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Woolly Ash Aphid – is the Alien Bug Posing a Threat to European Ash Trees? – a Review

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Abstract

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Prociphilus (*Meliarhizophagus*) *fraxinifolii* (Riley, 1879) (Hemiptera: Eriosomatidae) is an alien species in Europe that has been spreading quickly there. This paper presents the origin and current occurrence, classification, description, identification, and biology of this species. It also discusses the harmfulness and threats, especially the impact on host-plants and ecosystem, invasion rate and facilitating factors.

Keywords: Aphidoidea; biocapacity; climate changes; invasiveness forecast; species acclimatization; zoogeography

The occurrence of over 100 Aphidomorpha species was found out in Europe, which, according to the criteria of the Convention on Biological Diversity, are classified as alien species, and over 30% of them come from North America (Coeur d'acier *et al.* 2010). Some of them not only feed on their host plants of the native area but also extend their range of host plants to include species that are native to European flora and cause damage to them at the same time. Therefore, according to the CBD (2002), they can be regarded as strictly invasive species. In addition, such species extend their area of occurrence on a continuous basis. This happens both as a result of continuing direct human actions (trading in infected plants) (Hałaj *et al.* 2011) and as natural dispersal processes of such species related to their biological properties, which are often additionally intensified by climatic and environmental conditions that are becoming more and more favourable for them (Hałaj & Osiadacz 2015). The *Prociphilus* (*Meliarhizophagus*) *fraxinifolii* (woolly ash aphid, ash leaf curl aphid) should also be considered as one of such invasive, harmful aphid species.

Characteristics of species

Origin and current occurrence

P. (*M.*) *fraxinifolii* was first described in western areas of Mississippi (USA) and occurs throughout the North America from Canada to Mexico (Smith & Parron 1978; Peña-Martinez 1985; Maw *et al.* 2000; Torres-Acosta & Sánchez-Peña 2015). However, in the middle of the 20th century, it was found in Africa (Müller & Schöll 1958) and later in Chile (Carrillo 1977), China (Yu *et al.* 2015), and Iran (Tajmiri *et al.* 2016).

In Europe, this aphid was first observed in 2003 in Hungary (Remaudière & Ripka 2003). In subsequent years, it was found in Serbia (Petrović-Obradović *et al.* 2007), Bulgaria (Trenchev & Trencheva 2009), Great Britain (Baker & Martin 2011), and Spain (Pérez Hidalgo & Mier Durante 2012) (Figure 1).

In 2012 the woolly ash aphid was first observed in Poland (2 localities in Upper Silesia) (Hałaj *et al.* 2016). Till that time that particular aphid had not been recognised in Poland despite the systematic observations carried out since 2010, taking into

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consideration the state of aphid diversity in many regions (e.g. Hałaj & Osiadacz 2015; Osiadacz & Hałaj 2014, 2015). In 2013 this occurrence was confirmed and another three new localities were observed in Upper Silesia. However, it was in the next years that a breakthrough occurred. In 2014, this aphid was already present in the entire region (Hałaj *et al.* 2016). In 2015, apart from this region (other localities: Ruda Śląska Halemba, 28VII, 50°14'19''N, 18°44'38''E; Zabrze Kończyce, 30VII, 50°16'13''N, 18°47'91''E; Katowice Panewniki, 5VIII, 50°13'37''N, 18°55'32''E; Świętochłowice Zgoda 10VIII, 50°16'34''N, 18°54'16''E – all first record on *Fraxinus excelsior*), it was also found in other regions of Southern Poland: (Kraków, 10VI, 50°04'26''N, 20°03'34''E; Wiślica, 11VI, 50°21'04''N, 20°40'18''E; Sandomierz, 14VI, 50°40'49''N, 21°45'07''E; Rzeszów, 17VI, 50°01'09''N, 21°58'30''E; Szczawnica, 21VI, 49°25'38''N, 20°28'29''E; Wrocław, 25VI, 51°08'36''N, 17°02'17''E; Wieluń, 1VIII, 51°13'07''N, 18°32'26''E) and Western Poland (Rzepin, 2VII, 52°20'56''N, 14°50'03''E; Poznań, 20VII, 52°23'41''N, 17°00'06''E; Resko, 25VII, 53°46'07''N, 15°24'40''E) (Figure 1). Taking into consideration the distance between the first position in Poland and the last northernmost point (500 km), thatit would mean the surprising speed of the species spread, rising up to approximately 160 km per year. In 2015, the occurrence of *P. fraxinifolii* was also first observed in Germany in 2 localities (Lüben/Spreewald, 15VII, 51°56'22''N, 13°52'12''E and Bautzen, 10VII, 51°11'19''N, 14°25'24''E) (Figure 1).

