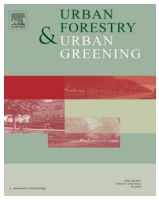
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# Stakeholder exposure to and knowledge of tree pests and diseases and their management in urban areas

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ABSTRACT

Urban trees and forests provide many benefits to the urban environment and are important for climate change adaptation. Yet, they are increasingly threatened by insect pests and diseases, hereafter tree pests/diseases. There is little evidence of the risk awareness and knowledge of different urban stakeholders of this growing threat, how they are affected by tree pests/diseases, and how they might respond to it. To fill this gap, we undertook an online survey of different key stakeholder groups associated with urban trees and forests in Germany. A majority of 75.8 % of the 186 respondents consider urban tree pests/diseases a severe problem and 51.1 % reported high knowledge of tree pests/diseases. There was a lack of knowledge of certain reportable quarantine pests/diseases (e.g., canker stain of plane, emerald ash borer, Xylella) and pest/disease management options (e.g., manual treatment methods and tree diversification). Respondents were most affected by the horse chestnut leafminer (61.3 %), ash dieback (58.1 %) and oak processionary moth (50.0 %). The most widely used pest remedial measures were improvements of tree living conditions (60.8 %) and purchases of plants from certified or trusted local sources (59.7 %). Multiple correspondence analysis showed a significant association between levels of knowledge of tree pests/diseases and pest management responses (11.7 %). Our results suggest that future efforts to improve urban tree health should be enhanced and tailored to the different requirements of various stakeholder groups. The findings of this first comprehensive study with a purely urban focus will inform the development of future activities that prevent or reduce the spread of tree pests/diseases in urban areas.
*Data Availability:* The survey respondents did not give permission for the full data to be accessed or used by third parties.

## 1. Introduction

Healthy and resilient urban tree populations and forests provide many benefits for society (Tyrväinen et al., 2005) and contribute to climate change adaptation (Wang et al., 2023). However, tree insect and disease infestations (hereafter tree pests/diseases) are on the rise in many urban areas worldwide, affecting trees' and forests' ability to contribute to the urban environment and human well-being (Raum et al., 2023). Growing global trade (Liebhold et al., 2012), climatic changes (Ramsfield et al., 2016), poor growing conditions (Mullaney et al., 2015), and a lack of tree diversity (Kendal et al., 2014) lead to increasing susceptibility of urban trees and forests to both native and non-native tree pests/diseases (Potter and Urquhart, 2017). Some outbreaks have attracted considerable media attention. This includes the accidentally introduced Asian longhorn beetle (*Anoplophora glabripennis)* in New York in the 1990s (Haack et al., 1997) and in Munich in the 2010s (Münchner Wochen Anzeiger, 2012; 2016), the invasive oak processionary moth (*Thaumetopoea processionea*) in London in the 2010s (Mathiesen, 2014) and, more recently, the canker stain disease caused by the fungal pathogen *Ceratocystis platani* in Istanbul (Lehtijärvi et al., 2018). Media attention often focuses on the potential impacts of the outbreaks, especially on tree mortality and pest management actions,

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such as sanitation felling of diseased or pre-emptive felling of potential host trees (Marzano et al., 2015). Non-native tree pests/diseases tend to be introduced unintentionally, often via plants and/or their substrates, without the knowledge of those transporting or planting these (Marzano et al., 2015). Yet, we lack research on tree pests/diseases, risk awareness and knowledge of pests/diseases and their management with a focus on urban areas.

Awareness raising among stakeholders could reduce unintentional introduction and spread, increase preparedness for such outbreaks (Marzano et al., 2016), and increase the overall effectiveness of pest management responses (Brasier, 2008; Stenlid et al., 2011). Improved risk awareness among key stakeholders, such as tree professionals, tree owners, and consumers, can underpin early detection programmes, such as the 'First Detector' (Gupta, 2010) and the 'Observatree' volunteer programmes (Gupta et al., 2022; Slawson and Moffat, 2020) who involve citizens to detect tree pest/disease outbreaks. A greater understanding of tree pest/disease impacts (Raum et al., 2023) can also increase support or participation in management programmes that involve potentially drastic eradication measures, such as chemical spraying or felling of affected trees or even potential host tree species (Brockerhoff et al., 2010; Quarles, 2008). Moreover, risk awareness and knowledge can lead to changes in cultural practices, such as the movement of firewood, potentially harbouring pests/diseases, within and across counties or states (for instance, during recreational camping trips) (Jacobi et al., 2011; Koch et al., 2014). Most importantly, greater awareness of the growing threat of tree pests/diseases in urban areas can help increase overall tree and forest health. This may involve changing general tree planting and management practices, such as increasing tree diversity or improving trees' growing conditions (Czaja et al., 2020; Sjöman et al., 2012).

Most studies on stakeholder risk awareness and knowledge of tree pests/diseases and their management focus on forests in the countryside. These include research on forest professionals (Hathaway et al., 1981; Hurley et al., 2012; Marzano et al., 2016), forest managers (Marzano et al., 2019), experts (Urquhart et al., 2017a), forest owners (Molnar et al., 2003), communities (Flint, 2007; McFalane et al., 2006), outdoor recreationists and tourists (Hall et al., 2020; Jacobi et al., 2011; Koch et al., 2014; Müller and Job, 2009), and the general public (Chang et al., 2009; Fuller et al., 2016; McFarlane et al., 2006; Sheremet et al., 2017; Urquhart et al., 2017b). Somewhat surprisingly, Marzano et al. (2016), who assessed awareness of tree pests/diseases and pathogens amongst tree/forest professionals in Europe, found that risk awareness is relatively modest even among this vital stakeholder group. Tree/forest professionals often represent the first line of defence, as they occupy critical positions along pest introductory pathways and plant supply chains. Their actions, such as buying plants, surveillance, inspections, tree planting, and management, are therefore vital to biosecurity (Marzano et al., 2016) and the future health of trees and forests. On the other hand, Green et al. (2023) surveyed a range of forest stakeholders on their perspectives on tree pests/diseases and the use of pest detection, identification and management tools in Europe. The most used approaches were the disposal of infested trees, physical controls, onsite biosecurity measures, and biological controls.

The few studies on risk awareness and knowledge of tree pests/diseases and their management with a focus on urban areas mainly assess single tree pest species or single stakeholder groups. Marzano et al. (2020a), for instance, examined the awareness, risk perceptions, and decision-making around oak processionary moths (*T. processionea*) (OPM) of land managers in Greater London, England. Although land managers were concerned about their duty of care, they managed OPM only in places where the caterpillars posed the highest potential risk to human health; exposure to its hair can cause severe skin rashes. Harper et al. (2017), exploring the emerging challenges faced by urban tree wardens throughout the US state of Massachusetts, found that urban tree health arose as a topic of great importance for this particular professional group. Nearly all interviewees reported monitoring for urban tree pests/diseases and a need for further training on this subject. An earlier study by Hathaway et al. (2002) assessed the risk awareness and knowledge levels of the Asian Longhorn beetle (*A. glabripennis*) amongst professional tree carers in the US city of Chicago. Only 35 per cent of those surveyed, including those who reported having 'high experience' dealing with pest infestations, felt 'informed' about the Asian Longhorn beetle.

Other authors assessed the attitudes of visitors and residents to pest management responses. Gutsch et al. (2019), for instance, examined how visitors to an urban forest in the German city of Berlin perceived pest management responses. The authors found an apparent predisposition against pesticide or biocide interventions while, at the same time, showing positive inclinations towards mechanical interventions. Similarly, Porth et al. (2015), who explored the attitudes of residents affected by an Asian longhorn beetle outbreak and eradication programme in Kent, England, discovered that residents within the management zone were generally supportive of the associated extensive felling of (potential) host trees, despite being significantly impacted by it (Porth et al., 2015). Marzano et al. (2020b) assessed the social acceptability of management responses to the emerald ash borer in the Twin US Cities of Minneapolis and St. Paul. Several studies looked at the attitudes of residents towards urban trees in general (e.g., Flannigan, 2005; Heimlich et al., 2008; Hitchmough and Bonguli, 1997) and at problems associated with urban trees in particular, such as falling branches, leaf litter, tree debris and infrastructure damage (e.g., Mullaney et al. 2015; Roy et al., 2012; Roman et al., 2021). Several of these problems can also be associated with tree pests/diseases (Raum et al., 2023). The pathogen *Inonotus rickii*, for instance, may decrease the density and strength of branches (Annesi et al., 2015), leading to breakages, and the horse chestnut leafminer *Cameraria ohridella* frequently causes early defoliation (Dzięgielewska et al., 2017).

Even though a lack of risk awareness and knowledge of forest pests/diseases among key stakeholder groups has been repeatedly identified as a driver of biological invasions (Stenlid et al., 2011; Dehen-Schmutz et al., 2010; Webber, 2010), it has received surprisingly little attention in the context of urban trees and forests. We also lack information on how urban tree/forest owners are affected by tree pests/diseases, even though in many cities, over half of the urban tree population can be on non-public/privately owned land (Klobucar et al., 2020). Similar paucity exists on how estate managers, caretakers, and tenants might prepare for or respond to evolving outbreaks of urban tree pests/diseases. No studies were found that have investigated the levels of knowledge of and pest management responses taken by city green space officers, horticulturists, urban planners and landscape architects, public decision-makers, and hobby gardeners. However, understanding the perspectives of these key stakeholders is crucial for effectively addressing the growing threat of tree pests/diseases. This study surveys key stakeholder groups dealing with urban trees in Germany to fill these knowledge gaps. As one of the largest member states of the European single market, Germany provides an important regulatory and trade context for plant health (Britannica, 2023). Our study aims to better understand the level of concern about urban tree pests/diseases of different stakeholder groups and their level of knowledge of, exposure to, and actions towards tree pests/diseases.

