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How Can Local and Regional Knowledge Networks Contribute to Landscape Level Action for Tree Health?

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Abstract: Forests worldwide are facing increasing pressures, with human travel and trade assisting the spread of pests and diseases. Climate change is likely to enhance the negative impacts of pests and diseases, which cause global declines and local extinctions. In this research we focus on three local and regional knowledge networks in the UK concerned with pests and diseases to explore to what extent the networks raise awareness and encourage other actions in their members, and identify what roles social capital and social learning play in these networks. A qualitative approach was undertaken. Three networks focused on pests and diseases were studied in the research, which involved 20 interviews with network members, and in situ discussions with two of the networks involving 41 members. Interviewees in the networks self-reported increased awareness and understanding of tree health issues as an important outcome of their participation in a network. The networks engaged in a range of actions, from knowledge exchange to developing guidance and running events, workshops and field trips. The role of the networks in supporting the development of social capital and social learning made an important contribution to the knowledge exchange and other actions undertaken, and highlights how networks can contribute to landscape-level action towards tree health. Stakeholders need to be included in responses to pest and disease threats, and networks can play an important role in raising awareness, knowledge exchange and linking up diverse land managers. This research provides evidence of the importance of networks in developing a collective approach, creating a stronger voice, aiding different organisations and individuals to work together, and providing an arena for social learning and developing useful relationships. A recognition of the importance of networks and the provision of some financial support could aid their continuation.

Keywords: land managers; networks; pests and diseases; tree health; resilience; decision making; behaviours; social capital; social learning

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1. Introduction

1.1. Global Threats Require Holistic Responses

Trees and forests contain significant carbon, in the trees themselves as well as in the soil and other vegetation, and are therefore globally very important to the carbon cycle and as part of the planet's greenhouse gas balance. The effective management of trees and

forests is important for climate change mitigation. There is a strong policy focus in the United Kingdom (UK) on tree planting and woodland expansion and creation, primarily to contribute to net zero targets, but also to deliver other benefits such as reducing flood risk, improving air quality and providing health and wellbeing benefits. However, forests worldwide are facing many increasing anthropogenic pressures. Climate change is altering their environmental conditions, while human travel and trade is assisting the spread of tree pests and diseases outside their natural ranges [1–5]. Global warming is likely to increase the negative impacts of pests and diseases [6], which can cause global and local declines and extinctions of valuable tree species. Dutch elm disease (*Ophiostoma* spp.),which is caused by a pathogenic fungus and spread by Elm bark beetles (*Hylurgopinus rufipes* Eichoff, *Scolytus schevyrewi* Semenov, *Scolytus scolytus* Geoffroy and *Scolytus multistriatus* Marsham), saw the loss of elm trees across the northern hemisphere in the 1960s and 1970s [7,8], while American chestnut (*Castanea dentata* (Marsh.) Borkh) has been virtually lost from the canopy of eastern North American forests due to Chestnut blight (*Cryphonectria parasitica* (Murrill) M.E. Barr.) [9]. In the Blue Ridge Mountains, as well as in eastern North America, an estimated 21-29% loss in tree biomass has been caused by exotic insects and pathogens [10]. In the UK, Ash dieback (*Hymenoscyphus fraxineus* Kowalski) is estimated to have a total economic cost of £15 billion over 100 years, in terms of lost biodiversity benefits [11], and is expected to kill over 90% of UK ash. The impacts of these pests and diseases are broad, affecting a range of ecosystem services provided by trees, including timber and fuel production, carbon sequestration, flood mitigation, water quality, health and recreation, and biodiversity [12].

Due to the scale of these challenges, solutions cannot be applied on an individual forest basis, but must be viewed holistically at the landscape scale, and beyond. In climate change research, the need for multilevel governance and research/practitioner networks has been highlighted as necessary to facilitate proactive adaptation and mitigation due to the global nature of climate change and the local nature of the resulting impacts [13–17]. In forestry, forest ecosystems and the services they provide are influenced by the surrounding landscape. For example, there have been calls to expand forestry decision support systems to the landscape scale to better account for climate change, biodiversity and ecosystem service provisions [18]. The uncertainties around future impacts of anthropogenic threats add to complications in the ability to enact responses via evidence-based, best practice management [19–21]. This is particularly evident in climate change research, where significant barriers persist to the integration of a large body of scientific evidence into policy and practice [22,23]. Similar issues arise in forestry, where climate change mitigation is limited by cognitive, institutional, normative and strategic obstacles, as well as political and economic issues [20]. Mitigation and adaptation to tree health threats therefore require collaborative action between multiple actors from a range of industries and disciplines [24,25], operating across the landscape.

In the UK, the response to current and future pest and disease threats has led to a range of government and organisational responses. The government produced a "Plant Biosecurity Strategy for Great Britain" in 2014 [26] and a "Tree Health Resilience Strategy" in 2018 [27]. The latter was developed in partnership with a range of key stakeholders. In it, the government sets out priority behavioural goals, which include working together to protect and value trees, putting biosecurity at the heart of onsite activities and buying practices, developing and applying the latest evidence, and building the knowledge and capability involved in applying the concept of resilience. While forests provide ecosystem services for society, many forests are in private ownership, which can result in varied management objectives and some woodlands that are not actively managed. National forestry statistics make the distinction between the area of public forest estate, i.e., that owned and managed by the national governments of the UK (at around 27%), and all other woodland, accounting for 73% by area, most of which is in private ownership, although some other kinds of public land are included, e.g., Local Authority woodland [28].