Classification, description and identification

Prociphilus Koch, 1856 belongs to Eriosomatidae (Heie & Wegierek 2009). This genus includes approx. 45 species occurring in the northern hemisphere, grouped in 6 subgenera (Blackman & Eastop 2016). *Meliarhizophagus* Smith, 1974 is one of them – it includes only one species that is presented in this communication – *P.* (*M.*) *fraxinifolii*. Apterous morphs (fundatrices and viviparous females) have bodies approx. 2.2–3.1 mm long, yellow and green to light green, covered with thick wax, especially in the distal part of the abdomen (Figure 2). Alate females, with bodies approx. 1.2–2.7 mm long, have green to green and orange abdomens. Antennae of these morphs

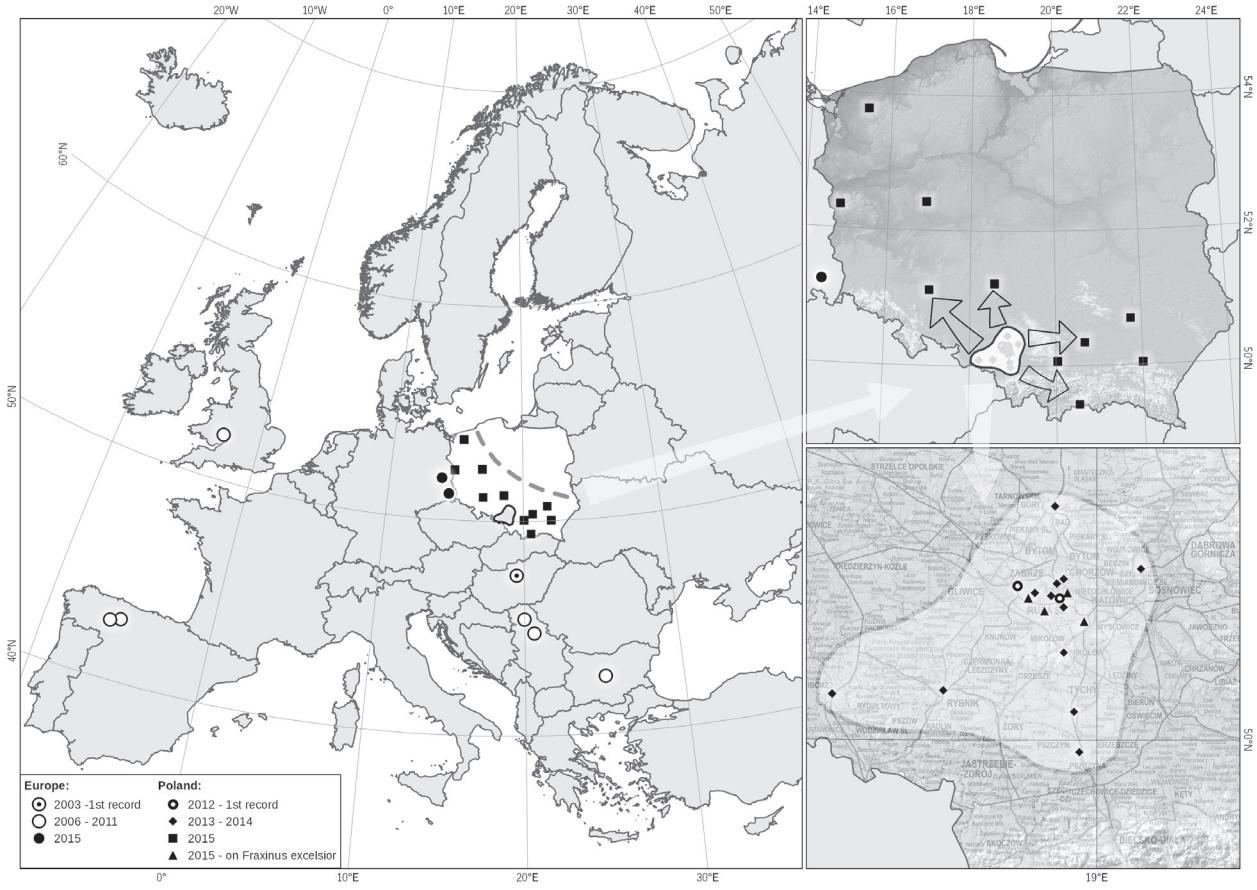

Figure 1. The colonisation of Europe by *Prociphilus* (*Meliarhizophagus*) *fraxinifolii*

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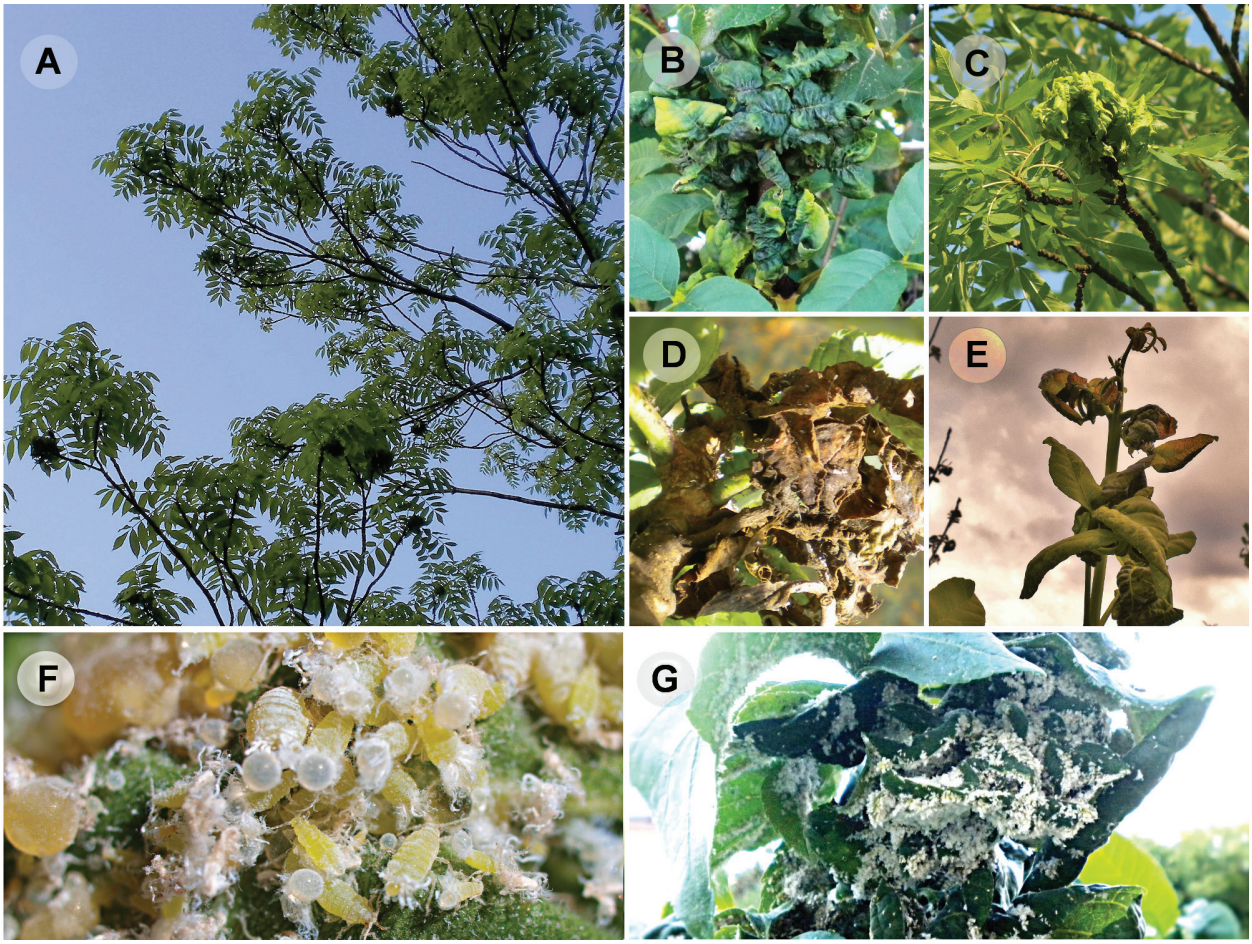