Specific questions are:

(1) What is the level of concern and knowledge of urban tree pests/diseases, and how does this vary by stakeholder group?
(2) Which tree pests/diseases and remedial measures are stakeholders most familiar with?
(3) How are stakeholders affected by urban tree pests/diseases, and by which species?
(4) How do stakeholders respond to and manage urban tree pests/diseases?
(5) How are different stakeholder groups informed about tree pests/diseases?

Based on the findings of the above literature, our assumption is that risk awareness and knowledge of urban tree pests/diseases may be relatively low amongst key stakeholder groups. In the following sections, we report on our survey and analysis approach, followed by the results of our analysis. We then discuss our findings in the context of the broader literature, focusing on the importance and challenges of raising risk awareness and knowledge amongst such a wide range of stakeholders. Specific suggestions are then made to improve awareness and specific knowledge.

## 2. Methods

### 2.1. Study site

The study was conducted in the central European country of Germany. Germany is highly urbanised, covers an area of 357,022 square kilometres, and has a population of over 84.4 million (Destatis, 2022). Seventy-five per cent of its population lives in cities, two-thirds of these in small- and medium-sized cities (BPB, 2021). Most of the country has a temperate climate, ranging from oceanic in the north to continental in the southeast and east (Britannica, 2023). Germany is a democratic republic of sixteen constituent states divided into a total of 401 districts (Fazit, 2023). Responsibility for urban green infrastructure in public spaces lies mainly at the district and city levels, each with differing competencies, responsibilities, and organisational structures (Mell et al., 2017). These also vary between states and even between different districts within the same state. Although there is a lack of comprehensive information explaining who is in charge of what, in most cities, trees on public land are controlled by public green space departments, forest departments, highway agencies, or railway agencies. In many places, however, a large share of urban trees is on privately owned land, with private landowners responsible for managing and controlling their trees (Klobucar et al., 2020; Pauleit et al., 2005).

Under the German general duty to ensure public safety (Verkehrssicherungspflicht), anyone who owns or manages land with public traffic on it has the legal duty to take the necessary precautions to protect third parties, i.e. to ensure the safe condition of that land, including tree condition (FLL, 2006). Owners or managers, however, are only liable for damage caused by falling branches or trees if they neglect to regularly inspect their trees visually. In terms of (urban) tree pests/diseases, those considered (or suspected) quarantine pests/diseases under the EU regulation 2019/2072 (EU, 2019) must be reported by law by anybody discovering them to the relevant public authorities in the German state where the pest/disease is detected. The European and Mediterranean Plant Protection Organization (EPPO) produces lists of pests/diseases regulated as quarantine pests/diseases. These lists and the public agency such pests/diseases have to be reported to can be found on the homepage of the German Government's plant research institute, the Julius Kühn Institute (JKI, 2021). If a quarantine pest/disease is confirmed, the relevant public authority must undertake every effort to eradicate the pest/disease, including on private land (JKI, 2021). In the latter case, the authority may take complete control, give direction, or supervise this process (JKI, 2021).

### 2.2. Survey methods and questionnaire design

We implemented an online survey between February and June 2023. An online survey method can potentially reach a large number of people in different locations relatively easily (Fielding et al., 2017). However, it is limited in reaching those with little access to digital communication (Ramsetty and Adams, 2020). The survey was targeted to reach key stakeholder groups in the context of urban trees and forests identified in the literature (e.g., Green et al., 2023; Marzano et al., 2015; 2020b; Hathaway et al., 2002; Harper et al., 2017), including professionals: i) arborists/tree carers, ii) landscape planners/architects, iii) foresters/forest workers, iv) tree nurseries/traders, v) city authority greenspace staff/horticulturists, vi) public decision-makers (mayor, assembly member), and vii) housing and estate managers/caretakers (single responses only). We also attempted to capture the following more general non-professional lay people groups: i) property/land owners, ii) tenants/leaseholders, iii) recreationists, iv) hobby gardeners, and v) members of conservation organisations (here, respondents could tick multiple responses). These categories, however, should not be seen as homogenous entities, and we expect considerable differences even within groups.

The survey was set up in SoSci Survey (version 3.1.06) (Leiner, 2019), a professional online survey software. We used a targeted snowball sampling approach to distribute information on the survey via key networks (Savin-Baden and Major, 2023). An invitation with background information and the survey link was sent out to at least one national umbrella organisation of each identified target stakeholder group with a request for promotion amongst their members (Appendix 2). Six organisations agreed to promote the survey through digital channels (newsletters, homepages) and in-person activities (a specialist committee meeting). These organisations represent five of the above seven professional groups and one of the above five general non-professional groups; umbrella organisations representing the two professional groups of estate managers/caretakers and tree traders/nurseries did not respond positively to our request to promote the survey (Appendix 2), leading to a low representation of these two groups. Still, there was a strong representation of the four general non-professional groups whose networks did not respond (Table 1). Potentially, a total of approximately 5–10.000 readers, i.e. potential survey respondents across the six networks, have been reached.

Following a review of the literature on other surveys on tree pests/diseases (especially Green et al., 2023; Urquhart et al., 2017b; Marzano et al., 2016), a questionnaire was developed with the support of several experts and practitioners. It consisted of 19 multiple choice, Likert-scale, closed-ended and open-ended questions (Q) which were divided into four sections: 1) General activities around urban trees and forests (Q 1–3); 2) Respondents' risk awareness and knowledge, including of a range of tree pests/diseases and introduction pathways, their exposure to these pests/diseases, and the sources of pest related information used (Q 4–8); 3) Respondents' knowledge and use of management responses, including what they would do when discovering tree pests/diseases and to whom they would report (potential) quarantine pests/diseases to (Q 9–13); and 4) Demographic variables (including stakeholder group categories, location, gender, age, and level of education) (Q 14–19). Responses to the last six questions were used to examine the degree to which socio-demographic characteristics influenced the knowledge of tree pests/diseases and specific management responses (the questionnaire can be found in Appendix 1). A pre-test of the survey was conducted in January 2023 with six unaffiliated respondents who deal with urban trees and forests in Germany.

Informed consent was obtained from all respondents. Responses were stored and processed, following EU REGULATION (EU, 2016/679) and German Data Protection Regulation (BDSG, 2018). No personal data was collected. The survey was approved through the University's ethical approval review process (2022–659-S-NP). The final dataset consisted of 196 completed surveys. Four respondents were from other countries, and another six had not given consent to make use of and further process the submitted data for this study and, as a consequence, were removed from the dataset, leaving a total of 186 responses for the analysis.

### 2.3. Data analysis

Descriptive statistics, a qualitative analysis of open questions, and quantitative statistics, including Kruskal-Wallis tests, and post-hoc and multiple correspondence analyses (MCA) (Creswell and Creswell, 2022; Le Roux and Rouanet, 2010) were employed to analyse the survey data, using SPSS 29, Excel 2019, and R Studio Software (version 2023.06.1+524).

**Table 1**
Descriptive statistics of the respondents' sample profile and demographic characteristics.

| Variable | Frequency/ no of respondents | Percentage [%] | Variable | Frequency/ no of respondents | Percentage (%) |
|---|---|---|---|---|---|
| **Professional groups** | | | **Frequency of time spent near urban trees** | | |
| City greenspace | 56 | 30.1 | Daily | 96 | 51.6 |
| staff/horticulturist | 31 | 16.7 | Several times per week | 60 | 32.3 |
| Tree care professional, | 25 | 13.4 | Several times per month | 17 | 9.1 |
| arborist | 25 | 13.4 | Several times per year | 8 | 4.3 |
| Forester, forest worker | 3 | 1.6 | Less than once per year | 4 | 2.2 |
| Landscape planner, | 2 | 1.1 | Other | 1 | 0.5 |
| architect | 1 | 0.5 | **Reasons for time spent with urban trees** | | |
| Public decision-maker | 39 | 21.0 | Private | 55 | 29.6 |
| Tree trader, nursery | | | Work | 122 | 65.6 |
| Estate manager, caretaker | | | Other | 7 | 3.8 |
| Other | | | None | 2 | 1.1 |
| **General groups** | | | | | |
| Property/land owner | 97 | 52.2 | | | |
| Tenant, leaseholder | 40 | 21.5 | | | |
| Recreationist | 96 | 51.6 | | | |
| Hobby gardener | 85 | 45.6 | | | |
| Member of nature NGO | 57 | 30.6 | | | |
| **Highest level of education** | | | **No of years of professional experience with urban trees** | | |
| Secondary school | 9 | 4.8 | Less than a year | 6 | 3.2 |
| Vocational qualification | 14 | 7.5 | 1–3 years | 14 | 7.5 |
| High school | 15 | 8.1 | 4–8 years | 36 | 19.4 |
| Professional qualification | 20 | 10.8 | 9–15 years | 32 | 17.2 |
| University degree | 123 | 66.1 | More than 15 years | 82 | 44.1 |
| | | | None | 16 | 8.6 |
| **Age class** | | | **Concern/knowledge of tree pests/diseases** | | |
| 18–24 | 8 | 4.3 | I've never heard of it before | 0 | 0 |
| 25–34 | 21 | 11.3 | I've heard of it but don't know much about it | 5 | 2.7 |
| 35–44 | 58 | 31.2 | I've heard about it and know something | 86 | 46.2 |
| 45–54 | 37 | 19.9 | I know a lot | 95 | 51.1 |
| 55–64 | 54 | 29.0 | | | |
| 65–74 | 3 | 1.6 | | | |
| 75–84 | 1 | 0.5 | | | |
| 85 and above | 0 | 0 | | | |

*Descriptive statistics:* using SPSS 29, numbers and frequencies were used to summarise the qualitative variables, e.g. reported activities around urban tree pests/diseases, degrees of awareness and knowledge on tree pests/diseases and use of preventive and management measures, as well as socio-demographic characteristics (Appendix 3).

*Qualitative analysis:* The open questions (7, 9, and 11), which generated qualitative data in the form of short textual responses, were analysed using content analysis (Babbie, 2020). Keywords and phrases were extracted from these questions, grouped, and synthesised, and the frequency of the resulting groups was then calculated in Excel 2019 (Appendix 3).

