranean Sea

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The compilation of data on alien Sipuncula species reported from the Mediterranean Sea to date yields a total of eight species belonging to four families. Four species have become established in the area, while two species are classified as casual and two as cryptogenic. The pathways of the introduction of alien Sipuncula species were shipping and the Suez Canal. The eastern basin had the higher number of alien Sipuncula species (seven species) mainly due to its proximity to the Suez Canal and dense shipping traffic. Among these species, Aspidosiphon (A.) mexicanus *has a wide distributional range in the region, but was considered as a cryptogenic species. The majority of alien Sipuncula species were found on soft subtrata in the region. Brief descriptions of the alien Sipuncula species and their distributional and ecological characteristics are given.*

Keywords: Alien species, vectors, Sipuncula, Mediterranean Sea

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INTRODUCTION

The extent of biological invasions has increased rapidly over the past half century (Pyšek & Richardson, 2010). The Millennium Ecosystem Assessment (2005) recognized biological invasions as one of the five main causes of declines of biodiversity and a major pressure on several types of ecosystems, with both ecological and economic impacts. The impacts of alien species on their new environment include altering ecosystem functioning (Raizada *et al.*, 2008), decreasing native species abundance and richness via competition, predation, hybridization and indirect effects (Blackburn *et al.*, 2004; Gaertner *et al.*, 2009), changing community structure (Çinar *et al.*, 2006; Hejda *et al.*, 2009), re-structuring the food web, altering gene pools (Occhipinti-Ambrogi, 2001), impacting human health and causing substantial economic losses (McGeoch *et al.*, 2010).

The Mediterranean Sea has been largely under the influence of alien species. Different transport pathways are involved in species transfer between different zoogeographic regions, but shipping and man-made canals (e.g. the Suez Canal) are the most important (Minchin *et al.*, 2006). Almost 1000 alien species have been reported from the region to date, of which 80% have been assigned to a single pathway and 12% to two or more possible pathways (Zenetos *et al.*, 2012).

Sipunculans are widely distributed in the world's oceans from intertidal to abyssal depths (Cutler, 1994). They play an important role in bioerosion of calcareous habitats and rocks (Cutler, 1968; Peyrot-Clausade *et al.*, 1992); as components of the diet of many fishes, sea anemones, decapod crustaceans, gastropods, sea stars, crabs and cephalopods (Kohn, 1975; Taylor, 1989); and as bioturbators and active burrowers in sediments (Murina, 1984).

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The phylum has almost 150 species worldwide (Cutler, 1994) and 36 species are known from the Mediterranean Sea (Açik, 2011; Ferrero-Vicente *et al.*, 2016). A total of eight alien Sipuncula species belonging to four families have been found from the region. Among them, four species (*Phascolosoma* (*P.*) *scolops*, *Phascolion* (*P.*) *caupo*, *P.* (*P.*) *convestitum* and *Aspidosiphon* (*A.*) *elegans*) were reported to have become established in the Mediterranean Sea, two species (*Apionsoma* (*A.*) *misakianum* and *Aspidosiphon* (*A.*) *mexicanus*) were considered as casual or established in the area, and two species (*Apionsoma* (*A.*) *trichocephalus* and *Nephasoma* (*N.*) *eremita*) were regarded as casual (Zenetos *et al.*, 2010; Açik, 2011; Çinar *et al.*, 2011; Ferrero-Vicente *et al.*, 2016).

This paper reviews the status of alien Sipuncula species reported from Mediterreanean coasts and gives comments on their establishment success, mode of introduction and ecological properties.

METHODS

The list of the alien Sipuncula species has been prepared based on species records along the coasts of the Mediterranean Sea. Their area of origin, mode of introduction, establishment success, depth and habitat distributions in the area are given in Table 1. The establishment success of alien sipunculans was grouped into three main categories, namely established, casual and cryptogenic. Established species are alien species with self-maintaining and self-perpetuating populations and species with at least two records in the area spread over time and space, while casual species are those which have been reported only once in the region. Cryptogenic species have no definite evidence of their native or introduced status (Zenetos *et al.*, 2010). Brief descriptions of the species and their distributional and ecological characteristics are also given. SURFER software was used for mapping of the distribution pattern of the alien Sipuncula species in the Mediterranean Sea.

