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Corythucha arcuata (Say, 1832) (Hemiptera, Tingidae) in its invasive range in Europe: perception, knowledge and willingness to act in foresters and citizens

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Abstract

The oak lace bug (OLB) *Corythucha arcuata* (Say, 1832) is an invasive alien species (IAS) that potentially could have many negative impacts on European oak health. Certain measures can be applied to counteract these effects. However, these measures may not be acceptable for forest managers or other stakeholder groups, such as private forest owners, environmental NGOs or the general public. Thereby, we set out to study the perception and knowledge of foresters and other stakeholders on the health status of European oak forests affected by oak lace bug and to investigate what forest health management measures would be acceptable to these target groups. An online survey questionnaire was designed and distributed via social networks, as well as professional networks via e-mails. The survey questionnaire was completed by 2084 respondents from nine European countries: Austria, Croatia, Belgium, France, Hungary, Italy, Romania, Serbia and Slovenia. Even though only a little over 60% of respondents reported they had noticed the discolouration of oak leaves caused by OLB, almost all (93%) considered it to be a problem. As respondents come from a country where *C. arcuata* is widespread and established, people's general knowledge and awareness of OLB began to increase. The survey revealed that foresters thought that the insect affected photosynthesis, acorn crop and the aesthetics of the trees, but cannot cause death of trees. However, they assume that the value of the wood would decrease (this fact is also supported by the respondents who are connected to an environmental NGO), but that OLB does not affect property value. However, forest owners claim that the value of the property can be affected and that people would avoid entering the forest. In terms of potential control methods, respondents preferred biological or mechanical measures over chemical ones. We consider this study to be a good basis for further research on the topic of perception, knowledge and attitudes related to OLB since we can expect that the IAS, such as OLB, will certainly spread to European countries that were not included in this survey.

Keywords

Attitude, citizen knowledge, Europe, forest health, IAS control measures, invasive alien species, survey

Introduction

Humans rely on healthy forest ecosystems to provide a wide range of ecosystem services (Trumbore et al. 2015). Furthermore, in the Sustainable Development Goals Report (2020), the United Nations have set two goals (13-Climate action and 15-Life on land) to the expansion of sustainable forest management to protect biodiversity and ecosystems in order to strengthen resilience and the capacity to adapt to climate risks. Assuming that trees are key components of forest ecosystems (Turner and Daily 2008; Bateman et al. 2013), the way in which forest ecosystem services are provided is strongly influenced by the health of these trees. However, various tree pests and disease threaten the health of forest ecosystems (Boyd et al. 2013). Although native forests are adapted to a certain level of disturbance, in addition to problems such as climate change or air pollution, more and more forests are also facing invasive alien species (IAS) (Trumbore et al. 2015). Invasive alien species are organisms that have been introduced by humans out of their natural environment, either deliberately or accidentally, have established and subsequently multiplied and, thus, begun to have negative effects on the newly-invaded ecosystem (Williamson and Fitter 1996; Juliano and Philip Lounibos 2005; EEA 2013).

Negative effects of invasive alien species can be particularly profound in long-lived ecosystems, such as forests (Régnière 2011). They can cause multiple consequences on the environment, the economy or even human health (Pimentel et al. 2000; Lovell et al. 2006; Meyerson and Mooney 2007; Vilà et al. 2010, 2011; Jeschke et al. 2013; Simberloff et al. 2013; Blackburn et al. 2014; Hulme 2014; Schindler et al. 2015). As a result of the increase in transport activity, human trade and the anthropogenic influence on the climate, forest ecosystems are increasingly disrupted by biological invasions (Régnière 2011). Until recently, invasive arthropods have been given less attention compared to other invasive organisms, such as plants, vertebrates or aquatic species (Kenis et al. 2009). In Europe, the rate of reports of invasive alien insect species has almost doubled in recent decades and currently insects represent 87% of invasive alien species on the European continent (Roques 2010).

Corythucha arcuata, the oak lace bug (OLB henceforth), is an insect from North America that was first reported in Europe in 2000 in northern Italy (Bernardinelli and Zandigiacomo 2000). Up until 2019, it had been detected in 20 European countries (Paulin et al. 2020). The insect causes discolouration of the foliage of the host trees (mainly *Quercus* spp.) caused by feeding of both nymphs and adults on the underside of the leaves. As oak ecosystems are extremely important both from an economic and ecological point of view in Europe, the species raised significant awareness. Recognising its potential degree of injury and invasion, the OLB was included on the EPPO Alert List in March 2001 and remained so until 2007, when it became clear that phytosanitary efforts could not stop its expansion (EPPO 2001, 2007). Furthermore, *C. arcuata* has also been suspected to be a nuisance as the adults may sting as was shown for *C. ciliata* (Say, 1832) (Dutto and Bertero 2013). However, this should not be confused with an aggressive behaviour like the stinging done by wasps. The real explosive expansion in Europe was observed only a decade after the first report, with the estimated total area of forests infested by OLB in only five countries (Croatia, Hungary, Romania, European part of Russia and Serbia) exceeding 1.7 million hectares in 2019 (Paulin et al. 2020).