*Quantitative statistics:* Multiple correspondence analysis (MCA) was used to explore the relationships among risk awareness and knowledge of urban tree pests/diseases, knowledge and use of different management responses, and the socio-demographic characteristics of the respondents. MCA is suitable for evaluating associations between more than two categorical variables (Le Roux and Rouanet, 2010; Hossu et al., 2019), thus fitting our data set. It is a generalisation of principal component analysis, where the associations between categorical variables are investigated by calculating the chi-square distance. MCA produces plots to graphically display the associations between the categorical variables. MCA was performed in R software using the package FactoMineR (Husson et al., 2011). We included questions 1–4, 6, 7 and 12 as active variables and questions 14, 15, 17–19 as supplementary variables (Le Roux and Rouanet, 2010) (Appendix 4). We interpret a category as a significant contributor to an axis if its contribution exceeds the average contribution (Le Roux and Rouanet, 2010). The supplementary variables, such as belonging to professional groups, gender, age, and level of education, helped us to interpret the associations between levels of risk awareness and knowledge about tree pests/diseases and response measures and the socio-demographic characteristics of the respondents. We considered only the first axis of the MCA since it explained variance the most. The average value of the modified rate of the first axis was 0.521, whereas that of the other axes were 0.248, 0.078 and 0.0571.

A Non-parametric Kruskal-Wallis rank sum test was used to investigate if there are differences between the professional stakeholder groups and variables such as their level of knowledge of tree pests/diseases (Q4), knowledge of management responses, namely where to report pests to (Q11) and their level of concern about urban tree pests/diseases (Q13). We then conducted a post-hoc test, using the Dunn test with the Benjamini-Hochberg method, to see which professional stakeholder groups were statistically different.

## 3. Results

The results are divided into four main sections: (1) sample profile and demographic characteristics, (2) risk awareness and knowledge of urban tree pests/diseases, (3) exposure to urban tree pests/diseases, and (4) responses and management activities to deal with urban tree pests/diseases.

### 3.1. Sample profile and demographic characteristics

The survey received a mixed number of responses from across the targeted stakeholder groups, with three professional groups poorly represented (Table 1). Of the 186 respondents, 65.6 % reported they were professionally dealing with urban trees, 44.1 % of these had more than 15 years of experience with trees, and 30.1 % were city authority greenspace staff/horticulturists. Of the 29.6 % who were spending time with trees for private reasons, 36 respondents were hobby gardeners, 33 recreationists, 23 property owners, 21 nature conservationists, and 14

tenants. The responses of estate managers/caretakers, tree traders/nurseries, and public decision-makers were very low (0.5–1.6 %) despite the latter group's network having promoted the survey.

The geographical distribution was also not entirely equal, with more respondents from the western and southern German states of Nordrhein-Westfalen (16.7 %), Bayern (15.1 %), and Baden Württemberg (14.0 %), with Brandenburg (15.1 %) in the northeast of Germany being the exception. No responses were from the small city state of Bremen. The male/female ratio of respondents was 59.7 % male and 36.0 % female. Respondents further indicated their level of education (Table 1) and the city where they lived and/or operated.

### 3.2. Risk awareness and knowledge of urban tree pests/diseases

Most respondents were interested in tree pests/diseases (82.8 %) and considered tree pests/diseases in urban areas a severe problem (75.8 %). No significant statistical differences were found between professional stakeholder groups in terms of their level of concern for urban tree pests/diseases (p-values $> 0.05$, Kruskal-Wallis rank sum test) (Appendix 4). Of that 22.0 % who agreed to the statement "urban tree pests/diseases are not a serious problem", 22.0 % were tree carers/arborists, 19.5 % were landscape planners/architects, and 19.5 % were city authority greenspace staff/horticulturists; another 19.5 % marked 'other'.

A slight majority of respondents reported that they know a lot about urban tree pests/diseases, and nearly half that they have some knowledge (Table 1). Professional stakeholder groups differed in their knowledge of tree pests/diseases ($p < 0.05$; Kruskal-Wallis rank sum test). However, the post-hoc Dunn test showed no significant differences between the groups of professional stakeholders (Appendix 4). Those who are very knowledgeable are city greenspace staff/horticulturists (33.7 %), tree carers/arborists (18.9 %), and foresters/forest workers (16.8 %). Among those respondents with only some knowledge are also city greenspace staff/horticulturists (27.9 %) and tree carers/arborists (15.1 %), as well as landscape planners/architects (15.1 %).

#### 3.2.1. Knowledge of specific urban tree pests/diseases

Knowledge of tree pests/diseases presently occurring in Germany or neighbouring countries, including potentially destructive quarantine pests/diseases, varied (Table 2). All respondents had heard of all 14 listed tree pests/diseases. The most widely recognised of the listed pests/diseases were the oak processionary moth, followed by the Asian longhorn beetle and the European spruce bark beetle; red-necked longhorn beetles and Xylella were recognised least. An additional 37 names of known tree pests/diseases were provided by 33 respondents (Appendix 3), including *Phythophera* (4), the wood leopard moth (3), and the elm zigzag sawfly (3). A slight majority (54.8 %) believed that the Asian longhorn beetle requires reporting; only 26.9 % listed Xylella and 19.4 % oak processionary moths (Table 2).

#### 3.2.2. Knowledge of tree pest introduction pathways and of responsibilities for pests/diseases

Respondents were asked to identify pathways that could potentially introduce pests/diseases into their state/city. The most frequently reported likely or very likely introduction pathways were timber products (timber, saw wood, wood packaging) (87.1 %), saplings/seeds (80.6 %) and soil or parts of trees (leaves, plant residues, bark) (81.2 %) (Fig. 1).

There was a divergence of views about who has primary responsibility for managing and controlling tree pests/diseases in urban areas, with the majority of respondents identifying (agreeing/fully agreeing) urban municipal green space departments (90.8 %), followed by land/forest owners (87.6 %), governmental environment/forest departments (75.8 %), and foresters/forest workers (65.5 %) (Fig. 1).

### 3.3. Sources of information on tree pests/diseases used

Respondents use multiple sources of information to gain knowledge of tree pests/diseases, the most popular source being work/colleagues (86.6 %), newspapers/journals (74.7 %), study or other educational activities (71.5 %), internet searches (62.4 %), and governmental organisations (56.5 %). City authority greenspace staff/horticulturists, tree carers/arborists, and foresters/forest workers were informed mainly by work/colleagues, newspapers/journals, and study or other educational activities (Fig. 2).

A majority of 66.1 % of the respondents had enough information to know what to do when encountering tree pests/diseases; 24.2 % indicated that they did not have enough information (Fig. 3). The latter included hobby gardeners (22), recreationists (19), landowners (16), city authority greenspace staff/horticulturists (15), tree carers/arborists (8), and landscape planners/architects (7).

**Table 2**
Respondents' awareness of and exposure to 14 tree pests/diseases (valid responses n = 186).

| | I have heard of it/seen it | I have been affected by it | Requires reporting |
|---|---|---|---|
| **Asian longhorn beetle*** *(Anoplophora glabripennis)* | 71,0 % | 4,3 % | **54,8 %** |
| **Canker stain of plane*** *(Ceratocystis platani)* | 52,7 % | 10,8 % | **6,5 %** |
| **Emerald ash borer*** (*Agrilus planipennis)* | 47,3 % | 4,3 % | **17,2 %** |
| **Xylella bacterial disease*** *(Xylella fastidiosa)* | 45,7 % | 11,8 % | **26,9 %** |
| **Red-necked longhorn beetle*** *(Aromia bungii)* | 44,1 % | 1,1 % | **22,6 %** |
| Oak processionary moth *(Thaumetopoea processionea)* | 72,6 % | 50,0 % | 19,4 % |
| European spruce bark beetle *(Ips typographus)* | 68,8 % | 49,5 % | 6,5 % |
| Horse chestnut leafminer (*Cameraria ohridella)* | 63,4 % | 61,3 % | 0,5 % |
| Massaria disease *(Splanchnonema platani)* | 59,1 % | 39,2 % | 4,3 % |
| Sooty-bark disease of maple *(Cryptostroma corticale)* | 57,0 % | 42,5 % | 11,8 % |
| Ash dieback *(Hymenoscyphus fraxineus)* | 55,9 % | 58,1 % | 1,1 % |
| Dutch elm disease *(Ophiostoma (novu-) ulmi)* | 55,9 % | 27,4 % | 1,6 % |
| Bleeding canker of horse chestnut *(Pseudomonas syringae pv. Aesculi)* | 52,7 % | 38,2 % | 2,2 % |
| Horse chestnut scale *(Pulvinaria regalis)* | 46,2 % | 33,3 % | 0 % |

* The five pests/diseases in **bold** required reporting at the time of the online survey

### 3.4. Exposure to urban tree pests/diseases

A majority of 68.3 % of respondents have noticed an infected/infested tree in their neighbourhood, and 62.9 % on trees they owned or managed. 19.4 % indicated they have had to remove or treat a tree on their own property, and 64.5 % on a property for which they were professionally responsible. 45.7 % of the respondents dealt with urban tree pests/diseases for work, and 18.3 % for private reasons. Respondents were most affected by the horse chestnut leafminer, ash dieback, the oak processionary moth, and the European spruce bark beetle (Table 2).

