Final Report

Network analysis – where do people get their plant health information?

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Learning together: a report on knowledge production, exchange and implementation for plant health across people in Scotland

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Authors are listed in alphabetical order. Elliot and Henry led on the conceptualisation of the social network analysis project and the data collection through Twitter, Althea and James led on the annotated bibliography, Robbie led on the survey and debate on stakeholder analysis, James and Mariella led on interviews and nursery data, Rehema and Mariella led on conceptualisation of the review and stakeholder engagement and Rehema pulled together the elements into the final report. However, this was an integrated, interdisciplinary project with cross -section collaboration.

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Table of contents	Page

EXECUTIVE SUMMARY

There has been increasing concern over plant health, especially over the past decade. The risks of invasion and spread of new pests and pathogens have escalated due to globalisation, international trade, climate change and changes in social practice. In order to understand these risks and be able to plan and put into place solutions, we need effective knowledge production, exchange and implementation.

Scotland's Plant Health Centre (PHC) wanted to understand where in Scotland people obtained information about plant health to enable more effective management. Together, University of St Andrews, Forest Research Scotland and SRUC undertook this review and scoping research to begin to address this issue and to offer initial recommendations.

Aims

1. **To sketch a conceptual framework for plant health knowledge flows**
2. **To review plant health knowledge flows amongst stakeholders**
3. **To discuss potential stakeholders and engagement**
4. **To empirically scope existing and potential knowledge flows**
5. **To employ social network analysis to scope knowledge flows**
6. **To provide conclusions and recommendations**

Chapter 2 describes our methodological approach. In Chapter 3, we develop a conceptual framework exploring how knowledge is produced, shared and implemented and how it is relevant in policy and practice. We show in particular how knowledge flows and use have been explored in previous studies on plant health, across the four broad and overlapping areas of forestry, agriculture, horticulture and environment, with particular relevance to Scotland. The transmission of knowledge does not guarantee a change in behaviour or uptake of new practices or technologies, and we described different conceptual frameworks to understand how people change attitudes and behaviour, or succumb to societal shifts in practice, are nudged or experience a tipping point such as pest invasion. We highlighted how the type of knowledge and knowledge flows required will be affected by: **Risk; Stakeholder awareness** and the types of deeper **stakeholder engagement** required to co-design and implement solutions and **Stage of invasion** – outbreaks occur along a time trajectory and different knowledge focus is required depending on whether a pest is Endemic or an outbreak trajectory requires Specific awareness, Alert awareness or Crisis management. Because this literature is broad and without clear boundary, and is spread across academic and non-academic literatures, we also offer an annotated bibliography of key texts and their potential use in plant health policy and practice in Appendix 1.

In Chapter 4, we discuss stakeholders who might be engaged about plant health in Scotland. We draw on the stakeholder categorisation of Dandy et al (2017) for **Vectors**, **Governors, Managers, Monitors** or **Networkers**. We added to this categorisation **Plant enthusiasts,** to include those interested in plants through place, activity or focus. An indicative stakeholder map (Appendix 2) was produced that included examples of state, private and third sector stakeholder groups and organisations across the plant health sectors.

In Chapters 5 and 6 we describe and analyse new empirical research to begin to explain how plant health stakeholders currently acquire plant health knowledge. In Chapter 5, we draw on key informant interviews, on a survey from an agricultural event and on emerging data from the horticultural sector. Results indicated differences between sectors, with two broad categorisations being visible: Agriculture (including some horticulture) and Tree Health (including forestry and many of the natural environment concerns). In Agriculture, prediction and prevention of pests are common practices, and chemicals are widely used against anticipated or identified pests. The agronomist is a key knowledge broker for arable farmers in particular, acting as a gatekeeper to academic knowledge and practical doctor in identifying symptoms, causes and solutions in plant health. There was scepticism about the trustworthiness of commercial companies. For the potato sector, academic papers were the most trusted source of knowledge and yet were used infrequently. Informal peer to peer discussion was used frequently, although trust depended on the peer and topic discussed. Trusted knowledge sources included face to face interactions at conferences or professional workshops. Twitter was both least trusted and least frequently used. Social media was important for some of the organisations overall, but was less used or trusted by practitioners and even by agronomists and other key actors. 'Younger' farmers use WhatsApp groups to communicate, but older farmers prefer face to face interaction. In the horticultural sector, government departments and key institutions were important sources of knowledge. Academic research was rarely directly accessed, and popular celebrity endorsement had little impact. These findings suggest that a multi-faceted engagement strategy on plant health is required that offers different forms of engagement, differentiates audiences, targets key knowledge brokers and translates academic research.

In Chapter 6, a study of online social networks using data from Twitter's Application Programming Interfaces (API) was conducted. Data was pulled daily from Twitter's API using a technique called network jumping. In total, approximately 150,000 tweets were gathered from key stakeholders in the plant health sector and those users with whom they engage. Results suggest that while Twitter allows for information to be transferred quickly and to a large number of people, plant health experts are not well-placed within Twitter networks to ensure that information permeates to those who need it most. Indeed, some of the sources of plant health information that are available to the public are less trusted than others. Currently, key stakeholders with backgrounds in policy and science are not well placed to control the online-narrative on plant health information. Furthermore, individual researchers are best suited to get accurate information to the largest number of users in the shortest period of time.

Recommendations

1. Develop a **stakeholder engagement strategy** including different knowledge exchange approaches for different stakeholder types and contexts, sectors, pests and stages of outbreak and that includes (and maintains existing) collaborations and partnerships as well as creating specific knowledge channels. Engagement should include commercial companies but PHC should be careful to always offer their own synthesis of commercial information.

2. **Further research is required on knowledge flows in relation to plant health specifically**, in Scotland, and in relation to other sectors.
3. **A more dominant Twitter narrative** by trusted plant health sources should be established, although this will currently reach only key individuals. The **use of WhatsApp could be expanded** with local, sector specific groups.
4. **Translating and distributing academic knowledge** for practitioners who trust but do not access this knowledge source is needed.

It was concluded that knowledge production, exchange and implementation is complex across a wide range of stakeholders in plant health in Scotland. Some key recommendations can be made regarding optimising knowledge flows, including development of a stakeholder engagement strategy that develops networks and collaborations whilst reinforcing existing key knowledge brokers and points whilst developing new knowledge channels and enabling subsequent bio-secure behaviours.

Chapter 1
Introduction

There has been increasing concern over plant health, especially over the past decade. The risks of invasion and spread of new pests and pathogens have escalated due to globalisation, international trade, climate change and changes in social practice (Marzano et al., 2017). In this Information Age, it has been questioned why people are not aware of, or do not put into practice, information about plant health protection. At an opening meeting of Scotland's Plant Health Centre (PHC) in June 2018, one of the gaps in understanding identified was realising where in Scotland people obtained information about plant health. The PHC wanted to know how they could reach stakeholders with relevant information to achieve changes in behaviour and improve prevention, identification and management of plant pests and pathogens. As a result, this work was commissioned and together, SRUC, University of St Andrews and Forest Research Scotland undertook a review and scoping research to begin to describe and understand knowledge flows and to offer initial recommendations. This report describes and analyses the work undertaken in the project. It incorporates material from a draft literature review and a preliminary progress report on Social Network Analysis previously presented to the PHC.

'Information' is often seen to be objective facts that exist external to humans and can be transferred unchanged amongst individuals and groups. However, information is subject to interpretation, has to be absorbed in order to be transmitted or have effect and is relational (influenced by social relationships). Hence, in this report we focus on 'knowledge' as a more appropriate way of considering what is known about plant health and how people produce, acquire and act on knowledge. In order to understand plant health risks and be able to plan and put into place solutions, we need effective knowledge production, exchange and implementation. Knowledge flows are particularly important for plant health in comparison with other areas of environmental management for the following reasons: identification and engagement of a wide range of stakeholders (Blackstock et al 2007; Reed et al., 2009), integration of different knowledge forms (White 2013) and the capacity to address both specific, short term issues and long term consequences are required. For example, pest invasions may require action within hours or days (Dandy et al 2017), but forests mature decades after planting and implications of agricultural decisions can be felt for many years on the land. It is thus important to know where people acquire knowledge about plant health and how they make decisions for the short and long term based on this knowledge.

In Chapter 2, we describe and explain our methodological approach, although detail of methods is offered in relevant chapters. In Chapter 3, we develop a conceptual framework exploring how knowledge is produced, shared and implemented and how it is relevant in policy and practice. We show in particular how knowledge flows and use have been explored in previous studies on plant health, across the four broad and overlapping areas of forestry, agriculture, horticulture and environment, with particular relevance to Scotland. Because this literature is broad and without clear boundary, and is spread across academic and non-academic literatures, we also offer an annotated bibliography of key texts and their potential use in plant health policy and practice in Appendix 1. In Chapter 4, we describe some mechanisms of identifying stakeholders: groups of people with an interest or responsibility in plant health in Scotland. We also provide an indicative stakeholder map in Appendix 2, listing and broadly categorising potential groups and organisations. In Chapters 5 and 6 we describe and analyse new empirical research to begin to explain how plant health stakeholders currently acquire plant health knowledge. In Chapter 5, we draw on key informant interviews, on a survey from a case study stakeholder group and on emerging data from a research project with plant nurseries. In Chapter 6, we describe the 'Twittersphere', developing novel research tools for Social Network Analysis across twitter in relation to plant health. Finally, in Chapter 7 we provide general discussion, recommendations and conclusions along with areas for future research.