Table 1. The list of alien Sipuncula species from the Mediterreanean Sea. The habitat and depth preferences of alien species along the coasts together with their possible origins, mode of introduction and establishment success are also given.

Species	O	MI	H	DR	ES	WMED	CMED	AD	EMED
N. (*N.*) *eremita* (Sars, 1851)	?PO	S	Ss	III	C	–	–	–	1
P. (*P.*) *caupo* Hendrix, 1975	WA	S	Ss	I–III	E	2, 3, 4, 5	6	–	–
P. (*I.*) *convestitum* Sluiter, 1902	RS	Su	Ss	IV–V	E	7	–	–	8
P. (*P.*) *scolops* (Selenka & de Man, 1883)	RS	Su	Hs,Ss	I–III	E	–	–	9	10
A. (*A.*) *misakianum* (Ikeda, 1904)	?IP/WA	?S	Hs,Ss	I–VII	Cr	–	6, 11	–	1, 11, 12, 13, 14
A. (*A.*) *trichocephalus* Sluiter, 1902	?IP	S	Ss	II–III	?C	–	–	–	15
A. (*A.*) *mexicanus* Murina, 1967	?IO/WA	?S	Hs,Ss	I–IV	Cr	11	6, 7, 11	7, 11	1, 13, 16, 17, 18
A. (*A.*) *elegans* (Chamisso & Eysenhardt, 1821)	RS	Su	Hs	I–II	E	–	–	19	1, 13, 14, 17, 20, 21

O, Origin (IP, Indo-Pacific; RS, Red Sea; WA, Western Atlantic; IO, Indian Ocean and PO, Pacific Ocean), MI, mode of introduction (Su, Suez Canal and S, Shipping), H, Habitat (Hs, hard substratum (including algae, sponge), Ss, soft substratum (including phanerogames)), DR, Depth range: (I: 0–10 m, II: 11–50 m, III: 51–100 m, IV: 101–200 m, V: 201–400, VI: 401–500 m VII: 501–2500 m), ES, Establishment success (E, established; C, casual and Cr, cryptogenic), WMED, Western Mediterranean; CMED, Central Mediterranean; AD, Adriatic Sea; EMED, Eastern Mediterranean.
1. Açik (2011); 2. Ferrero-Vicente *et al.* (2011); 3. Ferrero-Vicente *et al.* (2012); 4. Ferrero-Vicente *et al.* (2013a); 5. Ferrero-Vicente *et al.* (2013b); 6. Mifsud & Saiz Salinas (2011/2012); 7. Pancucci-Papadopoulou *et al.* (1999); 8. Murina (1964); 9. Murina & Zavodnik (1986); 10. Açik *et al.* (2005); 11. Saiz Salinas (2016), 12. Açik (2007); 13. Açik (2008a); 14. Açik (2010b); 15. Murina *et al.* (1999); 16. Açik (2009); 17. Açik (2010a); 18. Çinar *et al.* (2012); 19. Zavodnik (1998); 20. Wesenberg-Lund (1957); 21. Açik (2008b).

RESULTS AND DISCUSSION

Based on the compilation of papers on sipunculans reported from the coasts of the Mediterranean Sea, the phylum is represented by a total of eight alien species belonging to four families. The species are categorized by their origins, the mode of introduction and their habitat and depth preferences (Table 1). The establishment success is assigned for each species.

