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Invasion of the oak lace bug *Corythucha arcuata* (Say.) in Romania: a first extended reporting

Romică Tomescu, Nicolai Olenici, Constantin Nețoiu, Flavius Bălăcenoiu[§], Andrei Buzatu

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Abstract. In the context of globalization, the biological invasions affect all the countries, including Romania, where this phenomenon is increasingly visible in the last years. Besides the invasive forest insects already known to be established in Romania, a new species - *Corythucha arcuata* (Say, 1832), commonly known as the oak lace bug and originating in North America, appeared in the last years. It was reported for the first time in Romania in 2015, and it spread across the country in 2016-2017. In order to detect the species and to draw its distribution area, a species identification sheet, as well as a working protocol were developed, considering the insect morphology and the type of attack. During the vegetation seasons 2016 and 2017, the species was found in 67 out of the 124 surveyed locations, mainly in the southern and western parts of the country, but also in the eastern part. The main host species of the oak lace bug were *Quercus robur, Q. petraea, Q. cerris, Q. frainetto,* and *Q. pubescens*. It attacked the host trees in all habitats (tree stands, parks, nurseries, isolated trees etc.) and the intensity of attack varied from 1% to 100% of the leaves.
Keywords: *Corythucha arcuata*, oak lace bug, distribution, *Quercus* spp., Romania

Authors. "Marin Drăcea" National Research-Development Institute in Forestry, Eroilor Av. 128, Voluntari, Ilfov.

[§] Corresponding author: Flavius Bălăcenoiu (flavius.balacenoiu@icas.ro)
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Introduction

As a consequence of globalization, biological invasions by alien species can have important and, often, harmful impacts on the biological diversity and functions of the invaded ecosystems and can cause significant losses (Vilá & Hulme 2017).

The biological invasions have been affecting Romania since the end of the 19th century and the best-known invasive species of insects that have entered Romania, become established, everywhere spread and caused serious damages are *Viteus vitifoliae* (Fitch, 1855) – grapevine phylloxera, *Diaspidiotus perniciosus* (Comstock, 1881) - San José scale and *Lepi-*

notarsa decemlineata (Say, 1824) - Colorado potato beetle (Paşol et al. 2007). However, this phenomenon is becoming more and more visible in the recent years, following the integration of Romania into the European Union, when customs checks at border crossing points were reduced and the transportation of goods and persons greatly increased (Olenici & Duduman 2016).

In the Romania's forests, the most important invasive forest insects are *Hyphantria cunea* (Druy, 1773) (Simionescu et al. 1971), *Parectopa robiniella* Clemens, 1863 and *Macrosaccus robiniella* (Clemens, 1859) (Neţoiu & Tomescu 2006), as well as *Ips duplicatus* (Sahlberg, 1836), the latter generating major disturbances in some stands of Norway spruce (*Picea abies* (L.) H. Karst) during the last decade (Olenici et al. 2011). Recently, a new alien insect species, *Corythucha arcuata* (Say, 1832) (Heteroptera: Tingidae) - the oak lace bug (OLB), was reported in Romania (Don et al. 2016, Chireceanu et al. 2017a, b) affecting especially the oak species.

C. arcuata is a species originating in North America, which appeared for the first time in Europe in 2000, in Italy (Bernardinelli & Zandigiacomo 2000), after which it arrived in Turkey in 2002 (Mutun 2003). In the meantime, its distribution area extended and OLB arrived closer to Romania. In 2012 it was observed in Bulgaria (Dobreva et al. 2013) and in 2013 in Hungary (Csóka et al. 2013), Croatia (Hrašovec et al. 2013) and Serbia (Pap et al. 2015).

The species spread quite rapidly in the invaded countries. In Turkey, a few years after first record, OLB affected an area of about 28,116 km^2 (Mutun 2008). In Bulgaria, in just five year after the first record, *C. arcuata* invaded most of country, where about 85% of the leaves display discoloration (Simov et al. 2018).