Knowledge exchange and the provision of incentives to forest managers to improve landscape-level action for more resilient forests is therefore a key challenge for policy makers. In a study assessing awareness of tree pests and diseases across Europe, Marzano et al. [29] found that these levels of awareness were low. They argued that tree professionals could play a role in knowledge brokerage by communicating and disseminating their experience and knowledge to other less specialised colleagues. Information and knowledge exchange, however, presents unique challenges due to the fast pace of pest and disease threats and the development of new research and guidance, and a range of varied management objectives are held by different stakeholders. This creates a knowledge landscape that can be difficult for managers to navigate, leading to delays in taking action, undesired actions or inaction. For example, research on Dothistroma needle blight (*Dothistroma septosporum*) in the UK found that stakeholders had a high level of awareness of the disease; however, there was little action being taken to prevent or manage it due to uncertainties about the cause of the disease and its impact, identifying responsibilities for action, and some scepticism concerning the advice being provided [30]. In a bid to improve awareness among land managers, applicants to the recent Tree Health Pilot Scheme in the UK will be required to attend a mandatory seminar on woodland threats, which covers information on tree pests and diseases [31]. The scheme offers a range of different land manager types support in actions such as felling and replacing diseased trees.

1.2. The Role of Knowledge Networks in Responding to Tree Health Issues

One of the ways in which this knowledge exchange can take place is through networks that come together to deal with a specific issue of common interest. A number of tree health-focused networks have been established as a result of the demand for landscape-scale social learning, collaboration and response to arising tree health threats. Such partnerships and networks bring together landowners and managers, as well as a wide range of organisations, to debate and discuss different pest and disease issues and to consider what response or actions could be undertaken. The Organisation for Economic Co-operation and Development (OECD) defines partnerships as agreements to do something together that will benefit all [32], while Williams et al. [31] (p. 2) define networks as groups of people with a common interest who interact and cooperate for mutual assistance and support in relation to a common interest they have. We use the Williams et al. [33] definition of networks, but use the term local and regional knowledge networks (LRKN) to capture activity and action at a local and/or regional scale, rather than national. The stakeholders involved in these networks include local authorities, government bodies, non-governmental organisations, private sector businesses, landowners and managers, and communities.

These networks build up capacities through the provision of training, or organising social and practical events and other social interactions [34]. Through these actions, the improved creation, translation and dissemination of information and evidence takes place [35–37]. Social interaction, participation and knowledge sharing can all be part of social learning processes [38]. This positions networks as key arenas for addressing complex tree health issues through fostering adaptive and interdisciplinary social learning among different types of landowners and organisations. Social learning can be defined as "a change in understanding that goes beyond the individual to become situated within wider social units or communities of practice through social interactions between actors within social networks", [37] (p. 6). It has long been promoted as an important tool for collective decision-making and adaptation in the face of complex environmental threats with future uncertainties [39].

LRKNs are becoming increasingly important in raising awareness in areas facing specific tree pests and disease threats. One such network is EPIC (Emerging Pests In Colorado) in Colorado, United States (US). This state-wide forestry group aims to educate foresters about new pests and diseases as they arise. The group operates at different levels. It helped to drive a county-wide quarantine of Emerald ash borer (*Agrilus planipennis* Fairmaire) and was able to highlight impacts at the federal, state and local level (Pers. Comms from

EPIC member, December, 2018). In western Australia, there has been a transformation in biosecurity management from an industry-led to an institutional and community-led approach. The Australian government supports formally recognised biosecurity groups (made up of a range of stakeholders), which enable landowners to develop a coordinated approach to managing declared invasive pests, such as wild dogs (*Canis lupus* L.), red foxes (*Vulpes vulpes* L.), narrow-leaf cotton bush (*Gomphocarpus fruticosus* (L.) W.T. Aiton), and Mediterranean fruit fly (*Ceratitis capitata* Wiedemann), through secure funding mechanisms [40]. The groups have a range of responsibilities, such as surveillance and reporting and assisting with compliance, but also undertake knowledge-based activities such as promoting best practice management in local landholders, and engaging with stakeholders and citizen scientists for knowledge sharing. O'Brien et al. [41], in a qualitative study of woodland managers in the UK, found that land manager networks were important to individual woodland managers, and were often seen as useful sources of information and advice that help to build social capital (defined as connections between individuals and the trust and reciprocity that arises from them [42]) and contribute to social learning. However, in some of the newer and smaller woodland managers in the UK, there was a low level of awareness of the types of networks that might assist them with information and advice relevant to their managerial decision-making.

Some environmental networks additionally take on the role of governance networking, linking them to local and national policy. For example, the Oak Mortality Task Force in Canada put together a document informing legislators of priorities for research, management and education to support the creation of quarantines and regulation to contain Ramorum disease (*Phytophthora ramorum* Werres, De Cock & Man) [43]. The Grand River Partnership in the US worked with policy-makers to identify endangered species' habitats, which could potentially lead to stricter zoning decisions and larger riparian setbacks [44]. The Countryside Stewardship Facilitation Fund in the UK brings stakeholders together to develop plans and strategies to improve the natural environment at a landscape level [45].

