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***Armadillidium arcangelii* Strouhal, 1929 (Isopoda: Oniscidea): a step towards the conquest of Europe?**

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Introduction

In the year 2014, SJG published a description of an unknown *Armadillidium* Brandt, 1831 collected in 2005 and 2010 in the Mediterranean Biome glasshouse of the Eden Project, Cornwall, UK (Gregory, 2014). The species was provisionally attributed to *Armadillidium assimile* Budde-Lund (Gregory, 2010), but differed by its smaller size and in the shape of the 1st pleopod-exopod.

During the period 2014-2015 FN was sent numerous specimens of what appeared to be the same unknown species from several French localities ranging from the Italian border to the Atlantic coast, proving that this species could also live outdoors in North West Europe and was likely to be of European origin.

In the year 2021, following a thorough examination of the available literature by GA, it is possible for us to propose a name for this species and at the same time to re-examine the observations available in order to draw together an overview of its colonisation across Europe.

Here we present the first results obtained and provide criteria for the identification of this species, namely *Armadillidium arcangelii* Strouhal, 1929.

Description

A brief description of the specimens collected from the Eden Project, including drawing of the male characters (intended to differentiate from known UK species), is published by Gregory (2014). A picture of a specimen, collected from the Eden Project, is also present on the BMIG website <https://www.bmig.org.uk/species/Armadillidium-arcangelii>.

Good (and detailed) illustrations of the habitus of the male of this species are provided by Arp Kruithof (see Fig. 2) and by various observers on the iNaturalist website. For example:

<https://www.inaturalist.org/observations/66427092>,

<https://www.inaturalist.org/observations/42230944> and

<https://www.inaturalist.org/observations/67408049>.

General appearance

This species is one of the smaller *Armadillidium* in Western Europe, reaching only 8 mm for females (males being smaller). The ground colour varies from dark brown to a mixture of yellow and light brown mottling, females being less uniform and lighter than males. Dark specimens usually show conspicuously pale muscle attachment spots. Epimera are always lighter than the rest of the body. Dorsum with light granulations. The pereonite 1 posterior margin is regularly sinuous. See Figs. 1 & 2.



Figure 1: Detail of head & telson. Image Franck Noël



Figure 2: Habitus and details (head, telson).
Image Arp Kruithof: <https://waarneming.nl/observation/4090280/>

Cephalon

Fig. 3. The frontal shield (scutellum) is wide, only slightly protruding above the head, with the posterior edge slightly convex and curved over the vertex. Between this and the head, a very small, inconspicuous depression is present. In frontal view, the antenna lobes show a slight angle on their upper part.

Telson

Fig. 1 & 2. The telson is about as wide as long, with a narrow, rounded tip.

Male sexual characters

Fig. 4 & 5. The outer edge of the posterior lobe of the 1st pleopod-exopod is shallowly indented, showing a distinct, but shallow, angle centred on the position of the external part the tracheal field (Fig. 4, arrowed).

The 1st pleopod-endopod is straight for much of its length, but slightly curved outwards at the tip.

The 2nd pleopod-exopod is elongated with a slightly curved inwards tip. The 1st pleopod-endopod does not show any useful features for identification.

The 1st pair of pereopods show no particular modification which can be used for species identification. An enlarged foliaceous spine is present on the carpus of pereopod 1. The 7th pair is much stouter in males (especially the merus). The inner edge of the ischium is straight. The end of the sternal side shows a crown of 6 to 8 curved spines. The external side is depressed with a setose area extending for nearly 1/3 of the article, which is similar to the description and figures given for *A. apenninorum* in Verhoeff, 1928 (fig.10, p114 – reproduced in Fig. 6).

Attribution to *A. arcangelii*

Armadillidium Brandt is a diverse genus, endemic to Europe, North Africa and West Asia, with more than 180 species described (Boyko *et al.*, 2008), many of them occurring in Mediterranean regions (Schmalfuss, 2003).

The original descriptions made by Verhoeff, 1928 (of *A. apenninorum*) and Strouhal, 1929a; 1929b (of *A. marmoratum* and *A. arcangelii*, respectively) allowed us to attribute our observations to *Armadillidium arcangelii* Strouhal, 1929.

Armadillidium arcangelii is quite similar to *A. marmoratum* Strouhal, 1929, an eastern Mediterranean species whose distribution ranges from Greece to Egypt, which shows the same pigmentation pattern, with the epimera lighter than the dorsal part of the tergites, but its average size is much larger.

