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Review

Lessons from the Frontline: Exploring How Stakeholders May Respond to Emerald Ash Borer Management in Europe

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Abstract: The emerald ash borer (EAB) has caused extensive damage and high mortality to native ash trees (*Fraxinus*; sp.) in North America. As European countries battle with the deadly pathogen *Hymenoscyphus fraxineus* (ash dieback) affecting European ash (*Fraxinus excelsior*), there is concern that the arrival of EAB will signal the demise of this much-loved tree. While Europe prepares for EAB it is vital that we understand the social dimensions that will likely influence the social acceptability of potential management measures, and experiences from the USA can potentially guide this. We draw on differing sources including a literature review, documentary analysis, and consultation with key informants from Chicago and the Twin Cities of Minneapolis and St. Paul. In this paper, we focus on EAB management responses that involve chemical applications, tree felling and replanting, and biological control, and assess their likely social acceptability to stakeholders based on the perceived risks and benefits. Benefits involve protecting specific ash trees and slowing the spread of EAB across the landscape. Risks include collateral harm from insecticide use on human and environmental health, financial costs and liabilities, and the effectiveness of each approach. Biological control and replacing ash with other species are likely to be largely acceptable across contexts and stakeholder groups but pre-emptive felling and insecticide application could be more problematic if seeking widespread social acceptance. Based on our observations from the evidence collected we offer suggestions for approaching EAB management in Europe with a focus on improving prospects of social acceptability. Strong engagement will be necessary to establish the relevance and reason for using different management approaches and to build awareness and trust.

Keywords: emerald ash borer; social acceptability; risk/benefit; pest management; trees

1. Introduction

A new tree health threat is on the European horizon that could have a devastating impact on European ash (*Fraxinus Excelsior*) populations that are already beleaguered by ash dieback (*Hymenoscyphus fraxineus*). Emerald ash borer (*Agrilus planipennis*, EAB) is known to be present in European Russia and more recently Ukraine [1,2]. Potential means of EAB introduction further into Europe could be through wood packaging and waste wood, firewood and wood chips, and hitch-hiking on transportation [3]. European plant biosecurity agencies and forest managers are preparing for this destructive beetle particularly in light of the requirement of Regulation (EU) 2016/2031 ("Plant Health Law" that came into force in December 2019) to produce contingency plans for high risk organisms [4]. A source of considerable insight to inform this preparation is experience of EAB management in the USA [5,6]. The widescale loss of ash trees in the USA through EAB has created significant social and economic impacts with residents in urban and peri-urban neighborhoods having been particularly affected by EAB-induced ash mortality and the treatment or removal and replacement of large ash trees [6–9]. EAB has also been documented to have expanded its host range to species such as white fringe tree (*Chionanthus virginicus)* suggesting that it does not depend totally on ash to survive and could pose a serious risk to other important *Oleaceae* species in Europe [10,11]. As of January 2019, EAB had spread to 35 states in the USA and five provinces in Canada and killed or infested millions of ash trees [12]. As a result, a range of management approaches have been tried and tested across North America that could inform European counterparts on the likely societal acceptance of different options.

Much biological research, including detailed explorations of EAB life-cycle and impacts has been undertaken in the USA [5,13,14]. The economic dimensions of EAB impacts and management have also received some concerted analytic attention. For example, Aukema et al. [15] estimated that ash mortality resulting from spreading EAB infestation in the eastern USA would cost homeowners $380 million per year in the decade 2009–2019 concluding that EAB is the most destructive and costly forest insect to invade the USA. In contrast, documented social research and analysis around the social acceptability of EAB management remains lacking [16] with a few exceptions from the USA. Donovon et al. [17] explored the potential impact of a landscape transformed by wide-scale ash tree death on human health and found a strong association between tree loss and increased human mortality because of higher respiratory and cardiovascular disease. Kondo et al. [18] were able to link increased crime and the EAB-related loss of trees in an urban centre, explaining that abundance of urban greenspace leads to reductions in a range of criminal activities. They suggest that the loss of trees or the presence of dead and dying trees can contribute to a neighborhood looking uncared for with evidence that unattractive areas can encourage crime. Social consequences have also been briefly documented among Native American tribes in the east of the country for whom black ash trees (*Fraxinus nigra*) have cultural and religious significance, particularly for basket-making [5,6]. Nevertheless, while it is recognized that EAB effects have been widespread and acute with significant social and economic impacts, there is limited evidence of how stakeholders have responded to the EAB management approaches taken and little research exploring values and attitudes underlying the social acceptability of different possible actions. The consequence is that understanding of key social and community-scale issues is reliant on received knowledge and experience of managers.

