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ORIGINAL ARTICLE

Agrilus dureli: A new threat for European plant health?

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Abstract

With more than 3000 species, the jewel beetle genus *Agrilus* is considered the largest genus of the animal kingdom. Some of the species have been recognized as harmful to plants, but the majority of the genus remains unassessed. With *A. planipennis* it was found that, when introduced to a new environment, even (formerly) rare species only known to buprestid specialists can become invasive and cause enormous economic and environmental losses. One of the lesser-known species is *Agrilus dureli*, which has recently been found causing an outbreak on *Salix* species in China, leading to extensive dieback of the infested trees. In this article, the risk of *A. dureli* to European and Mediterranean plants is assessed.

KEYWORDS
Agrilus spp., buprestids, China, jewel beetles, pest risk, *Salix* spp.

***Agrilus dureli* - une nouvelle menace pour la santé des végétaux au niveau européenn ?**

Comptant plus de 3000 espèces, les *Agrilus* (au sein des coléoptères) sont considérés comme le genre du règne animal qui regroupe le plus grand nombre d'espèces. Certaines de ces espèces ont été reconnues comme nuisibles aux plantes, mais la majorité des espèces du genre n'ont pas encore été évaluées. Il a été découvert avec *A. planipennis* que des espèces (autrefois) considérées comme rares et connues uniquement des spécialistes des buprestidés pouvaient devenir envahissantes une fois introduites dans un nouvel environnement, et causer de très lourdes pertes économiques et environnementales. *Agrilus dureli*, l'une de ces espèces peu connues, a récemment provoqué une épidémie sur différentes espèces de saules (*Salix*) en Chine, entraînant des dépérissements importants des arbres infestés. Cet article évalue le risque qu'*A. dureli* présente pour les plantes européennes et méditerranéennes.

***Agrilus dureli* – новая угроза для здоровья европейских растений?**

Род златок *Agrilus*, насчитывающий более 3000 видов, считается самым многочисленным родом в животном царстве. На сегодняшний день, некоторые из видов были признаны вредными для растений, но бóльшая часть рода остается без оценки. В случае с *A. planipennis* было обнаружено, что при интродукции в

новую среду обитания даже (ранее) редкие виды, известные только специалистам по златкам, могут стать инвазивными и привести к огромным экономическим и экологическим потерям. Одним из менее известных видов является *Agrilus dureli*, который, как недавно было обнаружено, дал вспышку массового размножения на видах рода *Salix* в Китае, что привело к обширному усыханию зараженных деревьев. В статье оценивается потенциальный риск *A. dureli* для европейских и средиземноморских растений.

1 | INTRODUCTION

The genus *Agrilus* in the family Buprestidae comprises more than 3000 species (Kelnarova *et al.,* 2019) of which some are known to damage plants significantly due to their destructive larval activities. Depending on the species and climatic conditions, larvae live 1–3 years inside their host plants. This part of their lifecycle is the longest and most important in terms of impact, as larvae feed on wood and inner bark, and hence weaken the wood structure and disrupt the flow of nutrients and water. Adults in comparison live only for a few weeks and feed on foliage; their feeding causes insignificant impact compared to the larvae (Jendek and Poláková, 2014). However, only a very low number of this large genus have been assessed so far for their risk to plant health. These include *Agrilus planipennis*, *A. anxius*, *A. fleischeri*, *A. auroguttatus* and *A. bilineatus* (see,e.g., EFSA *et al.,* 2020a–c; EPPO, 2019, 2020; Schrader *et al.,* 2020, 2021). In particular, the case of *A. planipennis* shows that even (formerly) rare species only known to buprestid specialists can become invasive and cause enormous economic and environmental losses when introduced to a new environment. Many other *Agrilus* species are therefore suspected to pose a risk to plant health and one of those is *Agrilus dureli* Jendek. This species was described from museum specimens in 2011 (Jendek and Grebennikov, 2011). At the time, the host plants were not known and limited information was available on the beetle. Recent findings that *Salix* spp. (Figure 1a,b) and possibly *Populus* spp. are susceptible to *A. dureli* (Wu, 2020) make it a potential threat to European and Mediterranean ecosystems and plant health. In 2019, the European and Mediterranean Plant Protection Organization (EPPO) published a Pest Risk Analysis (PRA) on the closely related species *A. fleischeri*, another *Agrilus* beetle that was found to be a major wood-boring pest of *Populus nigra* var. *italica* and *P. tremula* var. *davidiana* in poplar plantations in Liaoning Province, China (Zang *et al.,* 2017; EPPO, 2019). Though only very limited information about this species was available, the EPPO PRA concluded that – with high uncertainty – impacts of *A. fleischeri* to the EPPO region would be low. The UK Plant Health Risk Register (https://secure.fera.defra.gov.uk/phiw/riskRegister/), which is precautionary by design, originally came to a different conclusion, scoring impact as 5 (on a scale from 1 to 5) and relative risk as 60 (on a scale from 1 to 125). Since very limited information was found on *A. dureli*, neither on its biology nor ecology, it is assumed, until more information becomes available, that *A. dureli* has similar traits to *A. fleischeri*.