By exploring the experiences and perceptions of members of three tree health knowledge networks, we investigate in this research:

- whether LRKNs facilitate action based on evidence-based learning;
- the role of LRKNs in raising awareness and supporting social learning;
- how LRKNs encourage and support mitigation and adaptation to tree pests and diseases on a landscape level to build long-term resilience.

We use UK-based LRKNs as the lens through which we investigate this globally applicable topic. The following section sets out the methodological approach to the study. We then present the results, followed by a discussion of the findings and some final conclusions.

The project was undertaken as part of a Department of Environment, Food and Rural Affairs (Defra)-funded policy co-design project. Land managers were involved in a process that explored their real-world behaviours and reactions to different policy options designed to support and incentivise their actions towards tree health. This paper focuses on the findings related to networks. We use the term networks in the rest of the paper to mean local and regional knowledge networks.

2. Materials and Methods

For this study a qualitative methodology was applied, focusing on three tree health networks. Currently there are very few networks focused solely on tree pests and diseases in the UK. Other networks include pests and diseases as part of a wider remit. We therefore included two networks that were created solely to focus on tree pests and diseases, and one larger, city-based network, that includes specific sub-groups that focus on a particular pest or disease. These networks were chosen due to their strong focus on tree pest and disease issues. Interviews, email exchanges, and in situ participations in network meetings were undertaken in different combinations with the three networks to collect data (Table 1). Twenty interviews were undertaken, following an interview guide (Supplementary information 1). Two people were interviewed twice to explore some of

the actions the networks were undertaking. Forty-one people participated in two network meeting discussions.

Table 1. Characteristics of the three networks studied and the methods the researchers used for data gathering.

Length of Time as a Network	Type of Stakeholders Involved	Focus of Network	Methods of Data Gathering
		Network 1	
Short term, 2–3 years	The stakeholders were mainly part of national and local government organisations, charities and businesses, but also there were individual members such as private landowners and land agents, and also wood processing stakeholders	One sub-working group in the network. The focus of the network is on a single pest/disease primarily [1].	Six interviews were undertaken with members of the network (one person was interviewed twice). Interviews included the chair (local authority representative), the chair of a sub-group within the network (retired independent person), and two network members, one from a government body and the other from an NGO. One interview with a person (NGO) who helped to create the network but is not a current member. Researchers attended at a network meeting with a slot for a focused discussion on the research. Twenty-one people attended the network meeting excluding the researchers.
		Network 2	
Medium term, 4–8 years	The stakeholders were part of government agencies and local government, NGOs, timber processors and members of private estates	The network focus is on two pests/diseases.	Six interviews were undertaken with members of the network including the chair (government body representative) and 5 network members, 2 of whom worked for different NGOs and 3 who worked for a government body. Researchers attended a network meeting with a slot for a focused discussion on the research. Twenty people attended the network meeting excluding the researchers.
		Network 3	
Long term–8+ years	The stakeholders were mainly corporate members, tree managers and tree officers. Additionally, the network includes nurseries, contractors and consultants.	Members of the network pay a fee to join. The fee pays for a secretariat and network events. Numerous sub-working groups exist within the network with at least two focusing on specific pests/diseases.	Seven interviews were undertaken with members of the network (one person was interviewed twice) including the chair (local authority representative), the chair of a network sub-group (local authority), the coordinator of the network and three people from different local authorities.

[1] Note: The specific pests and diseases focused on by the three networks are not provided as this would identify the networks.

In the interviews, in situ discussions and email exchanges, we explored what the aims and objectives of the networks were, when and how the networks formed, how long they had been running for and who was involved. We also discussed the leadership of the networks and what that involved, as well as exploring any actions the networks had taken in relation to pests and diseases, what challenges or barriers the networks faced, whether those involved thought the networks were sustainable in the long term, what evidence and information the networks draw on to aid their decision making and whether there were any mechanisms that might support the network's activities.

Interviewees completed a consent form that provided information about the research, which allowed them to prepare for the interview, and highlighted how their data would be used and that they would remain anonymous. Interviews took place face to face and over the telephone between October 2018 and February 2019. All interviews, whether face to

face (n = 3) or by telephone (n = 17), were scheduled with key people involved in the three networks. Interviews lasted between 45 min to over 1 h and were recorded and transcribed verbatim. Comprehensive notes were taken at the meetings of Network 1 and 2, which both included a slot in the agenda for focused discussion on the running and activities of the networks. Follow-up emails were also sent to selected network members asking specific questions regarding what might or might not have been achieved if the network did not exist. These data were imported into NVivo 12 for analysis. The data were then coded, which is a process of indexing or mapping textual data to allow for its analysis in relation to the research questions [46]. The thematic framework was developed using a deductive/dominant approach, based on the research questions and findings from the literature, while allowing for the creation of emerging codes [46,47]. The framework had seven themes: information; knowledge; learning; decision-making; policy support; action; and network identity.

3. Results

The following results section focuses on the key findings, firstly by accounting for the ways in which networks encourage collaborative and individual mitigation and adaptation to tree pests and diseases, followed by an outline of the levels at which networks operate and influence. The key network activities supporting mitigation and adaptation are then described in more detail; namely, how they contribute to building and disseminating evidence through knowledge exchange and social learning, and how they can help build social capital to improve the effectiveness of responses to pests and diseases. The following results also include reflections on the factors hindering or supporting networks in achieving their goals.