Aims

1. ***To sketch a conceptual framework to illustrate how the Plant Health Centre can best support knowledge flows for effective plant health management***
2. ***To review knowledge flows amongst stakeholders in relation to plant health, with particular relevance to Scotland***
3. ***To discuss how stakeholder engagement for enhanced knowledge exchange might be implemented***
4. ***To empirically scope existing and potential knowledge flows in relation to plant health in stakeholders in Scotland***
5. ***To employ social network analysis to offer detail of particular knowledge flows***
6. ***To provide conclusions and recommendations to support future practice and research in this area***

Chapter 2
Methods

Conceptual framework and literature review

The conceptual framework on knowledge flows in plant health was developed using widely applicable literature, not all specific to plant health. The bulk of the literature review comprised an iterative process to capture both particular expertise and a formal assessment of existing research. Initially, members of the research group provided known academic papers and grey literature reports that specifically related to plant health for individuals and groups in Scotland. Of necessity, we drew on literature from a far wider geographical area to understand knowledge flows and networks in plant health. We used cited references in this literature to snowball and deepen the pool of literature. In addition, we used a range of search terms and search engines to capture literature in specific areas from well known online databases (particularly Web of Science). Terms were modified until we were sure we had identified the specific known papers in addition to wider references, and terms were adapted so that we captured tens or hundreds and not tens of thousands of papers. This literature was then sorted into categories and was a) selected for analysis within the text of the literature review and /or b) listed in an annotated bibliography, using a template. This section thus includes not only a review of literature specifically citing plant health knowledge flows, but also a conceptual framework explaining how we might think about producing and exchanging knowledge in order to enhance the prediction, identification and management of plant pests and pathogens.

Stakeholder analysis and mapping

The conceptual framework revealed that any knowledge exchange programme requires an understanding of who is involved as well as how to engage them; knowledge cannot merely be transferred but different formats of information and opportunities for discussion and co-production of knowledge need to be created. The literature on stakeholder analysis was thus reviewed and an indicative stakeholder map was developed, drawing on the framing of Dandy et al (2017) from their plant health stakeholder analysis. This map is a list of categories and indicative stakeholders within each category, to illustrate the potential for a more complete map. It is built on experiences in particular previous projects (Marzano et al 2019; White et al 2019), but each project team member added additional stakeholders such that examples in tree health, agriculture, environment and horticulture were included.

Stakeholder perspectives on knowledge flows

Stakeholder perspectives of plant health knowledge flows were empirically tested using two methods in three case studies. Firstly, semi-structured interviews were undertaken with five key informants, selected to range across the different areas of plant health, with one in animal health. There was insufficient time within this scoping study to undertake a large internet survey. Hence, secondly, a focused survey was undertaken at a potato information day to capture written responses from participants in agriculture and offer detail and depth of knowledge flow perspectives. Thirdly, a summary was developed from emerging data on an ongoing research project on knowledge flows for plant nurseries. More detail of the participants and protocols is provided in Chapter 5 in order to facilitate understanding of results.

Social Network Analysis

A large-scale social network analysis of social media data was conducted in order to better understand how online platforms might be contributing to information regarding plant health. Data was collected daily from Twitter using a newly developed approach called network jumping. In total, about 150,000 tweets have been pulled from the Twitter API to date, springing from four key stakeholder's Twitter accounts. The patterns, connections conversations and topics are described in Chapter 6.

Ethical approval

Ethical approval for interviews and surveys was granted by University of St Andrews University Teaching and Research Ethics Committee and for social network analysis was granted by SRUC.

Chapter 3
What is the current understanding of plant health knowledge flows?

In order to be able to address questions regarding how people produce, acquire and act on information about plant health, we begin with a short conceptual framework and review of literature. First, we discuss what plant health comprises for the purpose of this report. Second, we consider the sectoral relationships in plant health. Third, we explore how we can identify who is involved. Fourth, we consider knowledge flows. Fifth, we discuss how knowledge can influence decision making and action. Finally, we highlight some key aspects of sustainability governance to be considered in managing knowledge flows for plant health outcomes.

What is plant health and how is knowledge important?

Strictly speaking, plant health can include the environmental conditions affecting the ability of plants to thrive, such as nutrients, water, wind, temperature, light or grazing pressure. However, the term 'plant health' has recently been associated principally with the invasion, spread and impact of plant pests and pathogens and it is this understanding that is used in this review. This also aligns with the principle remit of the Plant Health Centre, as funded by Scottish Government.

Knowledge flows in plant health will thus be important in different ways. The type of knowledge and flows required will be affected by:

- **Risk** – the UK risk register[1] details risk of various pests or pathogens, including uncertainties, likely pathways, relevant regulation and possible impact. High risk or potential high impact species, for example, will require greater knowledge flow.
- **Stakeholder awareness** of the importance and increased risks of plant pests and pathogens and the types of deeper **stakeholder engagement** required to co-design and implement solutions
- **Stage of invasion** – outbreaks occur along a time trajectory and different knowledge focus is required depending on whether an outbreak trajectory is:

[1] https://secure.fera.defra.gov.uk/phiw/riskRegister/

1. Endemic – a pest or pathogen is well established in Scotland but either requires management or its spread has to be recorded
   Or requires:
2. Specific awareness – public awareness regarding a pest or pathogen
3. Alert awareness – high alert required for possible invasion by a particular plant or pathogen, often with focus in particular areas
4. Crisis management – a pest or pathogen has just invaded and has to be managed rapidly in an attempt to stop spread.

Plant health sectors

Plant health is considered to be critical across forestry, agriculture, horticulture and environment. These sectors are briefly described on the Plant Health Centre website but their fields of practice overlap, and we explore this briefly here, further outlining the areas we feel each sector covers.

Forestry relates to the invasion, spread and impact of pests and pathogen on trees and forests. It affects:

- natural trees, forests and woodlands
- commercial plantations (usually coniferous)
- community woodlands
- urban and peri-urban street trees and parks
- landscaping (for roads or development)
- garden trees
- tree nurseries

Plant health in the natural environment relates to the invasion, spread and impact of pests and pathogen on natural flora. It has implications for:

- individual plant species, including trees
- habitats, including types of forests and woodlands
- areas and plants allocated natural significance, including National Parks, SSSIs etc

Plant health in horticulture relates to the invasion, spread and impact of pests and pathogen on cultivated plants. Horticulture is defined as the art or practice of garden cultivation and management (OED). It includes:

- flower growing and ornamental plants
- garden plants (in domestic, historic and commercial gardens)
- landscaping plants (in parks, urban greening, some developments)

- fruit and vegetable growing (at garden scale)
- plant nurseries

Plant health in agriculture relates to the invasion, spread and impact of pests and pathogens on crops. It includes:

- fruit and vegetable growing, including orchards (at field scale)
- production of grains
- production of crops for non-food uses (e.g. energy, medicines)
- some tree cropping (e.g. willow for biomass, Christmas trees)
- bulb and flower growing (at field scale e.g. daffodils)

There is a diverse literature and longstanding history in relation to tackling pests and pathogens in agriculture. More recently, there has been significant and relevant research recently in the field of 'tree health', which largely relates to forestry but also has relevance to parts of the natural environment sector as well as, to a lesser extent, agriculture and horticulture. We can thus see that there are some overlaps in considering sectors and plant health. The literature is not evenly spread across these sectors, as we will see below.

Sectoral differences in plant health knowledge flows

There appears to be a recent but partial literature in relation to knowledge flows in tree health, including unpublished papers from government departments and agencies and academic collations such as a recent book on social dimensions of tree health (Urquhart et al 2019). In relation to agriculture and horticulture, there is a longstanding interest in integrated pest management (IPM), but this only sometimes analyses social dimensions. There is a wide literature on human health and pesticide exposure, for example, but less on how farmers acquire knowledge. There is literature on how decisions are made regarding pesticide application, but largely focussed at a farm level rather than demonstrating how knowledge is exchanged across networks. The role of advisor and farmer decision making has been partially explored, and there is information on individual farmer attitudes. There is less literature specifically on horticulture; and the boundaries between agriculture and horticulture appear blurred, with searches often turning up the same papers. The literature on plant health and natural environment is difficult to define. There is a wide literature on knowledge production and exchange in relation to environmental management and a large literature on collaborative management, participation, trust and relationships. The literature on the natural environment in relation to plant health is largely (although not exclusively) on tree health and we have examples not only from Scotland but also from UK and further afield that explore stakeholders and knowledge flows in relation to pest and pathogen

spread and consequences. There is also a related literature on alien invasions in biodiversity conservation.

Hence, debates in the literature overlap, with relatively few papers specifically covering knowledge flows in Scotland in relation to plant health for all of the sectors studied in this review. Whilst this literature has been quite well developed in tree health at a UK or wider level, with some relevance to the natural environment, the literature is more diffuse in the other sectors.

Who is involved in plant health and how do we engage them?

Biosecurity challenges have led to more statutory frameworks, and a shift (in UK) from government control, primarily through inspectors, to a wider governance of plant health that also includes additional stakeholders in the private and third sectors (Dandy et al., 2017). This is in line with trends towards decentralisation (Kapoor, 2001) and greater collaboration (Davies & White, 2012). For the Plant Health Centre and other bodies to effectively manage plant health, we thus need to consider who produces knowledge, how it is exchanged and implemented across the relevant sectors and how we can engage different stakeholders.

Who is involved in plant health? A **stakeholder** is an individual, group or organisation with interest in and normally some influence over management (Prell et al., 2009). Stakeholders differ depending on their degrees of interest, their roles and responsibilities (Marzano, White, & Jones, 2018). The concept of 'stakeholder' was originally derived for business management and is often seen to be an individual or organisation with an interest in an issue; often as influencing or being influenced by the issue (Dandy et al., 2017; Prell, Hubacek, & Reed, 2009; Reed et al., 2009). However, it is also suggested that it is problematic to consider only instrumental roles and ignore the moral viewpoints or emotional responses of people (e.g. (Freeman, 1994). In order to identify stakeholders who are relevant to plant health, we need a form of **stakeholder analysis**. Such analyses can take different forms, varying from a list of known major actors to detailed analysis of the power, interests, responsibilities and attitudes of different stakeholders.

