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## ***Aricidea fragilis* (Annelida: Paraonidae) in the Mediterranean Sea: overlooked native or alien species?**

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### **Abstract**

The paraonid polychaete *Aricidea fragilis* Webster, 1879, a typically west-Atlantic species, is reported from the Mediterranean Sea on the basis of several individuals, from the Adriatic and Tyrrhenian Sea. Its differences with the other Mediterranean Paraonidae, and in particular with the morphologically close *Aricidea suecica meridionalis* Laubier & Ramos, 1974, are briefly discussed. The possible status of *A. fragilis* as an alien species in European waters is analysed. The scarcity of historical records, the relatively restricted distribution, and the population dynamics observed in European waters strongly support the hypothesis of an introduction, despite the wide temporal interval between the first record of the species in the 1930s and the currently ongoing range expansion and population explosion. Here we precautionarily suggest considering *A. fragilis* a cryptogenic species.

**Keywords:** *Polychaeta*, *Paraonidae*, *alien species*, *cryptogenic species*, *biogeography*

### **Introduction**

The introduction of alien species represents a major threat for natural ecosystems, and may severely affect the functioning of ecosystems as well as anthropic activities (Vilà et al. 2010), thus producing relevant economic losses (Pimentel et al. 2001). For this reason, monitoring of biological invasions represents a paramount tool in environmental management, in order to plan impact reduction and, where possible, eradication strategies (Wittenberg & Cock 2001). While for vertebrates and some invertebrate groups, such as insects, echinoderms and molluscs, it is relatively easy to assess whether a species is native or not, for several invertebrate groups this question is not so easily answered and represents an additional problem in alien species management, especially in marine environments.

In particular, polychaete worms are characterised by a high number of cryptogenic species (Carlton 1996). Poor understanding of the taxonomy of some groups has led to misidentifications and

lumping of different species under the same taxon, causing faulty information about the biogeography of the species. The increase of information on polychaete diversity and taxonomy may lead to the re-evaluation of alien species. This includes both the addition of overlooked aliens to lists of introduced species, and the de-listing of misjudged ones. Although the Mediterranean polychaete fauna is overall well known, alien polychaetes in the Mediterranean are in need of comprehensive revision, and some species should probably be considered cryptogenic, rather than truly alien.

In recent years a large paraonid worm belonging to the genus *Aricidea* became locally abundant, mainly in the Adriatic Sea, but also showing occurrences in the Tyrrhenian Sea, suggesting that it might represent a newly introduced species. In this work we briefly describe the species, in comparison with congeneric native taxa, discuss its attribution to *Aricidea fragilis* Webster, 1879 and discuss its possible non-native status.

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**Materials and methods**

Individuals of *Aricidea fragilis* were collected in Tyrrhenian and Adriatic Sea (Mediterranean) from soft bottoms, during regular environmental monitoring campaigns carried out yearly from 2010 to 2016 by the Italian Regional Agencies for Environment Protection (ARPAs) and the Centre for Marine Research, Ruđer Bošković Institute, in Rovinj (Croatia) (Figure 1). All individuals were fixed in buffered 4% formalin, and then preserved in 70% ethanol. Part of the studied material has been deposited at the Museo di Storia Naturale of the University of Pisa (MSNP). Non-type individuals of *Aricidea suecica meridionalis* Laubier & Ramos, 1974 were obtained for comparison from the same collection.

Drawings were obtained with the help of a camera lucida and of microphotographs, and refined with GIMP 2.8.16, following the guidelines in Montesanto (2015).

**Results**

*Taxonomic account*

Family **PARAONIDAE** Cerruti 1909

Genus *Aricidea* Webster, 1879

*Aricidea fragilis*, Webster, 1879

(Figure 2)

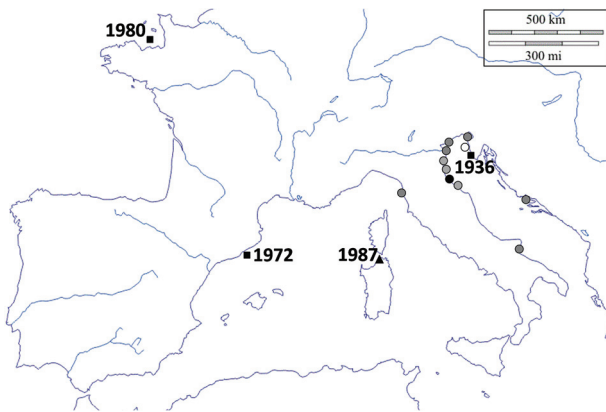


Figure 1. Known occurrences and dates of record of *Aricidea fragilis* Webster, 1879 in the northeastern Atlantic Ocean and Mediterranean Sea. Squares: records obtained from the literature; triangle: record from re-examination of material deposited in the collection of the Museo di Storia Naturale of the University of Pisa (MSNP); circles: new records from environmental monitoring campaign. Circle colours represent different years of collection: black = 2010; dark grey = 2014; light grey = 2015; white = 2016.

