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Assessing the Short-Term Impact of the Oak Lace Bug (*Corythucha arcuata*) on Growth and Wood Properties of *Quercus frainetto*

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ABSTRACT

The oak lace bug *Corythucha arcuata* (Say, 1832), an invasive sap-sucking insect originating from North America, has rapidly spread across Europe, raising concerns about its impact on oak forest ecosystems. This study evaluates the short-term effects of *C. arcuata* infestation on radial growth and wood properties of Hungarian oak *Quercus frainetto* Ten. in Kalyvas-Margaritiou public forest complex along the Xanthi-Drama national highway in northeastern Greece, Xanthi Prefecture, Eastern Macedonia and Thrace, Greece. Oak trees were sampled in areas with varying degrees of infestation to compare growth characteristics and evaluate potential physiological impacts. Results revealed no statistically significant differences in tree radial growth or late/early wood ratios (p=0.125 and p=0.0837, respectively) between infested and non-infested trees. The study also highlights the critical role of highways as dispersal corridors, with infestation levels decreasing with distance from the roads. While short-term impacts appear negligible, the potential for long-term consequences remains a concern. Continuous infestation could interact with other stressors, such as drought, defoliation, and climate extremes, posing risks to tree health, acorn production, and associated biodiversity. This study underscores the importance of monitoring invasive species and their cumulative impacts on forest ecosystems.

Keywords: invasive species; herbivory impact on trees; forest pest dynamics; forest resilience; tree radial growth; oak forest management; ecosystem stability

INTRODUCTION

Sap-sucking insects can impose various stressors on plants, including tissue damage, leaf discolouration, shoot stunting, gall formation, and transmitting pathogens (Baumann 2005, Gullan and Cranston 2014). Among these impacts, mucivory (the consumption of plant fluids by insects) is thought to cause greater localised physiological stress, particularly on photosynthetic capacity, compared to mechanical leaf feeding (Meyer 1993). Sap-sucking insects disrupt the flow of nutrients and water, further affecting plant health and growth (Haukioja et al. 1990). Despite their high species richness and frequent presence on forest trees, native sap-sucking insects are typically regulated at low densities by natural enemies, making them less significant as pests in their native habitats (Branco et al. 2023). However, when introduced into new ecosystems, these insects may escape their natural enemies, leading to population explosions and severe damage to native vegetation (Mlynarek 2015).

The oak lace bug (OLB) *Corythucha arcuata* (Say, 1832) (Hemiptera: Tingidae), native to northeastern America, has become a significant invasive species in Europe. Since its first European record in Italy in 2000 (Bernardinelli and Zandigiacomo 2000), it has rapidly expanded across most European countries (Csóka et al. 2020, Paulin et al. 2020, Gil and Grosso-Silva 2021, Riba-Flinch 2022, Huberson et al. 2024), reaching Greece in 2018 in Xanthi Prefecture, Eastern Macedonia and Thrace (Csóka et al. 2020). OLB primarily infests deciduous oaks such as pedunculate oak (*Quercus robur* L.), Hungarian oak (*Q. frainetto* Ten.), sessile oak (*Q. petraea* (Matt.) Liebl.), and Austrian oak (*Q. cerris* L.). Still, it can also exploit other host species (Csóka et al. 2020). Feeding by OLB adults and nymphs creates chlorotic discolouration and necrosis on the leaves, significantly reducing photosynthesis and stomatal conductance (Connell and Beacher 1947, Nikolić et al. 2019). Severe infestations can result in defoliation, compounding the physiological stress on trees (Mutun et al. 2009, Hrašovec et al. 2013). However, despite these effects, the impacts on tree growth remain largely unexplored (Ciceu et al. 2024).

Despite its known impacts on leaf physiology, the effects of *C. arcuata* infestations on annual tree growth remain underexplored. Deciduous oak forests in Greece, spanning 747,549 hectares and representing 29.8% of forested areas, hold significant ecological and economic importance. Growth reductions caused by OLB could result in considerable economic losses. While leaf-eating insects are known to reduce early-season growth (Muzika and Liebhold 1999, Colbert and Fekedulegn 2001), the effects of late-season infestations, such as those caused by OLB, are less well understood. The phenology of oak growth, primarily driven by environmental factors, is concentrated mainly in earlywood formation, which accounts for approximately 80% of annual growth by late July (Szőnyi 1962, Hirka 1991). As OLB populations typically peak in late summer (Bălăcenoiu et al. 2021), their impact on growth rings is expected to be more pronounced in latewood. Reducing latewood density could degrade wood quality, altering its physical and mechanical properties (Rao et al. 1997, Soheili et al. 2021).