Given that knowledge about plant health is critical across a range of organisations and sectors, it is important to build an understanding of who will be influenced *by,* or *can* influence, short and long-term issues/solutions, along with a means of engaging with, and hence integrating knowledge between them. Stakeholder analysis (Dandy et al., 2017; Prell et al., 2009; Reed et al., 2009) offers a *suite* of methods to establish boundaries, and then identify, categorise, and study the relationships (here, knowledge flows) between a complex network of actors

(Figure 1). This process typically begins in an iterative manner, identifying an initial batch of stakeholders (e.g. through expert opinion, literature review, or using an initial focus group to brainstorm individuals and organisations affected by the 'Plant Health' problem framing), and then branching out through subsequent interviews, snowball sampling, or surveys until saturation is reached (i.e. when no further 'Plant Health' stakeholders can be identified). At this stage, a clear boundary has been established and the analysis can proceed to categorisation of these stakeholders. Here, researchers can either draw on their own understanding – built up through an in-depth ethnography, perhaps – to classify stakeholders based on how they perceive the system to function (i.e. a top-down approach), or participants can classify stakeholders based on their own experiences (i.e. a bottom-up approach), or both approaches can be employed reciprocally (i.e. a mixed approach). This classification is typically based on the relative 'importance' of stakeholders – determined by a juxtaposition of their *interest* and *influence* (Figure 1). Following this, the relationships between stakeholders can be explored using Social Network Analysis (i.e. flows of communication and trust between actors – see Reed, 2008; Hauck, Schmidt and Werner, 2016), Knowledge Mapping (i.e. flows of knowledge or resources between actors – see Nissen and Levitt, 2004; Bhupatiraju *et al.*, 2012; Muñoz-Erickson and Cutts, 2016), or again, a mixture of both. For instance, Reed *et al.* (2009) propose the fusing of Social Network Analysis and Knowledge Mapping to stretch the "who knows who" to "who knows what" (Wrexler, 2001 cited in Reed *et al.*, 2009: 1940), which is to identify dominant knowledge(s), how actors acquire this knowledge, areas of seepage (i.e. missing organisations or sectors), bottlenecks (i.e. the hoarding of knowledge), and to encourage broader system innovation through knowledge hybridisation and second-order learning within these (potentially new) networks. To facilitate the latter, one might even create workshops, which bring together actors with knowledge, and those requiring that knowledge (see Reed *et al,*, 2009), to engender a process of co-learning for knowledge integration. Furthermore, such an analysis would reveal the structure of the network – which stakeholders are central, which are marginal, and if there are any clusters (Reed *et al.*, 2009). This can also be used to identify bridging organisations who produce, exchange, or implement knowledge more demonstrably than others (Berkes, 2009) – a bridge for 'horizontal' and 'vertical' collaboration, and between different 'systems', or 'ways', of knowing. Such modes of stakeholder analysis involve face to face interaction and debate, which not only helps map stakeholders but is also a form of engagement in itself. More recently, possibilities for stakeholder analysis using social media have arisen. Such studies can offer in depth information as well as patterns of communication (see Chapter 6), although each form of social media is restricted to those who use it.

Developing a stakeholder analysis is an important step, but there then needs to be consideration of how to communicate with and engage different stakeholders in different ways. Greater stakeholder participation is considered to deliver better environmental outcomes (Beierle & Konisky, 2000; Reed, 2008; Stringer et al., 2006). Advantages include instrumental (assisting with practical implementation and defusing conflict), substantive (highlighting multiple perspectives which leads to better understanding and selection of appropriate solutions) and normative (social and individual learning enriches participants and wider society) benefits (Blackstock et al., 2007). However, there are challenges in implementation and there has been some critique of participation processes, including a potential over emphasis on minority interests (e.g. Cooke & Kothari, 2001). Complex management situations can occur and pragmatic trade offs are sometimes required in dealing with stakeholders (Porth, Dandy, & Marzano, 2015).

'**Stakeholder engagement**' is the active solicitation of participation by those coordinating policy, practice, or research in a particular field (White et al 2018). The term is understood in different ways. This wider framing of 'stakeholder' as a person, beyond instrumental business interests (Freeman 1994) is relevant to plant health in that people have responded emotionally as well as rationally to plant health issues (e.g. responses to *Chalara*; felling of garden trees: Porth et al 2015). In addition, stakeholder engagement is complicated by the fact that individuals may differ in their views and hence representation of an organisation or initiative (White et al 2018). This influences how Plant Health Centre may wish to engage with organisations. Since stakeholder interactions, such as the development of collaborations, are also influenced by experience, trust, relationships and understanding (Davies & White, 2012), it can be useful to maintain an individual contact for an organisation but to remember that their participation will also be partially personal.

The term 'engagement' refers to the form of participation solicited, which may vary from information delivery to an empowering form of devolution of power (see White et al 2018). Recently, there has been more emphasis on empowering forms of participation, such as collaboration (Davies & White, 2012), co-design (Rehema M. White & van Koten, 2016) and partnership (Leach, Pelkey, & Sabatier, 2002). Hence, whilst the Plant Health Centre needs to understand knowledge flows, this can be a precursor to developing and strengthening collaborations and partnerships for knowledge production, exchange and implementation in the future.

Of the different sectors included in this report, tree health has been the field that has received most support, in recent years especially, to explore plant health stakeholders. Policy in UK

has promoted stakeholder engagement (DEFRA, 2014). However, mapping of tree health stakeholders reveals the complexity of individuals, organisations and relationships (Dandy et al 2017; Marzano et al 2015; Marzano et al 2018; White et al 2018). Research has focused on who has an interest, changes in interest and how engagement can support additional activities.

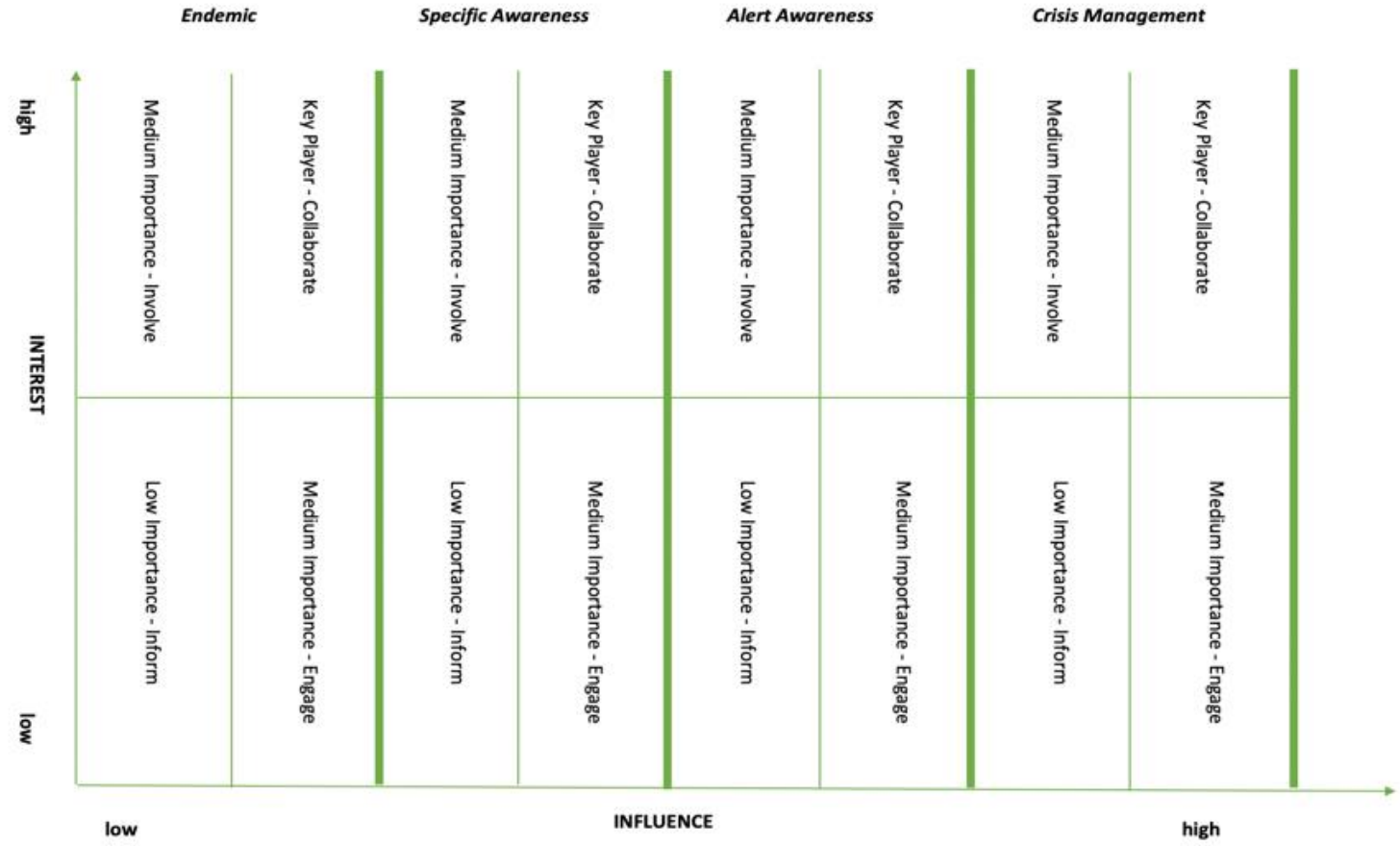
It has been suggested that engagement in plant health in UK is more effective when interactive, innovative or experiential means are employed (White et al 2018). Long term networks and collective interaction along with short term specific engagement interventions have been recommended for UK (Marzano et al 2018, White et al 2018). A challenge is to engage with stakeholders who have less interest or initial awareness, such as the public or hard-to-reach stakeholders in agriculture or landscaping. Whilst there have been some awareness raising campaigns, these have rarely been evaluated (Marzano et al., 2015).

Stakeholder engagement in environmental management has tended to focus on the few stakeholders who are most involved and has paid less attention to the public (Reed 2008). However, the role of 'the public' is interesting in plant health. In fact, 'the public' is a heterogeneous and poorly defined coalition of people and groups, and it has been suggested that greater public engagement could lead to significant advances in biosecurity (White et al 2018). Engaging with 'the public' through dialogic processes as well as information provision may also build generate support for drastic biosecurity responses, such as those seen by (Porth et al 2015), and could allow us to plan future plant health strategies more effectively.

