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Thesis summary for doctoral dissertation

RESEARCH ON THE ECOLOGY OF THE INVASIVE OAK LACE BUG (*CORYTHUCHA ARCUATA*)

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1. INTRODUCTION

For decades natural ecosystems have been under increasing pressure due to climate change and biological invasions. The arrival and establishment of non-native species, which is often linked to rising temperatures from climate change, is one of the main drivers of natural ecosystem degradation. While it's important to note that not all non-native species become invasive, the species that do usually have severe economic and ecological impacts. Among invasive species, arthropods form one of the largest groups, with insects making up a high proportion.

There is a documented global trend of exponential growth in the establishment rate of non-native species and studies show that there is no saturation in the accumulation of alien species worldwide. In Hungary the number of non-native insect species with known or suspected significant forestry impacts between 1881 and 2010 was more than 100. And from all these species the number recorded between 1981-2010 was higher than the number of species from the previous century.

The impacts of invasive species can be severe worldwide. Most often these influences become known due to economic importance (e.g.: oak damage due to gypsy moth in the USA, box tree moth damage in Europe), but there are also serious effects on the ecosystems as well.

Our forests are such endangered ecosystems with outstanding economic and ecological importance. However, increasingly frequent biological invasion threaten forests as well, leading to impacts such as early severe defoliation, increased tree mortality, or slower growth rates.

One major invasive insect species in Europe is the oak lace bug (*Corythucha arcuata* [Say] 1832 – Hemiptera: Tingidae). Infestations by this species in affected areas can potentially harm oak ecosystems and lead to substantial economic and ecological losses.

2. OBJECTIVES

There are many European studies about the oak lace bug (*Corythucha arcuata*). These primarily researched its ecology, distribution and control options (mainly chemical control) against it. Our work concerning its ecology focused on the following main aspects:

2.1. We aimed to assess the spread and distribution of the oak lace bug in Hungary and evaluate the severity of its impact at the county level to understand the nationwide scale of the damage.

2.2. We wanted to study the overwintering mortality of the species in natural field conditions. This long-term investigation aimed to reveal whether the climate of Central Europe, particularly Hungary, imposes any limitation on its future spread.

2.3. We aimed to test the species' physiological limits against short-term exposure to strong cold conditions and long-term exposure to temperatures below 0°C. This we wanted to study in laboratory conditions. Our results could help predict its potential future range expansion.

2.4. We aimed to survey the awareness, perception, and attitudes of forestry stakeholders and the broader public toward the oak lace bug, invasive species in general, and forest health management strategies. The goal was to understand how well-informed these groups are, and which types of interventions they find socially acceptable.

2.5. Our goal was to investigate the natural enemies of the oak lace bug in its introduced range, with particular attention to predators, parasitoids and naturally occurring pathogens. The aim was to evaluate whether there's any biotic agent capable of controlling the oak lace bug in Hungary or Europe.

2.6. An important aim was to identify natural enemies in the native range of the oak lace bug, particularly specialist parasitoids and predators that could potentially be considered for future classical biological control programs in Europe.

3. MATERIALS AND METHODS

3.1. Spread and impact in Hungary

In September 2019, with support from the Ministry of Agriculture's Forestry Directorate, we conducted a survey among forest managers regarding the domestic spread and damage caused by the lace bug. Forest managers provided data about infected forest areas, the extent of infestation, and the oak species affected. The infection was assessed using a three-level scale: 1. Individuals of the species and symptoms appear sporadically; 2. Specific trees or their parts are visibly infected; 3. Tree groups or continuous stands are heavily infected. Area data were recorded with rounding: to the nearest hectare below 10 hectares, in 10-hectare increments between 10 and 50 hectares, and in 50-hectare increments above 50 hectares. The submitted data were aggregated and analyzed at the county level.

3.2. Field overwintering mortality of the oak lace bug

Field studies on overwintering mortality were conducted at ten locations between 2017 and 2024. At three sites (Gyula, Mátrafüred and Szolnok), samples were collected over multiple years, while at seven others (Békéscsaba, Debrecen, Karcag, Kecskemét, Hetényegyháza, Püspökladány, and Szarvas), sampling occurred in a single year only. Samples were gathered in the second half of March; overwintering site materials—including microhabitat fragments such as loose bark and moss cushions—were placed into storage containers and transported to the lab under constant temperature conditions. In the lab, after warming, live and dead individuals were counted. Mortality rates were calculated using both a simple average and a sample-size-weighted average.

3.3. Resistance of the oak lace bug agains sudden freeze and prolonged cold temperatures

To study the effects of freezing, we collected samples in Mátrafüred, Szolnok, and Gyula. When selecting these sites, a key criterion was the confirmed presence of the oak lace bug across multiple years. For the short-term freezing impact study, samples were collected once a month between November 2020 and March 2021. To examine the effect of prolonged subzero temperatures, samples were taken in November, January, and March.