This study aims to determine whether *C. arcuata* infestation affects annual growth increments in *Q. frainetto* over the short term. By examining changes in growth rings and the earlywood-to-latewood ratio, we aim to provide insights into the pest's effects on forest productivity and wood quality.

MATERIALS AND METHODS

Study Area

The study was conducted in the public forest complex "Kalyvas-Margaritiou" in the northwestern part of Xanthi Prefecture, Eastern Macedonia and Thrace, Greece. The area spans 14,378 hectares, with coordinates ranging from 41°11′44″ to 41°18′50″ N and 24°34′52″ to 24°47′41″ E (Figure 1). The elevation varies from 70 to 1,440 m above sea level, averaging 750 m. The region experiences a temperate Mediterranean climate (Köppen-Geiger classification: Csa), characterised by hot, dry summers, with an average annual temperature of approximately 15°C and total annual precipitation of around 650–900 mm.

Forested oak stands, occupying 8,612 hectares, are dominated by Hungarian oak, sessile oak, downy oak (*Q. pubescens* Willd.), Austrian oak, and sporadically pedunculate oak (*Q. robur* subsp. *pedunculiflora* (K.Koch) Menitsky). These species form mixed or pure stands, often hybridising (Jensen 1988, Ponton et al. 2004).

Field Study

From late September to late November 2023, the study area was surveyed for OLB infestations, coinciding with the insect's peak population and maximum leaf discolouration (Gninenko et al. 2021). Infestation levels were recorded in representative oak stands at predetermined points, totalling 36 points. Four trees per site were selected for each point, totalling 144 trees. Branches were sampled using telescopic scissors to obtain representative crown samples. Fifty leaves were randomly collected per tree, totaling 720, sealed in airtight bags, and transported to the Laboratory of Forest Protection and Environmental Pollution, Democritus University of Thrace, for further analysis.

Using an Olympus SZX7 stereomicroscope, leaves were examined for OLB (adults, nymphs, or eggs). Following published keys, identification was based on morphological traits (Drew and Arnold 1977, Horn et al. 1979). Leaves with metachromatic spots but no insect presence were excluded to avoid misclassification.

Infestation Classification

The infestation degree of every leaf was classified using a four-grade scale (Figure 2):

I. No developmental stages or eggs detected;
II. Minor infestation with a few individuals or egg clusters per leaf;
III. Medium infestation with widespread stages and exudates;
IV. Severe infestation with abundant individuals, secretions, and discolouration.

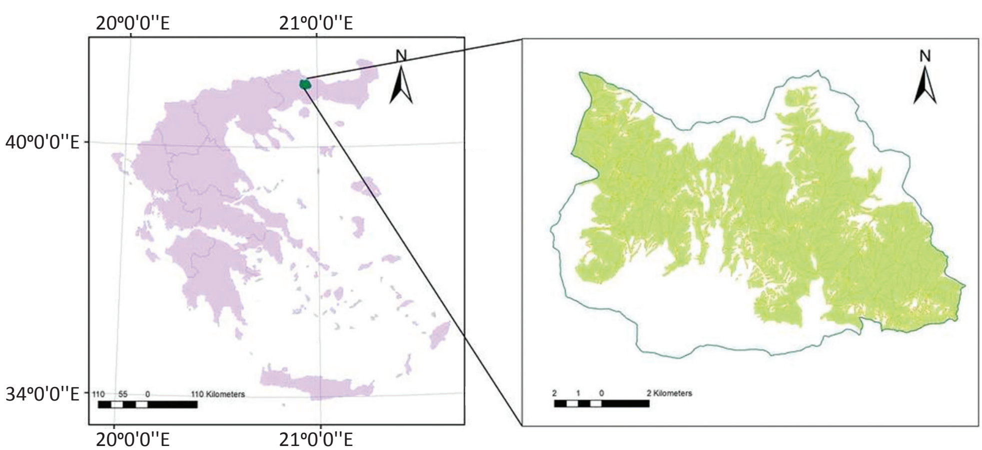

Figure 1. Location of the study area. Green colour represents forested and partially forested oak stands.