Network 1 was created to focus on one pest/disease specifically in relation to trees outside of woodlands. The network's aims include managing diseased trees in high-risk situations and exploring longer-term ecological and landscape resilience. Network 2 had a strong focus on one pest/disease initially, and more recently has included another as it has become more of an issue for the area where the network is located. It aims to bring together key stakeholders and groups to discuss tree health issues. Network 3 focuses particularly on trees in urban areas, and it has working groups focusing on specific tree pests and diseases.

3.1. Networks: Encouraging and Supporting Mitigation and Adaptation Actions

The main aim of the three networks was knowledge exchange leading to increased awareness and potential actions being undertaken by individual network members, aiming to encourage appropriate responses to current and emerging pest and disease threats. Changes in individuals' awareness and responses resulted from various forms of information transfer and knowledge exchange, most notably through social interactions and the development of tailored guidance for network members. A range of collaborative actions were also undertaken by the networks to facilitate suitable responses by diverse stakeholders across the landscape. These collective actions included exchanging information and knowledge, running workshops and field trips, developing guidance, collaborating and trying to influence policy (Table 2). Some networks were actively engaged in the translation of government and scientific advice as they felt it was important to produce practitioner-friendly documents with a strong focus on local context and easy readability for a variety of land managers.

We also asked interviewees about a counterfactual, i.e., what did they think would have happened or would not have happened if the network had not existed (Table 3). Interviewees identified outcomes and actions that would not have occurred without the network being in place, and also the outcomes and activities that may have happened without a network but which may have been delayed or have been less comprehensive. For example, translating and creating guidance could have been undertaken by an individual organisation, but potentially may not have got the same level of "buy-in" as guidance

developed by a network made up of multiple organisations and private individuals. These actions include bringing people with expertise together, supporting members of the networks and raising funds, the dissemination and synthesis of information, and other direct actions. Network 2 addressed structural barriers to responding to a novel disease within the forestry industry by building capacity in the supply chain for handling felled stock; for example, by guiding handlers of timber through the licensing process. The other two networks sought external funding opportunities, for example, to publish attractive documents, to undertake a survey (network 3) and to set up a replanting project (network 1) in collaboration with other organisations. The first attempt to gain funding for the replanting project was unsuccessful, but other proposals were made. The network specifically sought to replace trees lost to disease by setting up community nurseries and involving school groups in tree planting if they gained funding. Ultimately, it was the networks' role in knowledge exchange and social learning that was seen as the most significant contribution to building stakeholder capacity to mitigate and adapt to the threats of pests and diseases. This was illustrated by one respondent:

> *"A benefit from this is that information is cascaded by members of the group to colleagues, and that outbreaks of quarantine pests and diseases [. . .] in this region are often picked up and reported at an early stage potentially allowing more rapid management."* (Network 2, interviewee 8)

Table 2. Examples of actions undertaken by the networks aiming to improve the management of trees and woodlands facing pests and diseases.

Exchange Information, Knowledge	Run Workshops, Field Trips, etc.	Develop Guidance, Action Plans, Communication Plans	Collaborate, Share Information with Others	Influence Policy, Legislation
		Network 1		
Disseminated practical information	Ran w/shop sessions at a Local Nature Partnership conference. Organised field trips.	An action plan was developed before the network was formally constituted. The network once formed developed a communication plan, 4 guidance documents prepared by a sub-group, and risk assessments.	Shared lessons with other Local Authorities in England, learned from other Local Authorities, and sought external funding.	A member of the network sits on a government panel to discuss a specific disease.
		Network 2		
Provided up-to-date regional tree pest and disease situation reports and information about relevant future threats	N/A	Simplified and condensed existing guidance from the national level to make it relevant to the local context.	Learned from others and shared knowledge.	Aims to influence policy.
		Network 3		
Disseminated information on best practice	The network runs four technical seminars per year, as well as various field trips, workshops.	Developed a position statement on biosecurity. Simplified and condensed existing guidance.	A few network members visited Italy to explore a specific pest and disease and translated relevant evidence into English.	Aims to influence policy, legislation, and raise standards.

Table 3. Perceptions of the interviewees concerning whether they felt the actions and outcomes of the networks would have occurred even if the network had not existed. The activities of ringing people with expertise together, supporting members and raising funds are coloured in green, synthesising and communicating actions are coloured in blue, and other actions are coloured in orange.