2 | DESCRIPTION OF THE SPECIES

A detailed description of *A. dureli* is provided in Jendek and Grebennikov (2011). Briefly, the adult of *A. dureli* is 8.9–9.9 mm (holotype 8.9 mm) long, which is much smaller than reported by Wu (2020), who describes a length of 12.65 mm (averaged over 62 specimens). In that paper, the range is not given, therefore it is not known whether there were also specimens of 8.9−9.9 mm. It is assumed that Jendek and Grebennikov (2011) did not have many specimens available, so that the range in size was rather low in comparison to the observations of Wu (2020). Large variations in adult size have been observed in other *Agrilus* species too, e.g. *A. fleischeri* (7.3–11.7 mm) and *A. planipennis* (12–15 mm) (Jendek and Grebennikov, 2011).

The adult of *A. dureli* is cuneiform and brown to dark emerald green, with four white elytral dots (Figure 1c) and two or more white stripes on the sides of the body. Based on morphological features, *A. dureli* was placed together with *A. fleischeri* and 13 other species into the 'Spinipennis species-group' (Jendek and Grebennikov, 2011). Members of the group are featured as follows: medium to large size with large eyes, pronotum widest at middle, prehumerus carinal, elytra with two to four pairs of tomentose spots.

3 | FINDINGS AND CURRENT DISTRIBUTION

Jendek and Grebennikov (2011) refer to findings of the beetle in 'Ming County, Shanxi (China)' from 1992, and West Bengal, Maria Basti Parish, near Pedong, and Kalimpong, 40 km east of the city of Darjeeling (former British Bootang) in India, but the latter is a record from the end of the 19th century. In 2016, the species was discovered near Bejing (China) in the Mentougou area, where it is assumed to be native. However, little is known about this species' distribution (both native and introduced)

and its current pest status. Jendek and Nakládal (2019) reported a massive infestation of *A. dureli* on dozens of large *Salix matsudana* trees in Yanchizhen, causing extensive dieback. It should be noted that *S. matsudana* is considered a synonym of *S. babylonica* by some authors (Santamour and McArdle, 1988; Kuzovkina and Belyaeva, 2018), but is used here as a distinction between *S. matsudana* and *S. babylonica* as made in the descriptions of the *A. dureli* findings. Wu (2020) investigated areas in and around Beijing in 2019 and confirmed infestations of *A. dureli* in the Mentougou area. No other areas of Beijing were found to be infested. In the Mentougou area, the beetle was detected at 19 sites along or close to the river Yongding (Figure 1a), with damage mostly on *S. matsudana* but also on *S. babylonica*. Since these areas had a high density of *Salix* spp. and *Populus* spp., this may have slowed the spread of the beetles, exhibiting the typical pattern for *Agrilus* species to remain a short distance from their place of emergence if enough food and oviposition sites are available (Mercader *et al.,* 2009; Siegert *et al*. 2015; Mercader *et al*. 2016). Habitats included parks, riparian forests, and urban and garden trees. The trees infested were seemingly healthy. It is not known whether *A. dureli* could attack other *Salix* spp. that are not yet recorded as hosts. Wu (2020) also found a few poplars with D-shaped exit holes close to willows infested with *A. dureli*, but only assumed these were caused by *A. dureli* without further confirmation.