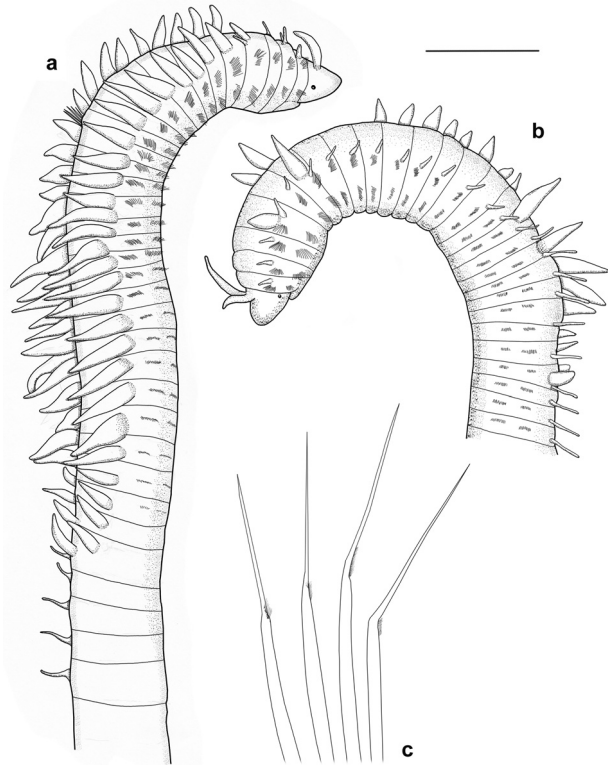


Figure 2. *Aricidea fragilis*, Webster, 1879: (a) typical individual from Cattolica (Italy); (b) individual with branched antenna from River Jadro Estuary (Croatia); (c) modified chaetae. Scale bar: a,b = 1 mm; c = 40 µm.

*Aricidea fragilis*: Webster, 1879: 255–257, pl. IX: 127–132; Pettibone, 1965: 129–131, figs 1–3.

*Aricidea (Aricidea) fragilis*: Strelzov, 1973: 57–59, fig. 21.

*Aricidea fragilis mediterranea (partim)*: Laubier & Ramos, 1974: 1113–1116, fig. 6D.

?*Aricidea (Strelzovia) suecica meridionalis (partim)*: Aguirrezabalaga, 2012: figs 91B, 91D, 92.

**Material examined. Adriatic Sea:** Cattolica – (43.994° N, 12.766°E), 11 m (15 November 2010): one individual; 11 m (03 June 2015): eight individuals; (43.980° N, 12.754°E), 3.5 m (03 June 2015): 15 individuals. Cavallino-Treporti – (45.433°N, 12.512°E), 13 m (03 October 2014): five individuals. Cesenatico – (44.207° N, 12.422°E), 3 m (19 May 2015): two individuals; 3 m (16 November 2015): five individuals. Lido Adriano – (44.413°N, 12.329°E), 6–9 m (18 May 2015): four individuals. Manfredonia Gulf – (41.586°N, 15.902° E), 8 m (29 September 2014): two individuals. 3 m (06/05/2015): 242 individuals. Po River Mouth – (44.797°N, 12.456°E), 14 m (03 October 2014): one individual. Porto Garibaldi – (44.686°N, 12.262°E), 9

m (20 May 2015): one individual; 9 m (19 November 2015): six individuals. River Jadro Estuary – (43.534°N, 16.471°E), depth unknown (25 August 2014): five individuals. River Mirna Estuary – (45.311°N, 13.586°E), 10 m (14 September 2016): 478 individuals. **Tyrrhenian Sea:** Porto Pozzo Bay – (41.191°N, 9.281°E), 1 m (October 1987): two individuals. Viareggio – (43.864°N, 10.225°E), 10 m (13 June 2014): one individual.

*Comparative material.* *Aricidea suecica meridionalis* Laubier & Ramos, 1974

**Adriatic Sea:** Gulf of Trieste – (45.747°N, 13.599°E), 15 m (October 1995): one individual. **Tyrrhenian Sea;** Livorno – (43.588°N, 10.252°E), 14 m: two individuals (April 1992); Gorgona Island – (43.549°N, 10.032°E), 110 m: one individual (August 2015).