The aim of this paper is to begin learning lessons about stakeholder responses to EAB management, drawing on available literature and practice-based knowledge and experience from two locations in the USA with extensive experience of EAB—Chicago and the Twin Cities of Minneapolis and St Paul. Although there is no guarantee that management methods and approaches implemented in the USA will be acceptable to urban communities in Europe, there will be a requirement for managers to carefully consider stakeholder needs and perspectives across different landscape contexts [19–21]. In Europe, ash (*Fraxinus excelsior*) is a native broadleaf that is wide-spread, well-known and loved and is considered an iconic species [22–25]. Ash can regenerate freely and is an important part of the landscape through its prominence in hedgerows, woodlands, brownfield sites, parks, urban streets and highway corridors. Ash is also a valuable source of hardwood [22]. An important species throughout Europe, ash trees are currently under threat from ash dieback, first identified in Poland in 1992 [26] and now present in 25 European countries impacting a broad range of stakeholders [27]. Public concern about the impact of ash dieback is high [28], amid fears that this disease will have a dramatic impact on ash dominated landscapes analogous with Dutch Elm Disease in the 1970s [29]. Several studies from the UK have highlighted that management responses to ash dieback have been largely reactive and based on perceptions of how different publics may respond as well as addressing the hazard itself [29,30]. Ambrose-Oji et al. [28] also emphasize the challenges of managing tree pests and diseases at the landscape scale when governance and responsibility for tree health lies within a complex system of public and private ownership [21].

The attitudes of stakeholders, communities, and the public towards different tree pest and disease management approaches are difficult to map for pests or diseases that have yet to arrive in a country [21]. Looking to the experience of EAB management in the United States enables us to identify the possible management response in Europe which is likely to be stem injection of insecticide, tree felling and replacement, and biological control. These elements of management will be more or less 'acceptable' to stakeholders based on their perceptions of risks and benefits associated with both the pest and the management options [21,29]. In general, risk perception refers to the way in which people analyze and interpret physical signals and/or information about potentially harmful events and activities and then form a judgement about seriousness, likelihood, and acceptability of the event or activity. It is widely understood that perceptions of risk influence attitudes, decision-making, and thus behavior [31–33]. As Slovic [34] points out, risk is socially constructed and is a blend of multiple variables including psychological, social, cultural, and political factors. Risk perceptions may be related to a number of other variables including whether there are any benefits (which in turn affect the amount of risk that people are willing to tolerate); the level of information and knowledge relating to the risk faced, and familiarity with the risk; trust in those with responsibility for providing information about, and regulating, the risk; and one's sense of control over exposure to the risk [34–37]. It may be useful to think of risk perceptions as encapsulating a wide range of 'rejection factors'. Similarly, perceptions of benefit may be thought of as a collection of 'acceptance factors' (see for example, [38]). Rejection factors include the extent to which people perceive that certain activities are likely to lead to negative welfare effects, to be harmful, unnatural, risky, dangerous, and lead to inequalities. Acceptance factors include the extent to which people perceive those same activities to be important, progressive, necessary, and advantageous. It is the relative importance (to the individual or to society collectively) that determines the balance between perceived risk and benefit. Thus, understanding risk perceptions is important in assessing the likely acceptability of any management approaches that could be applied to EAB. A study in the UK on how individuals have experienced and responded to ash dieback risks emphasizes that more evidence is needed to understand what people are specifically concerned about to inform risk communication efforts around tree health [29]. However, as Klein et al. [39] point out little attention had been paid to the influence of risk perceptions in decision-making about tree care and management in urban settings.

This paper begins by introducing a broad characterization of EAB management before focusing on insecticide use, felling and replanting, and biological control in Chicago and the Twin Cities. We then apply lessons learned from these locations and other available literature to assess perceived risks and benefits that could influence the social acceptability of different EAB management options in Europe and offer suggestions for future research and practical actions.