In Europe, OLB was found mainly on indigenous and exotic oak species, such as: *Q. bicolor* Willd., *Q. cerris* L., *Q. frainetto* Ten., *Q. hartwissiana* Steven, *Q. macranthera* Fisch. & C.A.Mey. ex Hohen., *Q. macrocarpa* Michx., *Q. petraea* (Matt.) Liebl., *Q. petraea* subsp. *iberica* (Steven ex M. Bieb.) Krassiln., *Q. pubescens* Willd., *Q. pyrenaica* Willd., *Q. robur* L., *Q. robur* subsp. *pedunculiflora* (K. Koch) Menitsky, *Q. virgiliana* (Ten.) Ten. (Bernardinelli & Zandigiacomo 2000, Forster et al. 2005, Dioli et al. 2007, Mutun et al. 2009, Csóka et al. 2013, Dobreva et al. 2013, Hrašovec et al. 2013, Don et al. 2016, Neimorovets et al. 2017, Simov et al. 2018). Insects of different developmental stages or only symptoms of attack were also noted on leaves of *Acer laetum* C.A. Meyer, *Castanea sativa* Mill., *Malus sylvestris* (L.) Mill., *Prunus avium* (L.) L., *Rosa canina* L., *Rubus idaeus* L., *R. ulmifolius* Schott, *Robinia pseudoacacia* L. and *Ulmus minor* Mill. (Hrašovec et al. 2013, Neimorovets et al. 2017, Simov et al. 2018).

The adults and nymphs feed on the lower side of the leaves of the host tress, producing numerous characteristic black spots, while on the upper side of the leaves the typical symptom is chlorotic discoloration (Bernadinelli 2006, Mutun et al. 2009). In the case of heavy infestations, the pest can cause tree defoliation or increase the susceptibility of the host to various diseases or pests (Connell & Beacher 1947, Mutun et al. 2009, Dobreva et al. 2013).

Due to the damage caused to the trees in the places where it was reported in our country and in the neighbouring countries of Romania, this species should be considered a potential forest pest, mainly to oak forests wich covered 16.3 % of the total forested area (IFN 2018). Likewise, *Corythucha arcuata* can be considered as a potential pest to urban zone or of individual trees. Consequently, the aim of the research was to obtain information on the pest invasion within our country.

Materials and methods

In order to detect the presence of *C. arcuata* and to collect the data in the field, a species identification sheet, as well as a working pro-

tocol were developed. The selection of the survey points was made considering the presence of the host species. Observations have been conducted on itinerary in 124 locations (Table 1, Supporting Information), both within the national forest fund (forest nurseries, plantations, tree stands etc.), and within parks and green areas or on isolated trees.

During the growing seasons of 2016 and 2017, data were collected regarding the presence/absence of the species and the intensity of the attack (expressed as percentage of injured leaves). The attack intensity was assessed by the degree of foliage fading, as a deviation from the normal colour of the host tree leaves. For separing the decolouration caused by *C. arcuata* from that cause by other factors (drought, pathogens, other insects etc.) we used a visual assessment considering the both sides of the leaf (Figure S1, Supporting Information). If on the upper face were observed yellowish to brownish spots and the underside of the affected leaves had adults, nymphs, shed skins and dark excrement scattered all around the leave (Mutun et al. 2008) then it was considered an attack caused by OLB.

In the statistical analyses, the data concerning the proportions were arcsine transformed ($x' = arcsin$ (sqrt(x)), to normalize the distributions and to ensure the homogeneity of variances (Zar 2010). The normality of distributions and equality of variances were checked using the Shapiro test and Levene test, respectively. Because the assumption of distribution normality was not fulfilled, the analysis of variance was performed using the Kruskal-Wallis test.

Results

Considering the evaluation methods described above, i.e. the presence of adults, nymphs and black spots characteristic on the lower side of the leaves or the chlorotic discoloration on the upper side, the species was found in 67 locations, out of the 124 observation places (Table S1 Supp. Info, Figure 1).

The species was found in various types of forests ecosystems (Figure 2A, B), the species was found in various types of forest ecosystems. At the lowest altitudes, it is established in meadow forests, in greyish oak and downy oak mixed thermophilic forests, or in common oak and Hungarian oak mixed thermophilic forests, while at higher altitudes it is found in common oak or sessile oak forests, or even in hilly mesophilic forests. The forests of common oak and the mixed forests of common oak and Hungarian oak that surround the city of Bucharest and extend within Giurgiu county, as well as the mixed forests of greyish oak and downy oak within Călărași county suffered a higher intensity attack (60-100%) than other oak forests within the country.