Mechanical control measures have been tested in several countries, such as the UK, Czech Republic and Romania (Williams et al. 2021), using yellow sticky traps or suction traps. However, the methodologies evaluated were more for early detection, surveying and monitoring and not for removal. For biological control to be effective, identification of suitable biotic factors are needed. Previous studies conducted on identifying potential predators and fungal pathogens have identified several species (Coccinellidae, Chrysopidae, mites, spiders, *Beauveria bassiana*) that can reduce insect numbers at different stages of development (Bernardinelli and Zandigiacomo 2000; Sönmez et al. 2016; Kovač et al. 2020; Paulin et al. 2020). Nevertheless, these studies have shown that natural enemies in Europe that might control OLB populations are not having any effects. Another proposed method of biological control could be to use a classical biological control programme against OLB in Europe that may be achieved by importing natural enemies of OLB from North America (Puttler et al. 2014). The use of the latter method will have to be carefully chosen and managed with discernment, because the introduction of an allogeneic species into Europe, even for biocontrol purpose, could have further negative impacts. A potential chemical control option was researched in a Romanian study in two isolated forests (Bălăcenoiu et al. 2021). The results showed that after more or less time (earlier to the contact insecticide and later to the systemic one), the treated forests were re-infested by OLB; hence, it could not be economically justified, especially given the large area of infested European forests. However, recommending the use of this control method in isolated cases, such as frequented parks, tourist attractions, gardens and park forests, may be possible, in view of limiting the discomfort caused by the OLB stings/bites on the human skin (Ciceoi and Radulovici 2018), depending whether insecticides are allowed in these areas, especially in urban areas.

In the last three decades, out of 77 studies that analysed social perception of invasive alien species, only 13 targeted the taxonomic group of insects (Kapitza et al. 2019). This means that we still have little information on whether and how the public perceive invasive alien insects and, in particular OLB, as well as what kind of management of these alien insects would be acceptable to the general public. A recent study showed that people generally support management of invasive species (Japelj et al. 2019). However, there is no such study targeting management of OLB.

The objectives of our study were to investigate perception and knowledge of the health status of European oak forests affected by OLB as perceived by several stakeholder groups (foresters, private forest owners, environmental NGOs and the general public), as well as to explore attitudes of these stakeholder groups towards actual and potential measures targeting OLB. We hypothesised that: a) selected stakeholder groups perceive OLB or, at least, the effect of OLB on oak species, to some extent, b) that attitude of stakeholder groups towards possible measures for OLB management may differ and c) that the sociodemographic characteristics of respondents may be significantly connected to their perception, knowledge and attitudes. We expected differences in perception and knowledge between respondents from countries where OLB has been already established and those where it is still not present. When it comes to attitudes towards specific measures for controlling OLB, we also expected that support of different stakeholder and sociodemographic groups may differ.

Materials and methods

The questionnaire was designed first in English (Suppl. material 1: Appendix 1) and then it was translated into several local languages to be distributed in European countries that showed a gradient of invasion of OLB: not occurring (absent: Belgium, United Kingdom), arrived not more than four years ago (spread: Slovenia, Austria, France) and invaded for more than 5 years (established: Croatia, Hungary, Italy, Romania, Serbia). For each country, there was at least one national contact person, who translated the questionnaire article from English into the local language. As the questionnaire distribution was made exclusively in digital form for each language, the questionnaire was uploaded to the Google Forms platform and continued to be computer-assisted web interview (CAWI method) until the study was completed. We used a snowball approach to distribute the questionnaire, sending it to relevant academic and professional contacts through mailing lists and advertised it on social media, such as Facebook, LinkedIn and WhatsApp. The survey was conducted in September and October 2020, when the effects of OLB were most easily noticed by the general public.

We aimed to reach particular target groups – foresters, environmental activists, nature lovers, forest owners and members of environmental NGOs, as well as the general public. During the period the questionnaire was accessible, we surveyed the self-declared pre-defined categories of respondents and re-advertised the questionnaire through the relevant channels to reach under-represented groups.

Questionnaire design

The questionnaire did not focus exclusively on OLB, but addressed some issues generally related to invasive alien species and was split into three parts, namely: 1) questions on invasive species in general, 2) a section that was specifically dedicated to the issue, knowledge and perception of the OLB in European oak forests and 3) a part with questions on respondents' socio-demographic characteristics. In this paper, we will present results related to OLB and sociodemographic characteristics of respondents.

The questionnaire was anonymous. There were no means by which respondents could be identified from their answers. By submitting their answers, respondents were informed that they will be analysed and used in the context of a research project, leading to publication in a scientific journal.

The questions were mostly a close-ended format, with several types of answers: binary answer (yes or no), multiple possible answers, Likert scale or open-ended. However, the open-ended questions (in which the respondent could give their own opinion) yielded a small number of responses and they were very diverse. We, therefore, did not perform any quantitative analysis, but instead extracted and synthesised the most frequent answers to be presented here.

Data analysis

To study the influence of OLB's time since introduction on respondents' perception and general knowledge of OLB and attitudes towards its management, the countries were grouped as described above into "not arrived", "recently arrived" and "present for greater than 5-years" categories. After the questionnaire was distributed within 10 European countries, given that we only received 15 responses from the United Kingdom, this information was removed from any further data analysis.

We analysed closed 'yes-no' questions (questions 1, 2, 4 and 6–8) using generalised linear mixed models with binomial error distribution and logit link and with country included as a random effect. The questions 9–10 (multiple possible answers) were analysed with an ordinal mixed model, with again country included as a random effect. We first built a full model including the following independent variables (Suppl. material 2: Appendix 2) as fixed effects: whether respondents self-identified as foresters (yes/no), landowners (yes/no), being connected to an environmental NGO, time spent in the forest (frequency of forest visit), gender, age and time since OLB introduction in the country (absent, spread and established). We then compared the full model with every possible model through a model selection procedure based on the Akaike's Information Criterion (AIC). The model with the lowest AIC is generally considered the best model, given the data and set of candidate models. Every model within 2 units is AIC units from the best model is considered as equivalent in their ability to fit the data.

Analysis and data visualisation were carried on using the R statistical programme (R Core Team 2020), with the packages “MASS”, lme4 (Bates et al. 2015), (Venables and Ripley 2002), ggalluvial (Brunson and Read 2020) and “ordinal” (Christensen 2019) being used.