The main pathways for the introduction of established alien sipunculans to the Mediterranean are shipping (one species) and the Suez Canal (three species). The eastern Mediterranean hosts a higher number of alien sipunculans (seven species) due to its proximity to the Suez Canal and dense shipping traffic (Çinar *et al.*, 2011). Of the eight alien sipunculans reported from the region, four species can be classified as established, two species as casual and two species as cryptogenic. The status of the casual species could be changed to established species if further evidence of their presence in other areas is provided. Although *Apionsoma* (*A.*) *trichocephalus* was found with a high density (400 ind. m^{-2}) in the Nile Delta (Murina *et al.*, 1999), this species was classified as a casual alien species in the region as there is no other evidence showing its successful establishment in the region.

Among the alien sipunculans, three species (*Phascolosoma* (*P.*) *scolops*, *Apionsoma* (*A.*) *misakianum* and *Aspidosiphon* (*A.*) *mexicanus*) occurred on both hard and soft substrata, four species (*Nephasoma* (*N.*) *eremita*, *Phascolion* (*P.*) *caupo*, *Phascolion* (*I.*) *convestitum* and *Apionsoma* (*A.*) *trichocephalus*) only on soft substrata, and one species (*Aspidosiphon* (*A.*) *elegans*) only on hard substrata. Established and casual alien sipunculans species were reported between 0 and 260 m depths. The cryptogenic species *A.* (*A.*) *misakianum* was found at 2287 m depth in South Crete and at 0–460 m depths in other parts of the Mediterranean Sea (Açik, 2014; Saiz Salinas, 2016). *Aspidosiphon* (*A.*) *mexicanus*, which seems to be another cryptogenic species, has a wide distributional range in the Mediterranean Sea. It was found at depths ranging from 25 to 429 m (Ferrero-Vicente *et al.*, 2016).

The morphological, distributional and ecological aspects of the alien sipunculans are given below.

Nephasoma (*Nephasoma*) *eremita* (Sars, 1851)

DESCRIPTION

Body wall smooth, pale creamy tan to dark reddish brown (Figure 1A). Cylindrical trunk with abrupt taper to introvert. Unclear transverse and parallel grooves present on trunk wall. Mouth at distal end of introvert surrounded by digitiform tentacles. Hooks absent. Two retractor muscles attached to posterior one-third of trunk. Oesophagus attached to retractor muscles by connective tissue. Two nephridia present. Nephridiopores anterior to anus.

DISTRIBUTION AND ECOLOGY

Nephasoma (*Nephasoma*) *eremita* was previously reported from the northern and southern Atlantic, Arctic, Antarctic and eastern Pacific coasts (Cutler, 1994). In the Mediterranean, it was only reported from the Levantine coast of Turkey (Anamur) on muddy sand at 75 m depth (Figure 2) and considered to have been introduced to the area in the ballast waters of ships (Açik, 2011). As only one individual of this species was found in the Mediterranean Sea, this species was classified as a casual alien species.

Phascolion (*Phascolion*) *caupo* Hendrix, 1975

DESCRIPTION

Body semi-transparent, lightly yellowish (Figure 1B). Introvert longer than trunk length. Scattered broad-based hooks with tip rounded. Cone-shaped holdfast papillae dark, sparse and tall. Blister-shaped papillae scattered along trunk. Ventral retractor muscle thinner than dorsal. One nephridium present. Two retractor muscles partially fused.

DISTRIBUTION AND ECOLOGY

Phascolion (*P.*) *caupo* was previously known from the southeastern United States (Cutler, 1994). In the Mediterranean (Figure 2), it was first reported from different areas of the Spanish Mediterranean coast with a high number of individuals between 7 and 45 m depths (Ferrero-Vicente *et al.*, 2016) and subsequently from the Maltese coast between 20