Tree stands were observed in the most locations (35), but OLB was also found on isolated trees (20 locations) or in parks (8 locations). The remaining observation places were located in other habitat types (plantations, seed orchards, alignments or tree nurseries).

Out of the three most common types of habitat affected by OLB, the trees in the parks were most severely attacked (40%), while the isolated trees and tree stands have an average attack intensity of 25% and 30%, respectively (Figure 3). However, there was no statistically significant differences between the average attack intensities in the three habitat types (p = 0.117).

Observations that focused on tree stands suggested that the intensity of the attack is much severe on the trees growing along the forest edge or in the full light, than on the trees inside the stand, the differences in the values reaching up to 60%. For example, at the Ciolănești observation point the trees inside the stand had only traces of attack (>5%) and the trees growing along the forest edge or in the full light were more severely affected (60-70%).

The altitudes where the presence of OLB was reported varied from 34 m (Călăraşi) to 534 m (Baciu-Cluj), and the annual average

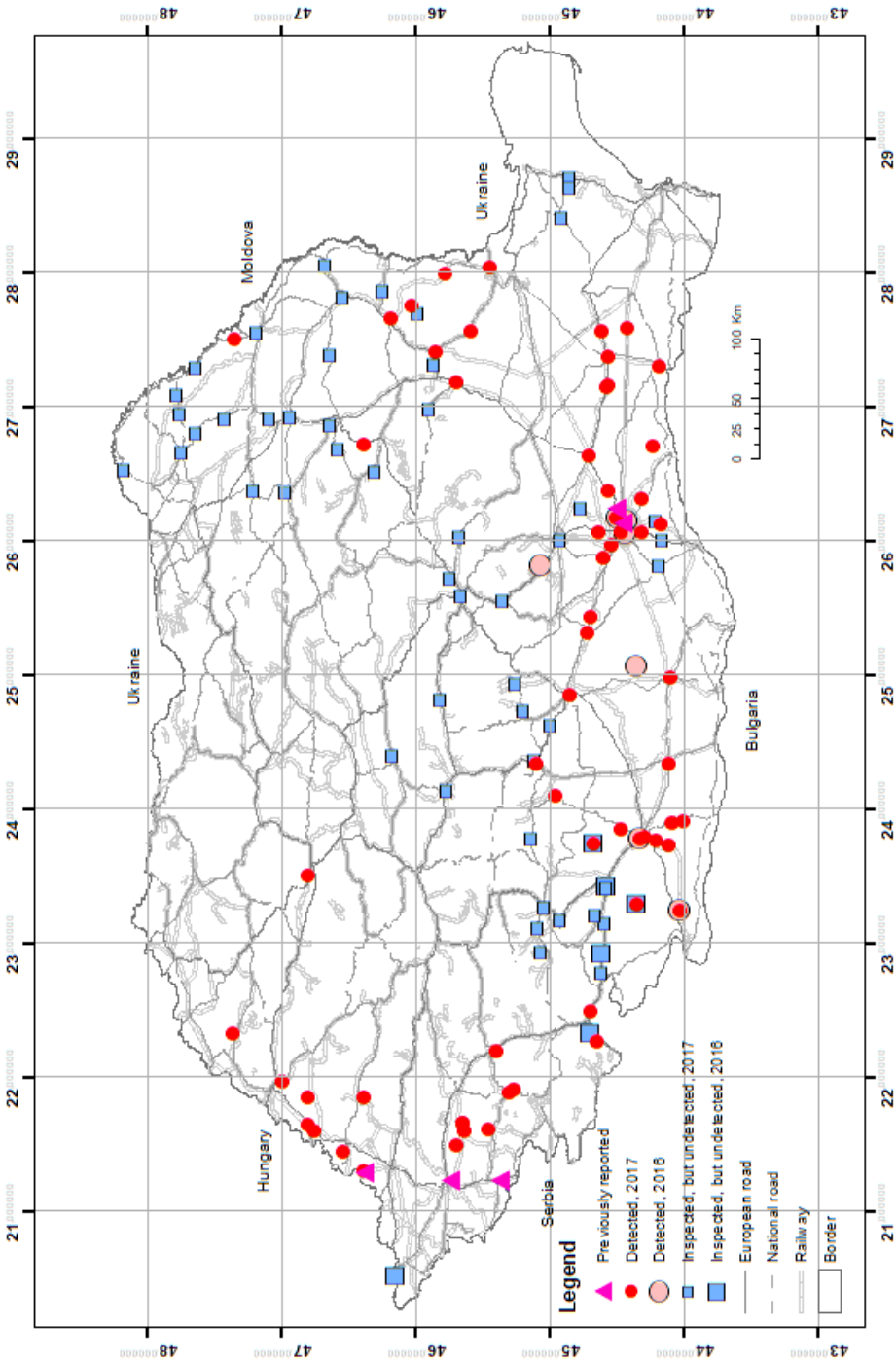

Figure 1 Distribution of OLB in Romania in the first two years after its first record