Results

Finally, in the nine remaining countries, the questionnaire was completed by 2084 respondents. Regarding socio-demographic characteristics, the questionnaire revealed respondents were as follows: foresters/non-foresters 37%/63%, forest owners/non-forest owners 21%/79%, environmental NGOs/non-NGOs 31%/69%, women/men 37%/63%.

1. General knowledge of respondents about OLB

Based on photos representing whole trees or single leaves impacted by the OLB, two thirds of respondents (66%) declared that they had seen such discolouration before (Fig. 1). Respondents who were foresters (z = 2.108, P = 0.030), connected to an environmental NGO (z = 2.877, P = 0.004) and frequent visitors of the forest especially individuals who went weekly (z = 2.347, P = 0.019) were more likely to respond

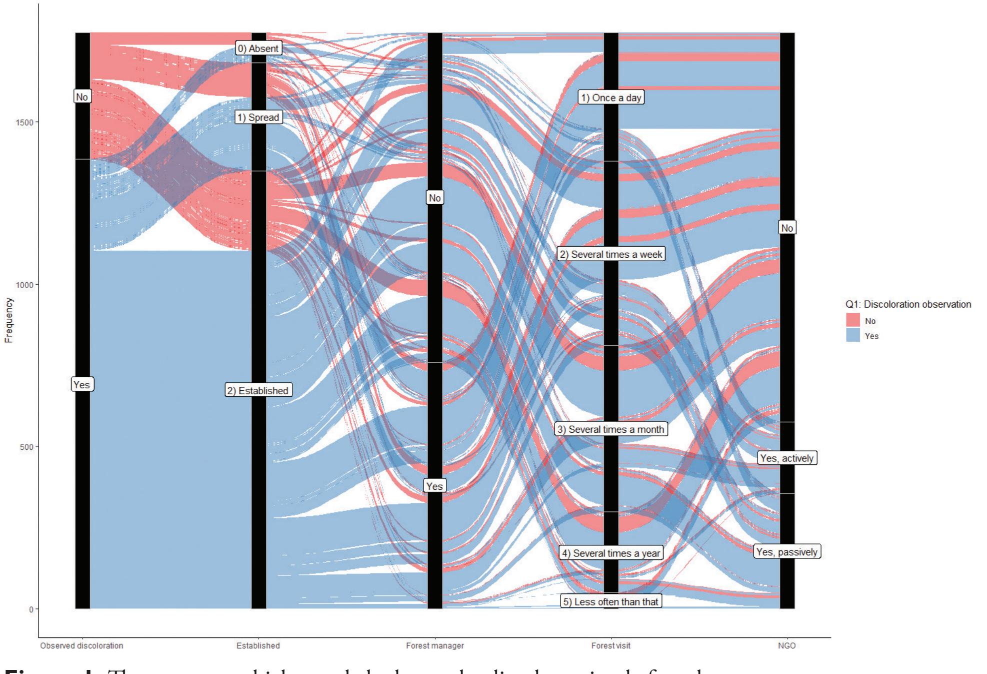

Figure 1. The extent to which people had seen the discolouration before the survey.

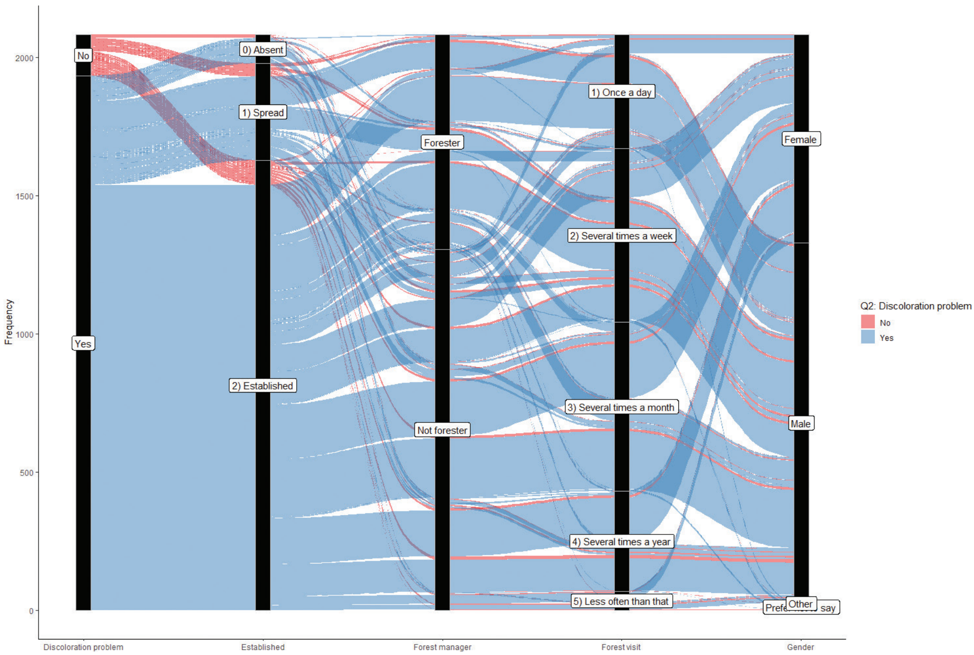

Figure 2. The extent to which respondents consider discolouration to be a problem.

that they had seen the discolouration before. In addition, the probability that the respondents from countries where OLB had been present for a while (established group) were more likely to have previously seen the discolouration compared to countries without OLB ($z = 2.356$, $P = 0.018$).

Almost all respondents (93%) consider this discolouration to be a problem, with frequent forest visitors and women being more likely to hold this opinion (Fig. 2).

In order to determine to what extent the respondents knew the cause of the discolouration, we listed several potential causal biotic and abiotic factors and offered them the possibility of a single answer. Only 5% of respondents perceived the colour of leaves normal given the season. Of the 95% of the respondents who recognised discolouration (i.e. abnormal leaf colour), 41% assumed it was caused by an insect, 36% by a pathogen, 14% attributed it to drought and 4% gave open answers (many respondents associated discolouration with pollution or climate change).