	Network 1	Network 2	Network 3
Outcomes that would not have happened without the network being in place	Support an integrated approach to the tree disease response from both a public safety perspective and ecological perspective.	None to report.	Network and informal information sharing at organised social events.
	Support and knowledge exchange with other counties to develop similar networks.		The ability to draw on the expertise of network members to develop a guidance document.
Outcomes that would have happened but would have been delayed or less comprehensive without the networks, resulting in significant consequences	The network brought attention to a disease and required a response. Due to the network, the local area is now recognised as one of the leading counties responding to the disease.	Up-to-date regional pest and disease information cascaded to members and other stakeholders.	Bringing together professionals from all sectors (due to the network members' level of knowledge and breadth of experiences, which is seen to be unsurpassed by any other organisation)
	The network acting as a "therapy class" for members who felt a sense of loss due to the impact of tree losses associated with a tree disease.	Information picked up and reported at an early stage for rapid management.	Dissemination of information, seminars, workshops could have been replaced, but would not be on such a wide scale and as good quality built through network relationships.
	The network developing capacity to engage with other organisations and attract the right group of people. The network adds credibility and authority to the work, facilitating the achievement of goals.	Benefiting from a range of contacts and at no cost when synthesising and disseminating information.	Others could have tried to undertake similar actions as an individual (e.g., synthesis and targeting information), but the content would not have been as well regarded if the network had not been involved.
	Broadcasting information would be more difficult because there was no one cross-sector/interest body able to fulfil this role.		
	Action plans and guidance documents could be developed by other organisations, but would have less impact without collective effort.		
Outcomes that would have happened but would have been delayed or less comprehensive resulting in modest or minimal consequences	Action plan that was produced before network formally got together.	Gaining funding to support the work of the network. Other organisations can successfully apply for funding without the network.	Somebody else (outside of a network) would have created a biosecurity position statement (but it would have potentially taken a different angle to that of the network).
	Capacity to raise funds (one bid was unsuccessful but the network has other funding pots in mind).		

Note: raising funds in greem, synthesis and communication in blue and other in orange.

3.2. Networks: Operating at Multiple Levels across the Landscape

The focuses of networks differed, with one operating at a regional landscape level and the other two operating at a local level. More notably, however, the networks influenced and collaborated at multiple levels. The core members of the networks, a subset of the key knowledge champions, collaborated on problem definition and knowledge translation. These key knowledge champions were well-connected tree health professionals who volunteered their time to help achieve the network's aims through actively participating in deliberative discussions and other network activities. Knowledge champions would often address the issue from a strategic point of view and link up with other national stakeholders. From there, other network members were engaged mainly through developing knowledge exchange products and regional or local events. Some knowledge exchange products, such as guidelines and pamphlets, were made publicly available, and thereby reached a wider public, non-member, audience as well. The personal networks of knowledge champions and their involvement in other initiatives allowed them to link up approaches and reach out to other networks, groups or organisations. Network members would also collaborate with other organisations, and share information and knowledge from the network with other peers as well as within their workplaces. In addition, several networks actively facilitated cross-network interactions. As an example, network 3 set up a forum with spokespersons from many other similar networks, covering a range of current tree health issues and bringing together the expertise of all the participating networks. Finally, although networks were geographically defined, some information was made available online, and therefore has the potential to reach interested stakeholders anywhere. Based on this, it is clear that while there are variations in how networks are structured, they can function as dynamic knowledge exchange mechanisms, linking up stakeholders at the local, regional and national levels, as illustrated by one respondent:

> *"So it was kind of bringing all those people together to have those conversations and then bringing experts in [. . .]. So we had meetings and then the attendees had larger meetings, or [. . .] larger events where more people would come as well. So, it was building a network locally and then trying to raise awareness more broadly with landowners and the wider sector."* (Network 2 interviewee 11)

As well as operating at different geographical levels, networks facilitate knowledge exchange between different groups of stakeholders including practitioners, NGOs, government employees and other industry professionals. This helps bridge the gaps between different stakeholder types across the region, improve the sharing of different sources of information, and ensure the representation of a greater diversity of voices. It was, however, pointed out that the wider the range and higher the number of present stakeholders, the more difficult it is to come to a consensus in a network. It was considered a paradox by some interviewees that the strength of a network is in bringing together different voices and opinions, while this is also one of the main challenges. Yet it was also highlighted that various actors with different objectives are still able to work towards a set of shared objectives.

3.3. Networks: Evidence-Based Knowledge Exchange and Social Learning

A key element of the networks' activity was to raise awareness of specific pests and diseases both within the core networks and then moving outwards to those land managers (individuals and organisations) within a given area who may need to know about a specific pest and disease. The interviewed network members highlighted many ways in which learning took place within the networks and beyond. While some awareness-raising and learning relied on traditional models of one-way dissemination of information, all networks engaged in a range of activities supporting dynamic knowledge exchange. The main knowledge exchange model (i.e., the combination of learning activities) varied based on network objectives. Knowledge sharing formats could be in-person formal events such as meetings, seminars, field trips and training, while informal knowledge exchange happened during breaks, social gatherings after seminars or at gatherings organised especially for

social occasions, such as Christmas drinks. Virtual knowledge exchange and key actions of the networks included developing media pieces, websites, guidance notes, action plans, position statements, management plan templates and leaflets.

> *"So it's learning from other people about how they've done it and then putting that into place. So hopefully it won't get here but if it does, I'm hoping we've got a half decent chance of getting it quickly enough."* (Network 3 Interviewee 7a)

Informal conversations would take place through letters, phone calls, emails and the signposting of documents. It was highlighted that the informal aspects of networks were seen as just as important as the formal aspects, as conversations during breaks or at the pub helped develop and strengthen relationships, develop trust, and share views and experiences, as described by one network member:

> *"There's a big social aspect as well to the [network] that probably isn't really referenced very much but there's a Christmas drink, there's a summer drink and there's a sort of trivial social but there's also quite an important . . . people sit down and have a chat about their work and issues. So that's actually a very important side to it and there's lots of information exchange on that slightly more informal basis [. . .] They are really important."* (Network 3 interviewee 15)

The processes of knowledge sharing among network members and their contacts was enhanced by network chairs, secretariats or other knowledge-sharing champions. Chairs and secretariats were often well-connected and well-liked individuals, and they used this status to keep other members engaged. Chairs and other knowledge champions (discussed under Section 3.1) were seen as pivotal in continuing activities and driving work forwards. It was, however, noted that most members were often limited by time constraints. Many network actions were delivered based on time volunteered by its members and the knowledge exchange engagements required to take this into account.