Figure 2. Pseudogalls caused by *Prociphilus* (*Meliarhizophagus*) *fraxinifolii* on about 40-year-old *Fraxinus excelsior* (**A–D**) and on about 5-year-old tree (**E**) in June. The colony of fundatrigeniae in July producing large amounts of honeydew (**F**) and in September with massive wax secretion (**G**)

consist of 6 segments, and on the basal part of the ultimate antennal segment, from 1 to 5 irregular secondary rhinaria occur and only 2 setae. On the head, there are 3 pairs of well-developed wax gland plates (2 pairs in the anterior part and one pair in the posterior part), which can be seen very well in total microscopic slides that were prepared. These features make it possible to distinguish the woolly ash aphid from native representatives of the subgenus *Prociphilus* [*P.* (*P.*) *bumeliae* (Schrank) and *P.* (*P.*) *fraxini* (Fabricius)], whose basic body colour is brown; the last antennal segment of alate viviparous females does not have any secondary rhinaria, and there are more than 2 setae and only 1 or not more than two pairs of wax gland plates occur on the head.

Biology

The biology of *P. fraxinifolii* has not been fully explored yet; however, papers by Smith (1974) and current observations provide some detailed information. This is an oligophage that feeds on ash trees in North America (*Fraxinus nigra*, *F. pennsylvanica*, *F. quadrangulata*, *F. sambucifolia*, *F. uhdei*, *F. velutina*). Outside the Nearctic, it has been found so far on *F. pennsylvanica*, *F. americana*, and *F. velutina*. Current research results in Europe show that the species has also attacked the native *F. excelsior*. The woolly ash aphid is monoecious as it does not change host plants during its life cycle, and with a full life cycle (holocyclic) (Figure 3). Fundatrices hatch already before leaf development in April–May. Initially, they feed on shoots at top angles of buds, and this is where a generation of fundatrigeniae appears, which include both alate and apterous morphs. As leaves develop, the aphids begin to feed at leaf bases and stalks and bracts; as a result, leaves become gradually deformed until they are tightly curled and clumped and often also discoloured to a red-brown colour. Inside the pseudogalls feeds a colony of fundatrigeniae, immersed in the thick wax

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produced by individual aphids. As the aphids excrete large amounts of honeydew, excrement droplets of considerable size can often be observed in the wax, frequently condensed and crystallised (Figure 2). Already in August (peak in October), alate sexuparae begin to appear in colonies that fly to the host's twigs and apterous sexuales are born there; fertilised eggs are also laid there. Deviations from the presented life cycle may occur. In summertime (from July), viviparous females distinctly change their feeding place to roots of trees and live there until autumn (October). Sexuparae are born at that time and return to the surface, give birth to males and oviparous females, thus closing the annual life cycle. Whole-year populations (anholocyclic, ones that multiply only by parthenogenesis) of the woolly ash aphid are also known. They live on roots and are almost always visited by ants (Smith 1974). In such cases, symbiotic relations have been described between these aphid populations and the edible mushroom *Boletinellus merulioides* (Brundrett & Kendrick 1987).