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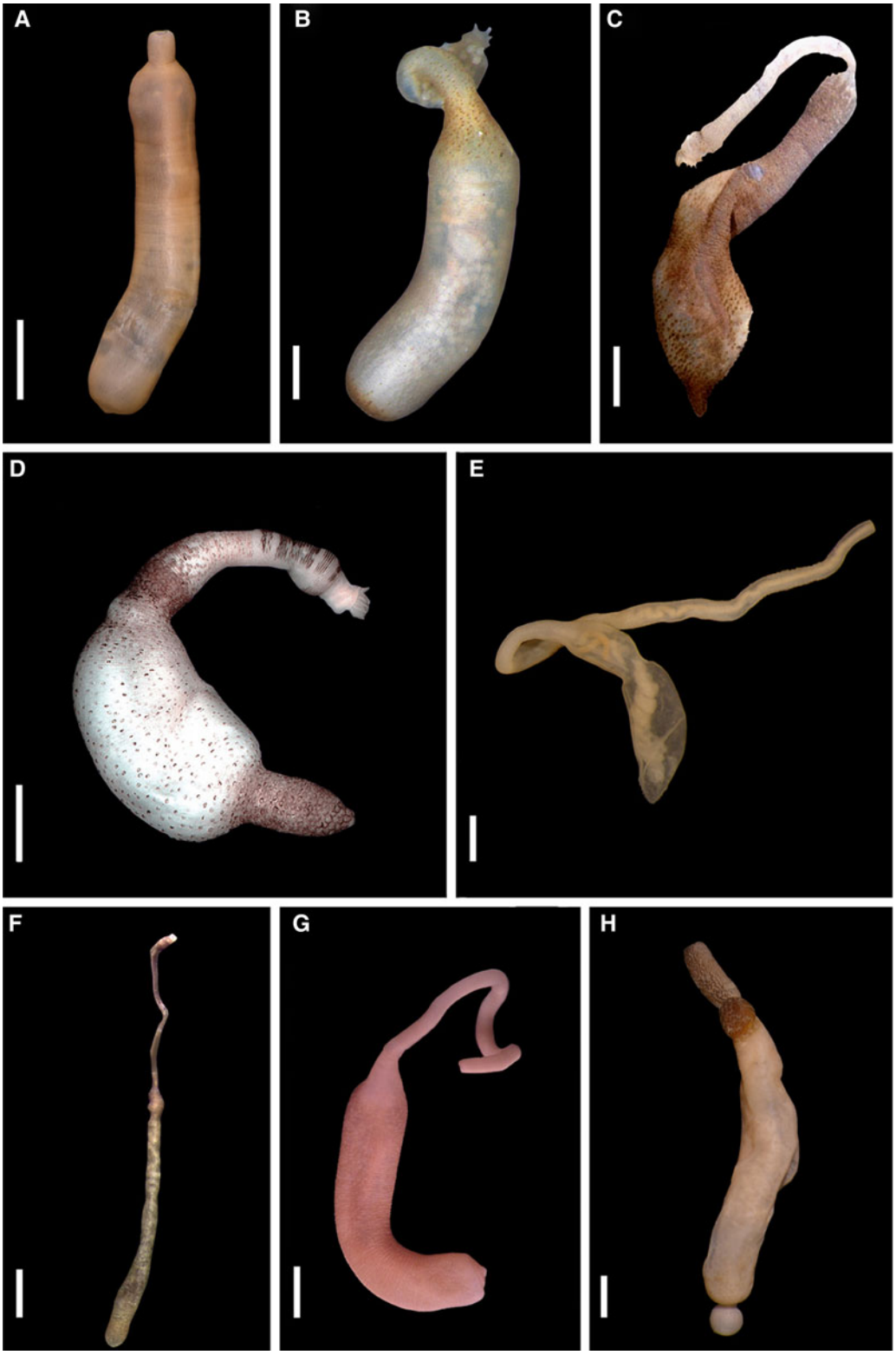

Fig. 1. External morphology of species. (A) *Nephasoma* (*N.*) *eremita*, (B) *Phascolion* (*P.*) *caupo*, (C) *Phascolion* (*I.*) *convestitum*, (D) *Phascolosoma* (*P.*) *scolops*, (E) *Apionsoma* (*A.*) *misakianum*, (F) *Apionsoma* (*A.*) *trichocephalus*, (G) *Aspidosiphon* (*A.*) *mexicanus*, (H) *Aspidosiphon* (*A.*) *elegans*. Scale bars: A = 2 mm, B = 0.5 mm, C and D = 2 mm, E = 0.5 mm, F = 1 mm, G = 2 mm, H = 1 mm (A, E = from Açik, 2011, B–D, F = from Ferrero-Vicente *et al.* 2016; G = from Açik, 2014, H = from Açik, 2008b).