After we presented them with a picture with OLB, indicating that it had caused the discolouration, we asked if they had seen this insect before – half of the respondents declared having seen the insect before (Fig. 3). Forest managers ($z = 7.422$, $P = 1.15e\text{-}13$), frequent forest visitors (once a day: $z = 2.824$, $P = 0.005$; once a week: $z = 2.335$, $P = 0.020$), younger people (18–25 years) compared to mature and older respondents (46–55 years: $z = -4.035$, $P = 5.46e\text{-}0$; 56–65 years: $z = -4.327$, $P = 1.51e\text{-}05$; more than 65 years: $z = -5.988$, $P = 2.12e\text{-}09$) or those from countries where OLB had been present for a while (established group countries)

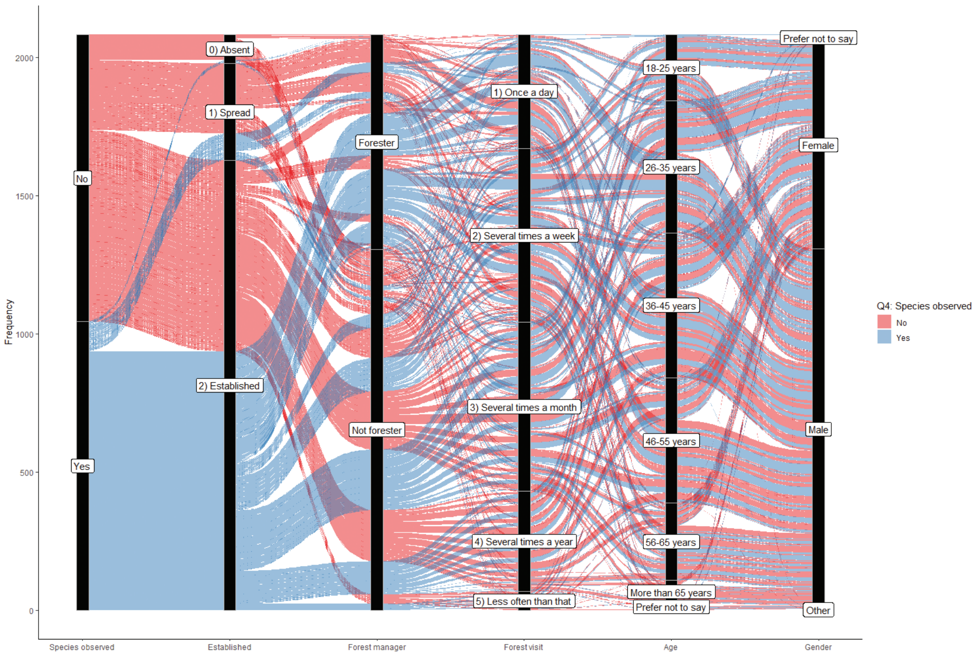

Figure 3. The extent to which people had seen the insect that causes leaf discolouration before the survey.

(established group: z = 4.682, P = 2.84e-06) were more likely to have seen the insect before (Fig. 3).

Respondents were further asked if they knew the name of the insect species they had seen or the one causing the leaf discolouration and offered them several responses. Most of the respondents correctly identified *Corythucha arcuata* (50%) or acknowledged their inability to recognise the species (42%). The rest of the respondents offered predefined answers, such as *Corythucha ciliata*, *Cameraria ohridella* Deschka & Dimić, 1986 or one of the native insect species.

We then informed our respondents that the correct answer was *Corythucha arcuata* (OLB) and asked them if they had ever heard of this species before. Half of respondents (51%) replied "yes" to this question (Fig. 4). More than three-quarters (77%) of those who said they had heard of this species before recognised the species in the previous question. Being a forest manager (Fig. 6B) (z = 9.305, P = < 2e-16), not a forest owner (z = -2.125, P = 0.034) or connected to an environmental NGO (passively: z = 2.087, P = 0.037; actively: z = 4.149, P = 3.33e-05) increased the likelihood that they had heard about *Corythucha arcuata* before the survey. Additionally, young respondents (18–25 years), compared to mature and older respondents (46–55 years: z = -2.556 P = 0.011; 56–65 years: z = -1.934, P = 0.053; more than 65 years: z = -2.696, P = 0.007), more frequent forest visitors (once a day: z = 4.368, P = 1.25e-05; once a week: z = 3.109, P = 0.002; once a month: z = 2.199, P = 0.028) and respondents who came from countries where OLB had already been reported (established group compared to absent group: z = 3.900, P = 9.61e-05) were also more likely to have heard about the species (Fig. 4).