This research project will deliver some information from stakeholders and insights on potential engagement in relation to knowledge, (see Appendix 2) but is only a scoping study. An excellent review of the key principles and practical lessons for effective stakeholder engagement to further facilitate this process in tree health is offered in a report for DEFRA[2].

[2] Marzano, M., Dandy, N., and Endicott, G. (2017) *Mapping, Analysis and Improved Understanding of Stakeholders and the Public to Help Protect Tree Health* Working Paper 7: Review of Public Engagement Strategies for DEFRA (not available online)

Figure 1: A model demonstrating how interest and influences can be mapped across stakeholders in plant health. Adapted from Reed at al., 2009



Knowledge and science

Knowledge is understood in different ways but is generally agreed to be a form of justified true belief (see Lehrer, 1990). In line with trends towards governance approaches, there has been a shift from information provision (Mode 1) to more participatory (Mode 2) knowledge forms (Gibbons et al., 1994) with increasing democratisation of knowledge (Carolan, 2006; Costanza, 2003), and a move towards post-normal science (Funtiwicz & Ravetz, 1993). More interdisciplinary, systems thinking, holistic, participatory approaches that include co-production and co-design across different knowledge forms, action research and action learning and recognition of blurred boundaries between knowledge production, exchange and implementation are thus emerging (White, 2013). This emphasises that for the Plant Health Centre, a stakeholder engagement strategy that includes (and maintains existing) collaborations and partnerships is in line with trends in sustainability governance.

Changing values and behaviours

Provision of information does not ensure that people act in response to the information as the information providers might logically expect. There is a wide literature on how to promote pro-environmental and pro-sustainability behaviours. In relation to plant health, such behaviours might include washing bicycles and cleaning boots after walking in forests, not importing non-approved plants, selling and buying certified plants or plants of known and legitimate origin, reporting pests appropriately and not facilitating spread of alien plants, pests or pathogens (see Marzano et al 2018).

Different models have explained how people develop pro-sustainability behaviours in response to knowledge or other stimuli. These include:

Values, Attitudes, Behaviours: the notion that values influence attitudes and hence behaviours, supported by social psychologists with a large literature explaining this (see (Steg & Vlek, 2009). For example, holding strong relationships with the natural environmental will build positive attitudes in relation to environmental protection and lead people to pro-environmental behaviours.

Social Practice: the theory that structured changes in society shift social norms and influence how individuals tend to act (e.g. Shove & Walker, 2010). For example, providing bicycle washing facilities and creating a norm that mountain bikers at a forest track wash bicycles before leaving will encourage further adoption of this behaviour.

Nudge through government policy: policies can be imposed that nudge people to undertake sustainable behaviours through subtle, context specific encouragement[3].

[3] https://www.unenvironment.org/news-and-stories/story/nudge-action-behavioural-science-sustainability

Demographic segmentation: it can be useful to employ market segmentation techniques to identify how populations can be identified for particular engagement strategies (Thompson, Anderson, Hansen, & Kahle, 2009). For example, in Scotland there has been a climate change segmentation undertaken by Scottish Government and in UK a biodiversity segmentation undertaken by DEFRA.

Sustainability governance

Plant health is not merely an environmental issue; it requires interdisciplinary (White 2013) and participatory (O'Brien et al 2013) approaches with understanding of plant pathology, ecology and technology, but also of human behaviour and human relationships with nature. Plant health can be seen to be a sustainability issue, presenting wicked problems which are complex and demand long term approaches to develop resilience; which often have no true or false solutions, only 'better than or 'as bad as' outcomes; which are each unique but require effective decision making (Rittel & Webber, 1973). Sustainability governance, the integrated policy support and management of a sustainability issue by government and non-governmental actors, (Jordan, 2008) is thus an appropriate approach to tackle plant health challenges.

Scottish context

When considering how Plant Health Centre might engage within Scotland, we can consider the Scottish context and relevance of wider literature. The recent focus on tree health in the literature is mainly at a UK level but there is some specific Scottish information. Some of the literature from Scotland on agricultural issues focuses on particularly relevant plant species (such as potatoes). Much of the literature on wider plant health issues derives from international sources, especially New Zealand and USA. We suggest that much of this is relevant, but there is a need for Scottish focused, contextualised research.

Knowledge flows in agriculture – wider literature and plant health sources

Whilst there is good coverage of stakeholders and possible engagement strategies in tree health, there is good coverage of knowledge flows generally in agriculture. We thus use agriculture as an area in which to further review literature on potential knowledge flows. In fact, within this body of literature on agriculture, information on knowledge sources and flows specifically in plant health and disease management within agriculture is limited (Wyckhuys et al. 2018). Much of the existing literature focuses on individual farmer perceptions and attitudes towards pesticides and Integrated Pest Management (IPM), with some information on learning networks and rarer insights into reasons for non-adoption of mitigation or protection measures (e.g. Cockburn et al. 2014, Beissinger et al. 2018). We

therefore combine plant health references with evidence for key sources of information and knowledge flows within farming more generally, in order to predict plant health knowledge flows in this sector.

Social relations and costs are key to knowledge flows, acceptance of new information and behaviour change. The most commonly cited sources of information for establishing management plans are tradition, common sense, personal experience and other managers in the region, with primary scientific sources and secondary literature consistently least used (Pullin et al. 2004, Sutherland et al. 2004, Beissinger et al. 2018). The accessibility of information and costs of using new or unfamiliar sources (time and financial), and perceived trustworthiness are key reasons for this (Sutherland et al. 2013, McCracken et al. 2015, Porth et al. 2015, Mankad et al. 2017, Toma et al. 2018).

Whether new knowledge results in behaviour change is influenced by factors such as compatibility with existing farming practices. A perceived mismatch between practical needs on the ground and the available market solutions or research evidence affects preferences and responses (Lamichhane et al. 2017, Barratt et al. 2018). Indeed, even recommendations from trusted sources are not always followed, and the relative advantage conferred by new techniques or crops (e.g. disease-resistant varieties), their complexity to implement and compatibility with existing practices are key barriers to uptake (Beissinger et al. 2018). All of these factors influence farmer perceptions of risk and benefit. Thus, accessible science-based information and case studies from other regions facing similar problems are important (Browne et al. 2009, Sutherland et al. 2013), but they are not sufficient to change individual or collective behaviour.

Social networks can stimulate change when they build on existing trust and specifically identify ‘enablers’ and ‘sticking points’. Enabling factors include awareness-raising, accessibility of information, improved integration and alignment of mechanisms and institutions (e.g. between policy, advisor and resource manager), and creating neutral spaces like knowledge networks which can generate more integrated analysis and improve communication (Turnpenny et al. 2016). Farmers and environmental managers more broadly build trust over the long-term, so new groups should be based around existing networks, and funding established agencies or their affiliates are more likely influence farmer behaviour in the short term than ‘contract’ advisory projects awarded to novice service providers (Dwyer et al. 2007, Mills et al. 2011, Sutherland et al. 2013). While national or broader networks may be needed to track threats, in practice networks with smaller group sizes provide flexibility for groups to develop their own solutions and

implementation rules that suit local management and environmental conditions (Mills et al. 2011, Garini et al. 2017, Prager & Creaney 2017, Muilerman et al. 2018, Oude Lansink et al. 2018).

Opportunities to be part of a solution are valued by many producers (Dwyer et al. 2007). Farm-specific attributes, like farm size and management style, also influence willingness to engage (Toma et al. 2018). In some cases, large farms may be effective in dissemination, so it may be worth directing extension efforts towards smaller farms to reduce disconnections that lead to some individuals lagging behind new knowledge and practices (Brodt et al. 2004, Goldberger et al. 2011). All of these issues require enhanced social skills amongst extension workers and researchers (Brinks and de Kool 2006, Sherman and Gent 2014). Plant health networks should be inclusive, stretching well beyond the growers who are often seen as the main actor for managing pests and diseases (Breukers et al. 2012, Beissinger et al. 2018, Lamicchane et al. 2018). A hierarchy of information provision and knowledge exchange approaches is needed to connect with various phases in the cycle of producer decision-making (Dwyer et al. 2007). A regular flow of articles in widely-consulted sector press, on radio or TV can influence thinking in the 'scanning phase', as can similar material targeted through sectoral or other specialist farming groups, and regional or national seminars and events. For educational/technical know-how and demonstration phases, personal engagement between advisers, specialists, individual farmers or groups of farmers are needed and should be carefully attuned to the priorities and networks of the target groups.

Biosecurity networks also need to be tailored towards various stages of disease prevalence (Dandy et al. 2017). A period of consolidation and instability is often required for new practices to become established, so intervention may be most effective after 'trigger events' that disrupt 'knowledge lock-in' and path-dependency associated with the *status quo* (Sutherland et al. 2012, Beissinger et al. 2018). This is evident in major farm transitions, such as shifts from conventional to organic farming (Sutherland et al. 2012), and in the uptake of IPM (Jeger 2000). Constraints to IPM adoption may decrease after a pest crisis, when different perceptions can converge and radical changes in control practise can emerge. Conversely, barriers can arise where changes in pest control practice are sought in situations with no immediate crisis, as there is no convergent perception of a need for change. Biosecurity measures therefore need to include vigilance, short-term immediate (crisis) management actions and longer-term support institutions and processes to enable stakeholders to adapt to new issues and species or cope with future invasion risks (Maclean et al. 2018). It is also essential to examine and learn from examples where disease

management recommendations were not adopted, and to be aware that growers may be called on to make simultaneous decisions about multiple pathogens (Beissinger et al. 2018). Finally, the influence of advice and recommendations can be very context dependent, and it is essential to recognise that pest and disease management decisions are made within a broader context (Dwyer et al. 2007, Beissinger et al. 2018). Efforts to improve preparedness are already underway for dealing with animal disease in Scotland and this provides a model to monitor and engage with to streamline farmer experience by building on trust and avoiding duplication (e.g. Boden et al. 2015).