2. Material and Methods

The opportunity to investigate the two locations discussed in this paper emerged from prior interaction and collaboration between the authors, particularly within IUFRO (International Union of Forest Research Organisations) Working Group 7.03.15 (Social Dimensions of Forest Health). This brought together social researchers in the UK with social and economic analysts in the USA with knowledge of EAB management in Chicago and the Twin Cities. 'Case' selection was, therefore, opportunistic but valid as both locations have seen substantial EAB management and thus offer excellent relevant opportunities for learning. The information presented in this paper is partial (focused primarily on specific, prominent elements of the management responses) and drawn from differing sources including documentary analysis, literature review and from practitioner knowledge, experience, and opinion. Co-authors utilized existing networks and contacts with experienced forest staff at state and municipal level. Key informants (see Table 1) were consulted about their experiences of EAB management in Chicago (n = 8) and the Twin Cities (n = 4). Key informants typically have unique expertise or experience of a particular subject matter and can provide high quality information in a relatively short period of time [40].

Table 1. Organizations (and key informants within) consulted to gather data on emerald ash borer (EAB) management in the two locations.

Location	Key Informants
Twin Cities	Rainbow Treecare, Minneapolis USDA Forest Service, St Paul Minnesota Dept of Agriculture, St Paul University of Minnesota
Chicago	The Morton Arboretum (n = 2) Dept of Public Works, Village of Riverside, Illinois Illinois Dept of Natural Resources (n = 2) Bureau of Forestry, Chicago Services Department, Village of Algonquin, Illinois Illinois Dept of Agriculture

As in many parts of the northeastern and midwestern USA, ash was heavily planted as a street tree across the Chicago region from the 1960s. The first confirmed detection of EAB in Illinois was in June 2006 west of Chicago and it is now widespread. An estimated three million ash trees can be found in the seven-county Minneapolis-St Paul ("Twin Cities") metropolitan area. The first known EAB infestation in the Twin Cities was in St Paul in 2009, but it is believed that EAB arrived as early as 2004 [41].

This paper draws upon a social study of EAB impacts in the Twin Cities [42], as well as additional unpublished presentations and reports that are specific to the two locations. In addition, two of the authors have either observed EAB management processes in situ and/or been involved in research and policy activities (see for example, [8,43,44]). One of the authors was a member of the Minnesota Community Forestry Partnership Group in St Paul. We also conducted a search of peer-reviewed literature using Scopus and Google Scholar and search terms such as "Emerald ash borer" and "social", "impacts", "perceptions", and "attitudes". Further literature searches were conducted on risk perceptions, risk/benefit approaches and their application to forest management issues.

There were different types and levels of researcher involvement and information available between the locations. The analysis is not, therefore, asserted as a full comparative case-study, understood traditionally [45] as structured and contextualized investigations of particular individuals, events, or institutions using consistent methods and research protocols. Rather, it is an observation of inter-related examples of response to EAB. In each of these locations, groups of stakeholders, often led by municipal bodies, have responded to the infestation and subsequent loss of ash trees—often in distinct ways. Investigation of these enables us to provide, first, a broad characterization of the social dimensions of tree biosecurity management—listing its main components—and then to unpack some of its most prominent constituent practices in detail. It is important to acknowledge that EAB management in the USA is ongoing and there are limitations on conclusions that can be drawn regarding the social acceptability of management approaches.

3. Management Approaches for EAB in North America

The arrival of EAB in the cities introduced above has triggered large-scale and multi-faceted responses from numerous stakeholders and this has been comprehensively reviewed [6]. Here we briefly identify the main practices that make up this response. The development of EAB *'readiness plans'* has been encouraged by the Federal government across the USA with local readiness planning including consideration of costs of management options, responses to events (such as confirmed proximal detection), use or not of insecticide treatment, felling strategies, utilization of the wood, and replacement of ash trees. Early detection of EAB is notoriously difficult [5] therefore much effort and resource has been invested in ***surveillance***, with enhanced methods being developed. For example, girdled 'detection' trees, which release stress signals [5] as well as traps with specific lures [46] have been tested for their effectiveness at early detection. Once it became clear that eradication of EAB in North America would not be possible, *quarantines restricting movement* of ash logs, firewood, and planting material were introduced by the Federal government to slow the spread of EAB [5]. Quarantine prohibits the movement of products that can carry the pest from infested areas (quarantined) to areas where the pest in not present (non-quarantined). Within the contiguous area of a quarantine, these products may move freely. Each state may choose whether to have the quarantine applied county by county or to have the entire state quarantined. In urban areas, stem injections of *chemical treatments* have progressed considerably and contribute to reducing the rate of mortality of ash. *Biological control* involving parasitoids has been another response and is proving to have potential for keeping EAB at manageable densities [47,48]. However, *removal of ash trees* (including pre-emptive felling of infested but apparently healthy trees or sanitation felling of dead or dying trees), particularly in urban centers, has continued apace, particularly as municipalities work to avoid development of hazardous trees and to *increase tree species diversity*.