Armadillidium arcangelii is also very close morphologically to *A. apenninorum* Verhoeff, 1928, another Italian species. Schmölzer (1954) in its key to *Armadillidium* separates *A. apenninorum* from both *A. marmoratum* and *A. arcangelii* by the shape of the outer edge of the posterior lobe of the 1st pleopod-



Figure 3: Cephalon, details.

Image Thomas Hughes

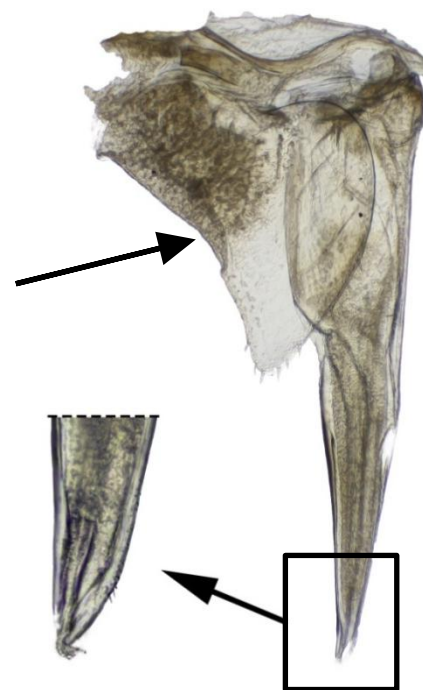


Figure 4: Adult male first pleopod.

Image Thomas Hughes

exopod, showing no angle with the tracheal field (Figs. 6 & 7). Also, the 1st pleopod-endopod is said to be straight, up to the tip (vs hardly noticeably curved outwards at the tip for *A. marmoratum* and *A. arcangelii*) (Schmölzer, 1954; 1965).

GA was able to collect specimens of *A. marmoratum* from Greece and these were compared, under a microscope, with specimens of presumed *A. arcangelii* from France. The 1st pleopod-exopod are similar in the two species but the tracheal field seems to be more developed in *A. marmoratum*. The 1st pleopod-endopod of *A. marmoratum* is straight for its entire length, not curved at the tip. Another character, which could be used for photo identification is the antenna flagellum, with the 2nd flagellomère being noticeably longer in *A. arcangelii* than in *A. marmoratum* (being of subequal length).