Harmfulness and threats

Impact on host-plant and ecosystem

The influence of aphid feeding on yield reduction in crops is commonly known (Van Emden & Harrington 2007). The influence of aphids on the development of forest-forming tree plants is also considerable as they feed on leaves in colonies (thus reducing the annual timber growth even up to 80%, by inhibiting the root growth; Dixon 1971) and also by inducing galls (Hałaj & Osiadacz 2013). In the case of the woolly ash aphid, harmful influences of feeding are pooled together. After the initial feeding period in colonies on shoots and leaves, distinct and compacted pseudogalls are formed from these leaves. As they are formed on tops of shoots and are there all year long, they significantly reduce the growth of shoots, which is considered the main cause of harmfulness of this species (Brown 2003). This was the reason why this species was included in CABI (2015) and EPPO (2015) lists. Additionally, these aphids produce honeydew in large amounts. Its excess blocks the assimilation apparatus and may cause the development of mould fungi on leaves that are still healthy, which may lead to natural and economic losses (Furniss & Carolin 1978). The fact that a part of the population may feed on roots in summer is also important. It is not excluded that on one host plant, apart from holocyclic populations (which induce pseudogalls), anholocyclic populations also occur, feeding on roots all year long, which is an additional burden for the plant.

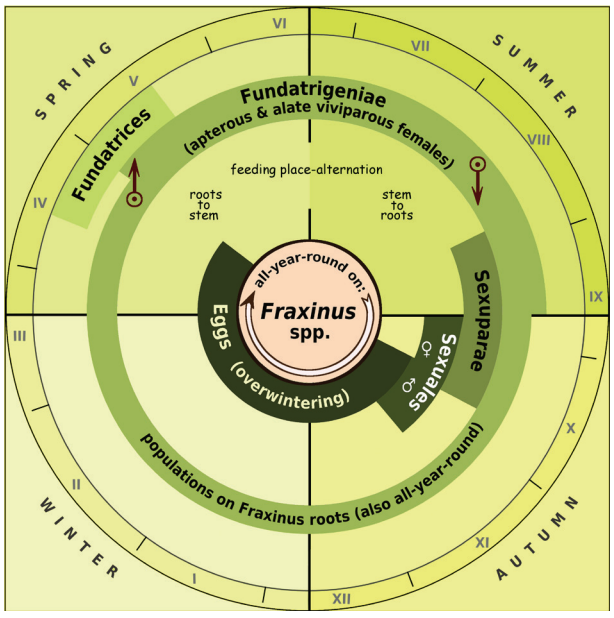

Figure 3. The life cycle of *Prociphilus* (*Meliarhizophagus*) *fraxinifolii*

So far, *P. fraxinifolii* has been found in Europe on planted American ash trees. Our observations have shown that, in 80% of the localities, this species is observed in naturally reproducing ash trees (self-sown) that grow in spontaneously formed plant vegetation. This especially applies to finding this aphid on *F. excelsior* (4 localities of Upper Silesia in Poland), which in these cases was an element of forest landscape. In more than half of the cases, ash trees had already revealed noticeable deformations including internode shortening and premature dieback of shoots. It should be noted that young trees were the most affected by this process. Therefore, the feeding of woolly ash aphids may influence not only the quality of the ash tree system (including the aesthetic value) but also additionally the possibility of their natural reproduction – achievement of an age at which the tree is capable of seed production. We suggest that the presence of *P. fraxinifolii* may be the greatest threat to European ash tree, which is additionally burdened by the occurrence of two native species of *Prociphilus* s. str. in many regions (Holman 2009; Osiadacz & Hałaj 2009). Despite the fact that these are heteroecious species that leave *F. excelsior* quite soon to migrate to the roots of fir trees (Heie 1980), they still deform host plants in spring and furthermore reduce their total assimilation surface.