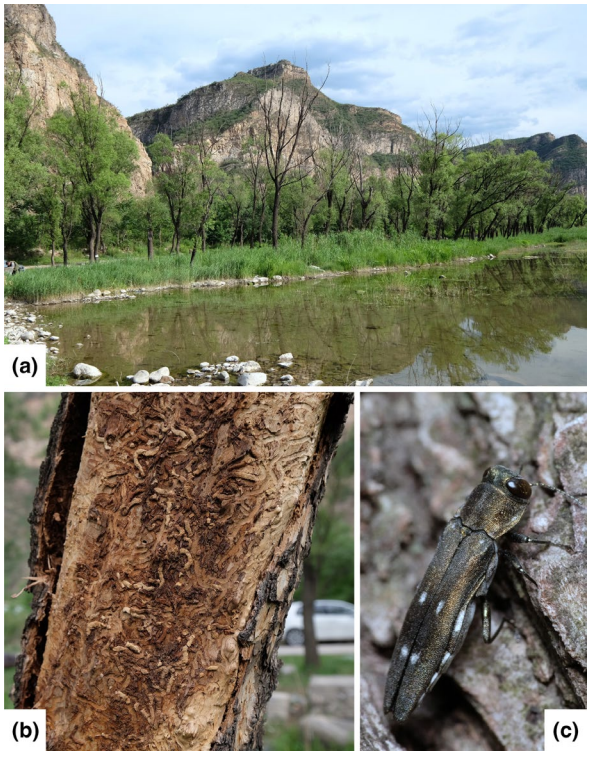

FIGURE 1 *Agrilus dureli* Jendek, 2011 on *Salix matsudana* in Yanchizhen (Beijing, China): (a) habitat, (b) galleries in bark and cambium, (c) ovipositing female. Courtesy: Jendek and Nakládal (2019) [Colour figure can be viewed at wileyonlinelibrary.com]

Since Jendek and Nakládal (2019) mention the presence of a few *A. viridis* in that area, these exit holes could have been caused by this latter species. Nonetheless, they also swept a single adult of *A. dureli* from *Populus* spp. in Dingjiatancun (China), thus the susceptibility of *Populus* species still remains uncertain. With this in mind, it should be noted that beetles (e.g. *Anoplophora glabripennis*, *A. planipennis* and *A. viridis*) have been found to switch to other host plants when introduced to new areas.

The Mentougou District of Beijing has a Köppen-Geiger (1986–2010) climate classification of 'Dwa' – Continental, dry winter, hot summer.

4 | FEEDING BEHAVIOUR AND REPRODUCTION

Both males and females of *A. dureli* were found feeding and mating on the foliage in crowns of infested trees, and females oviposited into trunks with thick bark in the afternoons (Figure 1c). In the Mentougou area, adults were found from the end of May to mid-July. Larvae were observed boring galleries into the cambium, and the year following the infestation, high densities of galleries, which can completely cover large sections of the tree, resulted in bark peeling away from dead trees (Figure 1b; Jendek and Nakládal, 2019; Wu, 2020). Since *A. dureli* larvae, like other wood-boring *Agrilus* species, feed and develop mainly in the cambium as well as the phloem and outer xylem, transportation of water and nutrients in the infested tree is disrupted.