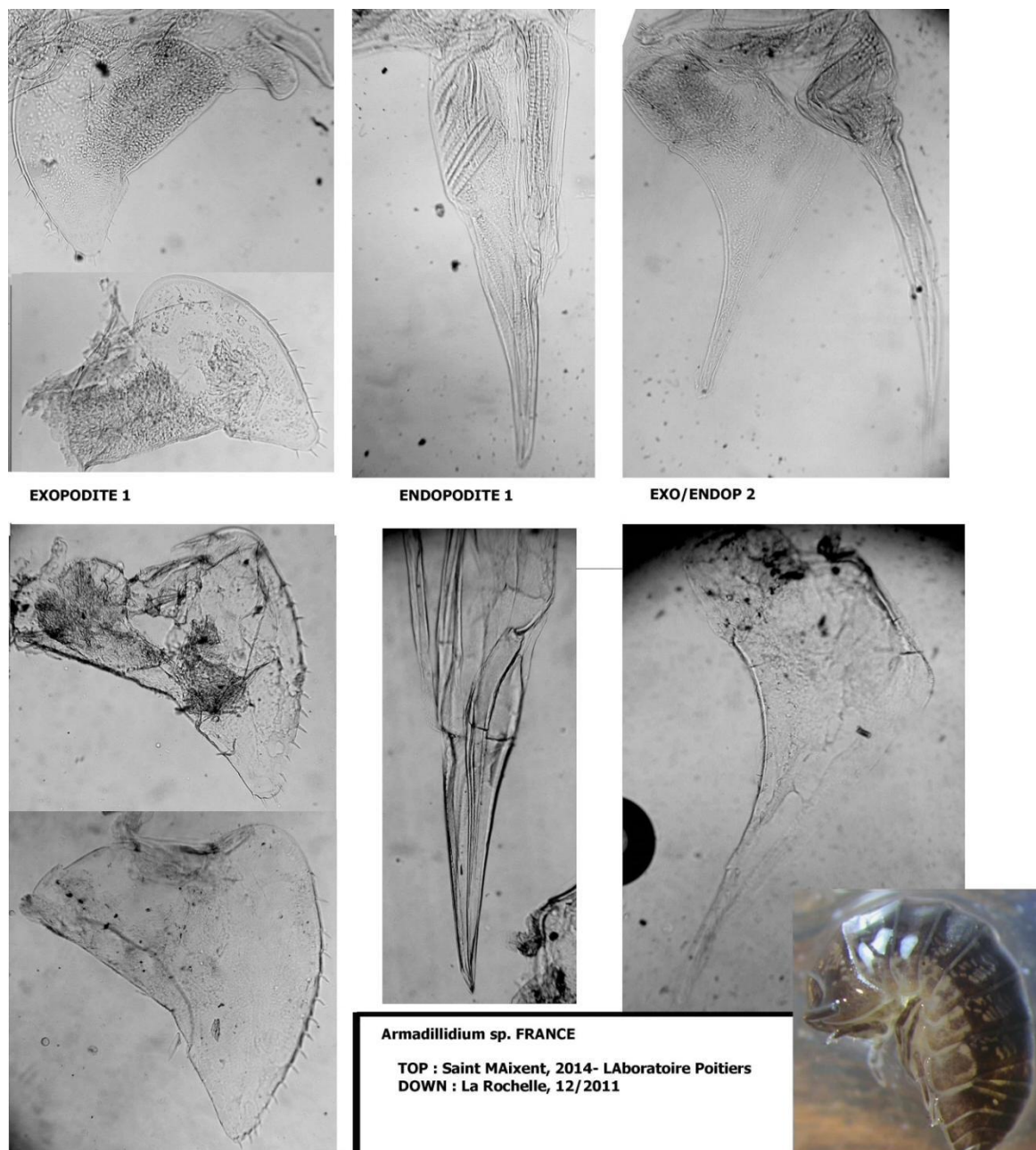


Figure 5: First records of *A. cf. arcangelii* in western France
 Saint Maixent, Equipe Ecologie Evolution Symbiose, University of Poitiers.
 Alexandra Lafitte, Didier Bouchon, Catherine Souty-Grosset leg.

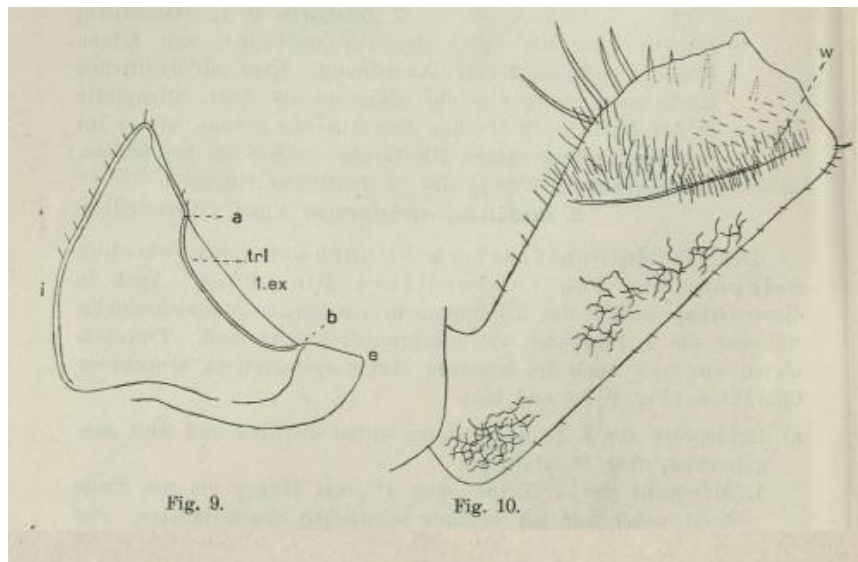


Figure 6: *Armadillidium apenninorum*. Drawing from Verhoeff, 1928.