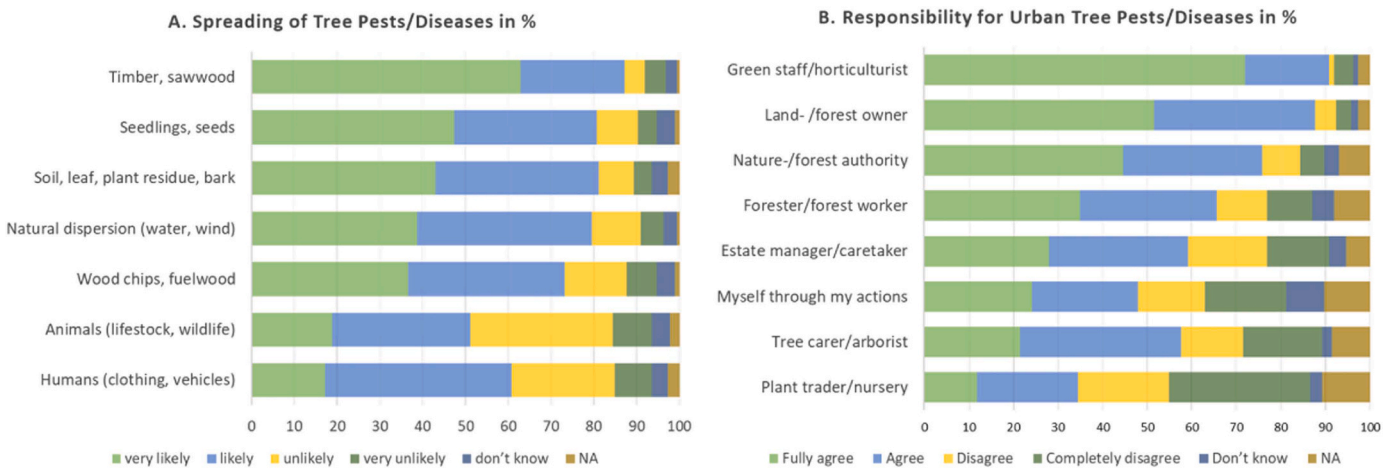



**Fig. 1.** A. Knowledge of introductory pathways of tree pests/diseases (multiple responses, valid responses n = 186). B. Knowledge of Assumed responsibility of urban tree pests/diseases (multiple responses, valid responses n = 186).

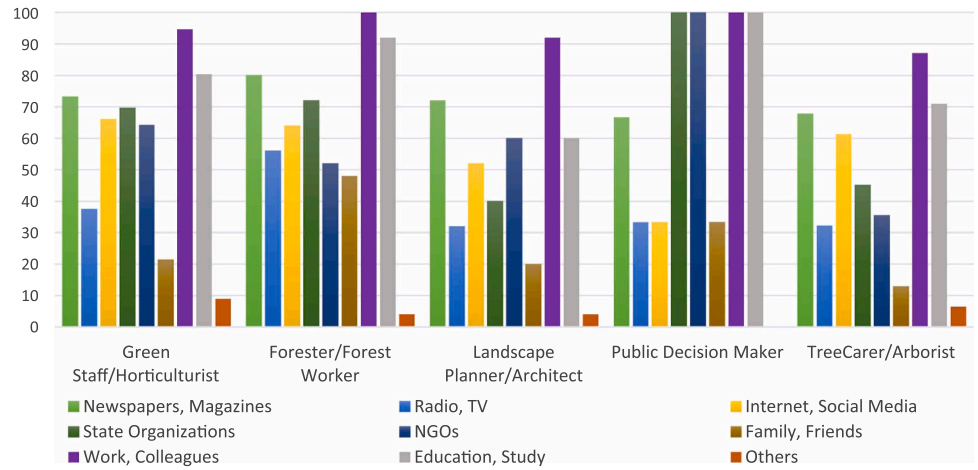



**Fig. 2. :** Sources of information on tree pests/diseases used by the most prevalent professional respondent groups in percentages (multiple responses).

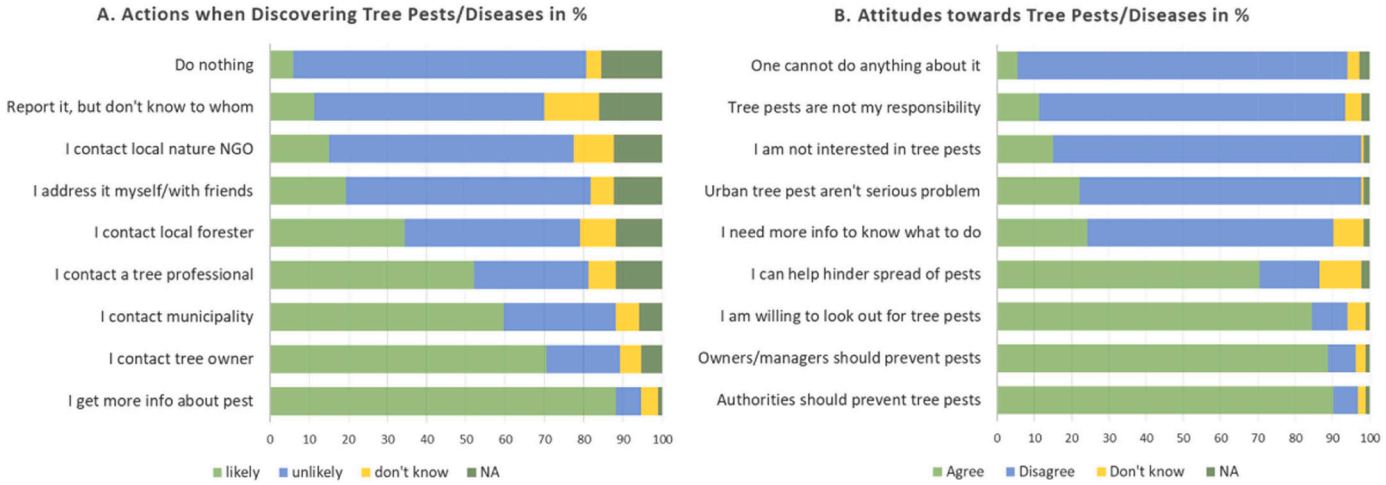



**Fig. 3. :** A. Actions taken by respondents when discovering urban tree pests/diseases in percentages (multiple responses, valid responses n = 186). B. General attitudes towards urban tree pests/diseases (multiple responses, valid responses n = 186).

### 3.5. Responses and management activities to deal with urban tree pests/diseases

When noticing (potential) tree pests/diseases in urban areas, 88.2 % of the respondents would try to obtain more information about the pest/disease, and 74.7 % were likely to take some action, including contacting the land or tree owner (70.4 %) or the relevant local public agency (55.2 %). Another 52.2 % would ask a professional to deal with the issue (Fig. 3). A further 18 respondents gave more specific answers to this question, including: taking samples of the pest (1); the action depends on the type of pest/disease (2), the location of the infested tree (1), and whether the pest/disease demands statutory reporting (1) (Appendix 3).

Most respondents felt that government agencies (90.3 %) should take action against tree pests/diseases or tree owners or managers (88.7 %). However, 70.4 % also agreed that their own behaviour can contribute to stopping the spread of tree pests/diseases. Most respondents (84.4 %) were also willing to look out for tree pests/diseases and report infestations (Fig. 3), including many landowners (85), recreationists (80), and hobby gardeners (73).

#### 3.5.1. Reporting of quarantine pests/diseases

135 (72.6 %) of the respondents said that they would know whom to contact to report the discovery of a suspected quarantine pest/disease, of which 107 listed specific places, including various governmental nature conservation agencies (28), plant protection agencies (18), agricultural agencies (12), greenspace agencies (11), forestry agencies (8), overlapping agencies (8), regulatory offices (3), the Julius Kühn Institute (3), public health agencies (2), landowners (2); another 8 gave unspecified responses (Appendix 3, Table 6). 34 respondents (18.3 %) said they would not know whom to contact to report the discovery of a quarantine pest, and 17 (9.2 %) did not respond to this question.

#### 3.5.2. Knowledge and use of different management options

Of the 12 listed examples for tree pest management options, the most heard of were control of import and inspections, and the most widely used by the respondents were improvements of tree living conditions and purchasing plants from certified or trusted local sources (Table 3).

**Table 3**
Knowledge and use of management options (multiple responses, valid responses n = 186).

| | Heard of | Used themselves | Neither/nor |
|---|---|---|---|
| **Control of import (trees and seedlings)** | 80.6 % | 3.2 % | 14.5 % |
| **Inspections of tree nurseries, ports** | 69.9 % | 3.8 % | 24.2 % |
| **Diversification of tree species** | 51.1 % | 21.0 % | 26.9 % |
| **Improvement of tree living conditions (watering, space)** | 52.2 % | 60.8 % | 7.5 % |
| **Sanitary/cleaning measures (boots, tools)** | 58.1 % | 40.3 % | 12.4 % |
| **Plant purchases from certified or local sources** | 52.2 % | 59.7 % | 4.3 % |
| **Chemical treatment of pests /diseases** | 65.6 % | 31.2 % | 12.4 % |
| **Manual removal of pests (traps, waterjet)** | 50.5 % | 42.5 % | 17.7 % |
| **Treatment with natural products (oil, soap)** | 59.1 % | 42.5 % | 12.4 % |
| **Biological treatment (natural enemies)** | 59.7 % | 44.1 % | 7.0 % |
| **Burning of nests or affected area** | 51.6 % | 11.3 % | 36.0 % |
| **Creation of barriers for insects (tape, nets)** | 66.1 % | 35.5 % | 9.1 % |

### 3.6. Relationship between levels of risk awareness and knowledge of urban tree pests/diseases and management responses and other factors

The MCA showed a significant association between levels of risk awareness and knowledge of tree pests/diseases and pest management responses on the first axis, accounting for 11.7 % of the variance (Appendix 4). The main difference was between respondents who were concerned about and knew of tree pests/diseases and management response options (1 tree/greenspace professionals) and respondents not being concerned and with limited knowledge of tree pests/diseases and their management (2 non-tree/greenspace professionals/others).