As the spread of EAB can be greatly accelerated through accidental movement by people, *engagement* ***activities*** to raise awareness of the pest, and means by which its impact can be reduced, have been an essential component of management.

3.1. Responses to EAB Management in the Twin Cities and Chicago

Social research conducted in relation to the social acceptability of EAB management options is relatively sparse in the case examples and indeed across the USA. Thus, we are unable to fully document community and other stakeholder responses to different approaches, and this highlights the urgent need for social analyses. Here, we focus on three elements of EAB management to explore what/whether risk perceptions may be linked to different actions. These include chemical insecticides, felling (with or without replacement trees), and biological control. The adjacent cities of Minneapolis and St Paul have taken different approaches to managing EAB with Minneapolis focusing solely on sanitation felling and replacement [49], while St Paul is using insecticide treatment to slow the rate of ash mortality in addition to felling [50]. The City of Chicago also opted for chemical treatment to keep ash healthy.

Both the Twin Cities and Chicago have invested in outreach programmes. An example from a Chicago suburb—Homewood—highlights that the authorities used local media and public meetings to spread the message about ash tree removal and replacement plans. The messaging focused on managing liability (J. Tresouthick, pers.comm.). In Chicago city, forestry staff used front door hangers placed on residents' houses to explain planned treatment in order to pro-actively address possible public objections to insecticide injections (J. Lough., pers.comm.). In the Twin cities there were campaigns to inform homeowners about signs of EAB and actions they could take in advance of EAB infestation, such as insecticide treatment to prevent ash mortality or pre-emptive removal of ash trees from their property. Outreach efforts used social media campaigns, direct mailings, community newspaper articles, door hangers, and ribbons around boulevard ash trees to advertise a web link for information about EAB [50].

3.1.1. Chemical (Insecticide) via Stem Injections

Through the development of chemical insecticides such as emamectin benzoate, it is possible to 'buy time' by keeping ash trees alive and to reduce EAB populations. This is considered a cost-effective way to extend the timeframe to complete ash removals and re-planting on public property, and to ensure that ecosystem services are not adversely affected [50]. Trunk injections can provide up to three years protection [5,6] and are particularly useful in urban environments where the costs of tree removal can be high. In the wider Chicago region where there has been disagreement over the use of chemical insecticides, there have been objections about the cost and effectiveness of insecticide treatment. Conflict is less often about use of the chemicals themselves, especially when they are applied through tree stem injections (J. Lough, pers.comm).

In the City of St. Paul, the forestry section of the Department of Parks and Recreation has also chosen to treat selected ash trees with insecticide in order to slow the rate of tree mortality but also to spread (over time) the felling of large numbers of ash trees, thus reducing the cost to a manageable level each year [50]. By treating high value ash trees and prioritizing removing and replacing smaller, unhealthy or poorly placed ash, the city was also able to avoid causing distress to residents by not stripping entire streets of their trees. This bought time for young, replacement trees to grow before the remaining treated ash trees were removed.

A focus group study of attitudes to EAB management and risk (comprising specialists and members of the public (n = 63) was carried out across Minnesota (including Minneapolis and St Paul) [42]. In relation to the use of chemical insecticides the authors found differences in perspectives between stakeholder groups in terms of efficacy and safety. The specialist group (n = 22) of scientists and resource managers with experience in EAB management was characterized as having a high level of confidence regarding safety but a moderate level of confidence in its efficacy. The 'interested public' (n = 30) of gardeners, aboriculturalists, environmental and neighborhood organizations were moderately confident in its safety and slightly more confident that it was effective. Participants from the 'general public' (n = 11) were very confident that chemical treatment would work but their confidence was low regarding safety. There were concerns amongst all participants related to potential unintended consequences for the environment, whether insecticide use would work, and if it would be cost-effective [42]. There were also fears about the misuse of chemicals and the potential of harm to humans and the environment from lack of training and knowledge of those applying them [42]. Other important issues raised included how to identify a reputable, trained contractor to carry out chemical treatments but also a lack of knowledge about who is responsible for street trees and what replacement trees are most suited to sites [42].