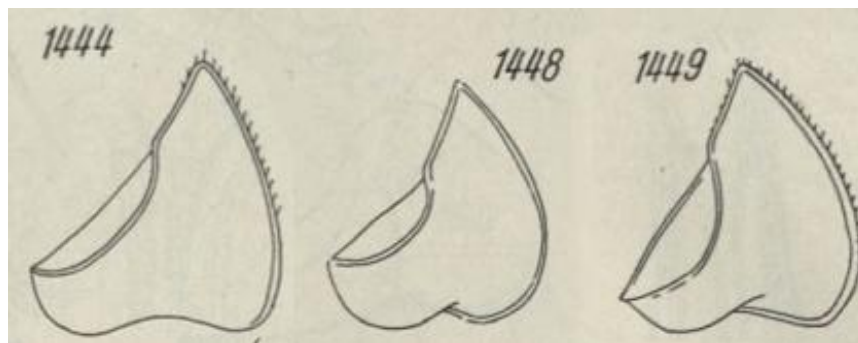


Figure 7: 1st pleopod-exopod from Schmölder (1965).

1444: *A. apenninorum*, 1448: *A. marmoratum*, 1449: *A. arcangelii*.

The similarity between *A. apenninorum* and *A. arcangelii* has caused some authors to suspect that they may be synonymous (Schmalfuss 2003, 2006a). Verhoeff (1936) seems to find differences in both the 7th male pereopod: “The 7th pair of legs of males is particularly important with regard to the carpus, since in *apenninorum* this is more than 2½ times as long as wide, whereas in *arcangelii* it is only twice as long as wide” and in the head formation [about *A. arcangelii*] “The frontal plate, which protrudes only slightly, appears flat when viewed from above and behind it there is a transverse gap”. The male specimens we were able to examine under a microscope always had a carpus fitting this description for *A. arcangelii*.

Given the small morphological differences and the same distribution pattern, *A. arcangelii* could be a junior synonym of *A. apenninorum* (Stefano Taiti, *pers. comm.*).

We accept that some differences do occur with the original description given in Strouhal, 1929 and subsequently in Verhoeff (1933; 1936) and Schmölder (1954; 1965). This is particularly the case for the 1st exopodite, which shows an angle (although not pronounced) at the posterior part of the tracheal field. In fact, this important feature is age-related, with young males having a more pronounced angle than adults ones and a less developed lobe. This is illustrated in Garcia & Cabanillas (2021, fig. 4, A & B), and see also individual variations of adult and immature males from France (Fig. 5, 1st column). Until a review of these three taxa is carried out, we consider that the specimens we have observed belong to the species *A. arcangelii*.

Recent data on the expansion of *A. arcangelii* across Europe

Identification work has been carried out on different forums or websites for several years, from photos posted by observers, by both FN and GA. In particular the forum naturamediteraneo (Italy), the forum of the World of Insects “insectes.org” (France) and more recently the site iNaturalist.org were consulted.

Until now, this species has been identified by different names: *Armadillidium* sp., *Armadillidium* sp. A, *Armadillidium* cf. *assimile*, etc. This does not facilitate proper monitoring of its dispersal across Europe. A review will soon be carried out to standardise the determinations, most of which have been collated on the GBIF website (www.gbif.org).

The following section summarises the available observations (outside Italy) that we have been able to collate regarding the expansion of *A. arcangelii* across Western Europe.

United Kingdom: Several specimens were caught in 2005 and 2010 in the Mediterranean Biome glasshouse of the Eden Project in south west England (Gregory, 2014 & 2010). The species has not been found outdoors and is probably not yet acclimatised.

France: The species was first recorded in 2014 and now seems to be dispersing along much of the Atlantic and Mediterranean coasts, probably following a residential and commercial “coastal sprawl”. The species was collected from the following Départements: Alpes-Maritimes (J.M. Lemaire rec.), Aude, Charente-Maritime (F. Noël rec. & det.), Deux-Sèvres (Poitiers’ University lab), Hérault (Many observations), Var, Gard (J.-M. Ruiz, 12.vii.2021) reaching Paris to the north (Jardín des Serres d’Auteuil, 06.ix.2019, T. Hughes rec.). We also have photographic evidence from Villeurbanne (Rhône) and near Grenoble (Isère), showing that the species is probably spreading north, following the Rhône valley. Most of the records come from gardens and public city parks and the species is more widespread near the coast than inland, maybe due to warmer winter climate.

The question of the abundance of the species in the Crau Steppe (Durance Valley, near Arles, Bouches-du-Rhône), where *A. assimile* has been mentioned for many years has been questioned recently (D. Pavon, *in litt.*). In fact *A. arcangelii* could have been present in these dry habitats for a long time, but confused with *A. assimile* by local naturalists.