Of particular significance was the development of new knowledge products through a process of peer-reviewing existing information, and group deliberation and translation of the findings into applicable, usable knowledge products for the network's target audiences. It was felt that the guidance benefited from collaboration between stakeholders, cross-sector involvement, and even from identifying information internationally. The guidance aimed to explain how science can inform management on the ground in a clear and succinct language, and in a way that can be tailored to individual local contexts or management objectives. Although it was noted that what people take away from guidance is individual, it was ultimately hoped that the prevention, treatment and felling of diseased or infested trees was undertaken by more aware network members and based on informed choices. Changes in response were expected to influence individual network members and other land managers;

> *"I think being presented with information in a factual way led people to react to the arrival of pest diseases in a positive way [. . .] and have a high level of compliance in dealing with infected [stands] in the [region] and as it's predominantly privately owned woodland that's affected most, it's hats off to them for dealing with something that has an extra financial implication for them, but they understand that if they do something that may mitigate the impact on the surrounding [stands]."* (Network 2 interviewee 8)

3.4. Networks: Improving Social Captial to Support and Enable Action

The building of social capital was evident among the networks. Networks were created in various contexts and their structures differed as a result. Some networks came together to work on a single specific issue, such as a recent pest or disease outbreak, but wider drivers were involved, such as a shared sense of loss and lost cultural values due to the tree disease. Members built trust over time and worked together to define shared objectives, often developing a shared identity.

> *"Yes and building relationships is the critical bit as when something happens you are ready, . . . they swung straight into action because they trusted each other. You have*

> *to have a shared mission and a shared objective and shared thought processes to help you deliver the end point."* (Assisted in developing network 1 but not part of it, interviewee 13)

However, agreement could not always be reached, and sometimes different viewpoints led to clashes. When network members were not in agreement, this could create complications around messaging and outwards branding and communication. Whether the process of agreeing and making decisions was straightforward or not, it was always perceived as valuable for the involved actors. For example, when certain stakeholders were not supportive of a message, this could lead to helpful debates about framing these messages within a wider context and from a number of different angles or viewpoints. Bringing everyone together reduced the need for the replication of knowledge exchange products, instilled a sense of pride in participants, and facilitated the building of trust. Networks were sometimes set up partly as a response to imperfect information, and credibility was then essential for the continuity and use value of the networks, directly influencing the uptake of information. Several networks felt that they were seen as a credible source of knowledge, partly because the documents developed by the networks had gone through a process of internal expert deliberation and validation. Furthermore, information-sharing as a network was seen as giving greater strength and voice to the cause, as illustrated by one network member:

> *"There is an element [. . .] that is advantageous if you are part of the herd, in that you are not the sole beast out there advocating something that everybody else is against. So, herd immunity gives you that cover and that is important. If everybody has agreed, then it is stronger to articulate this is not just our X organisation's view, this is our collective view."* (Network 1 interviewee 13)

Social capital was also built by the networks through the development of relationships. Once relationships have been built, they serve a valuable function, and there is often a demand for continued engagement among members, meaning the network is able to sustain itself. In general terms, the networks improved the accessibility of tacit, practical and scientific information on particular issues through improved connections between different stakeholders. The ability to call a contact from a network who would be able to provide a solution, collaborate on a problem or redirect to another expert in the area was perceived as an effective resource for problem-solving.

It was highlighted that the existence of social capital among network members across the landscape meant that upon the arrival of new pest and disease threats, knowledge and action could be mobilised more efficiently, ensuring a timely response. What this mobilisation looks like in practical terms depends on the network structure, but network 3 is a good example. This paid membership network with a funded coordinator operated a more structured model with working groups for different topics, which people were able to join based on relevance to themselves. Groups often came together when there was a need or something new occurred, e.g., an emerging pest or disease threat, or in order to respond to government initiatives and legislation. Some working groups were discontinued when they were no longer needed, while the members remained in the network. However, the long-term stability of networks relies heavily on the availability of facilitation. One network was funded through paid memberships and another network relied on the chair being continuously supported by a government body. While the funding of actions or events, or facilities used to host these events, was mentioned as a barrier or a driver on several occasions, it was often people's lack of capacity to develop and organise these that was a key issue. In fact, a couple of networks highlighted that even with increased funding, capacity would remain a challenge. However, network 2, who were supported by a government employee, were helping to set up another network in a different region of England.

Finally, the availability of networks increases connectivity between policy, industry and practice. A number of networks could actively feed into policy development. One

network had a direct link with a government body, as it was chaired by a government body employee. This also allowed a two-way flow between the government body and the network participants, and in some cases, information from the network would feed into the government body's strategies. Similarly, a member working for a local authority believed their participation had led to them influencing policies in their job role.