and 60 m depths (Mifsud & Saiz Salinas, 2011/2012). It was found in soft sediment and usually inhabited empty gastropod shells and polychaeta tubes (Mifsud & Saiz Salinas, 2011/2012; Ferrero-Vicente *et al.*, 2016). This species can be accepted as an established alien species for the region. It could have been introduced to the area by ballast waters of ships.

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Fig. 2. Distribution of *Nephasoma* (*N.*) *eremita* (✕), *Phascolion* (*P.*) *caupo* (▲), *Phascolion* (*I.*) *convestitum* (●), *Phascolosoma* (*P.*) *scolops* (★), *Apionsoma* (*A.*) *trichocephalus* (✚) and *Aspidosiphon* (*A.*) *elegans* (○) in the Mediterranean Sea.

Phascolion (*Isomya*) *convestitum* Sluiter, 1902

DESCRIPTION

Body wall semi-transparent (Figure 1C). Introvert with large, recurved hooks. Holdfast papillae highly variable, from large and bulbous to small and compact; some with granular material around border, others with hardened material around border or without hardened material. Dorsal retractor muscle with single origin whereas ventral muscle with two origins. Gut with loose coils. One nephridia present. Short, strong fixing muscle attaching coils to body wall between roots of ventral retractor. No spindle muscle. Two eyespots present.

DISTRIBUTION AND ECOLOGY

Phascolion (*Isomya*) *convestitum* is distributed from the Pacific, Indonesia, Gulf of Aden and Red Sea. It was rarely reported in the Mediterranean Sea (French coasts, Tyrrhenian Sea, Ligurian Sea and Egypt) on sand/silty sediment at depths ranging from 140 to 260 m (Pancucci-Papadopoulou *et al.*, 1999; Ferrero-Vicente *et al.*, 2016). It is a Lessepsian migrant (Açik *et al.*, 2005).

Phascolosoma (*Phascolosoma*) *scolops* (Selenka & de Man, 1883)

DESCRIPTION

Trunk opaque, light brownish (Figure 1D). Introvert with regular pigmented bands. Dome-shaped to mammiform, reddish brown preanal papillae at base of introvert. Less than 25 rings of hooks with visible triangle and clear streak. Two characteristic dark lines crossing clear area of each hook. Hooks unidentate, sometimes with small secondary tooth. Longitudinal muscles gathered into 19–24 bands. Spindle muscle well developed, attached to posterior end of trunk. Contractile vessel simple. Two pairs of retractor muscles and two eyespots present.

DISTRIBUTION AND ECOLOGY

Phascolosoma (*Phascolosoma*) *scolops* was previously reported from the Indo-West Pacific region, Red Sea and eastern Atlantic Ocean (Cutler, 1994). In the Mediterranean (Figure 2), it was first reported from the Adriatic Sea on hard bottom at 35–65 m depths (Murina & Zavodnik, 1986) and subsequently from the northern Cyprus on rocks, seagrass *Posidonia oceanica* and the algae *Cystoseira crinita* at 0–10 m depths (Açik *et al.*, 2005). As it occurs solely in the Indo-Pacific region and the Red Sea, it could be considered as a Lessepsian migrant (Açik *et al.*, 2005).

Apionsoma (*Apionsoma*) *misakianum* (Ikeda, 1904)

DESCRIPTION

Body wall thin, semi-transparent (Figure 1E). Introvert longer than trunk length. Small, numerous brown papillae on posterior part of trunk. Introvert with 50–82 rings of hooks. Most distal rings of small hooks with 4–5 spinelets. Intestine spiral attached to posterior part of trunk by spindle-muscle. Four thin retractor muscles originating near middle of trunk, both pairs close to ventral nerve cord. Bilobed nephridia similar in size. Nephridiopores located in front of anus. Two black eyespots present.