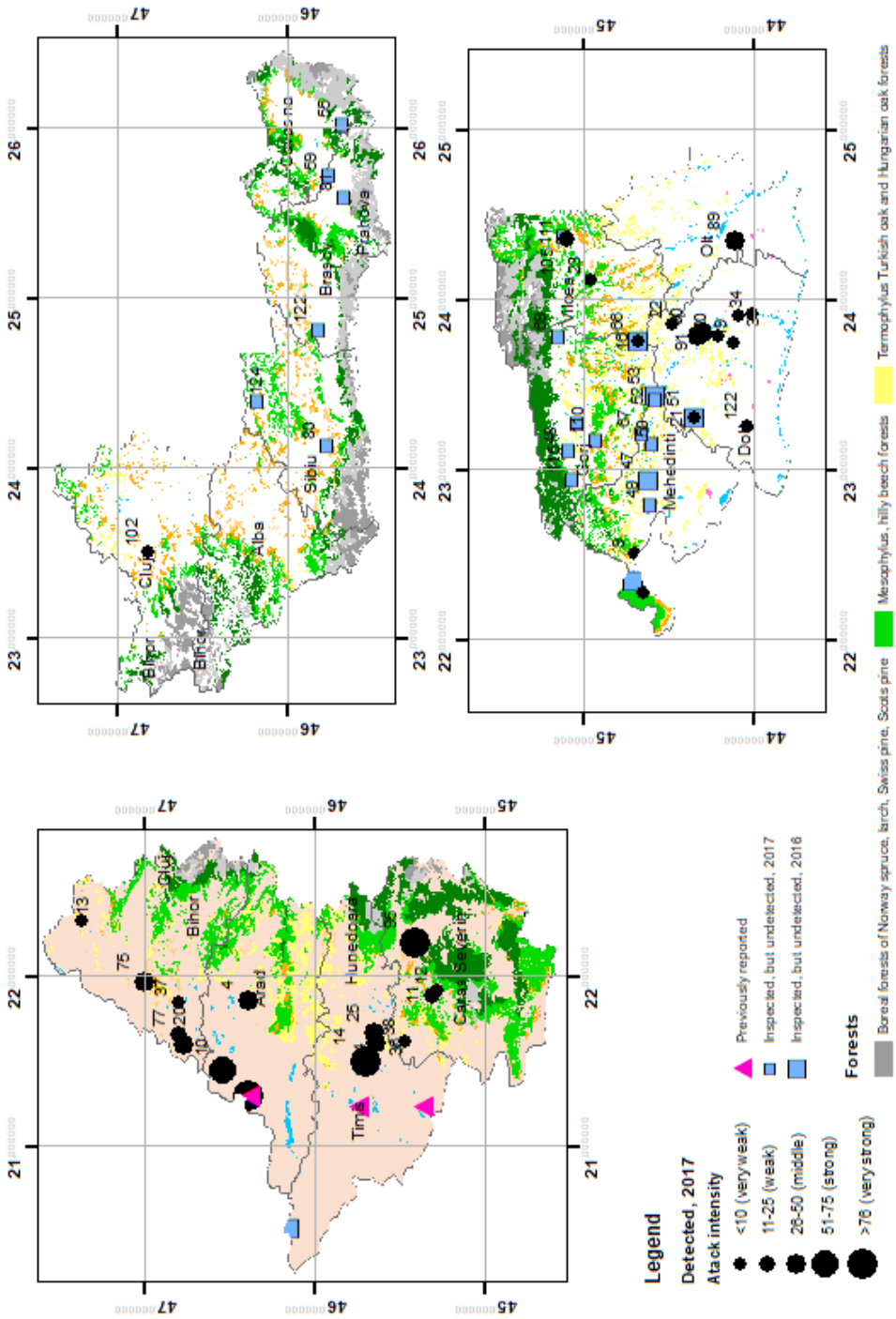

Figure 2A Observation sites and the intensity of attack on forest ecosystems in Western (left), Central (bottom) and South-western (top) counties of Romania. Site numbers similar to Table S1, Supp. Info.