Summary

In this chapter, we have explored the meanings of plant heath, and described overlaps across the different sectors to which plant health is of interest: agriculture, forestry, environment and horticulture. We also illustrated how recent focus on tree plant health overlaps forestry, environment and horticulture, with weaker links to agriculture. The literature specifically on knowledge flows in plant health is sparse, but there is a solid literature on stakeholders in tree health and on general knowledge uptake in agriculture. We explored how we can identify who is involved in plant health, describing a network of individuals, groups and organisations at different scales across the sectors. Not all stakeholders are equal, and the PHC would benefit from undertaking stakeholder analysis and then developing a stakeholder engagement strategy, using a range of engagement and knowledge exchange approaches varying from raising awareness in the publics, to developing networks with workshops and events for key stakeholders. The transmission of knowledge does not guarantee a change in behaviour or uptake of new practices or technologies, and we described different conceptual frameworks to understand how people change attitudes and behaviour, or succumb to societal shifts in practice, are nudged or experience a tipping point such as pest invasion. Finally, we highlighted key aspects of sustainability governance to be considered in managing knowledge flows for plant health outcomes. These include the need to maintain collaborations, partnerships and networks for particular areas of activity, to support specific knowledge flows during 'peacetime' management of plant health and 'crisis responses'.

Chapter 4
Who are plant health stakeholders?

The exploration of how knowledge flows, how knowledge flows can be enhanced and how they might best be adapted to improve plant health management requires an understanding of who plant health stakeholders are and how to engage them. In this chapter, we describe conceptual models available in the literature. As described above in Chapter 3, most of these models include an analysis of interest and power as well as the role of the group or organisation. Some indicate relationships between organisations. We then draw on existing knowledge for plant health and develop a stakeholder map to facilitate later practical action.

One relevant example of plant health stakeholders is offered from a study of stakeholders in the early detection of tree pests and pathogens in UK (Marzano et al 2018). It demonstrates the breadth of stakeholders, from specialist roles to 'the public' (Figure 2). Additional research has demonstrated which stakeholders have an interest and responsibility in tree health (White et al 2018). These analyses show that not only are predictable groups involved, such as plant inspectors and agencies, but also wider, more diffuse groups such as the public(s) and landscapers. Stakeholders range across the public, private and third sectors. For agriculture, core stakeholders will include farmers and extension agencies, and commercial entities such as pesticide manufacturers. In horticulture, plant enthusiasts and plant breeders will be included. In relation to the natural environment, a wider variety of NGOs may play a role.

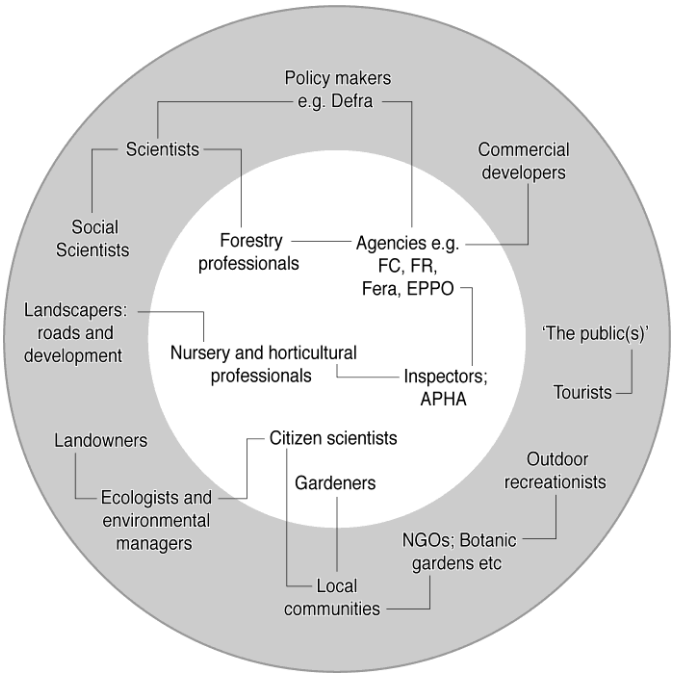


Figure 2: Core (in white centre) and peripheral (in grey outer area) stakeholders involved in early detection of plant pests and pathogens in tree health (Marzano et al 2018).

Stakeholder Categories

We drew on previous work by Dandy et al (2017) in which they defined stakeholders in tree health categories as:

- **Vectors**: individuals or groups who (usually unintentionally) spread pests amongst plants or locations, including those who trade in woodfuel, timber, live plants or with wood packaging and those who transfer pests directly or on equipment (e.g. arboriculture workers, foresters, tourists or outdoor recreationists).
- **Governors**: individuals and organisations who set formal and informal rules and regulations affecting tree-health. Such rules include trade agreements, legislation, institutional/organisational arrangements, or industry best practice initiatives and codes.
- **Managers**: individuals or groups with specific technical skills and responsibilities for tree management and pest and disease outbreaks and who manage pests at border points, such as inspectors. This category includes foresters, forestry and / or arboricultural contractors, forest planners and managers and sometimes local authorities and communities, in the case of community owned and managed woodlands.
- **Monitors**: those who produce and hold knowledge required to predict, detect, identify, or understand pests and disease outbreaks. This includes scientists such as

plant pathologists, entomologists, epidemiologists and modellers who work in academic or government research institutions, but can also include practitioner knowledge held by NGOs and by practitioners, expert volunteer knowledge held by some citizen science groups and local knowledge held by those who observe changes in trees and forests within their local place.

- **Networkers**: disseminate knowledge and awareness amongst stakeholders in tree health. They can overlap or also be part of another group; for example, government agencies or practitioner professional organisations.

We add to this list another category that we defined as

- **Plant enthusiasts:** those with an interest in tree, woodland and forest health and management. In many cases these individuals or groups will have a greater interest in the continued existence than active management. They include community members who use local community forests, conservationists concerned about forest biodiversity, gardeners, urban residents living near urban trees and schools teaching ecology. They tend to be lumped into 'the public'.

Scale

As well as category, we consider scale. Whilst we are particularly concerned with stakeholders in Scotland, UK policy and processes are of relevance, as are European policies, although the influence of the latter is unclear at the time of writing as our relationship with the rest of Europe is changing. International relationships will also be of influence, particularly in relation to trade routes or development of knowledge.

Stage of invasion timeline

Different stakeholders will be involved at different stages of an invasion trajectory.

1. *Endemic* – a pest or pathogen is well established in Scotland but either requires management or spread has to be recorded. May require engagement with those recording spread (agronomists, forestry practitioners or other managers)
2. *Specific awareness* –public and practitioner awareness regarding a pest or pathogen. Requires clear and consistent messages in numerous locations, physical and online, explaining why information is provided. Will require a network of people exchanging knowledge to ensure that new information can be integrated rapidly if required
3. *Alert awareness* – high alert required for possible invasion by a particular plant or pathogen, often with focus in particular areas. Requires new knowledge to be

exchanged rapidly, offering a clear and consistent message across different types of networks and fora, online and in person.

4. *Crisis management* – a pest or pathogen has just invaded and has to be managed rapidly in an attempt to stop spread. Requires both stakeholder engagement regarding particular management tools and policies but also wider engagement around the rationale for management and provision of information to all engaged stakeholders. Will require additional resource to address this escalating concern. These crisis moments can also be a way to engage new individuals and groups and grow the baseline networks and support for pro-plant health behaviours, and so the resource should be seen as investment in future knowledge exchange as well as in the moment.

Stakeholder map

Drawing on previously published data and on the experience of the researchers, we propose an initial stakeholder map (Appendix 2). This map is a list of categories and indicative stakeholders within each category, to illustrate the potential for a more complete map. It is built on experiences in particular previous projects (Dandy et al., 2017;Marzano et al 2019; White et al 2018), but each project team member added additional stakeholders such that various examples in tree health, agriculture, environment and horticulture were included. This is a stakeholder map rather than analysis because it does not include assessment of influence and interest, merely a listing with some untested categorisation. However, it should serve as the basis for future work developing a stakeholder analysis and engagement strategy.

Stakeholder engagement

A detailed stakeholder engagement strategy requires not only understanding of who stakeholders are and of their characterisation, but also of their engagement through a suite of methods including face to face events, online groups, public awareness campaigns and social media, in ways that inform, consult, engage or even empower participants (see White et al 2018, Reed et al 2009). Further discussion of this area is outwith the scope of this project.

Summary

In this chapter, we discuss stakeholders who might be engaged regarding plant health in Scotland. We consider previous mappings for tree health to illustrate the diversity and range of stakeholders. There are different ways of categorising stakeholders and we draw on the categorisation of Dandy et al (2017). They defined those relevant to tree health as **Vectors**,

Governors, Managers, Monitors or **Networkers**. We added to this categorisation another category that we defined as **Plant enthusiasts,** to include those interested in plants through place, activity or focus. An indicative stakeholder map was produced that included examples of state, private and third sector stakeholder groups and organisations across the plant health sectors. This might form the first phase of a stakeholder analysis but would require further work to illuminate interests, influence, stakeholder networks and knowledge flows and impacts. Additional research is required to develop a stakeholder engagement strategy.

Chapter 5
How is knowledge produced and exchanged in plant health? – Individual and sector perspectives

Introduction

In this chapter, we explore individual and sector perspectives from key informant interviews across sectors, a survey from a potato information day and summary notes from an emerging project on plant nursery knowledge flows.

Key informant interviews

Qualitative research including five key informant interviews were conducted in March 2019. Qualitative research permits the research to gain rich, deep data (Rehema M White, 2013). A key informant allows the researcher to obtain an in depth perspective from a participant targeted for their particular significant role or involvement in an issue (e.g. (Koontz, 2006). Interviewees were chosen based on their professional experience such that perspectives were gathered from across sectors related to plant health, including forestry, agriculture, horticulture and environment. Selection was also informed by initial results from the Social Network Analysis, such that we ensured that dominant lines of influence were included. One interviewee worked in animal health and was chosen to explore potentially interesting parallel experience and insights.

The interviews conducted were semi-structured and covered the topics: information on the interviewee's professional experience, their network (i.e. who they communicate with around plant health issues), trusted sources of plant health information, awareness levels around plant health in their sector, barriers to acting on plant health information, and their use of Twitter if applicable. The interviews lasted from 35 minutes to one hour. Two interviews were conducted face to face (horticulture and animal health) and the remaining three took place over the phone. Interviews were audio recorded with the consent of the interviewees, transcribed by project team members and then coded and analysed.