(*1) Tree/greenspace professionals:* Respondents who spent time near urban trees and dealt with tree pests/diseases for professional reasons were very well informed. This first group was generally associated with tree carers/arborists, city authority greenspace staff/horticulturists and decision-makers. The respondents (i) had heard of and believed the following pests/diseases to be quarantine pests: Asian longhorn beetle, emerald ash borer, red-necked longhorn beetle, and *Xylella* bacterial disease. They were (ii) affected by: ash dieback, Dutch elm disease, European spruce bark beetle, horse chestnut scale, horse chestnut leafminer, bleeding canker of horse chestnut, Massaria disease, canker stain of plane, oak processionary moth, sooty-bark disease of maple and Xylella bacterial disease. Among the management response measures they (iii) used were: diversification of tree species; improvement of tree living conditions; sanitary/cleaning measures; plant purchase from certified or local sources; chemical treatment of pests/diseases; manual removal of pests; treatment with natural products; and biological treatment. In this group, the respondents were more likely to be male, 35–44 years old, and highly educated.

(*2) Non-tree/greenspace professionals/others:* In the second group, respondents spent time near urban trees for private reasons and had no or less than one year of experience with urban trees. These respondents had limited risk awareness and knowledge of tree pests/diseases and had neither heard of nor been affected by nor thought any of the listed tree pests/diseases were reportable. Furthermore, they were not aware of any of the listed management options. These respondents were more likely to be female, 18–24 years old, and with an intermediate level of education.

## 4. Discussion

Raising awareness of the growing threat of urban tree pests/diseases and knowing how to deal with them is vital for urban tree health. This task is challenging due to the broad range of stakeholders involved. Our study found high levels of concern about urban tree pests/diseases, with at least half of the respondents reporting high levels of self-indicated knowledge of pests/diseases, including their potential spread. However, it also revealed a lack of knowledge of several quarantine pests/diseases, as well as management options. Knowledge levels also varied amongst the different stakeholder groups associated with urban trees and forests across Germany. Certain tree/green professionals (city authority greenspace staff/horticulturists, tree carers/arborists, foresters/forest workers) had higher levels than people dealing with trees for purely private reasons. The latter had not have heard of any of the listed tree pests/diseases or the listed management options. A particular discrepancy exists between known pests/diseases and the appropriate action considered. There is notable lack of knowledge of destructive quarantine pests/diseases and of what steps to take upon discovering them. Thus, our original proposition that both risk awareness and knowledge of urban tree pests/diseases might be low amongst key stakeholder groups was only partially confirmed. The growing threat from urban tree pests/diseases necessitates action from a wide range of stakeholders at the different stages of tree pest invasions (prevention, eradication, containment and control) (Williams et al., 2023; Green et al., 2023). Risk awareness is a prerequisite for undertaking appropriate action along these stages, especially since the introduction and

subsequent spread of non-native tree pests/diseases are mostly unintentional and frequently happen without the knowledge of those involved (Marzano et al., 2016). So is knowledge of tree pests/diseases and of where to report the discovery of suspected quarantine pests/diseases, as rapid action is crucial in limiting their spread (Turner et al., 2004; Green et al., 2023).

In our study, there was a particular lack of knowledge of several highly destructive non-native quarantine pests/diseases for which early detection and subsequent eradication are crucial. For instance, although most respondents had heard of the Asian longhorned beetle, only half of these thought it was a reportable pest. Even worse, although just over half had heard of canker stain of plane, only 6.5 % believed it was reportable. Both tree pests/diseases were already present in some isolated parts of Germany (EPPO, 2023), were on the EPPO list of reportable quarantine pests/diseases, and can cause high tree mortality if not caught early and eradicated (Haack et al., 2010; Lehtijärvi et al., 2018). Similarly, less than half of the respondents had heard of the dangerous pathogenic bacterium *Xylella fastidiosa*, currently spreading in Italy, Spain and Southern France, and the emerald ash borer, spreading from Russia westwards into Europe. Both cause widespread tree mortality in their paths (Trkulja et al., 2022; Orlova-Bienkowskaja et al., 2020), but only around a quarter of the respondents knew these pests/diseases must be reported. These findings are concerning, considering that early detection and eradication of dangerous quarantine pests/diseases is decisive for future tree health (Turner et al., 2004; Green et al., 2023). Especially as the cost-effectiveness of any action is inversely related to the spread and abundance of a tree pest/disease (Turner et al., 2004; Green et al., 2023). In a recent study of forest stakeholders in Europe (Green et al., 2023), the authors suggest that the wide range of quarantine pests/diseases might make it difficult to know them all.

In our study, respondents who deal with urban trees and forests for *professional* reasons considered tree pests/diseases a severe problem in urban areas. However, only half reported high general knowledge of pests/diseases (namely, city authority greenspace staff/horticulturists, tree carers/arborists, and foresters/forest workers). On the other hand, Marzano et al. (2016), whose study focused on forest professionals in Europe, found only modest knowledge of specific tree pests/diseases. A recent study by Green et al. (2023) suggests that professionals working in European urban environments were more aware of tree pests/diseases than those in rural environments. Similar to other studies, in our case, knowledge levels rose with the increasing age of the respondents (Marzano et al., 2016). Still, although risk awareness appears to be generally high in our study, it is somewhat concerning that around half of the professionals had only some knowledge of tree pests/diseases. Moreover, just under a quarter of city authority greenspace staff/horticulturists, tree carers/arborists, and landscape planners/architects were not even concerned about urban tree pests/diseases. Several authors also suggest a lack of knowledge of biosecurity practices among stakeholders from the forestry, horticulture and conservation sectors (Webber, 2010; Dehnen-Schmutz et al., 2010).

The most frequently taken actions by urban tree/greenspace professionals to support urban tree health in our study were diversification of tree species, improvement of tree living conditions, sanitary/cleaning measures, plant purchase from certified or local sources, chemical treatment of pests/diseases, manual removal of pests/diseases, treatment with natural products, and biological treatment. In contrast, Green et al. (2023), who surveyed a range of forest stakeholders on their perspectives of pest detection, identification and management tools, found that disposal of infested trees, physical controls, onsite biosecurity measures, and biological controls were the most used in Europe. Considering that, in addition to preventing the introduction of non-native tree pests/diseases in the first place, early pest/disease detection and rapid action/eradication are vital for future urban tree health, it is highly positive that a large majority of our respondents were willing to look out for tree pests/diseases and report infestations to the relevant authority. However, the number of different authorities listed for pest reporting was large, suggesting there may be confusion about where potential quarantine pests/diseases need to be reported. Considering that rapid action by the appropriate authority is vital for the success of any measures, this kind of information may have to be communicated more clearly.

Despite the significance of the *tree trade/nursery sector*, our study had limited success in reaching out to this stakeholder group, with only 2 % of survey respondents representing this sector. This somewhat corresponds with Green et al. (2023), who also found a weak response to their study on awareness, detection and management of new and emerging tree pests/diseases in Europe amongst plant importers and timber traders. Due to their high involvement in the plant trade, which is a 'key vector' for tree pests/diseases (Marzano et al., 2015), more efforts are required to reach this particular stakeholder group in future studies and tree pest/disease related activities.

In our study, *private urban landowners* report some knowledge of tree pests/diseases. While we cannot say that our findings represent the general group of private landowners, as most of the landowning respondents were also tree professionals, we suggest a relationship between direct exposure to urban tree pests/diseases and the awareness and knowledge of landowners. Professional education, training activities, or sources of information used may also play a role; however, this needs further investigation. The limited research available on landowners proposes, albeit somewhat intuitively and mainly in the context of forestry, that the awareness of landowners increases through experience of tree pests/diseases and when realising the scale of their potential loss (Marzano et al., 2015). Unfortunately, we did not manage to obtain responses from *estate managers/caretakers*, although they are likely to be responsible for many non-public urban trees and thus play an important role in pest/disease detection and management. A possible explanation for this could be that the issue of urban trees in general, and urban tree pests/diseases in particular, is perceived as unimportant to this group, including to their respective umbrella organisations.

Our study offers findings on another essential but understudied stakeholder group: *hobby gardeners*. Gardeners, who, in most instances, are also landowners (or tenants), are often in direct and regular contact with plants and trees on their own (or rented) land. Hence, they could be a decisive group to detect pests/diseases, report them or take action themselves. Gardeners in our study reported mixed levels of knowledge of urban tree pests/diseases, where a majority had only some knowledge. In comparison, those dealing professionally with urban trees had high levels. Although this may likely be due to their different levels of training and exposure to information on this topic, hobby gardeners may also be less likely to perceive themselves as stewards of the 'urban forest' (i.e., all trees in an urban area) and, hence, may have a lower sense of responsibility for their trees. Given the high number of gardeners amongst landowners, this may require a shift in attitude towards their essential role as urban tree stewards.

### 4.1. Implications of our findings and early suggestions to address different stakeholder needs

Studying stakeholder risk awareness and knowledge of tree pests/diseases can help identify groups that may benefit from more targeted information, support or training about the potential risks of pests/diseases and measures to reduce these risks (Green et al., 2023). Our findings suggest that such activities should clearly distinguish between a) tree/greenspace professionals and b) non-tree/greenspace professionals and other lay stakeholder groups. The former may call for more detailed knowledge on specific issues, whereas the latter may first require activities that increase their overall risk awareness. Still, other authors concluded that 'increased efforts' are necessary to improve risk awareness, even amongst some tree/greenspace professionals (e.g., Marzano et al. 2016). In both instances, though, such efforts may best aim to reach out to multipliers of key stakeholder groups (Urquhart et al., 2017b; Quine et al., 2011), such as the main trusted dissemination

channels they consult or their respected networks or umbrella organisations (e.g., membership associations, national plant health institutes, and EPPO). Increased exertions are also required to engage certain key stakeholder groups and potentially even their respective umbrella organisations in this topic in the first place. More attention should be drawn to the issue of biosecurity amongst all stakeholder groups. A thorough analysis of the requirements of various stakeholder groups involved in urban tree health through systematic stakeholder analysis (Raum, 2018; Reed and Curzon, 2015) would be an essential prerequisite for developing any future action.