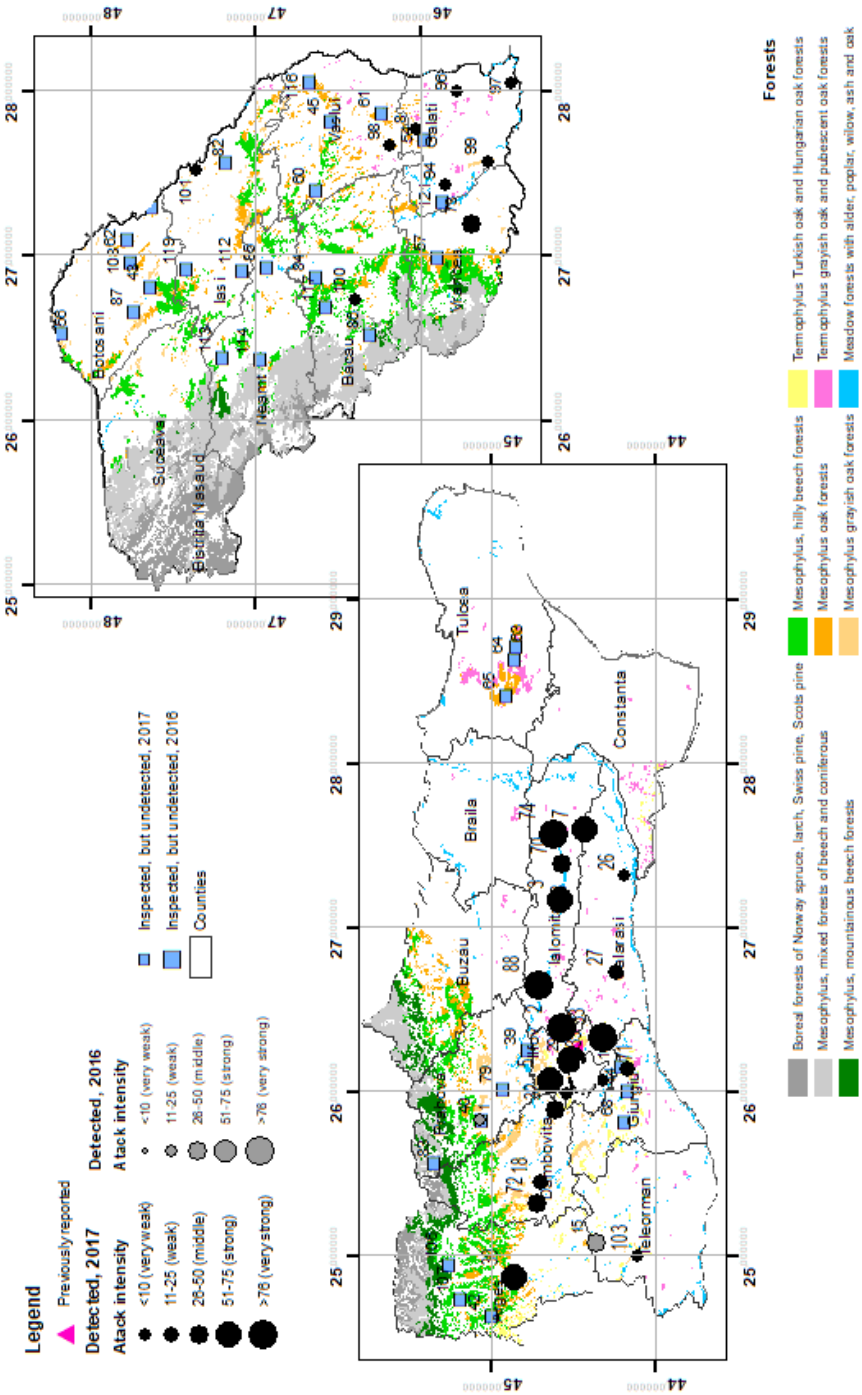

Figure 2B Observation sites and the intensity of attack on forest ecosystems in South-eastern (bottom) and Eastern (right) counties of Romania. Site numbers similar to Table S1, Supp. Info.

temperature varied from 8.2°C (Baciu-Cluj) to 11.7°C (Eşelniţa-Mehedinţi), the average temperature of the coldest month varies between -4.5°C (Călăraşi) and -0.8°C (Caransebeș), while the average temperature of the hottest month is between 18.9°C (Baciu-Cluj) and 28°C (Călăraşi). The annual average rainfall in those places varies between 419.6 mm (Hanu Conachi-Galaţi) and 860 mm (Ineu-Arad) and the average rainfall of the driest month between 14.3 mm (Macea-Arad) and 50 mm (Ineu-Arad), while the average rainfall of the wettest month is between 61.7 mm (Hanu Conachi-Galați) and 120 mm (Ineu-Arad). Consequently, the values of De Martonne aridity index vary between 20.46 (Hanu Conachi-Galați) and 45.98 (Ineu-Arad) (Table S1-S2 Supp. Info.).

In the 67 locations where the species was detected, it was found mainly on various species of *Quercus* (*Q. robur*, *Q. cerris*, *Q. frainetto*, *Q. petraea, Q. pubescens*), but also on *Ulmus minor* Mill. (1 location), *Tilia platyphyllos* Scop. (2 locations), *Tilia tomentosa* Moench (3), and *Prunus cerasifera* Ehrh. (1 location).

Discussions

C. arcuata was for the first time observed in Romania in August 2015, within "Pavel Covaci" University Botanical Garden of Macea (Don et al. 2016) and later, on 20 October 2015 in Arad (Rădac et. al. 2017). Several months later, in August 2016, the species was identified both around the municipality of Bucharest (Chireceanu et al. 2017), and at Băicoi, in Prahova