3.1.2. Pre-Emptive and 'Sanitation' Felling and Replanting

Before EAB, the City of Chicago had experience of an invasion by the Asian longhorned beetle (*Anoplophora glabripennis*, ALB). In 1998, the Chicago Bureau of Forestry pre-emptively removed all ALB host trees (healthy or not) in a quarantine zone around places where adult ALB were found. This was controversial at the time because some residential blocks lost multiple medium- to large-sized trees, dramatically changing the neighborhood's aesthetics. However, the city authorities felt that the short-term pain and cost were going to prevent long-term infestation and ongoing expense. Replanting of felled trees was swift and residents had some input in selecting tree species; these factors together alleviated some of the shock of losing so many trees. ALB was officially declared eradicated from Chicago in 2008, validating the pre-emptive removal strategy [51]. Similar strategies have been followed for EAB in cities and towns in the surrounding regions. Officials in the Chicago suburb of Homewood believed that the most cost-effective management approach was to remove and replace all ash trees pre-emptively. In public and local government discussions, it was clear that the short- and long-term financial cost of managing EAB was the most important factor to both officials and residents (J. Tresouthick, pers.comm.) All public ash trees were removed and replaced over an eight-year period, with 89 different species used for replanting.

In addition to the use of insecticides, the City of St. Paul removes infected trees quickly whilst also pre-emptively removing non-infested ash trees in stages to spread out the cost of removal and facilitate an increased diversity in the age and species of replanted trees [50]. Authorities in Minneapolis took a different approach after the Tree Advisory Commission (formed by the Minneapolis Park and Recreation Board MPRB) advised that insecticide treatment of trees on public land did not make sense financially or environmentally [49]. Particularly prominent in this discussion was uncertainty about the possible long-term impacts of insecticides on birds, pollinators, and other species. Minneapolis therefore chose to use an insecticide-free approach to managing ash, although homeowners may treat a boulevard tree adjacent to their property at their own cost [49,52]. As in St Paul, all infested ash trees are removed as soon as they are discovered. In addition, there is pro-active staged removal and replacement of public trees. The costs are substantial with a 2017 budget of $3,570,686 for tree removals and $2,567,788 for planting.

In Minnesota, Dunens et al. [42] found that risk perceptions, such as views over whether the ash tree population can be saved, influenced management options taken and support for, or opposition to, these options. While there was general support for sanitation felling of diseased or unhealthy trees, there was a difference between stakeholder groups over felling of 'healthy' ash trees. Generally, there was a high level of support for felling among 'specialists', moderate support among 'interested public', and low support among the general public. Key issues focused on the loss of high-value ash trees and changing the character of neighborhoods. Participants from the specialist and 'interested public' groups were concerned about creating a glut in the market for ash wood and understanding the most appropriate timber handling processes. The general public were also concerned about the costs of removal and 'who pays'. The specialist group noted that staged removal is better than removing large areas of ash in advance of the infestation to avoid high cost and aesthetic damage. There was support among all groups for proactive planting of diverse species [42].

3.1.3. Biological Control

The best sites for biocontrol control are generally infested areas with low to moderate EAB densities that are expected to be present for several years [6]. In the Chicago region, scientists have experimented with biological control of EAB using parasitic wasps that are native to North Asia (spp. *Tetrastichus planipennisi, Oobius agrili*, and *Spathius agrili*,). The findings of these studies so far suggest that the wasps will not save EAB-infested ash trees (J. Lough, pers.comm. [6]). However, over time, the wasps may keep EAB resurgence low enough to facilitate natural ash regeneration in forested areas.

In Minnesota, biological control of EAB was initiated by the Minnesota Department of Agriculture in 2010, and since then, EAB parasitoids have been released at over 30 sites of known EAB infestations in the state (R. Venette, pers. comm.). City foresters are optimistic that parasitoid releases will slow EAB population growth, but to date the evidence here also suggests that the parasitoids do not act quickly enough to slow ash mortality (R. Venette, pers.comm.).

3.1.4. Perceptions of Risks Associated with EAB Management

Cross-cutting themes that may influence risk perceptions around EAB management options include concerns around collateral harm such as impact of insecticides on human health, biodiversity, and the wider environment; costs of management and who pays; and the perceived effectiveness of each approach. Table 2 summarizes the 'rejection' and 'acceptance' factors associated with EAB management in our USA examples. These perceptions are general and not related to one specific stakeholder group but provide some insight into the potential social acceptability of each management option.