4. Discussion

The results from this study clearly indicate that knowledge networks for tree health can facilitate knowledge exchange and action at different levels across the landscape. Figure 1 illustrates how awareness, plans, strategies, and actions operated at different geographical levels in this research. This allows for multi-level governance that can include vertical (from national to local) and horizontal (across different bodies and sectors) cooperation [48]. The networks took note of national policy and strategies, and tried to integrate these at a local level by adapting them into a more user-friendly language. A network 1 member operating at the local level sat on a government panel as a local agent of change. Network 2 focused on the regional level in terms of awareness raised and knowledge exchanged, while networks 1 and 3 focused on the county/city level, developing more specific strategies for action, including knowledge exchange and bringing together NGOs, local government and public and private land managers and owners. The networks were keen to learn from each other; however, this depended on their awareness of other networks, and there was no single source of information from which networks could find out if there were others like themselves, meaning there was a strong reliance on word of mouth.

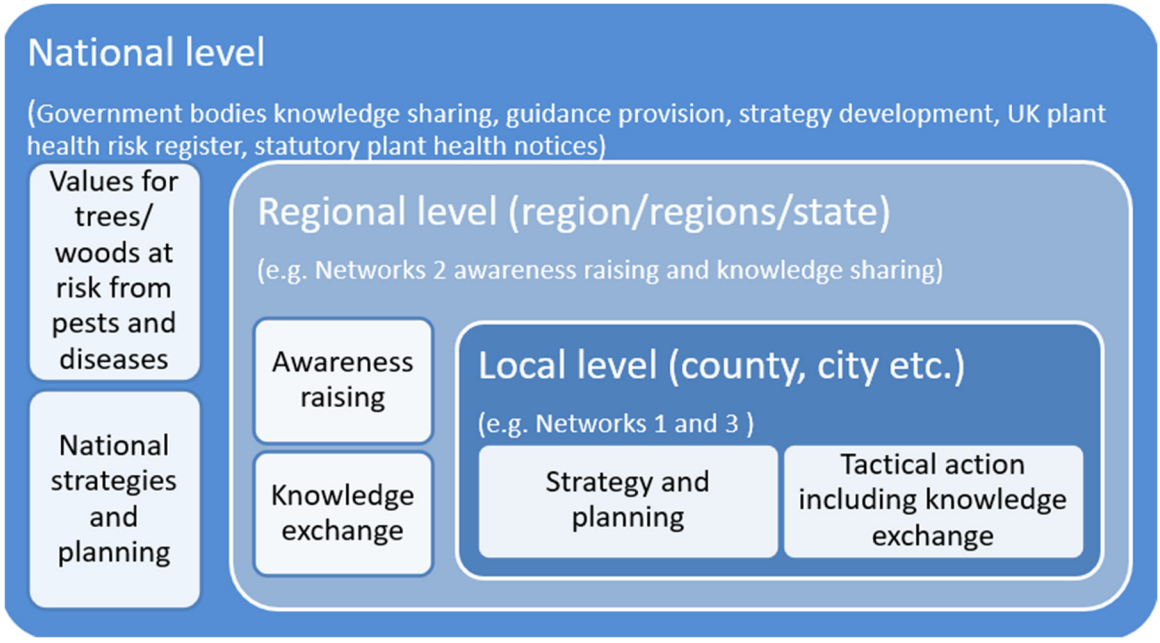

Figure 1. Mitigation and adaptation to tree pests and diseases on national, regional and local scales.

In this study, an outcome of the local and regional knowledge networks was the building of social capital, which supported the activities of the networks and was a key reason for network members to continue their engagement with the networks. The networks in this research face complex environmental problems fraught with complicated and at times contradictory information, a range of stakeholders with different management objectives, and competing land-use priorities. Mandarano [49] and Rickenback [50] suggest that bringing together network ties, the internal resources of individuals and/or organisations, and an external stimulus can contribute to sustainable collaboration in natural resource management. On an individual level, Sandefur and Laumann (p. 484) [51] describe the network approach as *"an individual's potential stock of social capital which consists of the col-*

lection and pattern of relationships in which she is involved and to which she has access". This research supports previous findings that networks can lead to improved individual and group social capital, which is valuable to natural resource management.

On the group level, the networks could help bring different stakeholders together to raise awareness of a tree health issue, come to a consensus on problem definition, and develop shared goals. This process is particularly important for building confidence in actions in spite of the many different voices and conflicting viewpoints across the industry and landscape. This reflects the findings of other networks faced with solving complex environmental challenges. For example, Borg et al. [52] in a study of social capital and governance in relation to forest biodiversity in Finland found that short-term governance networks operated on trust, and differences could be put to one side for the collective good of finding solutions to conservation issues. Trimble and Lázaro [53] similarly showed that stakeholders changed from focusing on individual interests to focusing on the collective interest of the group in a research/action partnership for fisheries management in Uruguay.

On the individual level, network events provided important opportunities for members to come together and have face to face interactions with peers and subject experts, and to share experiences and concerns, thus helping build social capital [54,55]. Increased access to personalised information for a range of stakeholders was seen as beneficial in personal problem-solving. Ultimately, these networks were seen to facilitate the timely raising of awareness and action on arising tree health issues. This mirrors the findings of Cockburn et al. [56], who highlighted the importance of interhuman relationships in facilitating actions of governance in social ecological systems.