5 | SYMPTOMS AND DAMAGE

D-shaped exit holes are typical for *Agrilus* species and can indicate an infestation, even when wilting has not yet become apparent, as observed for diffuse-porous tree species. Both *Salix* and *Populus* species are diffuse-porous or semidiffuse-porous trees, for which the general loss of hydraulic conductivity is less extensive than in ring-porous trees (e.g. *Quercus* spp. and *Ulmus* spp.) (Gizińska *et al.,* 2015). However, the first appearance of D-shaped exit holes can only be observed 1–2 years after the first infestation when a first emergence has taken place. In the beginning, these may only be very few, and possibly higher up in the tree canopy (at least in larger trees), so that early detection is not very likely. The immature life stages (those prior to the adult stage) are all cryptic (eggs in bark cracks, and larvae, prepupae and pupae in the cambium and xylem), making their detection difficult. Since the pupal chamber can partly be located in the upper part of wood, exit holes may still be visible when the bark is removed. Adults have been found to emerge through bark even 1–3 cm thick. When the bark is removed, larval galleries can be seen that are

twisted and filled with frass, as is typical for *Agrilus* species. In the course of the infestation, leaves turn yellow, branches wither and finally trees die.

6 | SPREAD CAPACITY

Since sufficient data on the flight capacity of this species are not available, it is assumed similar to other *Agrilus* species. For example, as part of an EFSA pest prioritization project, the spread rate of *A. anxius* was estimated by expert knowledge elicitation (EKE) (EFSA, 2019). The median of the maximum distance in 1 year was expected to be 1.3 km with a range from 90 m (5th percentile) to 6 km (95th percentile). For *A. planipennis*, it was found that when sufficient host plants are available, 88.9–90.3% of the larvae were detected on ash trees in newly infested areas within 100 m range from the tree where the adults had emerged (Mercader *et al.,* 2009). Monitoring experiments with girdled ash trees at two sites in Michigan (USA) over a period of 3 years showed that in the newly infested site, the beetles spread 0.4–0.7 km per year, while in the area where beetles had been present for longer, the spread rate was 1.2–1.7 km per year (Mercader *et al.,* 2016). EFSA (2019) conducted another EKE to estimate the spread rate of *A. planipennis*, and the experts concluded that the maximum distance expected to be covered in 1 year by natural and human-assisted spread at local level (i.e. long distance spread was excluded) is below 1500 m per year in 50% of cases and below 3000 m in 75% of cases, and ranges from 100 to 10 000 m in 98% of cases (EFSA, 2020c). The distribution of *A. dureli* found in the Mentougou area conforms to this trend, where extensive spread has not happened since the first findings in 2011 (Wu, 2020).

7 | RELEVANCE OF KNOWN HOST PLANTS

The two confirmed host plants, *Salix babylonica* and *S. matsudana*, are both native to China, but are widely used as ornamentals in gardens and parks in Europe (weeping willows, corkscrew willows). In China, *S. babylonica* is planted along riverbanks to prevent erosion and to reduce sediment deposition, and to prevent farmland from being flooded. It is not resistant to frost and therefore not present in colder climates. The hybrid *S. chrysocoma* (*S. babylonica* × *S. alba* var. *vitellina*) is often used instead (Newsholme, 1992). In Europe, *S. babylonica* is present in central and Southern parts. *S. babylonica* is quite robust to pollution, tolerating high levels of sulphur dioxide and absorbing toxic chemicals (CABI, 2019). It is not yet known whether the hybrid *S. chrysocoma* or other *Salix* species – or *Populus* species – would be susceptible to *A. dureli*. *Populus* and *Salix* both contain common pioneer species, which are widely distributed in Europe and have a tendency to hybridize. *Populus nigra*, *P. tremula* and *P. alba* are native to Europa and are, like other Salicaceae, of economic importance due to their 'multifunctional role for pollution mitigation, microclimate regulation and improved structural and biological diversity' (de Rigo *et al.,* 2016), and thus provide important ecosystem services (Gilioli *et al.,* 2014). High densities of *Populus* populations are located in Eastern Europe (EPPO, 2019). *S. alba* and *S. caprea* are both native to Europe and parts of Asia; their distributions covering much of Europe (http://www.euforgen.org/). Cronk *et al.* (2015) observed 20 different *Salix* species and 12 hybrids using a transect sampling approach at 42 locations from Greece to Norway. *S. alba*, *S. triandra*, *S. caprea* and *S. myrsinifolia* were the most frequently recorded species with counts at 20, 15, 14 and 14 sites, respectively. *Salix* species are a popular choice for managing riparian habitats as they are deep-rooted and therefore effective at stabilizing riverbanks, reducing flood risk and recovering leached nutrients (Cole *et al.,* 2020). Both *Salix* and *Populus* species can be coppiced to provide material for biomass (timber and biofuel) (Cole *et al.,* 2020) and are used as windbreaks or in shelterbelts.