Table 2. Summary of management approaches and potential reasons for acceptance or rejection.

Management Approach	Potential Reasons for Rejection	Potential Reasons for Acceptance
Chemical Insecticide (e.g., Emamectin Benzoate)	Objections about cost and effectiveness of chemical treatment (C, MP). Concerns about public safety e.g., safe and effective use of chemical treatments (MN). Concerns about unintended consequences and long-term impacts for biodiversity and the environment (MN). Fears about potential harm due to lack of training and knowledge among those applying the chemicals (MN). Insecticide treatment of trees on public land may not make sense financially or environmentally (MP).	Protects trees for up to three years providing more time to plan further management actions (MN). Helps spread the financial burden over time (SP). Without insecticides high value ash trees will be lost (C) Ensures ecosystem services are not lost on a large scale in a short time (SP). Confidence of professionals in the safety of chemical treatments (MN).
Pre-Emptive Felling	Public opposition to felling of 'healthy' ash trees (MN). Loss of neighborhood character (MN). Creates glut of ash timber in the market (MN). Financial cost (MN, OE).	Pre-emptive felling in stages helps slow the spread of EAB and spread the cost of removal once EAB arrives or spreads into new areas (SP, C). Helps to facilitate increased age and size diversity of replacement trees (SP). Avoids high costs and large-scale aesthetic damage (C).
Felling of Dead or Declining Trees	Safe disposal and movement of infested ash (MN). Public concerns about financial costs and 'who pays' (MN).	Reduces health and safety danger (SP). Public support for this action (MN).
Replacement Planting with Other Tree Species	High financial cost (C). Debates among forestry professional over species selection and suitability of species for different sites (MN).	Public support for diverse planting (MN, OE). Opportunity for stakeholder input to decision making about choice of species (C). Opportunity for general engagement about species diversification (C).
Biological Control Using Parasitoids	Might not be effective in certain contexts (C). Parasitoids do not act quickly enough to slow ash mortality (MP).	Keeps EAB at manageable densities (C). Helps to slow the spread (C). May persist and control EAB in natural areas over time (C). Could be an engagement tool as officials are 'seen to be doing something' (C).

Key: C = Chicago; MN = Minnesota; MP = Minneapolis; SP = St Paul; OE = other evidence (from literature review).

4. Increasing the Social Acceptability of EAB Management Options in Europe

The attitudes of stakeholders, communities, and the public towards different tree pest and disease management approaches is uncertain for pests or diseases that have yet to arrive in a country [21], and there is no guarantee that management methods and approaches implemented in the USA will be acceptable to European communities and stakeholders. Preparedness and early planning will be critical elements of EAB response in Europe but there are still difficult decisions to make. Pre-emptive felling and chemical control are likely to be the most controversial. However, in light of the USA experiences presented here we offer suggestions for improving social acceptability whilst also acknowledging the wider contextual factors affecting risk perceptions relating to ash in Europe—in particular the presence of ash dieback.

4.1. *Target Insecticide Use to Minimize Collateral Impacts, Manage Costs, and Maintain High Value Trees*

There is a widespread view in Europe that chemical use in the environment is bad [3]. However, as highlighted by our USA cases the benefits of using insecticide treatment are the ability to protect high value ash trees through the peak of EAB infestation, protect the ash canopy for as long as possible, spreads the costs of removal and provide some time for replanting and further management actions [6,53]. Cities and towns in the US that started chemical treatments early and are committed to continuing indefinitely have been able to preserve selected healthy ash trees, but with the understanding that if treatment is stopped, they will probably decline and die, especially if EAB densities are still high. Risk perceptions influencing negative reactions to chemical use are commonly based on safety concerns relating to indirect impacts on public health, biodiversity, and the wider environment as well as the costs and effectiveness of this measure. Analysis also suggests that the public are generally more supportive of tree pest management strategies they perceive to be more 'natural' (e.g., [19,21]). With this in mind, studies have looked at alternatives to chemical insecticide such as emamectin benzoate, assuming that natural-based products such as azadirachtin (extracted from neem) are more socially acceptable in environmentally sensitive areas and urban landscapes [53]. Evans et al. [3] recommend the testing and registration of both emamectin benzoate and azadirachtin for use against EAB in Europe. It is reasonable to conclude from this evidence that the selective ('smart') use of insecticides is likely to have significant benefits for EAB management in Europe.