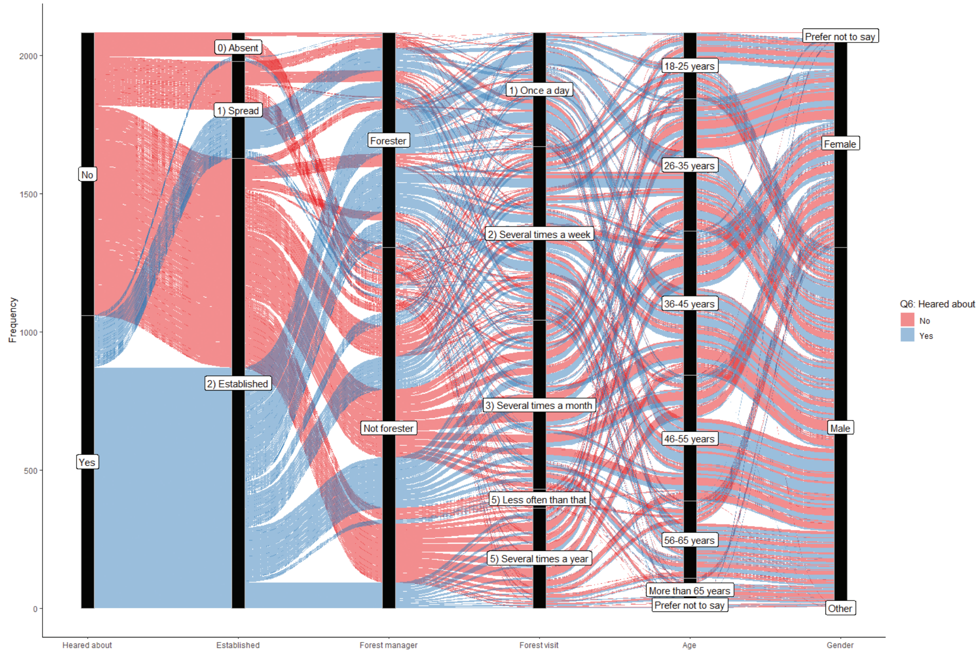

Figure 4. The extent to which respondents had heard about *Corythucha arcuata* after the species` name was mentioned in the questionnaire.

2. Perception of respondents about OLB effects on affected trees

Parameter estimates suggest that forest managers are of the opinion that even if OLB affects photosynthesis of the trees, it cannot cause their death in time, but it affects the aesthetics of the trees. None of the respondents considers that the insect has no effects on the trees. Forest owners (z = 2.489, P = 0.013) and younger people (older than 65 years: z = -2.580, P = 0.010) thought it affects the aesthetics of the trees. The likelihood that respondents are of opinion that OLB causes the die-off of infested trees in time was higher in countries where OLB already occurred (recent occurrence: z = 2.583, P = 0.010; established: z = 4.349, P = 1.37e-05) and higher amongst non-foresters (z = -4.675, P = 2.94e-06).

People who were not foresters (z = -2.065, P = 0.039), those who visit forests very rarely (once a day: z = -2.627, P = 0.009, once a week: z = -1.947, P = 0.052, once a month: z = -2.546, P = 0.011, once a year: z = -2.472, P = 0.013) and those who come from the countries where OLB had not yet been reported prior to the survey or only was established recently (spread group: z = -0.680, P = 0.496; established group: z = -3.020, P = 0.002), did not know what effects OLB might have on affected trees.

Respondents who are actively participating in an environmental NGO (z = 2.409, P = 0.016) and men (z = 2.517, P = 0.012) felt the need to add other effects besides the predefined list. They answered mainly in the same direction, highlighting that OLB was likely to affect oak growth, decrease the acorn crop or weaken the resistance system of trees to other factors.

3. Perception of respondents to the effects of OLB on society

Parameter estimates suggest that women (compared to men: z = -2.700, P = 0.007) or active members of an environmental NGO (z = 2.317, P = 0.02049) are more likely to be of the opinion that one of the impacts of OLB would be to decrease the value of wood, while forest managers are more likely to be of the opinion that OLB does not affect property value (z = -2.689, P = 0.007158). In addition, older people (z = 2.379, P = 0.0174) or people from established group countries, where OLB has been established longer (z = 2.297, P = 0.0216), are of the opinion that one of the effects would be that people will avoid entering the forest. Women (compared to men: z = -4.405, P = 1.06e-05) or young people (compared to mature people between 46 and 55: z = -2.679, P = 0.00739; between 56 and 65: z = -3.203, P = 0.00136), are more likely to consider that an important effect on society caused by OLB is the discomfort caused by the insect's stings/bites on the human skin.

It was statistically significant that respondents from countries where OLB has not arrived or recently arrived (absent and spread group), in comparison to where OLB has been longer established, oppose the idea that it does not have any effect on society (z = -3.843, P = 0.000122). People who are less than once per year in the forest did not know whether this affects society compared to people who are relatively frequent visitors in the forest (once a month: z = -2.441, P = 0.0147). The same is observed for people living in areas without OLB (absent group) compared to areas where OLB has been established for a while (z = -3.992, P = 6.55e-05). In addition, respondents from countries where OLB occurs (spread group: z = -2.029, P = 0.04251, established groups: z = -2.344, P = 0.01907), forest managers (z = 2.359, P = 0.01832), people who are actively participating in an environmental NGO (z = 2.331, P = 0.01974) and people in the age class between 36 and 65 years (compared to people older than 65: 36–45 years: z = 2.804, P = 0.00505, 46–55 years: z = 2.437, P = 0.01482; 56–65 years: z = 2.889, P = 0.00386) completed the questionnaire citing other effects that were not in the predefined list of answers. Most answers were similar and were generally focused on similar themes as potential negative impacts, such as economic costs for the owner, increasing CO_2, ecological imbalance and loss of social function of forests.

4. Attitude of respondents towards control methods of OLB

When asking respondents how strongly they would support removal of OLB to a certain extent, their attitudes towards certain measures differed. The respondents were more likely to support partial removal for the purpose of preventing further spread (Fig. 5) than complete removal for the purpose of total eradication (Fig. 6). Almost three quarters (72%) supported partial removal to varying degrees (mostly support/fully