**Strait of Sicily:** Gulf of Cagliari – (39.118°N, 9.067°E), 20 m (1982): one individual.

*Diagnosis.* Large-sized *Aricidea* (up to 1.5 mm maximum width, up to 100 mm maximum length); prostomium triangular, antenna subulate, slender, as long as prostomium or shorter; eyes present. Twenty-five to forty pairs of pointed, tapering branchiae; dorsal podial lobes cirriform with asymmetrical basal enlargement in branchial region. Modified neurochaetae pseudo-articulate, numerous, occurring in the whole post-branchial region.

*Description.* Mediterranean individuals are relatively large paraonids, with a maximum width from 0.6 to 1.4 mm; maximum length unknown, since all specimens are incomplete, but probably around 40–50 mm in the larger individuals (anterior fragments up to 32 mm for 108 chaetigers). Prostomium roughly triangular, with median antenna cirriform, pointed, approximately as long as the prostomium, with slightly enlarged basis; eyespots generally present. Three pre-branchial chaetigers; 25–37 pairs of well-developed, easily broken branchiae. Number of branchiae depending on the size of the individual: small individuals (0.6–0.8 mm width) with 25–30 pairs of branchiae, larger ones (1.2–1.4 mm width) with 34–37. Branchiae pointed and leaf shaped, not excessively elongate; 4–6 posterior pairs narrower, with elongate tips, last 2–3 branchiae distinctly shorter, without elongate tip (Figure 2(a)). Postchaetal notopodial lobes elongate throughout the whole body length, thicker, often with enlarged basis in pre-branchial and branchial chaetigers, long and thinner in the post-branchial region. Parapodia biramous, poorly developed, with capillary chaetae throughout the body. Modified neuropodial

chaetae occurring in thick bundles in the posterior part of the body, pseudo-articulate, with a shallow notch approximately at half of length. Clearly noticeable hairs in proximity of the articulation of the chaeta, distal part of the chaeta often deflected with respect to the proximal part (Figure 2(c)). Live colour pale pink or yellowish, preserved individuals whitish or yellowish (if not stained). Two individuals of five examined from the River Jadro Estuary (Croatia) are otherwise completely indistinguishable from the remaining material, but have a double antenna, formed by two equal, paired branches originating from the same basis (Figure 2(b)).

*Remarks.* Among the known Mediterranean species, the closest taxon seems to be *Aricidea suecica meridionalis* Laubier & Ramos, 1974. A close examination of five individuals of *A. suecica meridionalis* from the collection of the Department of Biology of the University of Pisa showed that they are very similar to *A. fragilis* in the large size, the length and shape of the antenna, and the pattern of notopodial postchaetal lobes; they are, however, strikingly different in the shape of modified chaetae (with a distinctly thinner arista after the subdistal notch, without hairs), the shape of the prostomium (sub-trapezoidal) and the length and shape of the branchiae (distinctly longer than the half of the body width, always without tapered tips). The remaining Mediterranean species are clearly different in size, shape of the antenna, number of branchiae and shape of modified chaetae. The similarities between *A. fragilis* and *A. suecica meridionalis* probably led to misidentifications; for instance, the drawings reported for *A. suecica meridionalis* by Aguirrezabalaga (2012, figs 91B, 91D, 92) show clear differences from the original description and the drawings in Laubier and Ramos (1974), and probably refer to *A. fragilis* as well.

*Distribution and abundance.* On the basis of data collected during this study, *Aricidea fragilis* occurs in a wide section of the Adriatic Sea, along both the western and the eastern coasts, and more sporadically in the Tyrrhenian Sea. The density of *A. fragilis* varied from three to 45 individuals/m<sup>2</sup> in the populations of the Riviera Romagnola (Cattolica, Cesenatico, Lido Adriano, Porto Garibaldi). In the Gulf of Manfredonia this species has been collected only from a single site near the Estuary of the Candelaro River, at shallow depth. The species was firstly collected, with only two individuals, in September 2014. However, the extensive sampling carried out in October 2014 did not find any individuals of this species, whereas in May 2015 *A.*

*fragilis* was sampled with a remarkably high density (1187–2145 individuals/m<sup>2</sup>). Along the eastern Adriatic coast, the species appeared common, but with relatively low density, at the Estuary of River Jadro, whereas it occurred again with very high density at the Estuary of River Mirna (990–1430 individuals/m<sup>2</sup>).