DISTRIBUTION AND ECOLOGY

Apionsoma (*Apionsoma*) *misakianum* was previously reported from the Indian, Pacific and western Atlantic Oceans (Cutler, 1994). In the Mediterranean (Figure 3) it was first reported from the Aegean Sea at 41–195 m depth (Açik, 2007, 2008a) and subsequently from the Levantine coasts of Turkey at 0–200 m depth (Açik, 2010b, 2011), from Crete at 69–2287 m depth, from Rhodos at 115–160 m depth and from Malta at 60–460 m depth (Mifsud & Saiz Salinas, 2011/2012; Saiz Salinas, 2016). It was previously mentioned that this species could have been introduced to the area by ballast waters of ships. This species is usually found in sandy/muddy sediments, but also has been reported from algae (*Halopteris scoparia* and *Ellisolandia elongata*), seagrass *Posidonia oceanica*, pores of calcareous rocks and rodolith facies (Açik, 2007, 2008a, 2010b, 2011; Mifsud & Saiz Salinas, 2011/2012; Saiz Salinas, 2016). It is often associated with empty tubes of serpulid polychaetes (*Vermiliopsis* sp. and *Serpula* sp.) and shells of molluscs (*Antalis panorma*) (Açik, 2007).

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Fig. 3. Distribution of *Apionsoma* (*A.*) *misakianum* in the Mediterranean Sea.

The majority of alien species (80% of total number of species) were generally encountered in shallow waters and no alien species in the Mediterranean has previously been reported at great depths (>200–500 m) (Çinar *et al.*, 2011). However, the sipunculan worm *Apionsoma* (*A.*) *misakianum* was recently found at 2287 m depth off South Crete (Saiz Salinas, 2016) and widely distributed in the Mediterranean Sea. Therefore, it is unclear at this stage whether this species is really an alien species for the region. With regards to its worldwide distributional ranges, there is a discontunity in its actual distribution; absent in the eastern Atlantic. This species was first reported in the Mediterranean by Açik (2007) from the Aegean Sea, but now it is known in almost every part of the Mediterranean. To clarify its alien status, the previous reports of species *Apionsoma* from the region should be re-examined to determine if *A.* (*A.*) *misakianum* occurred in the area for a long time. It is therefore suggested that this species should be accepted as a cryptogenic species, rather than an established alien species. Molecular analysis to be performed on specimens from different parts of the world might shed more light on where this species is originating from.

Apionsoma (*Apionsoma*) *trichocephalus* Sluiter, 1902

DESCRIPTION

Trunk slender, spindle-like and semi-transparent (Figure 1F). Introvert 8–14 times trunk length. Scattered round papillae at posterior end of trunk. Hooks and tentacles absent. Two pairs of thin retractor muscles attached to middle of trunk. Rectal caecum absent. Two bilobed nephridia present. Nephridiopores anterior to anus.

DISTRIBUTION AND ECOLOGY

Apionsoma (*A.*) *trichocephalus* was previously reported from the north and south Atlantic Ocean, north and south Pacific Ocean, Indian Ocean and Gulf Aden (Cutler, 1994). In the Mediterranean (Figure 2), the only published record of the species came from the Nile Delta on muddy bottom at depths ranging from 24 to 75 m (Murina *et al.*, 1999). This species could have been introduced to the area by ballast waters of ships as it was absent (or at least not reported) in the Red Sea. As there is only one documented report of this species in the region, this species is classified as a casual species.

Aspidosiphon (*Akrikos*) *mexicanus* Murina, 1967

DESCRIPTION

Body wall thin, light yellowish (Figure 1G). Anal shield weakly developed with ill-defined platelets. Caudal shield not clear. Introvert at typical angle (45–50°) with main trunk axis. Hooks unidentate, uncompressed, scattered and small. Intestinal spiral attached to posterior part of trunk by spindle muscle. Contractile vessel simple. Two single lobed nephridia present. Nephridiopores posterior to anus. Eyespots absent.