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Landing, invasion rate and facilitating factors

It is not known how *P. fraxinifolii* reached Europe. Despite the fact that its main host plant (*F. pennsylvanica*) was introduced already in the 18th century (Remaudière & Ripka 2003), it was detected only 15 years ago and such characteristic pseudogalls would certainly have been noticed by many entomologists. This implies various solutions to this puzzle. Firstly, it could actually be an accidental introduction at the beginning of this millennium. Secondly, this species may have been introduced much earlier but in anholocyclic form, which is much more difficult to detect. It was only the appearance of appropriate climatic conditions (related to global changes) that allowed it to use its biological potential more fully, which was related to the emergence of its holocyclic form (with a considerable number of alate fundatrigeniae and sexuales that are capable of dispersing). It is likely that this species appeared much earlier, even on several occasions but those were unsuccessful introductions ('tens rule'; Williamson & Fitter 1996), and only the aforementioned appropriate climatic conditions allowed its naturalisation. This process certainly took place in Upper Silesia of Poland. Observations were conducted for many years, and they made it possible to confirm the occurrence of stable populations of woolly ash aphid in this region, which are not only capable of surviving but also of mass dispersion and colonisation of new areas, moreover attacking native plants in the process. Therefore, *P. fraxinifolii* can be definitely considered an invasive species.

The rate at which the species is spreading is also surprising. The presented data show that it has spread over a large area in Europe over the past 15 years (Balkans, Central Europe, Iberian Peninsula, and British Isles). Although only single localities were observed here, it can be expected that it will occur much more often in these areas. Such a quick expansion of a species on a continental scale translates into the regional scale. Current research distinctly shows that, over only 4 years, it has spread to almost half of the Polish territory also entering in Germany (Figure 1).

Such a quick rate is caused by the high biological potential of woolly ash aphid, especially the mass production of winged dispersing morphs, relatively safe pseudogalls. As these morphs are also born in early spring and in autumn, even a slight rise in temperatures during these seasons seems important as it influences the reduction in losses in their numbers, especially during passive flights over longer distances (airborne plankton) (Hałaj & Osiadacz 2015).

The size of aphid populations is regulated by natural enemies, predators, and parasitoids. Among these, parasitoids, especially the specialised ones, play an effective and safe role (from the perspective of possible applications in biological control) (Raymond *et al.* 2016). However, despite the fact that they were detected in the native area of the woolly ash aphid, none have been found outside America yet. The data on predators is also scarce. Five species of natural predators were found in China in one of the recent studies: *Harmonia axyridis* (Pallas), *Chrysopa pallens* (Rambur), *Episyrphus balteata* (DeGeer), *Deraeocoris punctulatus* (Fallén), *Deraeocoris ater* (Jakovlev) (Yu *et al.* 2015). But in slightly earlier research conducted in Spain, it was observed that *Anthocoris nemoralis* (Fabricius) and also Chamaemyiidae larvae were predators of the woolly ash aphid (Pérez Hidalgo & Mier Durante 2012). In Poland, the presence of predators was found only in a few cases (25% of localities). Those were mostly representatives of Coccinellidae, Asian species *H. axyridis* and native *Coccinella septempunctata* Linnaeus and less frequently, predatory bug *Anthocoris nemorum* (Linnaeus). The low number of predatory species and individuals (e.g. 2–3 individuals observed in all colonies on a 5-year-old tree) that do not have a significant influence on the regulation of aphid population may also be important for the quick rate of their multiplication and spreading. In some cases, the presence of ants was observed: *Formica fusca* (Linnaeus), *Lasius niger* (Linnaeus), and *Myrmica rubra* (Linnaeus), which also improves the safety of an aphid colony.

CONCLUSION

The high biological potential allows naturalisation of this species' naturalisation, expansion of its reach and also extension of the number of host plant species to include native ones, which indicates its invasive nature. Despite the fact that *P. fraxinifolii* is classified as a species with low harmfulness, it seems that its harmfulness is much greater than it is thought believed. The presented biological properties of the woolly ash aphid presented, which imply damage to host plants and also to the ecosystem that it is a part of, seem to justify it. For these reasons monitoring of *P. fraxinifolii* is recommended.

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