county (this study). During 2016 it was also noted in other two locations in the western part of the country, at Timișoara and Denta (Rădac et al., 2017), but also in Dolj county (at Craiova and Balasan) and in Teleorman county, at Ciolănești (this study). Perhaps the species was present already in 2016 in many other locations, but the number of observation places was very low and thus its presence was not detected.

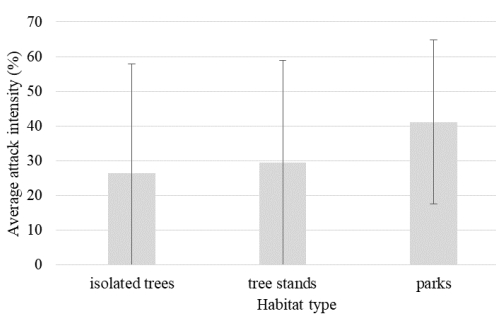

Figure 3 Intensity of the attack (mean ± standard deviation) in the main sampled habitats

All the above-mentioned places are located in the southern part of the country, but in 2017 the species was found far northern, both in the western and the eastern parts of Romania, at distances of up to 350 km from the previously known infested places. That means either a very high speed of spreading, or the occurrence of the species in Romania several years earlier than first detection. It is known that the species has spread fast in southern and central part of Europe (Csepelényi et al. 2017a, Jurc & Jurc 2017, Simov et al. 2018), as well as in Turkey (Mutun et al. 2009, Küçükbasmaci 2014, Çerçi & Koçak 2016), and Russia (Neimorovets et al. 2017). However, it seems that the species entered Romania already in 2013, a year when symptoms like those cause by OLB attack were noted by two of the authors (R.T. and C.N.) at oak trees in the southern part of the country, but there have been no specific investigations to determine their cause at that time. This hypothesis is supported by the fact that OLB had already been noted in 2012 in Bulgaria (Dobreva et al. 2013) and in 2013 in Hungary and Serbia (Csóka et al. 2013, Pap et al. 2015).