Collected specimens were transported under cool conditions to the University of Natural Resources and Life Sciences (BOKU) in Vienna, to the Institute of Forest Entomology, Forest Pathology and Forest Protection. Laboratory experiments were supervised by Martin Schebeck. In the laboratory, for short-term cold tolerance testing, bugs were attached to thermocouple and cooled at a constant rate. For long-term cold tolerance, individuals were stored in plastic containers at –3°C and –5°C in an incubator for 7, 14, or 21 days. After the experiments, vital signs were checked once the insects had warmed to room temperature. Cold tolerance and mortality rates were analyzed using a generalized linear mixed model (GLMM).

3.4. Public and professional perception survey

For the public opinion survey, we developed the questionnaire in English through international collaboration with 12 colleagues from 10 countries. To facilitate broader distribution across different countries, it was translated into local languages. In every country, the questionnaire was distributed digitally and made accessible via the Google Forms platform. There were two main topics included. First was general knowledge of what is an invasive species and what are their predicted effects. Second was the perceptions of the oak lace bug and opinions on methods of controlling it. Responses were anonymous, and participants were asked to provide sociodemographic information. Among the results from participating countries, only responses from residents living in Hungary were analyzed.

3.5. Natural enemies in Europe

The study of natural enemies of the oak lace bug in Europe was carried out through field observations. In areas with mass occurrences of the bug, we searched for organisms that feed on its egg clusters, larvae, and adults. A large number of egg clusters were also collected in 2018, and these were observed in Petri dishes in laboratory for three weeks to detect possible emerging parasitoids. The natural enemies discovered were preserved in 70% ethanol solution for later identification.

3.6. Natural enemies in the native range

To study the natural enemies of the oak lace bug, in early July 2023, we collected egg clusters at 13 different sites across five U.S. states. At our request, David Bechtel, from the University of Tennessee's Department of Entomology and Plant Pathology, collected additional egg clusters on three occasions between June 20 and August 24, 2024, in Knoxville, Tennessee. After collecting, the egg clusters were monitored at room temperature for one month in 25 ml containers. Parasitic wasps that emerged were preserved in 2 ml Eppendorf tubes containing 70% ethanol for later identification. We later counted the oak lace bug eggs in the parasitized samples.

4. RESULTS AND DISCUSSION

4.1. Spread and impact in Hungary

The oak lace bug was first recorded in Hungary in 2013, in Szarvas, although personal communications suggest that it may have been present in the south-eastern part of the country 2-3 years earlier. By 2019 it was present in every county of Hungary. According to the survey conducted among forest managers in 2019, a total of 113,798 hectares of oak forests were infected across the country. Of this, 82,044 hectares experienced strong, stand-level infestation. These figures represent approximately 19% and 14% of Hungary's total oak forests, respectively. Based on submitted reports, the most heavily infested counties were Somogy (26,679 ha), Baranya (23,111 ha), and Pest (12,036 ha). These counties have significantly higher forest cover than the national average, along with a larger proportion of oak stands. In some counties (e.g., Bács-Kiskun, Békés, Jász-Nagykun-Szolnok, Zala), most reported areas fell into category 3 (heavy infestation). In recent years, total estimated oak lace bug infestation has surpassed 300,000 ha—meaning that about half of Hungary's oak forests, including Turkey oak stands, are infected.

4.2. Field overwintering mortality of the oak lace bug

The average overwintering mortality across the four study years was low. The weighted average mortality based on sample size was 29%. Among individual collections, the lowest mortality rate was 9%, and the highest was 63%. On a yearly basis, average values ranged between 12% and 54%.

Oak lace bug infestation was exceptionally high in the study areas during the observation periods, as indicated by widespread leaf discoloration and desiccation. Prior to the winters we examined, most populations were probably either starving or attempting to feed on alternative host plants (e.g., *Rubus*, *Acer*). Nevertheless, mortality remained relatively low despite the likely starvation.

The findings confirm that most European climates (or at least the cold temperatures during winter) can support the species' continued spread; winter conditions in Hungary caused only limited mortality. Further expansion toward Northern and Western regions is unlikely to be significantly hindered by cold winters, especially given the trend toward shorter and milder winters due to climate change.

4.3. Results of sudden freeze and prolonged cold temperature resistance experiments

Cold tolerance tests showed that throughout the study period, the oak lace bug withstood sudden cooling below 0°C, tolerating temperatures between -7.5°C and -29.7°C without freezing. Comparing supercooling point (SCP) values across locations revealed significant differences; average values in Mátrafüred were higher, particularly when compared to those from Szolnok. However, the coldest SCP was also recorded in the Mátrafüred sample from February—one individual reached -29.7°C.