8 | DETECTION AND IDENTIFICATION

In principle, many *Agrilus* species can be identified by molecular methods. Such methods could be expected to be more reliable than morphological identification because there is a high number of morphologically similar species belonging to the genus *Agrilus* (Jendek and Grebennikov, 2011). Worldwide, more than 3 000 species are described; in Europe, around 100 native species have been identified so far (Jendek and Grebennikov, 2011; Kelnarova *et al.,* 2019). Both *A. fleischeri* and *A. dureli* are mentioned by Kelnarova *et al.* (2019), but are not considered for analysis in a phylogenetic study of 329 *Agrilus* species using three marker genes. Hence, molecular diagnosis is apparently not possible in this case as no reference sequence material is accessible via GenBank or the Barcode of Life Data system.

9 | PATHWAYS

EPPO (2019) identified the import of plants for planting, round wood (with or without bark) and sawn wood of hosts, wood chips, hogwood, wood packaging material, bark and cut branches as pathways for the introduction of *A. fleischeri*. These pathways would apply to *A. dureli*, as host plants and sites of attack are quite similar. Hence, proposed phytosanitary measures are as follows (compare EPPO, 2019): origin of plants for planting from pest-free areas or pest-free sites of production under complete physical isolation. Round wood and sawn wood of

>6 mm thickness should originate in pest-free areas or be debarked followed by heat treatment, irradiation or fumigation. Wood packaging material in international trade is regulated through treatment in accordance with the international standard ISPM 15.

Commission Implementing Regulation (EU) 2018/2019 of 18 December 2018 'establishing a provisional list of high risk plants, plant products or other objects, within the meaning of Article 42 of Regulation (EU) 2016/2031 and a list of plants for which phytosanitary certificates are not required for introduction into the Union, within the meaning of Article 73 of that Regulation' currently lists '*Salix* L.' and '*Populus* L.' as high-risk plants, meaning that their introduction into EU territory should be provisionally prohibited.

10 | DISCUSSION AND CONCLUSIONS

At this point, only limited information on *A. dureli* is available, but some identified facts on its biology and observed damage in its assumed native area indicate that it could present a risk to plant health in Europe. These include (a) the presence of host plants, (b) their ecological and economic value, and (c) the apparent similarity with other *Agrilus* species that have been identified as presenting a threat to plant health. Though the Köppen-Geiger (1986–2010) climate classification of 'Dwa' is not found in the EPPO region (MacLeod and Korycinska, 2019), the full extent of the distribution of *A. dureli* is still unknown and may yet include similar climates to those found in the EPPO region; furthermore, host plants are widely spread in the EPPO region. The distributions of *A. planipennis* and *A. fleischeri*, though most likely wider than that of *A. dureli*, also include the Beijing area. The former has established in European Russia and the likelihood of the latter establishing in the EPPO region was rated high with moderate uncertainty (EPPO, 2019). It is therefore anticipated that *A. dureli* could establish where poplars and willows are grown (with some uncertainty over which poplar and willow species would be attacked). It is known for some *Agrilus* species (as well as for other wood-boring insects) that when introduced to new regions, hosts not coevolved with the beetles can be more susceptible, and even healthy trees can be infested and killed (Chamorro *et al.,* 2015, citing others).