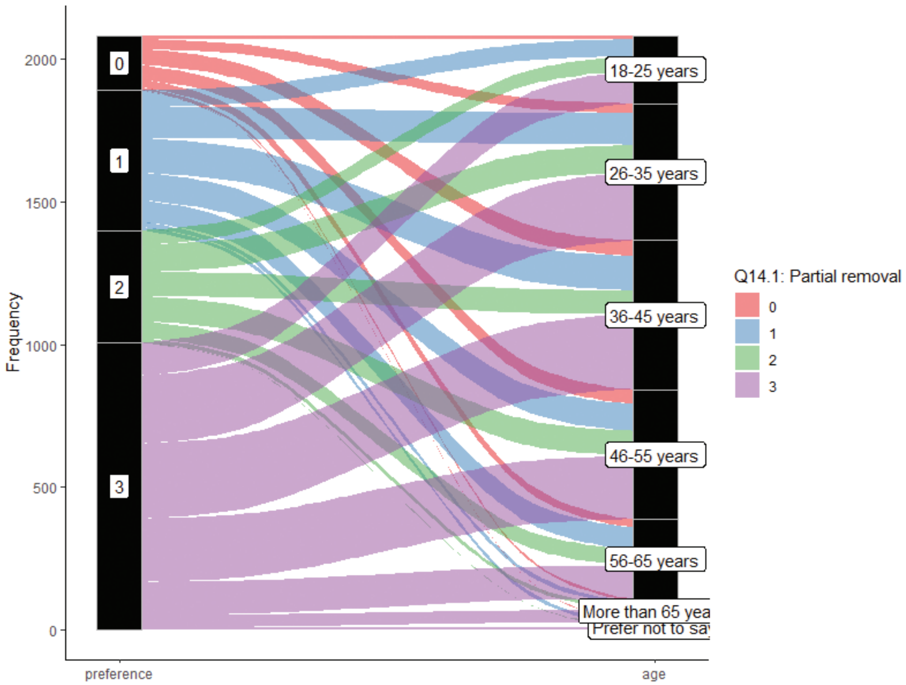

Figure 5. Attitudes of respondents towards the partial removal of oak lace bug (OLB). 0 = I do not support; 1 = I partially support; 2 = I mostly support; 3 = I fully support.

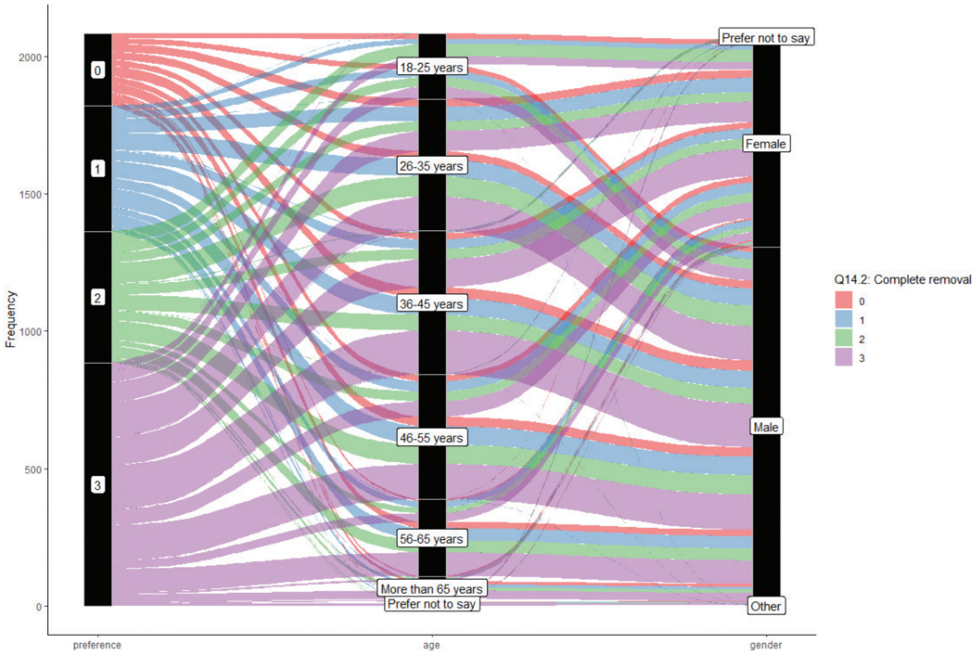

Figure 6. Attitudes of respondents towards the complete removal of OLB. 0 = I do not support; 1 = I partially support; 2 = I mostly support; 3 = I fully support.

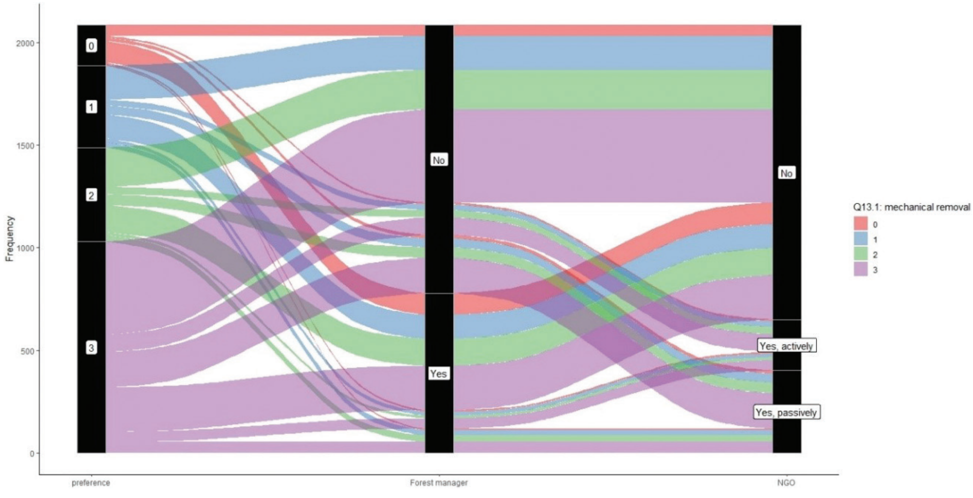

Figure 7. The influences of socio-demographic characteristics (foresters/other, environmental NGO/other) on support for mechanical control measures. 0 = I do not support; 1 = I partially support; 2 = I mostly support; 3 = I fully support.

support), while two thirds (64%) supported complete removal to a greater or lesser degree (mostly support/fully support). At the same time, 13% of respondents did not support complete removal and partial removal was not supported by 9% of respondents.