By the end of 2017, OLB was found in the central part of the country only at Baciu, Cluj county, although common oak and sessile oak are widespread in that area. Consequently, the general distribution of OLB in Romania at this time supports the hypothesis that this species entered the territory of the country both from south and from west, and that its spread was

aided by intense road and railway transport, like in the other countries (Dobreva et al. 2013, Jurc & Jurc 2017, Simov et al. 2018).

Even if we accept the hypothesis that the species arrived in Romania since 2013 or even earlier, we should note that the invasion process occurred much faster than the invasions of other species which spread quite rapidly in Romania, like *Cameraria ohridella* Deschka & Dimić, 1986.

OLB occurs wherever the host species are present, in tree stands, nurseries, parks, seed orchards (Jurc & Jurc 2017, Neimorovets et al. 2017, Simov et al. 2018), and the sun-exposed trees (in parks, forest stand edges etc.) seem to be more severe attacked, as noted by Kay et al. (2007) and Barber (2010). However, in our study the attack intensity in the three habitat types does not significantly differ because the infestation varied very much from place to place, observations being conducted both in the zone with established populations with high population density, and on the "invasion front line", with lower population density.

The climatic conditions in the locations where OLB was found in Romania are similar with those in some states of North America, where the species is native. Moreover, in its native area, the species survive even in more extreme conditions (Bernardinelli 2006a) so that it is no surprise that the species survived in the south-eastern part of Hungary during the relatively cold winter of 2016–2017 (Csepelényi et al. 2017b) and also in the western and southern parts of Romania.

The indigenous species of *Quercus* (*Q. cerris*, *Q. frainetto*, *Q. petraea*, *Q. pubescens*, *Q. robur*, *Q. robur* subsp. *pedunculiflora*), which are hosts of the insect in Romania, were already mentioned from other countries and all of them seem to be suitable food sources for this insect species (Bernardinelli 2006b), while trees of *Q. rubra* L., present in three different places (Bucharest, Voluntari and Călărași) in the proximity of infested trees of indigenous oaks were not attacked. Similar symptoms of attack and similar insects were noted on leaves of *U. minor*, *P. cerasifera*, *T. tomentosa* and *T. platyphyllos*, and the last three species seem to be new hosts of *C. arcuata*. However, new investigations are necessary, because such symptoms are caused on leaves of *Tilia* and *Prunus* also by *Stephanitis pyri* (Fabricius, 1775) and the two lace bug species are very similar in their habitus (Golub & Soboleva 2018).

The intensity of the attack in 2016-2017 varied greatly from one place to another and in most places (77.6%) of those in which the pest was found, the intensity of the attack was below 50%. However, in the southern and the western parts of the country, there were places with severe infestations and attack on 70-100% of the leaves. In the same period, severe infestations and OLB outbreaks were reported in the eastern part of Hungary, even at the border with Romania (Csepelényi et al., 2017), as well as in the southern part of Russia (Neimorovets et al. 2017). This indicates that the species has a high reproduction potential, several generations per year (2-3), very favourable multiplication and spreading conditions (numerous host species spread over wide areas crossed by roads and/or railways with heavy traffic and the lack of any natural limitative factors in this invasion stage).

Conclusions

During the investigation period of 2016-2017, *C. arcuata* was found in Romania in 67 locations, out of 124 inspected places. OLB was found on a wide range of host species, most frequently on *Q. robur*, *Q. frainetto*, *Q. petraea*, *Q. cerris,* and *Ulmus minor.* Similar symptoms and insects were found on leaves of *T. platyphyllos*, *T. tomentosa*, *and P. cerasifera*, species which appear to be new hosts of OLB in Europe. The current paper represents the first extensive inventory in Romania on the occurrence of *C. arcuata.*

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Supporting Information

The online version of the article includes the Supporting Information.

Fig. S1. Attack of *C. arcuata* on leaves
Table S1. Observation sites
Table S2. Climatic characteristics