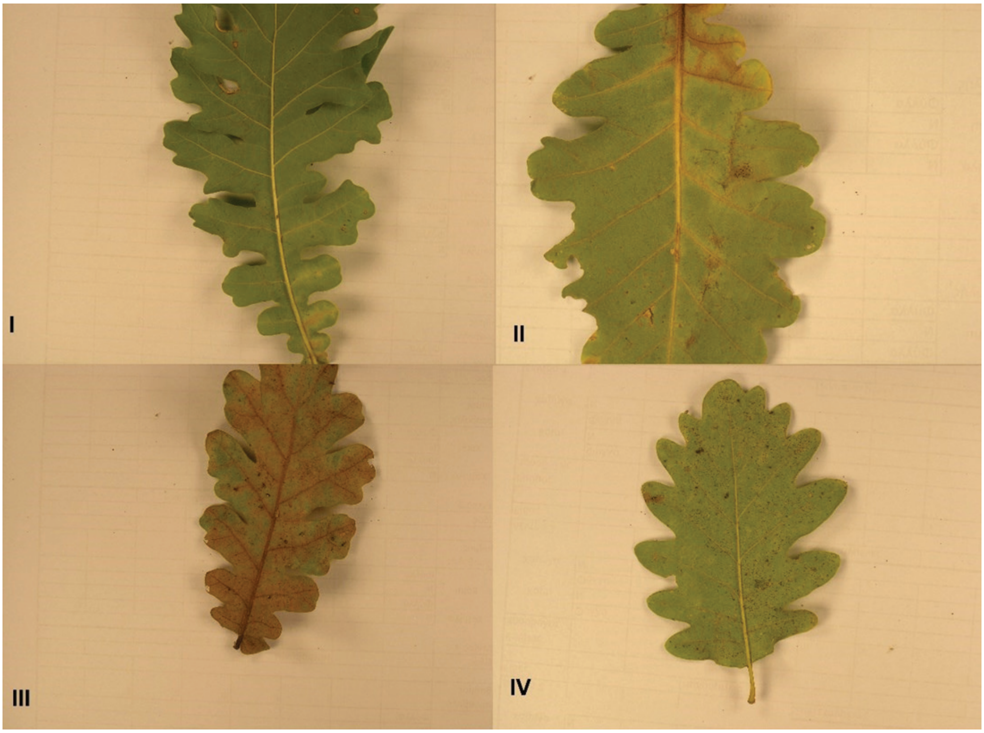

Figure 2. The four-grade scale of the infestation degree of leaves: **I.** No developmental stages or eggs detected, **II.** Minor infestation, **III.** Medium infestation, **IV.** Severe infestation.

Trees were categorised into four infestation levels based on the percentage of affected leaves:

0. No infestation;
1. Minor infestation (most leaves classified as grade II);
2. Moderate infestation (most leaves classified as grade III);
3. Severe infestation (most leaves classified as grade IV).

Growth Analysis

In January and February 2024, four dominant, healthy *Q. frainetto* trees were selected from each infestation category (16 trees total). Increment cores were extracted at breast height from the north-facing side of each tree to minimise the effect of sunlight exposure on growth patterns using a Pressler increment borer. Samples were air-dried and prepared for growth ring analysis (Figure 2). Growth rings from the past ten years (2013–2023) were examined. Each ring was divided into earlywood and latewood, using a density-based segmentation approach in Natsumushi v1.10.1 software.

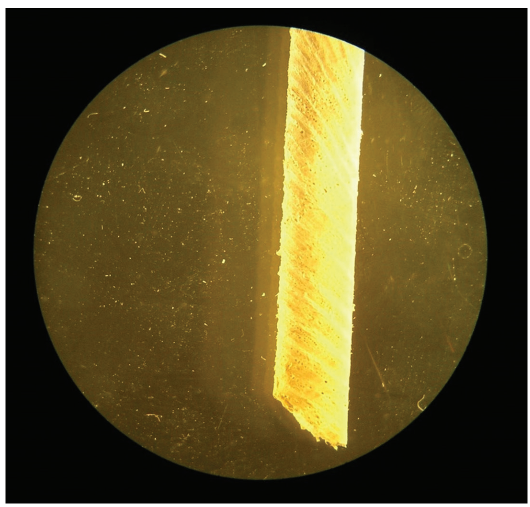

Figure 3. Air-dried and prepared the increment core.