Key findings from all five interviews are summarised in the first section. In the second section the findings are outlined in more detail and organised by interview. The third section includes

a table summarising the trusted information sources and pests and diseases mentioned by individual interviewees. Due to the small sample size and the wide range of professional experience of the interviewees it is difficult to draw general conclusions around effective plant health knowledge exchange from these interviews alone. However, these findings, together with the additional scoping activities noted in this report, are useful in informing future knowledge exchange efforts and help triangulate the research in this scoping study.

Key findings

- The content and delivery of communication regarding plant health needs to be tailored to the intended audience.
- Encouraging more biosecure behaviours among wider publics (e.g. boot and bike cleaning before visiting forests) is a long-term process requiring a "drip feed" approach – consistent communication including small easily-achievable actions.
- Pest and disease outbreak response requires fast-paced cooperation across multiple disciplines – therefore appropriate knowledge networks should ideally be established in "peace time".
- Exchanges with the national forest estate can be efficiently targeted through a single employee acting as a conduit. The private forestry sector can be reached through organisations like Confor, the ICT and RFS. Individual forest landowners are harder to reach as they are bombarded with information on various topics.
- Communication with urban and peri-urban audiences on issues regarding tree health will likely be more effective channelled through the Royal Horticultural Society (who are also key stakeholders in the Twitter data – see Chapter 6) or community groups rather than traditional forestry organisations.
- Arable farmers often rely strongly on their agronomist advisors for crop health information. Arable farming magazines are also read by many farmers and others in the sector.
- There are strong commercial interests involved in the agricultural crop protection industry especially; those working in the sector are therefore careful and sceptical about their sources of information.
- The full range of biosecurity "best practice" measures in the horticultural trade can seem onerous and economically unfeasible, especially to smaller businesses. To avoid disengagement, it should be made clear that even small improvements are better than none.
- In the context of strategic groups (e.g. Scottish tree health advisory group), effective knowledge exchange (as opposed to one-way knowledge transfer) is difficult to achieve in large groups of 30 or more people.

- Knowledge gaps exist around pest and disease risk affecting "wild plants"[4] – impacts of outbreaks affecting system critical species could be substantial. Further gaps exist around pest and disease risks, particularly to trees, in the longer term (e.g. 50 – 300-year timescale).

Interview findings by interview

AGRICULTURE

The interviewee was a Scotland-based agricultural consultant specialising in cereal crops (does not advise on vegetables or potatoes).

Farmers and plant health information sources

"In my experience it's a very small percentage of arable farmers that really know the pests and diseases … [most] are not really that interested. They want someone to come along, look at the crop, write them a script or tell them the chemical straight away … and those that are keen are very keen."

- The interviewee is contracted to look after the crops of around 15 – 20 arable farmers in a 50-mile radius.
- They contact the farmers weekly and has long-term relationships with most of them. Other farmers, who are not regular clients, will call on an *ad-hoc* basis when they have a problem.
- They will often visit farms during the growing season for regular inspections.
- The large majority of farmers are not interested in learning about crop health themselves but would rather rely on their agronomist to do that for them. Some farmers rely almost completely on their agronomist and have no interest in other sources of information.
- Keen farmers with personal knowledge of crop health probably identify diseases quicker and react quicker than those farmers relying on agronomists.
- Agronomists use email to alert farmers to crop health risks (has a group mailing list).
- Many of these farmers are also part of a WhatsApp group, which is used by all members for various crop-related discussions including crop health: "*it's very quick, that's the main thing … you can send a picture and say what's wrong with this? And within five minutes you've got a response*".
- The age range of the farmers is anything between 18 – 80 but there is a certain demographic that will be interested in plant health "*it'll be the thirty-something ones that are really engaged in plant health*"

[4] The term "wild plants" is used as a catch-all for plants and trees growing in the wider environment that are not usually considered under agriculture and forestry e.g. heather and alder.

- Preferred forms of communication vary with farmers of different ages: "*the older ones want to see you and speak to you over a cup of tea in the kitchen, the younger ones ae quite happy with a WhatsApp*"
- Interviewee will also visit livestock farmers when they have problems with grass but this is on an ad-hoc basis.
- They will receive daily phone calls regarding crop health from some farmers during the growing season but this appetite for information almost completely stops "*once the combines start rolling*".

Interviewee plant health information sources

"… the meetings in the season are really good because what you think is going to happen season on season are completely different - different disease levels and different diseases ... and different chemicals and amounts you're putting on."

- The interviewee gets the bulk of their crop health information from fortnightly internal Skype conference calls with other advisors.
- Crop diseases usually spread up from the south, so colleagues based further south can relay information.
- The agronomists do not use websites or Twitter and try to avoid email newsletters where possible, preferring direct calls and face-to-face contact with colleagues: "*I like the way it is because I think we as a society use so many emails nowadays*".
- Specialist arable farming magazines are a popular source of information for agronomists and keen farmers.
- They attend some annual roadshows, e.g. put on by AHDB and Arable Scotland.
- Colleagues are a trusted source of crop health advice because their information is based in part on independent trial results. Other sources are often sponsored by chemical companies and therefore the information is "*very heavily biased*."
- However, the interviewee has face-to-face meetings with trade representatives from chemical companies (e.g. DuPont and Syngenta) for technical updates on crop protection.

FORESTRY

The interviewee has a background in forest management and has worked in policy and tree health in Scotland for the last decade.

Trusted information sources

"We have Scottish government, the RHS, the FC website, the FCS website, the Scottish government website, Observatree, plant health portal, the risk register, my gosh all these sources of information."

The interviewee values direct relationships, either via phone or face-to-face, with those in Forest Research as well as other UK and Scottish government organisations. When it isn't possible to ask individuals direct questions, the Observatree website includes a variety of online resources including videos and live webinars.

Engaging with the forestry sector

To get information to the private sector the interviewee goes through Confor, the Institute of Chartered Foresters, Tilhill and the Royal Forestry Society. It is easier to reach practitioners working on the national forest estate as they have an employee devoted to tree health and resilience who can "*act as a conduit*". In the private sector there is no single person to go to "*cascade information*".

It is more difficult to communicate with individual landowners "*who are inundated with all sorts of information about – very often farming and forestry, water and all that. They're the same as us – they're limited in resources … so that's potentially quite a difficult audience to reach. Can we do it through interfaces with agriculture? Can we share information and get the two land uses closer together? I'm sure we can but there's a long way to go*."

Communicating around tree health and appropriate resilience actions is complex: "*Unfortunately it's not a black and white environment. We've got nuanced arguments to get across and that makes it a real challenge*."

The interviewee believes the best way to engage with forest managers and other practitioners on tree health issues is face-to-face. Ideally there would be more tree health officers involved in outreach, but this is very resource intensive. Seminars can be a more cost-effective way of bridging the gap. The Forestry Commission used to run "Forest health days" two or three times a year to reach practitioners from different sectors: "*typically we might get 60 or 70 people to each one – which is a good way of communicating. Hearing people first hand and seeing the whites of their eyes and to get those questions asked and answered, they're very, very effective.*" Confor have also run similar seminars in the past.

Although we were focusing on knowledge flows, this interviewee offered further detail regarding a failure of knowledge acceptance in the forestry sector. They said that it was

difficult to embed some of the more resilient behaviours in the forestry sector, one example being species diversification. It is a challenge to encourage forest managers to diversify their species choice away from Sitka and other types of spruce to reduce susceptibility to pests and diseases.

Encouraging biosecurity-related behavioural change

"I think everyone has been relatively slow off the mark in understanding that … some of the early advice was impractical. It's not realistic to expect members of the public to disinfect their boots, their bikes and their dogs before they go into the forest and then when they get back …. You have to be pragmatic in making those small steps … Getting that sort of message across is extremely difficult. It's a cultural change issue."

The interviewee acknowledged that the forestry sector needs to be more proactive to improve resilience to pests and diseases both within the sector and the wider public:

"… in the past I think [our approach to tree health] has been largely reactive … it would be good if we could be more proactive particularly in relation to what people could be doing now, before it becomes an issue, what are the things we can be doing when it comes to biosecurity."

The interviewee also highlighted the differences in attitudes and behavioural change depending on whether the impact of pests and diseases are visible or not:

"… when [forest managers] have an entire stand of lodgepole pine dying with Dothistroma [Needle Blight] then it's quite easy to get action taken on that. Rather harder in the early days to get people … and avoid that situation."

"For most people going out into Scotland you don't go out and see tree health issues ... generally speaking it looks alright. So trying to convince people that these actions are necessary you're up against it. Until you get areas like south west Scotland where it's very obvious why we're trying to stop it – you need people to act before it becomes a problem."

Engaging with publics on biosecurity issues

The interviewee discussed the difficulties of creating new cultural norms regarding biosecurity in the publics engaged in forests and other spaces, and indicated the need for multiple and ongoing information sources to increase awareness and encourage behaviour change.

"Relatively low-level biosecurity becomes a cultural change. How do you put that over? There's nothing particularly riveting about it. These aren't grand changing methods. Saying to people, please come to the forest with clean boots and bikes and enjoy the forest. It's not the strongest sounding thing in the world [but it's] actually very important … those individual actions. It's

how you put that across. It can be quite difficult, but we also need to recognise that cultural change just doesn't happen overnight. It has to be a drip feed…"
"… we want to be constantly reminding people through all the various channels, whether the Royal Horticultural Society, the local garden society, just reminding them of some of the things we're advocating can actually be very helpful in their own personal lives."
The interviewee believed mass media to be an effective means of communicating to publics: "*I think actually having someone live on TV or the radio if they're respected in their field – that can be very powerful*" and also suggested having "*some champions out there leading it*". Events such as big mountain biking competitions could provide an opportunity to get the message out about preventing the spread of disease through bike cleaning for example.