More specifically, our work suggests that *tree/greenspace professionals* may require more information that is detailed and/or training on topics, such as on some tree pests/diseases, especially quarantine pests/diseases not yet present in their district, state, or country, and on management response options. Increasing awareness of quarantine tree pests/diseases and what to do when discovering them is particularly important for effective pest prevention (Green et al., 2023). Such efforts, as already pointed out by others, should not simply consist of more scientific information relating to each tree pest/disease as it emerges, although this type of information is also clearly needed (Marzano et al., 2016). Instead, European forest professionals expressed a specific need for better accessibility of information, information sharing, and training (Green et al., 2023). Although Green et al.'s (2023) study had a particular focus on forests, forest professionals also wanted access to more pest management and detection tools, including maps showing the spread and range of tree pests/diseases, pest identification apps, handheld detection devices, drones, citizen-science monitoring, and eDNA metabarcoding. Detection and accurate identification of tree pests/diseases are vital to taking the most appropriate measures against a pest/disease (Petter et al., 2023) in both rural and urban areas. Synthesised information, maps of tree pests/diseases and identification smartphone apps may be provided by either EPPO or national level plant health institutes (e.g., the Julius Kühn Institute in Germany).

*City authority greenspace staff/horticulturists* may also require specific training in communicating and engaging with the public. A recent survey on woodland management on the periphery of the German city of Munich found that although it was important to municipalities that the public visiting these woodlands had a high level of acceptance of the necessary tree management measures they had to undertake, they did not involve the public comprehensively when planning these activities (Lupp et al., 2017). Such engagement may become particularly important when infested or potential host trees must be felled, as woodland visitors may object to such measures. A study exploring these tensions in the context of an Asian longhorn beetle outbreak and eradication programme in southern England in 2012 recommended that outbreak management activities pay more attention to good communication and engagement, as they are crucial for cultivating trust (Porth et al., 2015). In contrast, *tree traders/nurseries* and *garden centres* may have to become more aware of their responsibility when importing and selling potentially diseased plants. They may require more guidance on the best sources of trees and on how to avoid infested materials to lower the risk of pest introductions. Making them more accountable may also be necessary, potentially via stricter regulation and/or import control or increased surveillance. However, more research is urgently needed on this particular stakeholder group.

For *non-tree/greenspace professionals and other lay groups*, such as estate managers/caretakers, landowners, tenants, recreationists, and members of conservation groups, we may first have to raise awareness of the potential threat of (urban) tree pests/diseases via a range of tailored activities. Again, these may best aim to reach out to respected multipliers of these groups, who may offer general information, support, and perhaps even training. Networks and umbrella membership organisations may be more trusted whilst also understanding the needs of their members better (Quine et al., 2011). These may, thus, be important hubs for risk communication and education activities about tree health (Urquhart et al., 2017b). This approach, however, necessitates a greater understanding of the requirements of these stakeholder groups and their (professional) umbrella organisations or networks (Quine et al., 2011; Urquhart et al., 2017b). In some instances, risk awareness of urban tree pests/diseases may have to be raised with such umbrella organisations/networks first. In our study, for instance, we found less readiness amongst landowner and tenant associations, property management associations, recreation, and even nature conservation networks to promote the survey through their channels, suggesting that these may require further sensitising of the growing threat of urban tree pests/diseases.

Others, such as *private owners* of urban trees and forests, may require more tailored activities. In a recent survey of woodland owners in Munich's periphery, respondents expressed a want for more advice and support, including on urban tree safety issues associated with tree pests/diseases and on how to communicate necessary safety measures to the public (Lupp et al., 2017). For instance, some interviewed woodland owners reported being criticised or even confronted when felling trees for safety reasons. However, there was little awareness of the importance of communicating with residents or the general public when such measures had to be carried out, nor did these owners have the resources or experiences to do so. As the risks of tree pest/disease outbreaks and, thus, the risks to public safety increase (due to falling branches or trees), urban private tree/woodland owners urgently need more support. *Property managers/caretakers* are likely to require similar support. Such support, possibly in the form of guidance and training, could become part of the advisory and support services offered by municipal greenspace/forest agencies or forest management associations. A tailored advisory service for urban tree and woodland owners may include pest control, human safety, and visitor management (Lupp et al., 2017). However, the advisory needs of urban tree and woodland owners have barely been investigated, calling for more attention.

Our findings suggest that *hobby gardeners*, who tend to have some knowledge of urban tree pests/diseases, would require access to more general information and/or training. This may include information on identifying pests/diseases, pest/disease introductory pathways, management responses, and whom to contact when discovering potential quarantine pests/diseases. A study by Urquhart et al. (2017b) showed that although groups such as gardeners (and woodland visitors) demonstrate higher levels of risk awareness *"together with a willingness to adopt biosecure behaviours, they are also the most likely to be engaged in activities which can potentially lead to the spread"* of tree pests/diseases (e.g., through the inadvertent purchase of infected plants or the movement of organisms from one place to another). The authors, therefore, suggest targeting these stakeholder groups in the short term to raise their awareness about the importance of adopting appropriate biosecurity measures. Membership organisations/networks, such as national and local horticultural/gardening associations, and potentially the horticultural industry itself, may be particularly well placed to provide biosecurity information to their members or customers (e.g., about responsible plant purchasing, how to detect and where to report quarantine pests/diseases, and practical measures to avoid the spread of tree pests/diseases) (Urquhart et al., 2017b). A summary of the above identified stakeholder needs and early suggestions to address these can be found in Table 4.

### 4.2. Limitations

An inherent limitation of survey questionnaires is self-selection bias, as not everyone who receives an invitation to a survey fills it in, leading to a bias. Those who participate in surveys may have attributes or motivations that differ from those who do not. Moreover, an online survey approach can limit or hinder the reach of those with no or little access to or experience with digital forms of communication (Ramsetty and Adams, 2020), or with a language barrier. Still, it provides consistency and is arguably the most useful approach to reaching a wide range of stakeholders across a wide geographical area, especially when resources

**Table 4**
Summary of the above stakeholder needs and early suggestions to address these.

| Stakeholder Group | Stakeholder Needs | How to address them |
|---|---|---|
| **Tree/greenspace professionals** | | |
| Tree carer/ arborist | ▪ some are still unconcerned<br>▪ modest knowledge of quarantine pests/ diseases<br>▪ modest knowledge of management options &<br>▪ of were to report pests/diseases<br>▪ limited knowledge of biosecurity practices | ▪ raise risk awareness<br>▪ improve accessibility to information<br>▪ provide opportunities for knowledge exchange<br>▪ offer access to detection & management tools<br>▪ offer specific info & training on:<br>o quarantine pests/diseases<br>o management options & reporting<br>o biosecurity |
| Forester/forest worker | ▪ modest knowledge of quarantine pests/ diseases<br>▪ limited knowledge of biosecurity practices | |
| City greenspace staff/ horticulturists | ▪ some are still unconcerned<br>▪ limited knowledge of biosecurity practices<br>▪ of were to report pests/diseases to | ▪ raise risk awareness<br>▪ provide specific training on:<br>o as above<br>o communicating & engaging with the public |
| Tree trader/ nursery | ▪ tree trader networks reluctant to promote the survey | ▪ involve in future studies & activities<br>▪ provide specific guidance on:<br>o sourcing trees to avoid infested material |
| Landscape planner/ architect | ▪ some are still unconcerned<br>▪ lack general & specific knowledge | ▪ raise risk awareness<br>▪ offer general info & training |
| **Non-tree/greenspace professionals and other lay groups** | | |
| Estate manager/ caretaker | ▪ networks reluctant to promote the survey,<br>▪ indicating a lack of risk awareness | ▪ engage with umbrella organisations<br>▪ raise risk awareness (via multipliers)<br>▪ then, offer tailored info, support, training (similar to owners) |
| Property-/ landowner | ▪ have some knowledge of tree pests<br>▪ networks reluctant to promote the survey,<br>▪ indicating a lack of risk awareness | ▪ engage with umbrella organisations<br>▪ raise risk awareness (via multipliers)<br>▪ provide easy to access contact points for reporting & support<br>▪ offer info & training (via state advisory services, forest assoc.) on:<br>o pest/disease identification<br>o introduction pathways<br>o management options<br>o tree safety issues<br>o dealing with public (owners) |
| Tenant/ leaseholders | ▪ mixed level of knowledge of urban tree pests/diseases<br>▪ but the majority has limited knowledge<br>▪ networks reluctant to promote the survey,<br>▪ indicating a lack of risk awareness | |
| Hobby gardener | ▪ mixed levels of knowledge, but<br>▪ majority has limited knowledge<br>▪ may have a lower sense of responsibility for their trees | ▪ provide easy access to contact points for reporting & support<br>▪ offer general info & training (via networks. & garden centres) on:<br>o pest/disease identification<br>o introduction pathways<br>o management options, biosecurity, reporting |
| Recreationist | ▪ networks reluctant to promote the survey,<br>▪ indicating a lack of risk awareness | ▪ engage with umbrella organisations/ networks<br>▪ raise risk awareness (via multipliers)<br>▪ offer tailored info & possibly training through these channels |

are limited. The reliance on the self-reporting method of data collection is another potential limitation as it could result in potential data inaccuracies due to misunderstanding a question(s) or intentional deception by the respondents (Dillman et al., 2017). However, the type of questions used in this survey made the latter rather unlikely.

Although the sampling strategy covered a range of stakeholder groups identified in the literature as important for urban tree health, differing levels of support for promoting the survey amongst their networks may have contributed to an overall mixed number of responses, especially amongst the professional groups. Therefore, answers from city greenspace staff/horticulturists are slightly overrepresented in this survey; those stakeholder groups with a low number of responses may not necessarily be representative of the total study population of these groups (Dillman et al., 2017). With the study's exploratory nature and limitations due to the chosen sampling strategy, it would be useful to investigate and capture more stakeholder perspectives from these underrepresented groups in future studies. This, however, requires greater efforts to reach out to these stakeholders. Future studies should also expand on our findings by investigating other countries in the EU or even worldwide.