Regarding the significant influence of socio-demographic characteristics, the results were more complicated. It appeared that, with increasing age (although not significantly), respondents were more likely not to support the removal of OLB. Men (compared the women: z = 2.750, P = 0.005956) or those who were between 36 and 45 years old (compare to people older than 65 years: z = 3.853, P = 0.000117) were more likely to support complete removal.

When asked how strongly they would support various removal measures, it was obvious that respondents preferred biological or mechanical control measures (69% mostly and fully support), over chemical ones with only 9% of the respondents who did not support mechanical removal. The degree of support for chemical control measures was more balanced, with 48% supporting them (full support: 9%, partial support: 39%), whereas 39% did not support chemical control measures. Biological control received more approbation, with 77% of the respondents supporting this approach to a large extent (from mostly to fully support), while only 4% of the respondents did not support this. Given that chemical control measures were unsupported, if we compare it to the other two approaches, data analysis showed that it was statistically significant and that foresters were more likely not to support mechanical control measures (z = -4.549, P = 5.4e-06), while passive NGO members strongly supported it (z = 2.232, P = 0.0256) (Fig. 7).

When asked what measures they would take if the species appeared on their private property (e.g. garden), a vast majority of respondents (81%) would support complete removal. Furthermore, 17% would support partial removal, while only 2% would not

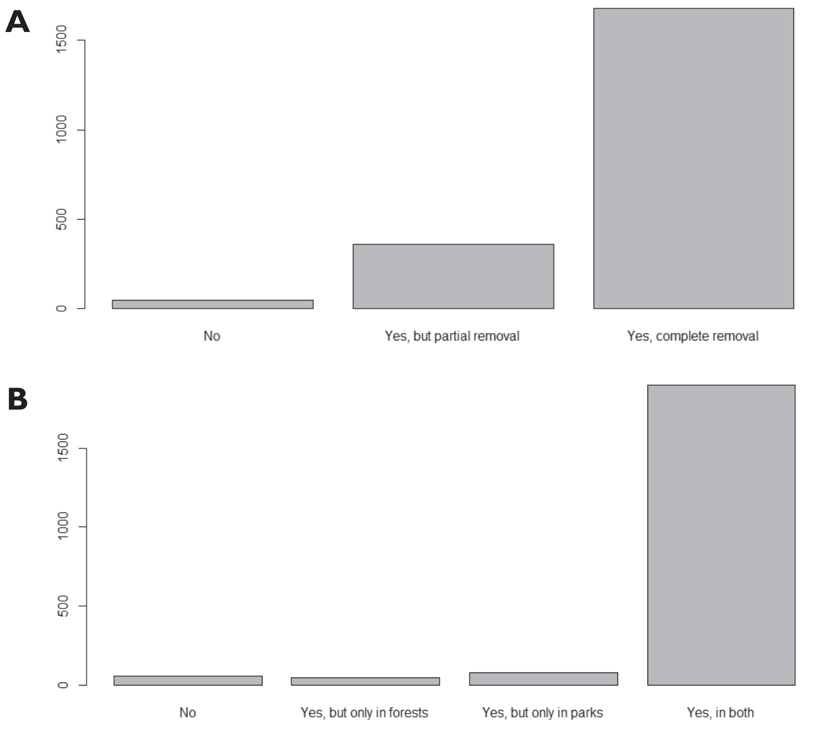

Figure 8. A the extent to which respondents would be willing to remove OLB if it appeared on their private property **B** the extent to which respondents supported the removal of OLB from forests or parks.

support removal of OLB at all (Fig. 8A). When asked what specific method of OLB removal they would use, 49% of respondents would choose a biological method, 31% would choose a mechanical method and only 18% a chemical method.

The removal of OLB as a principal control approach was supported by a large majority of respondents, of these 2% supported insect removal only in forests and 4% in parks, while 91% of them in both settings. Only 2% of respondents did not support removal of OLB if it caused damage (Fig. 8B).

Discussion

The results from the study were encouraging in that the foresters and NGOs were most likely to say that they had seen this discolouration before undertaking the survey, leading us to conclude that they had the basic professional training to distinguish a forest affected by diseases or pests. Furthermore, the fact that 93% of respondents considered this discolouration to be a problem, suggests that there is general public interest and awareness in the health of European oak forests.

The observation that half of the respondents who answered had seen this insect before undertaking the survey, despite its small size and relatively recent introduction into Europe, may be due, on the one hand, to the large numbers of foresters and frequent forest visitors who participated in the questionnaire. However, in part, it is also likely due to the media interest that, in the last few years, has intensely covered the invasions in several cities in Europe where OLB is already established and damage is more visible, such as in Belgrade, Bucharest, Budapest and Zagreb. In addition, the estimation parameters in this study tended to confirm the hypothesis of a previous case study (Japelj et al. 2019) that argued that women or more frequent visitors to the forest, were more likely to correctly recognise an IAS that was not easily visible.

Regarding the occurrence of OLB in the different countries, it was understandable that it is almost impossible to have seen or heard of this insect species before for residents of a country where OLB has only recently been reported or, moreover, if it has not yet been reported. Consequently, these people seem to underestimate the potential consequences of the species. Therefore, programmes to raise public awareness of various invasive species, such as OLB, should be part of a comprehensive future IAS early detection programme.

Although respondents declared having some concern about photosynthesis, forest managers did not consider OLB as a threat to trees and forest health. These results mirror current knowledge on OLB ecology, with severe attacks reducing tree photosynthesis by up to 60% (Nikolić et al. 2019), but given that the radial growth of *Quercus* species mostly occurs in the first part of the vegetation season before OLB symptoms are visible (Szőnyi 1962; Járó and Tátraaljai 1985; Hirka 1991), impacts on tree growth have not been demonstrated so far. However, there is an assumption that the cumulative effect of repeated damage over many years will likely have a significant impact over time (Paulin et al. 2020).