In order to underpin this 'smarter' insecticide use, more work is needed to understand the values at risk from loss of certain ash trees in specific locations and who is likely to accept or reject the use and application of chemicals. Flint [54] established that respondents with high environmental values were less likely to support chemical use but there is little published evidence available on whether the method of application makes a difference to perceptions of risk. There is also a need to build knowledge regarding the benefits and effectiveness of chemical use in a European context.

4.2. Stage Felling Efforts where Possible to Minimize Sudden Change to Landscape and Sense of Place and Explore Feasibility of, and Attitudes Towards, Dedicated Replanting Schemes

Although the removal of (non-infected) host material may be an effective preventative treatment, pre-emptive felling can instigate strong reactions against the perceived forced removal of 'healthy' ash [55]. The ecological benefit of removing all host trees in an EAB infested area would be to slow the spread [56], but there are economic benefits, in terms of front-loading costs as well as aesthetic and health and safety benefits by avoiding many dead ash trees in the environment. However, evidence shows that pre-emptive felling can lack acceptability due to the values attributed to healthy trees and negative perceptions attached to tree loss [17,18,53,55]. McCullough [6] highlights that removing healthy ash trees as a proactive measure against EAB creates greater anxiety and negative reactions amongst residents in the USA than treating trees with insecticides. It could be an unpopular management response to EAB in some parts of Europe, particularly in urban and peri-urban areas. It has been previously shown in a European context that widespread felling of healthy trees can lead to stark changes in neighborhood or landscape appearance and character, affecting strongly felt place attachments and generating negative attitudes towards sanitation felling [20]. Additionally, felling is expensive. The scale of removal will have an impact on general tree maintenance budgets and residents may have to cover costs of certain management actions themselves, which can lead to stress and opposition. Sanitation felling can furthermore create challenges and risks through increased amounts of timber and the need for monitoring its movement and disposal. Studies (e.g., [20,57]) have attempted to identify additional reasons for opposition to the felling of host trees and found that a lack of trust in agencies carrying out the management is a factor, as is a lack of belief that such actions will be effective in controlling a pest.

Our USA cases suggest that opposition from residents and local communities was reduced if there was a perceived benefit from an immediate replanting programme and if residents were given a choice of species for replacement. Heimlich et al. [58] studied residents' preferences for trees to replace mature ash that were scheduled for removal in Ohio. They note that surveys of US residents have highlighted an inclination towards large trees, but the focus of the survey was on the value of large street trees rather than ash specifically. However, residents did register a preference for planting of new tree species before removal of ash [58]. Municipalities in the USA have also used the large-scale post-EAB planting opportunity to diversify the tree species on public land thereby increasing resilience and reducing the overall threat of future large-scale loss of trees from a new or unknown pest or disease. Dedicated replanting schemes as part of Europe's response to EAB therefore appear to offer significant positive opportunities.

There is also likely to be some benefit to staged removal of ash trees, not only in terms of alleviating the peaks of management costs, but also so residents and visitors can continue to enjoy the benefits of seeing and engaging with trees whilst coming to terms with the eventual loss of some or most of the ash. A key area of research in this regard will be to solicit European stakeholder preferences for different species options and to assess the cost implications, the availability of alternative species, and biosecurity of existing procurement channels.

4.3. Improve Knowledge of Biological Control Options in Europe and Their Efficacy

Research (e.g., [19,59,60]) has repeatedly shown high levels of support for biological control as a management response to tree health problems, including within Europe, and this appears to be due to the perception that it is a more 'natural' approach. Indeed, classic biological control through introduced species (such as parasitoid wasps for EAB) interacts closely—ecologically and socially—with 'natural' predation and other controls. Numerous studies have investigated biological control and natural predation of EAB with mixed results that suggest limited concrete impacts on outbreaks, whilst revealing some complex interactions [6]. Research suggests that parasitoid biological control is most useful in the latter stages of an EAB outbreak, acting to suppress beetle populations and being particularly useful to support ash regeneration [6]. Natural predation by bark-foraging bird species (e.g., woodpeckers) can potentially help regulate EAB populations at later stages (e.g., [6,61]) However, the introduction of parasitoids can affect (reduce) natural predator foraging behavior [62] and, vice versa, parasitism can be affected (reduced) where infested trees are exposed to woodpeckers [63]. Clearly further research is needed to better understand the role of introduced and natural enemies of EAB in mitigating outbreak impacts—especially in the European context.