## 5. Conclusion

Urban trees and forests provide a multitude of benefits to the urban environment. Yet, they are increasingly threatened by tree pests/diseases. The long-term health of our urban trees requires an understanding of this growing threat and of how to manage it. In this exploratory study, we surveyed nearly 200 stakeholders from a range of key stakeholder groups from across Germany to assess their knowledge of tree pests/diseases, how they are affected by urban tree pests/diseases, and how they might respond to this rising challenge. No previous study had investigated these issues concurrently. Although most of our respondents consider urban tree pests/diseases a serious issue and over half reported high knowledge levels of tree pests/diseases, our results suggest that there is a need for targeted efforts to improve understanding of this growing threat and how best to deal with it among different stakeholder groups. Specifically, tree/green professionals often require more specific information, support, and training. Groups still unengaged in urban tree health, such as estate managers/caretakers or public decision-makers, need awareness raising first. Multipliers of these stakeholder groups, such as professional umbrella organisations, might be best suited to provide tailored information, support, or even training also for non-experts. However, this calls for greater collaboration between governmental institutions and umbrella organisations. Our study underscores the critical importance of raising risk awareness and knowledge on urban tree pests/diseases amongst a diverse range of stakeholders. The insights gained from this research will inform the

development of future activities tailored to the needs of different stakeholder groups involved in urban tree health.

## CRediT authorship contribution statement

**Dr. Susanne Raum:** Writing – review & editing, Writing – original draft, Visualization, Validation, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Monika Egerer:** Writing – review & editing, Supervision, Methodology, Funding acquisition, Conceptualization. **Stephan Pauleit:** Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization. **Gerd Lupp:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Constantina-Alina Hossu:** Writing – review & editing, Visualization, Validation, Software, Methodology, Formal analysis, Data curation.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.ufug.2024.128456.

## References

Annesi, T., Calienno, L., Picchio, R., De Simone, D., Lo Monaco, A., 2015. Degradation of some technological features in the wood of ornamental species caused by Inonotus rickii (Pat.) Reid. Drew. Pr. Nauk. Doniesienia Komun. 58 (195), 5–18.
Babbie, E.R., 2020. The practice of social research. Cengage AU.
BDSG (2018). Bundesdatenschutzgesetz 2018. Bundesrepublik Deutschland, Berlin.
BPB (2021). Bevölkerungsstand. Bundeszentrale für politische Bildung. Bonn. ⟨www.bpb.de/kurz-knapp/zahlen-und-fakten/datenreport-2021/bevoelkerung-und-demografie/329469/bevoelkerungsstand/⟩.
Brasier, C.M., 2008. The biosecurity threat to the UK and global environment from international trade in plants. Plant Pathol. 57, 792–808.
Britannica (2023). Germany. ⟨www.britannica.com/place/Germany⟩.
Brockerhoff, E.G., Liebhold, A.M., Richardson, B., Suckling, D.M., 2010. Eradication of invasive forest insects: Concepts, methods, costs and benefits. N. Z. J. For. Sci. 40 (suppl), S117–S135.
Chang, W.Y., Lantz, V.A., MacLean, D.A., 2009. Public attitudes about forest pest outbreaks and control: case studies in two Canadian provinces. . Ecol. Manag. 257, 1333–1343.
Creswell, J., Creswell, D., 2022. Research Design. Qualitative, quantitative, and mixed methods approach. Sage, Thousand Oaks.
Czaja, M., Kołton, A., Muras, P., 2020. The Complex Issue of Urban Trees—Stress Factor Accumulation and Ecological Service Possibilities. Forests 11 (9), 932.
Dehnen-Schmutz, K., Chas-Amil, M.L., Touza, J., 2010. Stakeholders' perceptions of plant invasions in Galicia, Spain. Asp. Appl. Biol. 104, 13–18.
Destatis, 2022. Bevölkerung in Deutschland. Stat. Bundesamt Dtschl., Wiesb.
Dillman, D.A., Hao, F., Millar, M.M., 2017. Sage Research Methods. SAGE Publications Ltd.
Dzięgielewska, M., Adamska, I., Mikiciuk, M., Nowak, G., Ptak, P., 2017. Effects of biotic and abiotic factors on the health of horse chestnut trees in an urban area of north-western Poland. Ecol. Quest. 27, 25–38.
EPPO (2023). EPPO's activities on plant quarantine. European and Mediterranean Plant Protection Organization. ⟨www.eppo.int/ACTIVITIES/quarantine_activities⟩.
EU (2016). Plant Health Regulation 2016/2031 on protective measures against plant pests. European Council.
EU (2019). Commission Implementing Regulation (EU) 2019/2072 on protective measures against pests of plants. European Commission, Brussels.
Fazit & A.A. (2023). Tatsachen über Deutschland. Fazit Communication GmbH, Frankfurt am Main, in Zusammenarbeit mit dem Auswärtigen Amt, Berlin. Home | Tatsachen über Deutschland (tatsachen-ueber-deutschland.de).
Fielding, N., Lee, R., Blank, G., 2017. The SAGE Handbook of online research methods. SAGE Publications Ltd.
Flannigan, J., 2005. An evaluation of resident's attitudes to street trees in southwest England. Arboric. J. 28, 219–241.
Flint, C.G., 2007. Community perspectives on spruce beetle impacts on the Kenai Peninsula, Alaska. For. Ecol. Manag. 227, 207–218.
FLL (2006). Die ZTV Baumpflege. Forschungsgesellschaft Landschaftsentwicklung, Landschaftsbau e.V. Gilching.
Fuller, L., Marzano, M., Peace, A., Quine, C.P., Dandy, N., 2016. Public acceptance of tree health management: results of a national survey in the UK. Environ. Sci. Policy 59, 18–25.
Green, S., Dehnen-Schmutz, K., Drakulic, J., Eschen, R., Orazio, C., Douma, J.C., Jactel, H., 2023. Awareness, detection and management of new and emerging tree pests and pathogens in Europe: stakeholders' perspectives. NeoBiota 84, 9–40.
Gupta, A., 2010. Emerald ash borer first detector: a volunteer early detection programme. NZ J. Sci. 40, 123–132.
Gupta, N., Slawson, D.D., Moffat, A.J., 2022. Using citizen science for early detection of tree pests and diseases: perceptions of professional and public participants. Biol. Invasions 24 (1), 123–138.
Gutsch, M., Larondelle, N., Haase, D., 2019. Of bus and men: How forest pests and their management strategies are perceived by visitors of an urban forest. Urban For. Urban Green. 41, 248–254.
Haack, R.A., Herard, F., Sun, J., Turgeon, J.J., 2010. Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: a worldwide perspective. Annu. Rev. Entomol. 55, 521–546.
Haack, R.A., Law, K.R., Mastro, V.C., Ossenbruggen, H.S., Raimo, B.J., 1997. New York's battle with the Asian long-horned beetle. J. For. 95, 11–15.
Harper, R.W., Bloniarz, D.V., DeStefano, S., Nicolson, C.R., 2017. Urban forest management in New England: Towards a contemporary understanding of tree wardens in Massachusetts communities. *Arboricultural*. Journal 39 (3), 162–178.
Hathaway, J.M., Basman, C.M., Barro, S.C., 1981. Assessing tree care professionals' awareness and knowledge about the Asian Longhorned beetle. Gen. Tech. Rep. Nc. 397.
Heimlich, J., Sydnor, T.D., Baumgardner, M., Obrien, P., 2008. Attitudes of residents toward street trees on four streets in Toledo, Ohio, U.S. before removal of ash trees (Fraxinus spp.) from emerald ash borer (Agrilus planipennis). Arboric. Urban For. 35, 47–53.
Hitchmough, J.D., Bonguli, A.M., 1997. Attitudes of residents of a medium sized town in southwest Scotland to street trees. Landsc. Res. 22, 327–337.
Hossu, C.A., Iojă, I.C., Onose, D.A., Niță, M.R., Popa, A.M., Talabă, O., Inostroza, L., 2019. Ecosystem services appreciation of urban lakes in Romania. Synerg. Trade-offs Mult. users. *Ecosyst. Serv.* 37, 100937.
Hurley, B.P., Slippers, J., Wingfield, M.J., Dyer, C., Slippers, B., 2012. Perception and knowledge of the Sirex woodwasp and other forest pests in South Africa. Agric. Entomol. 14, 306–316.
Husson, F., Lê, S., Pagès, J., 2011. Exploratory Multivariate Analysis by Example Using R. CRC Press Taylor & Francis Group.
Jacobi, W.R., Goodrich, B.A., Cleaver, C.M., 2011. Firewood transport by national and state park campers: a risk for native or exotic tree pest movement. *Arboriculture and Urban*. Forestry *37* (3), 126.
JKI (2021). EU Regelungen - Pflanzenquarantäne. Julius Kühn Institut - Bundesforschungsinstitut für Kulturpflanzen. Quedlinburg. Regelungen EU - Pflanzenquarantäne - pflanzengesundheit.julius-kuehn.de.
Kendal, D., Dobbs, C., Lohr, V.I., 2014. Global patterns of diversity in the urban forest: Is there evidence to support the 10/20/30 rule? Urban For. Urban Green. 13 (3), 411–417.
Klobucar, B., Östberg, J., Jansson, M., Randrup, T.B., 2020. Long-term validation and governance role in contemporary urban tree monitoring: a review. Sustainability 12, 5589.
Koch, F.H., Yemshanov, D., Haack, R.A., Magarey, R.D., 2014. Using a network model to assess risk of forest pest spread via recreational travel. PloS One *9* (7), e102105.
Le Roux, B., Rouanet, H., 2010. Multiple correspondence analysis, Vol. 163. Sage.
Lehtijärvi, A., Oskay, F., Doğmuş Lehtijärvi, H.T., Aday Kaya, A.G., Pecori, F., Santini, A., Woodward, S., 2018. Ceratocystis platani is killing plane trees in Istanbul (Turkey). For. Pathol. 48 (1), e12375.
Leiner, D.J. (2019). SoSci Survey (Version 3.1.06) [Computer software]. Available at ⟨https://www.soscisurvey.de⟩.
Liebhold, A.M., Brockerhoff, E.G., Garrett, L.J., Parke, J.L., Britton, K.O., 2012. Live plant imports: the major pathway for forest insect and pathogen invasions of the US. Front. Ecol. Environ. 10, 135–143.