Principality of Monaco: Located near the Italian boarder, in some stations *A. arcangelii* is by far the most abundant isopod, reaching remarkable densities (up to 500 individuals in a single pitfall trap implanted on a vegetated roof with *Sedum* spp.) (Lemaire & Raffaldi, 2016).

Spain: Javier A. Canteros took some images of one possible female, 27.iii.2021, north of Barcelona (posted on iNaturalist) and both J.-A. Canteros on 27.iii.2021 and A. Rubio near the same place on 9.vii.2021. Other records posted on iNaturalist include observations from D. Fhuerta near Valence, and from M. Delbas near Girona (Catalunya). Garcia & Cabanillos (2021) have published a record from Ambroz, near Madrid (05.ii.2021) and Garcia & Rojas (2021) an observation from Cádiz, Puerto Real (23.ii.2021). The species seems to be well established and distributed in most Spanish provinces, and it probably has been present in this country for many years.

Portugal: Some observations were posted on the iNaturalist website. The species now seems to be well established in Portugal. A photo from Albufeira (southern Portugal) by Luís Lopes Silva on 23.vii.2020 seems to fit the species. Other specimens were seen and photographed in the Vale do Gardiana NP, Beja District by Joao Tiago Tavares on 08.iv.2019 and by Luis Lopes Silva on the coast between Faro and Portimao, 22.viii.2021. The northernmost record for Portugal is from Viseu, seen by Rui Macário Ribeiro on 19.iv.2020.

Belgium: A possible observation is posted by Alex « Yaminatori » on the iNaturalist forum. The photo is quite distant but the pattern would fit the description of *A. arcangelii*. The specimen was photographed in the center of Ghent, 19.vi.2020. Subsequently, Pallieter De Smedt went to the exact

locality but failed to find the species. Similarly, no specimens were found in isopod samples from pitfall traps during a study on green roofs in the city of Antwerp in 2020. The presence of *A. arcangelii* in Belgium is thus doubtful.

Austria: Matthäus Greilhuber collected some specimens of *A. arcangelii* and took photographs of a dissected male under a microscope that he posted on the iNaturalist forum. These came from the Campus Gertrud Frölich-Sandner in Wien, 18.iv.2020.

Croatia: Danijel Ostović posted some picture of one specimen climbing on a wall in “Gajnice”, a mixed residential and industrial area of Zagreb 23.viii.2021. They show typical male pattern (mostly dark with light epimera) and triangular telson.

Poland: In 2019, Artur Szpalek posted photographs on forums in order to identify strange Armadillids found in Lavender (*Lavendula* sp.) plants south of Warsaw; these plants originating from The Netherlands. This record gives evidence of the dispersal of *A. arcangelii* via plant material from The Netherlands. A paper, including this record, about interesting observations based of ‘citizen science’ data will be published soon (Radomir Jaskula, pers. comm.).

Germany: A specimen showing typical pattern is posted on iNaturalist forum by “Recall79”, from a house in Langen (Hessen) 18.vi.2021. Unfortunately, only one photo was posted and we were not able to confirm the identification.

The Netherlands: As the Lavender reported in Poland (see above) came from the Netherlands, we contacted Arp Kruithopf. He then remembered an old record from 2008, when he photographed a male coming from the sales area of a garden centre in Deurningen (north of Enschede, near the German border). The photos were posted on the national forum Waarneming.nl ~ <https://forum.waarneming.nl/index.php/topic,469101.0.html> where it is possible to see all relevant characters, including pleopods, to confirm *A. arcangelii*.