Statistical Analysis

To assess infestation across different oak species, infestation data for each tree were analysed and summarised using R version 4.4.2 (R Core Team 2024). A bar graph was generated to illustrate infestation levels across oak species.

Latewood-to-earlywood ratios were calculated, and resistance to infestation was evaluated using the Lloret et al. (2011) formula, as the ratio of growth during 2018–2023 (Gca) to growth before infestation, 2013–2017 (Gprev):

$$Rt = \frac{Gca}{Gprev} \tag{1}$$

Differences in ring widths and earlywood-to-latewood ratios between infestation categories were analysed using t-tests and one-way ANOVA. Before applying these analyses, homogeneity of variances was confirmed with F-tests. The results indicated that *Q. frainetto* had the highest number of sampled trees and exhibited the greatest diversity of infestation levels, making it the most suitable species for focused analysis.

RESULTS

In the surveyed area, the oak lace bug (*Corythucha arcuata*, OLB) was primarily found in oak forests along the Xanthi-Drama national highway, where it exhibited the highest infestation levels. Infestation appeared to be the highest near roads, though precise distances were not measured. The infestation severity varied across oak species, as shown in Figure 4. *Q. frainetto*, with the highest number of trees sampled, exhibited the greatest diversity of infestation levels, making it the best species for focus. At the same time, *Q. petraea* and *Q. pubescens* had lower infestation diversity, mostly at levels 0 and 1 of the analysis.

The radial growth analysis revealed no statistically significant differences in the annual growth rings before and after the first recorded infestation in 2018 (Table 1, p=0.125). Similarly, no significant variations were observed in the growth rates of trees across different infestation levels. The tree resistance index (RtR_tRt), calculated as the ratio of growth during infestation years to pre-infestation years, consistently approached 1, regardless of infestation degree (Table 2).

The ratio of latewood to earlywood remained stable over the last five years across all trees and infestation levels (p=0.0837, Table 3). This indicates no observable impact on the proportion of wood produced during different parts of the growing season. As a result, no evidence was found for reductions in timber production or alterations in wood mechanical properties attributable to OLB infestation.

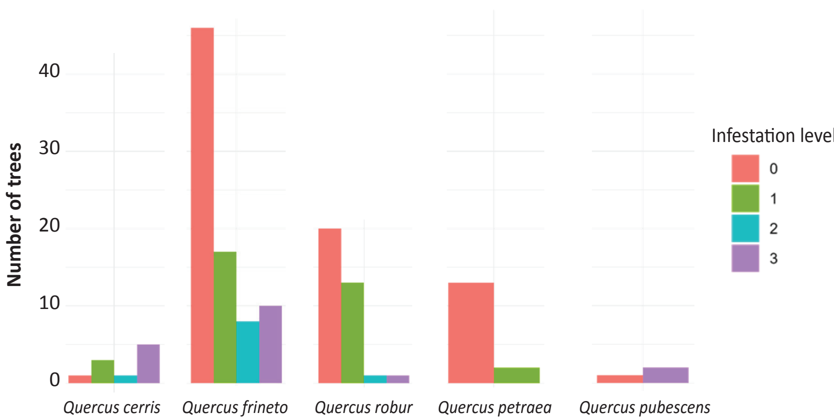

Figure 4. The infestation severity in the sampled trees.

Table 1. t-Test: Paired Two-Sample for Means. Gca: growth after 2018, when the first OLB was recorded, Gca: growth 5 years before 2018.

	Gprev	Gca
Mean	6.946875	6.997563
Variance	0.488623	0.611055
Observations	16	16
Pearson Correlation	0.97989	
Hypothesised Mean Difference	0	
df	15	
t Stat	-1.19442	
P(T<=t) one-tail	0.12543	
t Critical one-tail	1.75305	
P(T<=t) two-tail	0.250859	
t Critical two-tail	2.13145	

Table 2. Physical traits and Resistance (Rt) of trees to OLB infestation Bhd: Breast height diameter (cm), h: height (m), Gprv: growth 5 years before 2018, Rt: tree resistance.