Prolonged exposure to sub-zero temperatures demonstrated that continuous -5°C for three weeks did not cause significant mortality in oak lace bugs. The highest mortality rates across all samples were found in individuals collected in March. Those collected during that month showed over 40% mortality after 21 days of exposure to cold; in all other cases, rates were significantly lower.

4.4. Results of the public and professional perception survey

A total of 808 Hungarian residents completed the questionnaire. Of the respondents, 32% were forest managers or forest owners without forestry qualifications. According to the survey results, 93% correctly defined the concept of invasive species. 60% had previously seen the oak lace bug, and 82% of these correctly identified the bug. 83% percent believed the lace bug could eventually lead to the death of trees and 74% thought it affects photosynthesis. The latter assumption is supported by a Serbian study, which confirmed that strong oak lace bug feeding reduced photosynthetic activity by almost 60%. Regarding control measures against the lace bug, 78% supported biological control, while only a small portion (19%) favored chemical treatments.

Overall, it can be stated that society's knowledge level about invasive species and the oak lace bug in this particular study's case is adequate. Based on the research, most of the population supports measures against the lace bug and prefers less environmentally harmful methods (mechanical or biological) among available treatments.

4.5. Natural enemies of the oak lace bug in Europe

In the past 7 years — despite regular, targeted searches — only a few spider species, lacewing larvae, and ladybugs have been identified as generalist predators of the oak lace bug. However, these have no significant regulatory effect. No parasitoids have been successfully reared from samples collected in Hungary, and no reliable parasitoid rearing is known in Europe either.

Field observations show that the oak lace bug is infected by entomopathogenic fungi, mainly *Beauveria bassiana* and *B. pseudobassiana*, but these species do not exert a meaningful impact. It is worth noting that the complete absence of natural enemies with a significant regulatory effect is also true for the plane lace bug (*Corythucha ciliata*), which has been present in Europe for 60 years and in Hungary for nearly 50 years.

4.6. Natural enemies of the oak lace bug in its native range

The study of the oak lace bug's natural enemy during sampling showed that the previously documented specialist egg parasitoid, *Erythmelus klopomor* previously documented from the state of Missouri, is present in areas where oak lace bug can naturally be found. During the first collection we gathered 401 samples, and in 2024 an additional 22 samples were collected. Altogether 707 parasitoids were reared from 107 samples. Mortality rate at the separate locations caused by the parasitoid differed between 3.6% and 27.5%, with overall mortality rate from the 14 locations being 14.5%. Our first collecting only covered a single time in the growing season, and the second collecting only gave us a small sample. But field observations of low oak lace bug numbers, especially in natural habitats, suggested the presence of an effective, specialist natural enemy. Therefore, further investigation of *E. klopomor* is recommended. It is considered necessary to monitor parasitism rates throughout the entire growing season and to study the parasitoid's impact on non-target species for classical biological control.

5. SUGGESTIONS FOR FUTURE RESEARCH

Based on current scientific results there are several unanswered questions about the effects of the oak lace bug. Further research is recommended to enable the protection of diverse and ecologically important oak forest ecosystems.

For this purpose, it is crucial to study the impact the oak lace bug has on specialist native insects associated with oak hosts, especially herbivorous insects. This should be investigated through field sampling, followed by laboratory analysis and rearing of specialist arthropods in the lab.

According to literature, the oak lace bug can influence the photosynthetic activity of oaks. In the long term, this may affect the health of oaks and organisms directly linked to them. Additional research is suggested on the health of root-associated fungi in infected and uninfected oak trees.

Finally, control of the lace bug is highly important. However, many questions remain regarding the previously studied *Erythmelus klopomor*. It is essential to study the parasitoid's ecology and its effects on other species in laboratory settings.

6. NEW SCIENTIFIC RESULTS

6.1. In 2019, the oak lace bug was present in all counties of Hungary. At that time, the infested area reached 113,798 hectares, of which more than 82,000 hectares were infected at the stand level. The infestation was the most severe in the southern counties. By 2024, estimates suggest the affected area expanded to 300,000 hectares, meaning that half of Hungary's oak forests (including Turkey oak stands) were infested.

6.2. Over seven years of field studies, a total of 30,686 lace bugs were collected. Mortality rates in individual samples ranged from 9.1% to 62.5%. The average overwintering mortality rate, weighted by sample size, was 29% across all samples. Based on this, the bug is able to overwinter successfully in Hungary and can also establish and spread in countries to the North. This was also reinforced by later publications about the European spread of the oak lace bug.

6.3.1. Laboratory experiments revealed that the oak lace bug is highly resistant to sudden freezing. The tests, which measured the temperature at which internal body fluids crystallized showed that the highest point was 7.5°C and the lowest was -29.7°C. None of the individuals survived this crystallization, which indicates that the species is 'freeze intolerant'.