Greece: Specimens attributed to *A. arcangelii* have been found in Greece three times now. The first one concerns individuals observed and collected in the garden of one of us (GA), from April 2019 until June 2021. The origin of this population isn’t known for sure, but it is speculated that the individuals were either unintentionally transported there via ornamental plants and/or bags of soil, or that they moved freely between the various interconnected gardens of the neighbourhood, many of which are in a semi-abandoned state. It is also worth noting that the faunal composition of the garden consists almost exclusively of both strongly synanthropic invasive and indigenous species. The first category contains the ant *Nylanderia jaegerskioeldi* (Mayr, 1904), the millipede *Oxidus gracilis* (C. L. Koch, 1847) and the slug *Ambigolimax valentianus* (Férussac, 1822) and the second one the isopods *Agabiformius lentus* (Budde-Lund, 1885), *Armadillo officinalis* Duméril, 1816 and *Porcellionides pruinosus* (Brandt, 1833), the millipede *Pachyiulus flavipes* (C. L. Koch, 1847), the slug *Limacus flavus* (Linnæus, 1758) and the snail *Xerotricha conspurcata* (Draparnaud, 1801). The second record concerns specimens observed and photographed by Savvas Zafeiriou in 26.vi.2019 in the suburb of Glyfada, south of Athens. Around 20 individuals were found walking around inside a potted plant containing succulents in Savvas’s garden, which is also in a semi-abandoned state. The specimens were originally misidentified as *Armadillidium atticum* Strouhal, 1929, but after closer examination of the photos by one of the authors (GA), they proved to belong to *A. arcangelii* instead. The third and final record is about a single individual observed and collected alive by one of us (GA) in April 2021. The specimen was found about 1-2 km away from the house of the author, climbing on the exterior wall of a garden, itself built next to the local entrance of the subway. This garden was also in a semi-abandoned and disturbed state.

Turkey: A group of 28 individuals is photographed by Tandoğan Oruz 22.v.2021 near a town park in the town of Tire (Izmir) (Fig. 8). Details observed following microscopic examination were also sent later and match the description of *A. arcangelii*.



Figure 8: *Armadillidium* cf. *arcangelii* from a group of 28, Tire (Turkey).
Posted on iNaturalist by Tandoğan Oruz.



Figure 9: Habitus of a female specimen, *Armadillidium* sp.. Marina Gorbunova, near Sebastopol
<https://www.inaturalist.org/observations/53949598>

Black Sea region: Individuals matching *A. arcangelii* / *marmoratum* in pattern were photographed by iNaturalist user "daniil_polyakov" on 10.viii.2020 in the Russian Adler Microdistrict, some kilometers northwest of the borders with Republic of Abkhazia. The habitat in which they were found (adjacent to the sea) is typical of the Eastern Mediterranean *A. marmoratum*, but as the region is outside of the known distribution of this species and no specimens have been examined yet, we can't tell for sure if it belongs to *A. arcangelii*, *A. marmoratum* or a superficially similar species. Finally, the recent discovery

of some *Armadillidium* populations in the northern Black Sea (north of Sebastopol) by Marina Gorbunova is interesting (Fig. 9). The individuals show a pattern that closely, but not entirely, matches that of *A. arcangelii* / *marmoratum*. However, because no individuals have been closely examined and at least one group of species that can look similar to *A. arcangelii* / *marmoratum* (the "*Armadillidium insulanum*-complex") is known to inhabit the nearby regions of Aegean and southern Black Sea coasts (Schmalfuss, 2006b), we don't feel safe ascribing this record to species level.