Even though those respondents who were foresters and those associated with environment NGOs were of the opinion that OLB could decrease the value of the wood, it is difficult to quantify how much the value of timber might be influenced by the insects repeated attack until it is established exactly what impact OLB has on radial growth following years of damage.

In terms of property value, private forest owners in our survey were of the opinion that their property would be affected and that, at the same time, people would also avoid entering the forest. To the best of our knowledge, we are not aware of studies exploring the connection between property value and trees infested by OLB. However, another study showed that the invasive species, coqui frog (*Eleutherodactylus coqui*), after it was accidentally introduced into Hawaii, resulted in decreases of up to 64% in property value (Meyerson and Mooney 2007).

The discomfort/annoyance caused by the insect's stings/bites on the human skin is perceived especially by the people who happened to be stung and will become more frequent as people visit infested oak forests and especially those who visit parks in cities where OLB is already present (Paulin et al. 2020). This perception was all the more expected as Europeans have experienced skin inflammation caused by the stings of a similar insect, the sycamore lace bug (*Corythucha ciliata*), in the past (Dutto and Bertero 2013; Izri et al. 2015). In this study, women were more likely to consider that these stings may be one of the negative effects of OLB on society. Similarly, research conducted in Scotland concluded that women were more likely to be prone to a bad reaction to insect bites (Logan et al. 2010). It is not evident why the parameter estimates suggest that foresters "don't think it has effects", although it could simply be because they consider that OLB has no other effects other than those mentioned by us in the questionnaire.

Our results on the level of support for the removal of OLB complement another study (Japelj et al. 2019) which concluded that respondents were more likely to choose less radical measures for management of invasive plants and animals. In our research, the results showed that this conclusion also applies to invasive insects, more specifically OLB, since our respondents were more likely to choose partial removal of OLB and not its complete eradication. In any case, given the current pattern of invasion across the European oak forests for this species (Mutun et al. 2009; Csepelényi et al. 2017; Simov et al. 2018; Tomescu et al. 2018; Csóka et al. 2019; Paulin et al. 2020), the complete removal would now be impossible. In addition, in this study, women were more reluctant to support complete removal of OLB, which is in line with other studies (Fuller et al. 2016; Japelj et al. 2019). Furthermore, our research showed that the age of respondents also makes a difference. Partial removal was more supported by younger respondents, while complete removal was more supported by older respondents.

The respondents in the survey clearly rejected chemical control measures. This result was in line with both Jetter and Paine (2004) who argue that urban populations prefer to control harmful insects by mechanical or biological methods rather than chemical ones and Japelj et al. (2019) who argue that mechanical and biological control measures are the public's most preferred options for invasive species management. In these two previous studies, respondents chose the mechanical removal method in the first instance and the biological approaches a second option, whilst in our research, respondents preferred biological measures over mechanical ones. In addition to the two previous studies, our research also found women more supportive of biological control measures. Regarding mechanical control measures, there was a difference between foresters and environmental NGOs with the latter stakeholder group finding these measures more acceptable.

Nevertheless, studies to date have shown that mechanical measures are recommended more for early detection, surveying and monitoring and tend not to be used for widespread control programmes. Interestingly, recent management knowledge regarding chemical measures to control OLB seems to suggest that they are also only effective to a certain extent (Bălăcenoiu et al. 2021). For other management approaches, it is not known whether they are likely to work and, to date, no biological agents have been identified that may be influential in reducing OLB populations. Hence, further research into control options is urgently needed, but it is good to know that there is a broad public consent when measures are subsequently developed.

Biological control has strong potential, because the public sees this as a sustainable solution. However, caution should be taken, especially as it can have unwanted side effects as has been seen with *Harmonia axyridis* that was introduced into Europe in 1964 as a biological control agent of aphids on fruit trees (Katsoyannos et al. 1997) or other exotic biological control agents (Van Lenteren et al. 2006). When the assessment of the biocontrol agent is not done properly, the public will be against this option and, more importantly, the released species can become a harmful invasive species itself.

Our results show that our respondents (98%) would support removing OLB if it appeared on their private property, either partially or totally and the results are in line with the study of Japelj et al. (2019) in which 96% of respondents would agree with the elimination of any invasive species if it appeared on their private property. Furthermore, when respondents were asked if they would support removal of OLB from forests or parks if it causes damage, over nine-tenths supported its removal both in parks and in forests.

The strength of our survey was that it was evaluating responses from numerous countries along the invasion gradient. Most comparable studies only cover a smaller geographical area and, therefore, only focus on management of one part of the biological invasion gradient. Taking the whole gradient into account, as done in this current study, enables researchers to see differences in attitudes towards the species in different stages on the invasion of OLB. Of course, cultural and social differences might also play an important factor and it is, therefore, important to focus on these changes in attitudes and use them in communication messages. Our results indicated that there were differences between the different country groups for OLB and, hence, it is important to take this into account for other IAS in the future.

This research is the first pan-European survey which studies the perception of the population on a gradient of invasion caused by OLB. Our study has certain limitations. The study is exploratory, voicing perception, knowledge and attitudes of our respondents and the results cannot be generalised on the entire targeted stakeholder groups in respective countries. However, our results are indicative and, despite not being representative, are still in line with similar studies. Hence, we consider this study to be a good basis for further research on the topic of perception, knowledge and attitudes related to OLB since we can expect that this IAS will certainly spread to other European countries that were not included in this survey.

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Supplementary material 1

Annex 1. The questionnaire

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Data type: Survey

Explanation note: The questionnaire used to collect the survey data.

Link: https://doi.org/10.3897/neobiota.69.71851.suppl1

Supplementary material 2

Appendix 2

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Data type: docx. file

Explanation note: Independent variables descriptions.

Link: https://doi.org/10.3897/neobiota.69.71851.suppl2