Alongside social capital, networks are also valuable spaces for social learning. There is a great deal of uncertainty about the future impacts of tree health issues and the management methods likely to be effective in mitigating these threats. Social learning can be a powerful tool for knowledge exchange and adaptation in governance systems dominated by complexity and uncertainty. Social learning goes beyond the simple transmission of facts, involving exchanges of knowledge and debates, these being processes through which ideas and understandings may change [57]. Different ways of learning, knowledge sharing and building trust were evident in the networks assessed in this study. Lauber and Brown [58] argue that social learning creates the foundation for technical and conceptual learning, and suggest that relationships and social processes are important for information translation and supporting knowledge generation. The translation of scientific evidence into practical recommendations was among the key network functions. The implications of tree health issues vary geographically based on local ecologies and management objectives. Networks provided important opportunities for local and regional stakeholders to deliberate over what actions would be appropriate in their own contexts. A previous case study of a community/researcher partnership in the Canadian Arctic similarly showed that knowledge produced by this partnership was more applicable in the local context [59]. Another study of local stewardship practitioners in South Africa emphasised the importance of the local experiences and knowledge of these practitioners who acted as relational hubs in the landscape [56].

Social learning has previously been found to be contingent in the development of trust among stakeholders and researchers collaborating in the adaptive management of rangeland [60], while another study hypothesised that social learning emerged from the interrelation of trust, commitment and reframing in an innovation network for local development in northern Holland [61]. Either way, trust was seen as important to the collaboration between stakeholders and to the uptake of guidance and advice. This further aligns with Inkpen and Tsang's [62] argument that shared goals, shared culture and trust are among the main conditions enabling knowledge transferal.

The aforementioned processes can take a long time. Measham [63], in a study of European Union Catchment Demonstration Initiatives, found that evidence of social learning arose in these initiatives after fifteen months, and it was five years before the participants had learnt enough to implement the desired management actions with confidence. This

highlights human resources as the main resource for and potential limitation to knowledge networks. While the networks mentioned some resources that could have benefited their operations, such as funding or a place to host meetings, human factors constituted both the driving force behind networks and the main barriers. The long-term sustainability of networks depends on knowledge champions, and outputs are often produced through volunteered time. Previous research into learning and collective action through partnerships for national park practitioners similarly found human factors to be as supportive or preventative as time and funding [64]. The importance of champions was also highlighted in the study of practitioners in South Africa [56]. Here, stewardship practitioners were found to create linkages between stakeholders across the landscape and facilitate social learning processes, leading to new relationships, improved knowledge sharing and the long-term sustainability of initiatives. Furthermore, these practitioners built "linking" social capital by linking the networks with other provincial or national-level actors. It is therefore important to recognise the importance of knowledge sharing champions and network members, and the voluntary contributions they often make. Furthermore, network supporters and participants will initially need to allow ample time for social learning processes, such as discussions and deliberation.

Not many direct actions were taken by the sampled networks, but this is likely a result of the focus of networks on knowledge exchange activity, encouraging members and other individuals to take appropriate actions to deal with pests and diseases on their own land. It is difficult to pinpoint the actions undertaken by network members, and even more difficult to attribute resilience outcomes to social learning interactions [65]. In fact, very few studies have attempted to attribute land manager actions to sources of information or social networks [66]. However, our results indicate that the interviewees' actions had been influenced by their participation in a network. While further research is needed to fully understand how social learning and social capital built by networks influence individual actions as well as collective network actions, this research shows that local and regional networks can play an important role in knowledge exchange, facilitating strategic landscape-scale mitigation and adaptation in the face of tree health threats. There is potential for networks to consider paid membership to support their activities and for governments to specifically support and facilitate networks, or aid networks in finding suitable sources of funding to enable them to be sustainable, as well as enabling the sharing of network knowledge and undertaking actions at a national level. This would enable emerging networks to learn from those that already exist and bring together diverse stakeholders at the local and regional landscape levels.

5. Conclusions

The threat of tree pests and diseases is increasing in many countries, including the UK, with climate change and the globalisation of trade leading to greater risks. Dealing with these threats requires actions from many organisations and individuals. Stakeholders need to be included in responses to pest and disease threats, and networks can play an important role in raising awareness, knowledge exchange and linking up diverse land managers. There are few local and regional knowledge networks in the UK focused solely on specific tree pests and diseases. However, given the increase in pests and diseases in the past decades, more networks are likely to emerge, and forest and land manager networks might place more of a focus on tree health in the future. The interviews highlighted that those involved in networks found practical approaches, such as case studies of actions other land managers take, as well as field trips, to be particularly effective ways of enabling knowledge exchange, followed by practical guidance. The interviewees in the three networks provided evidence of the importance of their networks in developing a collective approach, creating a stronger voice, aiding different organisations and individuals to work together, and providing an arena for social learning and developing useful relationships. The long-term sustainability of the networks is unclear; they often rely on a core set of people who undertake much of the network activity in a voluntary capacity. As outlined in our

introduction, there is currently a drive to expand tree and woodland cover in Britain to meet net zero targets, but there are growing threats to these trees from various pests and disease. Partnership work, effective knowledge exchange and social learning through networks such as those outlined in this paper are likely to become increasingly important when dealing with threats to tree health. Our research highlights that these networks are under-resourced and struggle with capacity. A recognition of the importance of networks and the provision of financial support could aid their continuation.

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