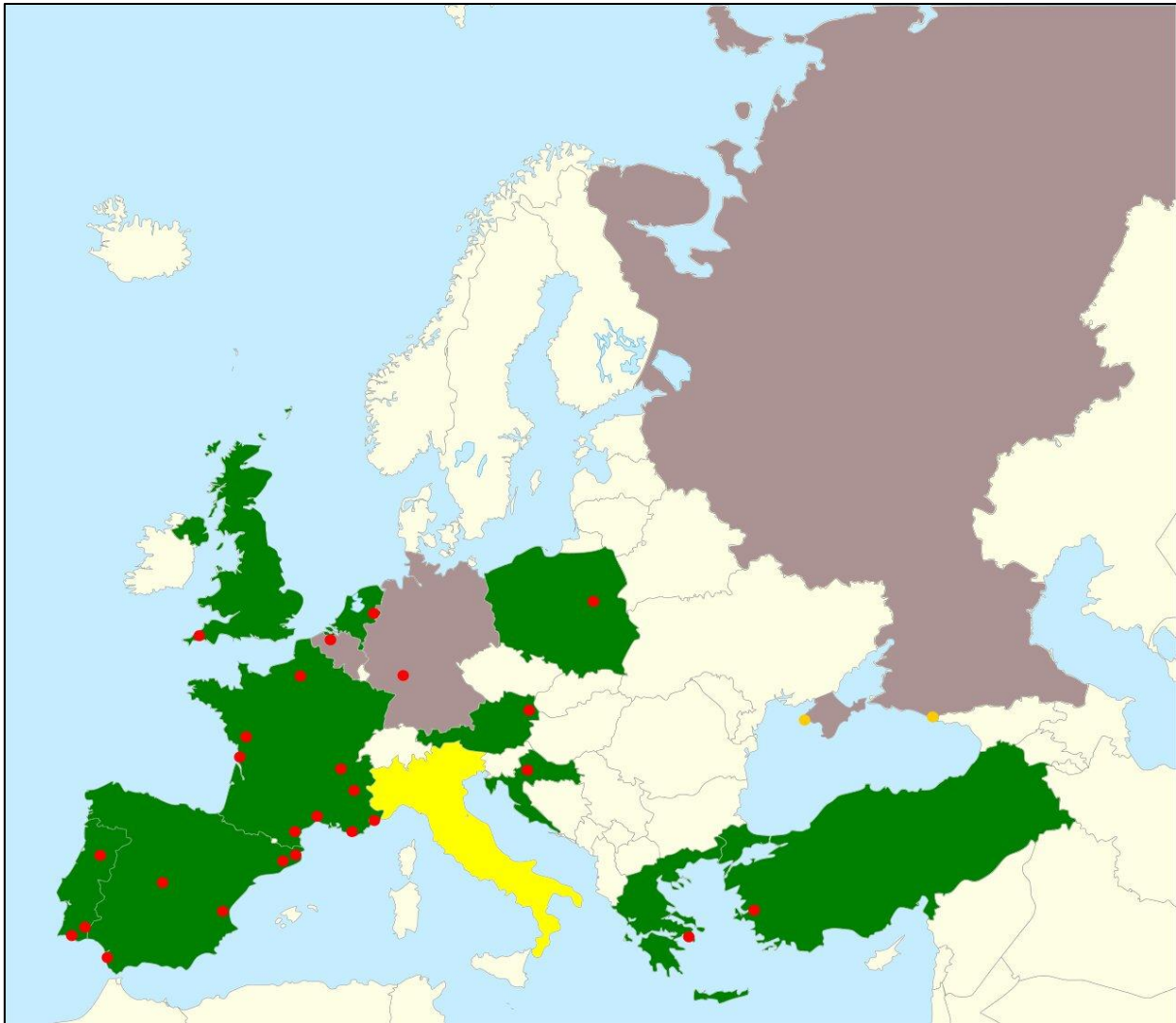


Figure 10: Map of known distribution of *A. arcangelii*

- Country of origin (mainland Italy).
- Countries with verified records (high quality photos and/or examined males).
- Countries with possible, but unverified records (low quality photos and/or only females).
- Specific regions/locations in which specimens were observed/collected.
- Black Sea records with matching phenotypes, that could either belong to *A. arcangelii*, *A. marmoratum* or an indigenous lineage, such as the *A. insulanum*-complex.

Conclusion

The recent expansion of *A. arcangelii* is documented, with records from most of the western European countries (Fig. 10), albeit some still needing to be confirmed by male characters. The species seems to be now quite widespread along the Mediterranean coasts from France to Portugal and is also expanding north along the Atlantic coast and, inland, along the Rhone valley.

Most of the records are made in synanthropic conditions, and anthropochory is documented in Poland, from Lavender plants imported from The Netherlands. Most observations come from gardens or city parks, providing evidence of anthropogenic dispersal via the horticultural trade.

In some localities, particularly on dry habitats, *A. arcangelii* is now the most abundant *Armadillidium* species and even seems to surpass the local *A. vulgare* and *A. nasatum*, suggesting it may be more competitive in some synanthropic habitats. The species is also known from natural, less modified habitats and was recently found in Ré island (Charente-Maritime, France) on sand dunes near *A. album* specimens (F. Noël, pers. obsv.).

Recent discussion also raised the hypothesis of a long unsuspected presence, in the Rhône valley, not far from the Italian border. Here possibly the species went unnoticed, being confused with immature *A. assimile*.

The apparent rapid expansion should lead to an increase in the number of observations across Western Europe and a definitive establishment of the species in some countries. The future development of this species should be monitored and its interactions with other *Armadillidium* species should be studied.

Also, dedicated taxonomic work should be undertaken on the complex *A. arcangelii* / *marmoratum* / *apenninorum*. We reiterate the problem of age-biased variability of the 1st pleopod-exopod, used in old descriptions and we encourage researchers to perform barcoding on populations of both *A. marmoratum* and *A. apenninorum* in order to compare sequences with those of *A. arcangelii* already obtained.

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