The interviewee and their organisation have struggled to engage with urban and peri-urban populations on tree health issues: "*the big gap for us at the moment – no question – has been the urban areas, the central belt where there isn't a major forest resource*". They suggested that the Royal Horticultural Society, local authorities and local groups (e.g. gardening groups and community woodland groups) are better placed to engage with these populations as they know their audience.

Outbreak management
The interviewee stressed that a multidisciplinary approach is required during outbreak response: "*I think that was the key thing for me that tree health is very rarely a single issue in terms of how we advise what we do about it … I soon realised it was an iterative process and generally multidisciplinary and if you don't do it that way it can go horribly wrong in terms of practicalities and misplaced expectations and sometimes unintended consequences*".

The Scottish Tree Health Advisory Group (STHAG)
The interviewee believes STHAG has been effective overall in achieving what it has so far set out to do but improvements are needed in terms of two-way knowledge exchange between members:
"[STHAG] was a focal point to A) talk to people and B) to listen to people as well. So in its first guise I think it did actually achieve that purpose – It was a wake-up call for everybody and it was a good buy-in to it. It became a victim of its own success really … everybody wanted to be on it and I think that's when we realised actually these things need to function as a unit and when you start getting 30-40 people at a meeting it really is too unwieldy to achieve that. It becomes information giving rather than … [encouraging] ratification, endorsement, criticism."
"I think we're still critical of our performance and we're still struggling to get three sectors of sustainable forest management, the nursery side and the harvesting/processing side to go out

there, with their own agendas to help advise the practitioners … in my view [it] has been primarily information giving … we've still got a way to go to get there to a genuine two-way process …"

HORTICULTURE

The interviewee is a Scotland-based plant health researcher involved in biosecurity communication. Their communication role predominantly involves the public but also horticultural trade organisations, e.g. HTA, and heritage gardening groups such as Plant Heritage. They worked with an organisation that had public areas for management.

- The interviewee's main sources of plant health information include RHS, CABI and EPPO.
- The interviewee is particularly concerned about Phytophthora strains and the arrival of Xylella as well as the statutory action against it: "We're really concerned obviously about Xylella … [but] frankly the statutory action against it is more scary".
- They believe that general awareness in the horticultural sector is quite high and that trades people are "*really aware of plant health as a business liability*".
- They highlighted structural barriers to best practice including costing and availability, e.g. sourcing plants locally especially for trees and big landscaping projects

Engaging with publics

Methods of public engagement discussed included stalls set up at science fairs with microscopes for children to use and fungal forays with experts from the mycological society. Some colleagues had developed a game regarding plant health:

"… we'll set up some iPad with the game and kids are absolutely drawn to it and will sit there and play … it's actually a great way to talk to parents because the kids are happy there for a bit and the parents don't have anything to do."

Displays used by the interviewee's team are designed to inform publics on how diseases are spread and the impact they can have but also to give people advice such as "*buy from a safe supplier, buy local if possible, pack safely, don't take meats and plants and seeds with you when you travel, wash your shoes and tyres, wash your pet's paws*." The same approach has been taken in areas affected by felling as a result of *Phytophthora ramorum*. The public are being informed why the site looks like a mess and then given advice about how they can help prevent the spread of diseases. The team try to balance messages like these by highlighting the positive side of plant-microbe interactions including diseases. This can be done by showing the positive role that decaying trees have within a balanced ecosystem.

The Royal Highland Show was suggested as a place to interact with people who may not have previously engaged with plant health issues, but the interviewee was sceptical about engaging with this harder to reach audience: "*in all brutal honesty I think most people – if they stop and talk for any amount of time would tend to be interested anyway*".
On how to engage people on plant health issues if resources weren't an issue:
"… big images. I think at airports would be a really good way to reach people. Just right there. Yeah, sides of buses. TV ads I think. Again, that's for the old people."
On whether messages to the public around plant health need to be stronger:
"I think it depends on the context and tailoring the messaging appropriately but yeah I think we need to let people know it's serious and it's real issue."

Engaging with the horticultural and plant conservation sectors
Communication with horticultural and plant conservation organisations usually takes the form of presentations, seminars, workshops and training days. A recent training day was attended by between 30 – 50 various stakeholders involved in plant health, biosecurity and public communication.

The interviewee changed the way they presented biosecurity measures to audiences after giving a presentation to a conservation organisation at a separate event:

"… at the end of [the presentation] you could just see, there was no energy in the room at all because they all felt there was no way they could meet this standard. There were all these terrible things coming and it was just doom … I learned from that, that telling people – making it clear that there's the best you can do but also little changes make a difference – if it's just switching from having plants on soil to MyPex – that's good … Letting people know that small changes are good. You don't have to feel like you have to do everything. Just do a bit, it helps."

Informal evaluations of communication efforts
Disinfecting footbaths were being used in some public areas to help prevent the spread of diseases and signs were put up to inform people of their purpose and to encourage their use. The team monitored the footbaths to see if people were using them and noticed a lot of people walking around them and jumping over:
"… earlier [the signs] had been really text based – a lot of information about what the plant diseases are and what they effect and where they're a problem and why they're important, but nobody was ever going to read it ever … We looked at that and thought this isn't working … So we redid the signs to make it really visual so you don't have to read it to understand what

it is, you just see it and we saw people did change their behaviour. They did stop and wipe their feet. We saw that the footbaths are actually wearing out faster than they used to. So that was an informal evaluation."

Informal evaluation of biosecurity measures among staff also takes places occasionally. Are staff reading signs or acting on email updates? If not, why not?

Twitter

"I find it is the most useful time waster. It's really good for finding out about new research – highlighting items in the news I wouldn't otherwise see. Highlighting science news and cat pictures – all of those things. I don't know if I am particularly influential on Twitter and I don't know that I would necessarily reach anybody who wouldn't already be looking for that information. I find it more important for consumption."

Prominent handles on Twitter for plant health information were mentioned including: @fmartin1954; @pascal_frey; @SFSHAMOUN; @ohanlonrichard; @Plantpathdog.

ENVIRONMENT

The interviewee's background is in forestry, but their role encompasses work on plant health more generally as well as climate change and conservation. Their current role is policy and research focussed.

Knowledge gaps regarding "wild plants"

The interviewee stressed the gap in research when it comes to "wild" or "non-commercial" plants as opposed to farmed crops such as potatoes:

"… getting information [on "wild plants"] is difficult because there isn't a lot of information to get … some of them like heather have a little bit of work".

"… for some of the other plants [besides potatoes] we're just at the start of understanding how that plant grows and we don't have any baseline information about what diseases it might get. So, if you know nothing then you're unlikely to be doing a lot of research or getting a lot of information. That doesn't mean it's not important, it just means, you don't know enough to win an argument if an argument is based on where we are sure there is a problem."

The interviewee stressed that some of these under-researched plants play very important roles in their respective ecosystems and the impact of pests and diseases could be huge: "*…the impact of a really serious disease [on heather] would have a colossal impact. You would end up with a massive effect, either erosion, runoff … species lost, all sorts of things*."

Other important species mentioned by the interviewee that receive little attention regarding plant health include alder (important for river functioning but susceptible to various phytophthora strains) and blueberry (regarding both native species and commercial

varieties). Information sources on "wild plants" recommended by the interviewee include Scottish Natural Heritage, the Game and Wildlife Conservation Trust and the Moorland Forum.[5]

Knowledge gaps around tree health

The interviewee highlighted a gap in knowledge regarding future threats to trees. In the context of protecting species that rely on old trees it is necessary to act before the arrival of a particular threat such as temperature increases or exotic pests and diseases:

"What can we say about the future viability of tree species? Not just in the next five years, but in the next 100 years, 200 years ... I need to know enough to make some kind of decision, I need to know what the plant health issues are over the next century."

"The standard that we ought to be pursuing is: do we know the future plant health status, are there any things that we can tell are going to disturb our happy, peaceful lives?"

The interviewee stressed the importance of identifying "system critical elements" to help target resources. Some system critical elements we can be sure about such as the need to reduce grazing in some instances to ensure natural regeneration of trees and therefore the functioning of a woodland ecosystem.

When there is uncertainty around a particular approach to management then a diversity of approaches can be recommended:

"… conservation [practice] generally, has been working on the principle that we'll gather people together and they'll work out what's the right thing to do and then we'll get everybody to do it. And to turn up and say, "we don't know what the right thing to do is, so let's all do something slightly different", that's a fundamental departure for that sort of philosophical procedural underpinning in conservation."

This more open-ended approach could also encourage behaviour change among land managers:

"I have spent a significant part of my career trying to persuade private landowners to do the things that I want them to do and it's never worked very well … wouldn't it be nice if we could say "listen guys, we have to raise some concerns with you about your management of the site, but we want to give you as much choice as possible so here's some options, you pick from them, and we'll go round and say, that's fine. That's seems to be a much happier message to take to some wealthy landowner who is not very instinctively disposed to have people tell him what to do."

[5] For a list of forum member organisations see: http://www.moorlandforum.org.uk/who-are-we

Knowledge transfer vs. knowledge exchange

The interviewee feels that although researchers often recognise the need for knowledge exchange over the more "paternalistic" concept of knowledge transfer, they "*actually tend to work more on a knowledge transfer basis. There is still too much of "we will tell you things, we've done this project and we will tell you" … in terms of the constructing of the project, I think too much comes from the research end and not enough comes from the user end*."

The interviewee highlighted the importance of research that is structured to enable decision-making. This structuring can be enhanced by knowledge exchange from early in the research process. They demonstrated this point through an anecdote whereby an organisation involved in conservation changed their policy and stopped the removal of "non-native" sycamore from ash woodlands after the results of an academic paper showed that sycamore was a good functional replacement for ash trees:

"It was kind of accidental that that allowed us to take a decision, but nevertheless it was structured in a way that allowed us to take a decision. Lots of research that we might expect to help us doesn't help us because the structuring of the problem hasn't involved any knowledge exchange. It's been someone's assumption of what the problem is, and then we'll go away and find the answer and then we'll tell them."

ANIMAL HEALTH

The interviewee is a knowledge broker, primarily between science, policy and industry in the field of animal health.