Lupp, G., Börtitz, K., Kantelberg, V., Koch, M., Pauleit, S., 2017. Urbanes Waldmanagement zwischen Ansprüchen der Gesellschaft und Besitzerzielen. Schweiz. Z. F. üR. Forstwes. 68 (5), 261–268.
Marzano, M., Ambrose-Oji, B., Hall, C., Moseley, D., 2020a. Pests in the City: Managing Public Health Risks and Social Values in Response to Oak Processionary Moth (*Thaumetopoea processionea*) in the United Kingdom. Forests 11 (2), 199.
Marzano, M., Dandy, N., Bayliss, H.R., Porth, E., Potter, C., 2015. Part of the solution? Stakeholder awareness, information and engagement in tree health issues. Biol. Invasions 17, 1961–1977.
Marzano, M., Dandy, N., Papazova-Anakieva, I., Avtzis, D., Connolly, T., Eschen, R., Glavendekic, M., Hurley, B., Lindelow, A., Matosevic, D., Tomov, R., Vettraino, A.M., 2016. Assessing awareness of tree pests and pathogens amongst tree professionals: a pan-European perspective. Policy Econ. 70, 164–171.
Marzano, M., Hall, C., Dandy, N., Fisher, L.C., Disstorrance, A., Haight, R., 2020b. Lessons from the Frontline: Exploring How Stakeholders May Respond to Emerald Ash Borer Management in Europe. Forests 11, 617.
Marzano, M., Woodcock, P., Quine, C.P., 2019. Dealing with dieback: forest manager attitudes towards developing resistant ash trees in the United Kingdom. For.: Int. J. For. Res. 92 (5), 554–567.
Mathiesen, K. (2014). Oak processionary moth population exploding in London. The Guardian. Accessed 08.08.2023. Oak processionary moth population exploding in London | Invasive species | The Guardian.
McFarlane, B.L., Stumpf-Allen, R.C.G., Watson, D.O., 2006. Public perceptions of natural disturbance in Canada's national parks: the case of the mountain pine beetle (*Dendroctonus ponderosae Hopkins*). *Biol. Conserv*ervation 130, 340–348.
Mell, I., Allin, S., Reimer, M., Wilker, J., 2017. Strategic green infrastructure planning in Germany and the UK: A transnational evaluation of the evolution of urban greening policy and practice. Int. Plan. Stud. 22 (4), 333–349.
Molnar, J.J., Schelhas, J., Holeski, C., 2003. Controlling the southern pine beetle: small landowner perceptions and practices. *Bull. 649, Auburn Univ.*, Ala.
Mullaney, J., Lucke, T., Trueman, S.J., 2015. A review of benefits and challenges in growing street trees in paved urban environments. Landsc. Urban Plan. *134*, 157–166.
Müller, M., Job, H., 2009. Managing natural disturbance in protected areas: tourists' attitudes towards the bark beetle in a German national park. Biol. Conserve 142, 375–383.
Münchner Wochen Anzeiger (2012). Feldkirchen – Bedrohung aus Asien. Accessed: 08.08.2012. ⟨https://www.wochenanzeiger.de/article/128375.html⟩.
Münchner Wochen Anzeiger (2016). Der Asiatische Laubholzbockkäfer. Accessed: 08.08.2023. ⟨https://www.wochenanzeiger.de/article/158334.html⟩.
Orlova-Bienkowskaja, M.J., Drogvalenko, A.N., Zabaluev, I.A., Sazhnev, A.S., Peregudova, E.Y., Mazurov, S.G., Komarov, E.V., Struchaev, V.V., Martynov, V., Nikulina, T., Bieńkowski, A.O., 2020. Current range of Agrilus planipennis Fairmaire, an alien pest of ash trees, in European Russia and Ukraine. Ann. For. Sci. 77.
Pauleit, S., Jones, N., Nyhuus, S., Pirnat, J., Salbitano, F., 2005. Urban Forest Resources in European Cities. In: Konijnendijk, C., Nilsson, K., Randrup, T., Schipperijn, J. (Eds.), Urban forests and trees: a reference book. Berlin, Heidelberg. Springer, Berlin Heidelberg.
Petter, F., Giovani, B., Trontin, C., 2023. International Cooperation to Support the Diagnosis of Forestry Pests: The Role of EPPO and Euphresco. *Forests* 14, 1461.
Porth, E.F., Dandy, N., Marzano, M., 2015. "My garden is the one with no trees:" residential lived experiences of the 2012 Asian longhorned beetle eradication programme in Kent, England. Hum. Ecol. 43, 669–679.
Potter, C., Urquhart, J., 2017. Tree disease and pest epidemics in the Anthropocene: an analysis of drivers, impacts and policy responses in the UK. Policy Econ. 79, 61–68.
Quarles, W., 2008. Light brown apple moth: crisis of trust. IPM Pr. 3 (4), 1–13.
Quine, C.P., Barnett, J., Dobson, A.D., Marcu, A., Marzano, M., Moseley, D., Uzzell, D., 2011. Frameworks for risk communication and disease management: the case of Lyme disease and countryside users. Philos. Trans. R. Soc. B: Biol. Sci. *366* (1573), 2010–2022.
Ramsetty, A., Adams, C., 2020. Impact of the digital divide in the age of COVID-19. J. Am. Med. Inform. Assoc. 27 (7), 1147–1148.
Ramsfield, T.D., Bentz, B.J., Faccoli, M., Jactel, H., Brockerhoff, E.G., 2016. Forest health in a changing world: effects of globalization and climate change on forest insect and pathogen impacts. Forestry *89* (3), 245–252.
Raum, S., 2018. A framework for integrating systematic stakeholder analysis in ecosystem services research: Stakeholder mapping for forest ecosystem services in the UK. Ecosyst. Serv. *29*, 170–184.
Raum, S., Collins, C.M., Urquhart, J., Potter, C., Pauleit, S., Egerer, M., 2023. Tree insect pests and pathogens: a global systematic review of their impacts in urban areas. Urban Ecosyst. *26*, *587–604*.
Reed, M., Curzon, R., 2015. Stakeholder mapping for the governance of biosecurity: a literature review. J. Integr. Environ. Sci. 12 (1), 15–38.
Roman, L.A., Conway, T.M., Eisenman, T.S., Koeser, A.K., Ordóñez Barona, C., Locke, D. H., Vogt, J., 2021. Beyond 'trees are good': Disservices, management costs, and tradeoffs in urban forestry. Ambio 50, 615–630.
Roy, S., Byrne, J., Pickering, C., 2012. A systematic quantitative review of urban tree benefits, costs, and assessment methods across cities in different climatic zones. Urban For. Urban Green. 11 (4), 351–363.
Savin-Baden, M., Major, C.H., 2023. Qualitative research: The essential guide to theory and practice. Taylor & Francis.
Sheremet, O., Healey, J.R., Quine, C.P., Hanley, N., 2017. Public preferences and willingness to pay for forest disease control in the UK. J. Agric. Econ. 68 (3), 781–800.
Sjöman, H., Östberg, J., Bühler, O., 2012. Diversity and distribution of the urban tree population in ten major Nordic cities. Urban For. Urban Green. 11 (1), 31–39.
Slawson, D.D., Moffat, A.J., 2020. How effective are citizen scientists at contributing to government tree health public engagement and surveillance needs - an analysis of the UK Open Air Laboratories (OPAL) survey model. Insects 11, 550.
Stenlid, J., Oliva, J., Boberg, J.B., Hopkins, A.J.M., 2011. Emerging diseases in European forest ecosystems and responses in society. Forests 2, 486–504.
Trkulja, V., Tomić, A., Iličić, R., Nožinić, M., Milovanović, T.P., 2022. Xylella fastidiosa in Europe: From the Introduction to the Current Status. Plant Pathol. J. 38 (6), 551–571.
Turner, J.A., Bulman, L.S., Richardson, B., Moore, J.R., 2004. Cost-benefit analysis of biosecurity and forest health research. N. Z. J. For. Sci. 34, 324–343.
Tyrväinen, L., Pauleit, S., Seeland, K., de Vries, S., 2005. Benefits and Uses of Urban Forests and Trees. In: Konijnendijk, C., Nilsson, K., Randrup, T., Schipperijn, J. (Eds.), Urban Forests and Trees. Springer, Berlin, Heidelberg.
Urquhart, J., Potter, C., Barnett, J., Fellenor, J., Mumford, J., Quine, C.P., 2017a. Expert risk perceptions and the social amplification of risk: A case study in invasive tree pests and diseases. Environ. Sci. Policy 77, 172–178.
Urquhart, J., Potter, C., Barnett, J., Fellenor, J., Mumford, J., Quine, C.P., Bayliss, H., 2017b. Awareness, concern and willingness to adopt biosecure behaviours: public perceptions of invasive tree pests and pathogens in the UK. Biol. Invasions 19, 2567–2582.
Wang, C., Ren, Z., Chang, X., Wang, G., Hong, X., Dong, Y., Wang, W., 2023. Understanding the cooling capacity and its potential drivers in urban forests at the single tree and cluster scales. Sustain. Cities Soc. *93*, 104531.
Webber, J., 2010. Pest risk analysis and invasion pathways for plant pathogens. N. Z. J. Sci. 40 (suppl), 45–56.
Williams, G.M., Ginzel, M.D., Ma, Z., Adams, D.C., Campbell, F., Lovett, G.M., Bonello, P., 2023. The global forest health crisis: A public-good social dilemma in need of international collective action. Annu. Rev. Phytopathol. *61*, 377–401.