DISTRIBUTION AND ECOLOGY

Aspidosiphon (*A.*) *mexicanus* is known from the western Atlantic Ocean, Indian Ocean and Mediterranean Sea (Pancucci-Papadopoulou *et al.*, 1999). In the Mediterranean, only a few specimens of this species were recorded from Malta, the Lampedusa Islands, the Adriatic and the Greek coasts until 2008 (Pancucci-Papadopoulou *et al.*, 1999). Records made after this date showed that this species is widely distributed from littoral waters to 429 m depth (Figure 4) in the eastern and western basins of the Mediterranean Sea (Açik, 2008a, 2009, 2010a, 2011, 2014; Mifsud & Saiz Salinas, 2011/2012; Çinar *et al.*, 2012; Saiz Salinas, 2016). It has been collected from sandy mud, muddy sand, sand, mud, gravel bottoms, empty mollusc shells, rocks, *Posidonia oceanica* and *Zostera marina* (Ferrero-Vicente *et al.*, 2016). As it is distributed in the western Atlantic and Indian Oceans, it is difficult to determine at this stage from where and how it has been introduced to the Mediterranean. Therefore, this species should be accepted as a cryptogenic species at the time being. A molecular analysis is needed to understand its origin (Açik, 2011).

Aspidosiphon (*Aspidosiphon*) *elegans* (Chamisso & Eysenhardt, 1821)

DESCRIPTION

Body wall thin and semi-transparent (Figure 1H). Introvert as long as trunk length. Ungrooved anal shield granulous.

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Fig. 4. Distribution of *Aspidosiphon* (*A.*) *mexicanus* in the Mediterranean Sea.

Caudal shield usually weakly developed. Bidentate hooks on rings located on distal part of introvert. Dark conical hooks scattered on proximal part of introvert. Intestinal tract with about 14–20 coils, attached by spindle muscle. Retractors originating from 14 to 30% of distance to posterior end of trunk. Nephridiopores anterior or posterior to anus. Two black eyespots present.

DISTRIBUTION AND ECOLOGY

Aspidosiphon (*A.*) *elegans* was previously reported to be a common species in the shallow waters of the Indian and western Pacific Oceans, and the Red Sea (Cutler, 1994). Wesenberg-Lund (1957) firstly reported it within the Mediterranean from the Israeli coast (Figure 2). It was later found at 0–14 m depths in the Rijeka Bay (Adriatic Sea), and in shallow waters along the Turkish and Lebanese coasts (Figure 2) (Zavodnik, 1998; Açik, 2008b, 2014; Saiz Salinas, 2016). This species has been found in various habitats including *Posidonia oceanica*, algae, calcareous rock, mussel and the coral *Cladocora caespitosa* (Açik, 2008a, b, 2010a, b, 2011).

Aspidosiphon (*A.*) *elegans*, a lessepsian migrant, is known to be a bio-eroder of calcareous substrates such as rocks, stones and corals (Cutler, 1994). When it attains a high population density in the area, it may cause serious damage to these habitats. The magnitude of its impact on the habitats as a bio-eroder species should be studied and monitored.

The records of the alien sipunculan species found in the region is increasing day by day, partly due to the increase in the number of studies conducted in the area, and partly through the impacts of pathways and the range extensions of alien species (Çinar *et al.*, 2005; Zenetos *et al.*, 2012). Invasive alien species may have ecological, economic or health-related influences, especially after they succeed in establishing dense populations, or presenting invasive characters. This study sheds more light on the morphological, distributional and ecological features of alien sipunculans in the Mediterranean Sea. Such studies might also provide extensive information about ecological and functional roles of aliens in the ecosystems. Therefore, monitoring of alien species especially in large international harbours, estuarine areas, deltas and aquaculture facilities should be performed.

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