## Discussion

Despite being the first species of *Aricidea* to have been described (Webster 1879), as well as one of the largest and most conspicuous known Paraonidae, *A. fragilis* is poorly known from several points of view. Redescriptions by Pettibone (1965) and Strelzov (1973), based chiefly on western Atlantic specimens collected not far from the type locality, show discrepancies from the original description. In particular, Webster's individual apparently shows a shorter antenna (half of prostomium length vs about the same length in redescrptions). However, the pattern of notopodial lobes in the pre-branchial region, the large size, the high number of branchiae and the shape of neuropodial chaetae in the post-branchial region are consistent between the original description and the subsequent redescrptions. Unfortunately, the holotype of *A. fragilis* seems to be lost, as there is no trace of it in any of the museums where it is likely to have been deposited (Gil et al. 2017). Considering that in the original description Webster believed he was describing an Orbiniidae, and thus stressed chiefly features distinguishing his specimen from other known orbiniids, for the moment we are compelled to also rely on redescrptions, even if a redescription of the species from the type locality (Virginia, north-western Atlantic Ocean) and the possible designation of a neotype are needed. Also, the fact that Webster described a live individual, whereas subsequent redescrptions are based on fixed material, could account for discrepancies. It is not unlikely that *A. fragilis* will turn out to represent a species complex. However, the Mediterranean material described herein closely corresponds to the redescription by Pettibone (1965) based on north-western Atlantic specimens, though not from the type locality. In European waters outside the Mediterranean Sea *A. fragilis* has been reported only from the English Channel (Dauvin & Gentil 1980; Dauvin et al. 2003), sometimes as the dominant species (Quiroz-Martinez et al. 2012). The vast majority of records of *A. fragilis* in the Mediterranean Sea are due to misidentifications of other species (Strelzov 1973). However, in the available literature we identified two reliable Mediterranean records of this species. The first one refers to individuals recorded in the Bay of Rovinj

(Croatia) in 1936 (Vatova 1949), initially reported by Fauvel (1940) as *Aricidea jeffreysii* (McIntosh, 1878). Strelzov (1973) examined these specimens and attributed them to *A. fragilis*. According to Strelzov (1973) these individuals should have been deposited in the Musée National d'Histoire Naturelle (MNHN) of Paris, but this material is not listed in the online database of the MNHN. The brief description of these individuals corresponds to *A. fragilis* in regards to size and number of branchiae. Later, Laubier and Ramos (1974) described *Aricidea fragilis mediterranea* as a new subspecies, pointing at a bottle-shaped antenna, a smaller size and a lower number of branchiae as diagnostic characters towards the nominal subspecies. Specimens described in this paper from the region of Marseille (France), which include the holotype of the species, actually correspond morphologically to *Aricidea pseudoarticulata* Hobson, 1972; for this reason, *A. fragilis mediterranea* is currently considered synonymous with that species (Aguirrezabalaga & Gil 2008). However, the two individuals of *A. fragilis mediterranea* collected by Laubier and Ramos (1974) in the Bay of Roses (Spain) at 15–23 m depth do not correspond to *A. pseudoarticulata*, showing instead morphological features that are strongly consistent with *A. fragilis*, such as a higher number of branchiae and a subulate antenna. On the basis of all gathered data, the distribution of *A. fragilis* in European waters covers the western Mediterranean, the Adriatic Sea and the English Channel (Dauvin & Gentil 1980; Dauvin et al. 2003). Within our material we identified two individuals characterised by bifurcate antenna; all other features correspond completely to those of the other studied specimens. The occurrence of bifurcate or bifid antenna in *A. fragilis* has been already reported by Dauvin and Gentil (1980), but was apparently overlooked in subsequent accounts of the species (Gaston 1984; Lovell 2002). The variability of the number of branches in the median antenna raises doubts regarding the reliability of species diagnoses mainly based on the presence of a single antenna vs double antenna (Aguirrezabalaga & Gil 2009), since this could actually be due to casual regeneration errors, as suggested by Laubier and Ramos (1974).