It is known that for *Agrilus* species no reliable (single) method exists for detecting low levels of infestation (EFSA, 2020a, EFSA, 2020b, EFSA, 2020c). Detection methods include trapping, biosurveys with wasps and girdling of trees, but these usually are not effective with regard to timely detection and early response, which are critical factors to prevent impacts on plant health.

Since general symptoms and especially D-shaped exit holes are common to *Agrilus* species and other species from the subfamily Agrilinae (namely *Coraebus* sp. and *Meliboeus* sp.), and the fact that native *Agrilus* species are also present on potential host plants of *A. dureli*, first signs or symptoms following an introduction of *A. dureli* in the EPPO region may not be quickly identified (EFSA, 2019). Immediate action, such as felling of infested trees, is problematic, since native *Agrilus* species may be under protection. For example, several native *Agrilus* species in Germany are listed on the 'Red List' (e.g. Bußler, 2003; Gottwald, 2017) and two *Agrilus* species are listed as 'Nationally Scarce' in Britain (Natural England, 2014). Adding to these obstacles is the above-described lack of a molecular method to identify the species reliably. Studies on the risk that *Agrilus* species already pose or still may pose to plant health worldwide underline the importance of such methods to be developed and improved.

Beyond the obvious damage to host plants, the holistic impact on ecosystem services should also be considered when assessing the risk of plant pests (Gilioli *et al.,* 2014; Schrader *et al.,* 2021). These are benefits from an anthropogenic perspective that directly or indirectly support human survival and their quality of life. They include provisioning services, such as fibre, biochemical and natural medicines (in case of *Salix*, the anti-inflammatory alcoholic β-glucoside Salicin), or ornamental resources ('weeping willow'). Furthermore, regulating services, such as air-quality regulation, climate regulation, water regulation and cycling and cultural services that directly benefit people, and supporting services, such as nutrient cycling, photosynthesis and primary production that are needed to maintain the direct services, are considered (MEA, 2003; Harrington *et al.,* 2010). Though both *Salix* spp. and *Populus* spp. are not apparently tree species that represent high economic values in terms of high-quality timber production, they represent valuable tree species at sites that are not well adapted for other tree species. It is very difficult to pin down the exact biodiversity value of one tree genus over another. However, in a number of comparisons of insect and mite species-richness associated with tree species in Britain, Russia and Sweden by Southwood (1961), and Kennedy and Southwood (1984), *Salix* is consistently near or at the top of the list. In their expansion of Southwood's work, this time on native German tree species, Brändle and Brandl (2001) found that *Salix* had the highest insect and mite species-richness (728 species of phytophages). In another attempt to quantify the value of different tree and shrub species to wildlife in Britain, Alexander *et al*. (2006) also assigned 5 stars (the highest possible value) to the 'blossom' score for *Salix*, as catkins are a very important source of nectar and pollen for bees and other insects in early Spring. *Salix caprea* and *S. cinerea* are assigned 4 stars for epiphyte communities whilst *S. fragilis*, *S. alba* and other rough-barked willows are assigned 4 stars for mycorrhizal fungi species-richness. *Populus* species also have a relatively high number of associated foliage invertebrates (Southwood, 1961; Kennedy and

Southwood, 1984; Brändle and Brandl, 2001), scoring 4 stars in the assessment by Alexander *et al.* (2006). These facts underline the importance of protecting *Salix* and *Populus* species in Europe against the damage caused by plant pests.

Since *Salix* and *Populus* are currently regulated as high-risk plants, the probability of *A. dureli* being introduced into the EU is low at present. However, the listing is provisional and a commodity risk analysis for these two genera would need to consider all potential risks related to them. When conducting this commodity risk analysis it may therefore be indicated to take into account potential risks posed by this *Agrilus* species as well.

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