Infestation degree	Tree no.	bhd	h	Gprev	Rt	Mean	St Dev
0	13	42	8.5	7.38	1.002710	1.007532	0.014710
	91	40	11.5	7.44	0.989247		
	101	29	9.3	6.64	1.022590		
	89	30	12.2	7.06	1.015581		
1	33	36	10.9	6.83	0.989751	1.008006	0.033754
	10	24	9.2	7.88	1.045685		
	81	52	13.7	8.64	1.025463		
	102	25	9.1	6.58	0.971125		
2	34	37	13.1	6.35	1.009449	0.997031	0.026787
	35	44	13.5	6.89	0.969521		
	36	49	12.3	7.45	1.028322		
	8	18	12.8	6.26	0.980831		
3	73	34	15.8	6.42	0.976636	1.013750	0.024987
	74	39	12.6	7.05	1.021277		
	5	28	9.2	6.48	1.027778		
	6	18	8.6	5.80	1.029310		

Table 3. ANOVA parameters in the late/early wood ratio in the last 5 years, between and within different degrees of infestation.

	Sum of squares	df	Mean square	F	P - value
Between Groups	0.016561304	3	0.005520435	2.303284961	0.08369
Within Groups	0.182154199	76	0.002396766		
Total	0.198715503	79			

DISCUSSION

The first detection of OLB in Xanthi in 2018 (Csóka et al. 2020) marked the beginning of its rapid expansion across the region. We do not know if its first recording is also the gateway to the country. Still, its rapid invasion makes OLB the most threatening invasive arthropod in European oak ecosystems (Ciceu et al. 2024). Its presence has since been confirmed in Drama Prefecture and Corfu Island (GBIF database) and nearby Bulgaria (Dobreva et al. 2013). The observed infestation patterns, predominantly along roadways, align with the insect's known dispersal mechanisms, primarily involving anthropogenic transport via vehicles (Simov et al. 2018, Tomescu et al. 2018). The lower infestation levels in more remote areas support this hypothesis, suggesting limited natural dispersal beyond human-impacted zones.

The lack of significant differences in radial growth and wood quality across infestation levels suggests that, in the short term, OLB does not adversely affect tree growth or timber properties. This could be attributed to several factors. First, the timing of the oak lace bug's life cycle may mitigate its impact. The insect reaches peak populations and causes the most severe leaf damage late in the growing season, after the completion of earlywood formation, which constitutes the bulk of radial growth (Hirka 1991). Second, the physiological resilience of oaks, which are adapted to intermittent defoliation and environmental stressors, likely plays a role (Nikolić et al. 2019).

Despite these findings, long-term effects remain uncertain. Prolonged infestations may amplify stress on trees, particularly when combined with other biotic and abiotic stressors such as defoliating insects, drought, and heatwaves (Pap et al. 2018, Drekić et al. 2020, Stojanović et al. 2021). Chronic infestations could also reduce acorn production, critical for forest regeneration and wildlife, and alter the dynamics of oak-associated organisms.

CONCLUSIONS

The findings indicate that OLB infestation does not significantly affect oak growth or wood mechanical properties in the short term. This resilience is likely due to the timing of the insect's activity and the oak's physiology's inherent adaptability. However, it is crucial to acknowledge the potential long-term consequences. Prolonged and heavy infestations may exacerbate stress when compounded with other environmental and biotic pressures, such as climate change-induced droughts, heatwaves, or defoliation events. These factors could compromise tree health, productivity, and ecosystem services.

Furthermore, infestations may influence oak ecosystems beyond tree growth. Potential reductions in acorn production could disrupt regeneration processes and adversely affect wildlife dependent on this critical resource. Additionally, oak-associated communities, including insects, fungi, and microorganisms, might experience changes due to shifts in tree vitality and leaf chemistry. Therefore, understanding these cascading effects is vital for devising effective forest management strategies.

Future research should focus on:

1. Longitudinal studies to monitor the cumulative effects of infestation;
2. Evaluations of acorn yield and quality under infestation pressure;
3. Impacts on oak-associated organisms and trophic interactions;
4. Examination of potential synergies between OLB and other stressors;
5. Developing integrated pest management strategies to mitigate risks.

Given the rapid spread of OLB, these insights are critical for ensuring sustainable oak forest management and biodiversity conservation.

Author Contributions

AT and PK conceived and designed the research, carried out the field measurements and performed laboratory analysis, processed the data and performed statistical analysis, secured the research funding, supervised the study, helped draft the manuscript, and wrote the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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