In the present work *A. fragilis* has been reported from the Adriatic and Tyrrhenian Sea, chiefly from silty sand between 1 and 14 m depth; this is strongly consistent with the known ecological features of the species, which is mainly known from shallow-water, muddy environments. *Aricidea fragilis* is a large species of Paraonidae; the largest individuals can attain a total length of approximately 100 mm (Pettibone 1965), and Adriatic specimens, though smaller, are

still among the largest representatives of this family. Paraonidae are quite well known in the Mediterranean Sea and Eastern Atlantic Ocean (e.g. Laubier & Ramos 1974; Katzmann & Laubier 1975; Aguirrezabalaga & Gil 2008, 2009), and it appears very unlikely that such a large and conspicuous species could have gone unnoticed. Among the known Mediterranean species, *A. fragilis* mostly resembles *Aricidea suecica meridionalis* Laubier and Ramos, 1974, a rare and poorly known Mediterranean taxon which, however, has never been reported in high abundances (Laubier & Ramos 1974; Mikac 2015). Another possibility is a confusion between *A. fragilis* and *A. fragilis mediterranea*, due to the fact that two of the individuals of the latter taxon described by Laubier and Ramos (1974) actually belong to *A. fragilis*.

The presence and origin of *A. fragilis* in the Mediterranean Sea is puzzling. Although the biogeography of Paraonidae is still poorly understood, mainly because of the lack of molecular studies, the Paraonidae faunas in the western Atlantic and eastern Atlantic/Mediterranean appear quite different from each other, and shared species are few (Fauchald et al. 2009; Aguirrezabalaga 2012). For this reason, the status of *A. fragilis* as a native species in the eastern Atlantic Ocean and the Mediterranean Sea is debatable. The distribution of *A. fragilis* in European waters appears patchy and still limited to restricted areas, such as the English Channel, Balearic Sea, Tyrrhenian Sea and Adriatic Sea, although its actual distribution is probably wider. Also, the high density with which it occurs in relatively small areas of the English Channel (Dauvin & Gentil 1980; Quiroz-Martinez et al. 2012) and of the Adriatic Sea (present data) could point at an alien origin of this species. Pullulative dynamics, i.e. an explosive population growth followed by a sharp decline and a subsequent stabilisation at intermediate densities, are often observed in establishment processes of alien species (Galil 2000). Moreover, several west Atlantic species, which are considered aliens in the Mediterranean, have been first reported for the northern Adriatic Sea, mainly because of the strong similarity to Atlantic environments regarding physical, chemical and ecological features (Mizzan 1999). Records of *A. fragilis* outside of the Adriatic Sea are still scattered and sporadic. Despite the records from the Bay of Roses (Laubier & Ramos 1974), Porto Pozzo Bay and Viareggio (present data), the species is apparently still scarce in the western part of the Mediterranean Sea. Careful examination of all Paraonidae sampled during environmental monitoring activities along the whole Tuscan coast from 2013 to 2016 (Sbrilli 2016) highlighted the occurrence of only one individual. *Aricidea fragilis* seems, therefore, still sporadic in the Tyrrhenian and Balearic Seas; however,

local blooms, such as that observed in the Gulf of Manfredonia, are not unexpected.

Despite the several clues supporting the hypothesis of an alien origin of Mediterranean individuals of *A. fragilis*, some points are still unclear. The individuals from the Northern Adriatic identified by Fauvel (1940) as *A. jeffreysii* and later examined by Strelzov (1973), who attributed them to *A. fragilis*, are puzzling and may suggest, instead, that *A. fragilis* is actually a native species. However, this does not explain why this very conspicuous species has not been reported in the subsequent 70 years, despite a number of works carried out on Adriatic polychaetes (Mikac 2015). Possible means of introduction of *A. fragilis* in the Mediterranean Sea, moreover, are not clear. This is mainly due to scarce information about the reproductive features of Paraonidae (Rouse & Pleijel 2001) and to the subsequent uncertainty about possible pathways of introduction for this family. In the presence of long-lived planktonic larval stages, an introduction through ballast waters appears the most likely explanation (Lavoie et al. 1999), whereas, in the case of short-lived planktonic phases, or direct development, introduction is more likely to have occurred with mussel farming material (Zibrowius 1983). Population dynamics, current distribution in European waters and historical data on benthic communities strongly support the hypothesis that *A. fragilis* is an overlooked alien species in the Mediterranean Sea and in the English Channel. Even if its introduction in the Mediterranean Sea probably dates back to the 1930s, and sporadic records are known from the second half of the 20th century, *A. fragilis* has become abundant in the Adriatic Sea only in the last decade. The reasons for these strange dynamics are unknown, and might have to account for a lag time between introduction and demographic explosion (Crooks 2005), or repeated introductions of this species. A careful re-examination of benthic samples from the whole Mediterranean Sea and, if possible, a molecular comparison with topotypic material are needed in order to understand the actual distribution of this species and clarify whether it is alien or native to the Mediterranean Sea. Given the taxonomic and biogeographic uncertainties surrounding this taxon, we here suggest listing it as a cryptogenic species.

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No potential conflict of interest was reported by the authors.

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