6.3.2. Within lace bug populations, long-lasting sub-zero temperatures caused significant mortality only among individuals collected in March and stored at low temperatures for 21 days. In this case, mortality reached 40%, which was not significantly higher than the average field mortality rate. These lab findings confirm that winter cold is unlikely to significantly limit the bug's spread.

6.4. According to the questionnaire results, the general public, as well as foresters and forest owners, in the case of our study, possessed an adequate level of knowledge about what invasive species are, and what the oak lace bug and its effects are. Regarding control methods, mechanical and biological solutions were favored more strongly than chemical control options.

6.5. Field observations over seven years showed that only opportunistic predators consumed the oak lace bug. No parasitoids emerged from lab-reared field samples. Although the bug is infected by entomopathogenic fungi (*Beauveria bassiana, B. pseudobassiana*), their impact appears to be minimal. Our conclusion is that natural enemies present in Hungary and Europe are not capable of effectively regulating oak lace bug populations.

6.6. Based on our studies performed in the oak lace bug's native range, the bug rarely appears in high densities. During the study, successful rearing of the egg parasitoid *Erythmelus klopomor* was achieved from all six states in the USA (Delaware, Maryland, Pennsylvania, Tennessee, Virginia and West Virginia). Current knowledge suggests this species is a specialist, relatively easy to collect and rear, and could form the basis for a classical biological control program.

7. Publications and presentations

7.1. Publications related to the subject of the dissertation

Articles published in English language scientific journals

Bălăcenoiu, F.; Japelj, A.; Bernardinelli, I.; Castagneyrol, B.; Csóka, G.; Glavendekić, M. et al. 2021: *Corythucha arcuata* ((Say, 1832) Hemiptera, Tingidae) in its invasive range in Europe: perception, knowledge and willingness to act in foresters and citizens. Neobiota 69: 133–153. **Q1**

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Ciceu, A.; Bălăcenoiu, F.; de Groot, M.; Chakraborty, D.; Avtzis, D.; Barta, M. et al. 2024: The ongoing range expansion of the invasive oak lace bug across Europe: current occurrence and potential distribution under climate change. Science of the Total Environment, 949. **Q1**

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Paulin, M.; Hirka, A.; Eötvös, Cs.B.; Gáspár, Cs.; Fürjes-Mikó, Á.; & Csóka, Gy. 2020: Known and predicted impacts of the invasive oak lace bug *Corythucha arcuata*) in European oak ecosystems – a review. Folia Oecologica, 47(2): 131–139. **Q3**

Paulin, M.J.; Eötvös, C.B.; Zabransky, P.; Csóka, G.; & Schebeck, M. 2023: Cold tolerance of the invasive oak lace bug, *Corythucha arcuata*. Agricultural and Forest Entomology, 25(4), 612–621. **Q1**

Book chapter in English language

Csóka, Gy. & **Paulin, M.** 2022: Oak Lace Bug - *Corythucha arcuata* Say, 1832: In: Haraszthy László (ed.) Invasive animal species in Hungary, Rosalia handbooks 5. Duna–Ipoly National Park Directorate, Budapest, 149–154

Articles published in Hungarian scientific journals

Eötvös Cs.B.; Tóth M.; Hirka A.; Fürjes-Mikó Á.; Gáspár Cs.; **Paulin M.;** et al. 2023: A tölgy-csipkéspoloska [*Corythucha arcuata* Say, 1832)] rövid távú terjedését befolyásoló tényezők tölgyeseinkben. Erdészettudományi Közlemények 13(2): 131–144.

Paulin M.; Hirka A.; Mikó Á.; Tenorio-Baigorria I.; Eötvös Cs.; Gáspár Cs. és Csóka Gy. 2020: A tölgy-csipkéspoloska Magyarországon – helyzetkép 2019 őszén. Növényvédelem 56(6): 245–250.

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6.3. Presentations related to the subject of the dissertation

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Paulin M. J.; Melika G.; Triapitsyn S.; Bechtel D. & Csóka Gy. 2024: *Erythmelus klopomor* - promising candidate for classical biological control against the invasive oak lace bug. The International Oak Symposium: Science-Based Management for Dynamic Oak Forests; Knoxville, Tennessee, USA, 2024.10.07–10.

Paulin M. J.; Melika G.; Triapitsyn S.; Bechtel D. & Csóka Gy. 2025: *Erythmelus klopomor* – A promising candidate for classical biological control against the invasive oak lace bug. Forest Protection Colloquium 2025; Vienna, Austria, 2025.04.03–04.

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Presentations held in Hungarian

Paulin M., Eötvös Cs. B., Zabransky P., Csóka Gy., & Schebeck M. 2023: Az inváziós tölgy-csipkéspoloska, *Corythucha arcuata*, hidegtűrése Közép Európában: a további terjedés lehetősége? III. Debreceni Alkalmazott Rovartani Konferencia (online) 2023.05.25.

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