The fact that these methods—especially natural predation—are generally considered one of the most acceptable forms of management demands they are given significant consideration. In Europe there have been observations that indicate the native parasitoid *Spathius polonicus* found in several European countries may play a role in regulating EAB [3]. Evans et al. [3] recommends exploring the potential of a rear and release programme to augment natural populations as well as studies on the efficacy of introducing Chinese or Russian parasitoids [3]. However, there are likely to be some perceived risks attached to introductions of non-native control species [46] with concerns that biological control in this form can go wrong—the case of the cane toad (*Rhinella marina*) in Australia is a commonly cited example. The current evidence demonstrating only limited effectiveness of these methods may also influence support for investing in this approach.

4.4. Engage in Early Outreach, Involving Stakeholders in Decision Making about Actions to Take

As our USA examples show, a combination of management responses will be needed but a collaborative approach and strong engagement will also be essential as the pest spans public and private spheres (see also [55,64]). Minimizing the spread of EAB and its impact requires cooperation between multiple stakeholders. The experience of Chicago suggests that it is critical to involve the public in discussions about the possible damage that EAB will do in a community and the range of management options, before it arrives. The dangers and challenges of conducting stakeholder engagement and communication only at the onset of an outbreak have been similarly demonstrated [20,57]. However, studies have consistently shown that knowledge and awareness of tree pests and diseases is generally low in Europe [19,35,65]. As well as raising awareness about the pest, it will be important to provide clarity on the efficacy, longevity, and costs of each management option and to build trust between agencies responsible for management and stakeholder communities. For example, a UK study on residential experience of outbreak management from ALB [20] showed that residents wanted communication on what the pest looked like, the impact it can have, but also whether the measures implemented were likely to be effective. In Canada, a study highlighted the backlash from property owners to the removal of apparently healthy ash trees as a measure to slow down the spread of EAB [57]. They attributed this opposition to lack of trust in the scientific argument for felling and the authorities carrying out the action, and concerns about the engagement process where they felt that their opinions were not taken on board [57].

Early communication and engagement at different scales and with different audiences to build knowledge and trust is needed to encourage greater participation in tackling EAB and agreement on approaches to take. There will also be an additional element in Europe around understanding the impacts of ash dieback on the values that people hold for ash and whether this cumulative concern will lead to greater resolve to save the remaining ash or the opposite where they will give up [3]. In developing communication strategies in Europe, we should be wary of taking an 'information deficit' model which assumes that citizens are passive receivers of information and will act accordingly [29]. Rather, we will need to build a broader knowledge base through empirical studies on the many ways in which people interact with tree health risks and their management in order to understand how to promote long-term sustainable biosecure behaviors [29]. A useful study in this regard attempted to understand and mitigate movement of firewood by domestic campers in the USA, a major pathway for EAB spread [66]. Several surveys of campers in Wisconsin were conducted as part of the 'Don't move firewood' campaign to understand their knowledge and views of the risks of moving firewood and motivations to change behaviors. Results from the surveys suggest there were positive changes in people's behaviors and that mild regulation coupled with persuasive education was successful in reducing the movement of firewood [66,67]. The studies also found that perceived peer pressure and disapproval from close social groups such as friends and family could influence whether people actively moved firewood [68].

Understanding risk perceptions across a broad spectrum of stakeholders and other factors likely to influence behaviors will facilitate more effective communication and engagement programmes in Europe whilst also enhancing recognition of the challenges EAB will present for policy and biosecurity managers.

5. Conclusions

EAB has reached Europe's borders and we recommend a key part of preparing for the pest must be to develop a greater understanding of the social dimensions of its management. This should include stakeholders who have a potential role in preventing, preparing for, or managing EAB as well as the many members of the public who will experience the impacts of the pest and any management approaches taken. Social studies to date suggest there is widespread support for management of tree pests and diseases, but we need better evidence on the perceived risks and benefits that will influence the social acceptability of different approaches across Europe. This type of evidence will help inform managers about the likely acceptance or rejection of the management actions available to them. Insights from cases presented in this paper and wider literature have enabled us to describe the EAB management we can expect to see in Europe and begin to assess likely stakeholder views of different approaches. Success in reducing the social, ecological, and economic consequences of EAB will rest on strong inter-linkages between the different dimensions of EAB policy development and management. We have offered suggestions for next steps but argue that preparations for EAB's arrival should include in-depth social research in a European context to better understand how EAB impacts and likely management options are perceived and understood—particularly in the context of experiences with ash dieback.

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