Engaging with key external stakeholders

The interview mentioned there is a "*very clear policy audience*" in animal health, which makes communication relatively straightforward. The plant health policy picture is likely to be more disparate.

They have trusted relationships with key individuals across institutes and disciplines, e.g. within modelling and data teams, in a conscious effort to "*de-silo ourselves … and to facilitate cross-institutional relationships and collaboration*".

Animal health knowledge brokers often work within the Scottish Government offices:

"… we don't make our relationships in formal meetings, we make our relationships with those people as individuals at lunch time – that type of relationship building which is kind of hard to describe … you know people as people and they understand your intentions, and they've known you for long enough in peace time so that it becomes much easier to then say in an emergency when time is really tight, to be able to go and ask "who's the right person?" and "can I borrow them?" and "is it okay if we can look at X and y?"

The interviewee highlighted the usefulness of online communication tools like Slack and Yammer to coordinate on projects and particularly during outbreaks – can be used within organisations and with external partners. However, new tools can be met with resistance from colleagues.

Participatory workshops

Scenario planning workshops are run every year or so on different topics. They take a "participatory" format to try and encourage creative approaches:

"… participatory workshops, at least theoretically, offer an opportunity for equal voices from very diverse backgrounds and enable side by side engagement between people of different hierarchies. So, one of the ground rules was that you don't bring that hierarchy into the room, everybody's on an equal playing field, so you have a farmer, next to a retailer, next to a policy maker, next to an industry lead, next to a person who buys food … it's very non-judgemental, or theoretically anyway. In principal it's non-judgemental and it's positive and because of that it allows you to, in theory, be very creative if you're open minded enough to do that."

Engaging with publics

The interviewee stressed the difficulty in reaching a range of different audiences with limited resources "*because the messaging is very different*."

One way the interviewee's organisation tailors communication to different audiences is to use a "layered" website whereby the front-end of the website is designed for the interested lay person but allows the user to dig deeper into more technical information: "*we try very hard that our front-end is trying to tap into the interested public*".

The general public are not their primary audience, but they seek to communicate with them in more passive ways: "*like through social media, or through our website, and blogs and through different approaches – we have a presence at the Royal Highland Show, some of our staff communicate and spend time at science festivals*…"

Twitter

"… our social media strategy is really about trying to be in line with our mission, which is about promoting best evidence for animal health and in particular with a scope in Scotland, so we're interested in stories …. that we produce in terms of our research and putting that out there. But equally we're also interested in acquiring knowledge through our social media links to find out who's doing what in those spheres, and that's where it comes back to that first network about understanding the way different people are placed in different academic networks."

Table 1 Summary of trusted information sources, and pests and diseases mentioned by interviewees

	Agriculture	Forestry	Horticulture	Environment
Trusted sources of plant health information	James Hutton Institute; ADAS; AHDB website; Agronomists (e.g. Scottish Agronomy; SRUC; IVI; Procam); Magazines (e.g. Arable Farmer, Crop Production Magazine, Potash News, Farmers' Weekly, Scottish Farmer); SRUC crop protection report (via email or post); Roadshows (e.g. AHDB, Arable Scotland)	Scottish tree health advisory group (STHAG); UK plant health risk register and plant health portal; Forest Research; Observatree; RHS; FC and FCS;	RHS; CABI (sentinel field guide); EPPO (website)	Scottish tree health advisory group (STHAG); SASA; James Hutton Institute
Pests and diseases mentioned	Romularia; yellow rust (and other rusts)	Phytophthora Ramorum; Ash dieback; Dothistroma Needle Blight; Xylella; Hylobius; Heterobasidion; Pine tree lappet moth; pine beauty moth	Phytophthora Ramorum (and other strains); Xylella (statutory action against Xylella is also a potential threat); Golden mealybug; Asian longhorn beetle	Dutch elm disease; various Phytophthoras (specifically on alder); unknown threats to heather and blueberry

PHC – Survey Analysis

SSCR's Potato Committee Winter Meeting was identified as an Ideal opportunity to engage and gather data from a range of actors with a stake in plant health. The meeting included a range of presentations from academics and industry representatives with a specific focus on potato health, and afforded unique networking opportunities before, during and after the event. Attending the event added a degree of depth to the study and provided for a better-understanding of the production, exchange and implementation of knowledge within an industry that continues to be plagued by the invasion and spread of diseases, pests and pathogens. Observation of the event and short surveys handed out at networking opportunities allowed us to reach fringe stakeholders, and to generate a rich understanding of how they engage with knowledge at the industry-science-policy interface.

Surveys were left on lunch tables and handed out to willing participants throughout the event. We amassed 24 respondents who came from a variety of organisation types and roles. Their

roles included potato breeders, distributors, marketers, packers and traders, in addition to crop consultants, farmers, government officials, industry and research representatives. The roles within these organisations also varied: the majority of respondents were managers (4), farmers (3), researchers (3) and agronomists (2), in addition to a consultant, executive director, technical advisor, technician and retiree, amongst others. On average, from those that answered the question, participants had spent 15.5 years working for their current organisation, ranging from 1.5 years to 35 years. In terms of age, the majority of respondents were 45-64 (46%), followed by 25-44 (38%), 65+ (13%) and 16-24 (4%). Of those who provided their gender, 39% were female and 61% were male.

All in all, the meeting revealed a real thirst for knowledge and information on the health of potatoes, and potential solutions to plant health challenges. From the outset, there was a striking emphasis on the role of communication and collaboration with opportunities and the results of collaborative projects openly aired by speaker after speaker. One research institute, for instance, spoke of the value in holding knowledge exchange days at the end of each given project, whilst other representatives advertised various peer-to-peer learning opportunities like the Farm Demo Hub – an online inventory for farmers to find and host open days to facilitate networking and the active demonstration of best practice. Throughout the day, it became clear that there is a real premium attached to robust scientific approaches to the identification of issues, and potential solutions. In addition, the role of networks in the dissemination and exchange of knowledge and information was a recurring theme that appeared to bind attendees, organisers and presenters alike. Some of those that were engaged, however, spoke of a hoarding of knowledge, particularly those that are deemed to have the 'best' knowledge, information or resource.

Table 2: Ranking of frequency of use of each form of knowledge exchange (where data are ranked so 1 is most used and 8 is least used)

Source	*Maximum*	*Minimum*	*Median*	*Standard Deviation*	*Average*
Academic Papers	8	2	6	1.81	5.55
Conferences	6	1	3	1.39	2.96
Professional Workshops	6	1	3	1.56	3.33
Professional Magazines	7	1	4	1.96	4.14
Informal with Peers	7	1	3	2.11	3.25
Email Bulletins	8	1	5	2.36	4.53
Twitter	8	1.5	7	2.24	6.03
Websites	8	1	5	2.14	4.66

Respondents were asked about which sources of knowledge they used, which they most trusted and how we might optimise knowledge exchange for plant health. Questions regarding knowledge source enabled respondents to rank options from a set of provided categories. Since some respondents marked two or more categories with the same rank, data had to be adjusted such that equal ranks were given the median rank value and lower ranked options were given the next lowest rank available.

The first question asked respondents to rank where they personally acquire their knowledge and information regarding plant health from 1 (most frequent) up to 8 (least frequent) of those options that they use. One respondent omitted this question. The most frequent means of obtaining knowledge and information from categories that participants use was Conferences, followed by Informal with Peers and Professional Workshops (Table 2). The most infrequent was Twitter, followed by Academic Papers and Websites. Moreover, over one-third (35%) of participants did not use Twitter at all. The only category that every participant uses is Conferences. Additional comments highlighted some difficulties in terms of the accessing Academic Papers, particularly because of the associated fees and the relative complexity of content. One respondent also indicated that they sourced knowledge and information from Trade Federations.

The second question asked respondents to rank the best way of getting knowledge and information across everyone in their sector from 1 (best) up to 8 (worst) of those options they feel are relevant. Two respondents omitted this question. As displayed in Table 3, the best

way to get knowledge and information across everyone was Professional Workshops, followed by Conferences and Email Bulletins. The worst was Twitter, followed by Academic Papers and Websites. With a median of 6 and a relatively low standard deviation, the results suggest that respondents generally consider Academic Papers to be a limited means of disseminating knowledge and information across the sector. Additional comments indicated that conferences attract a lot of farmers and are a good means of knowledge transfer, and that academic papers are not usually used within the agricultural sectors. One respondent also indicated that Phone Calls would be useful means of sharing knowledge and information.

Table 3: Ranking of which knowledge forms were best (from 1: best to 8: worst)

Source	*Maximum*	*Minimum*	*Median*	*Standard Deviation*	*Average*
Academic Papers	8	2	6	1.65	6.23
Conferences	6	1	3	1.55	3.43
Professional Workshops	7	1	3	1.70	3.00
Professional Magazines	8	1.5	4	1.57	3.93
Informal with Peers	7	1	3.75	2.07	3.75
Email Bulletins	7	1	3.25	2.30	3.65
Twitter	8	1	8	2.33	6.25
Websites	7	1	5.5	2.11	4.68

The third question asked respondents to indicate if they had a role in communication, and if so what form of knowledge exchange they use and to whom. Seven respondents omitted this question. Of those that answered the question, 78% had a role in communication and 22% did not. As displayed in Table 4, everyone with a role in communication used Informal with Peers (100%), with Conferences (64.71%), Email Bulletins (64.71%) and Professional Workshops (52.94%), being the next most common. Twitter and Websites were used by under half of those with a role in communication, whilst Professional Magazines (29.41%) and Academic Papers (17.56%) were used least. Almost every method of communication was used to share knowledge and information with Agronomists, Colleagues and Growers, whereas Industry Representatives and Schools were only engaged through Professional Workshops. Informal with Peers and Professional Workshops were used to disseminate knowledge and information to the broadest range of recipients, whilst Academic Papers were only used to engage with a scientific audience. One respondent indicated that they also use Study Tours to share knowledge and information.

The fourth question asked respondents if they actively seek knowledge on plant health, and to provide some additional comments. One respondent omitted this question. Perhaps unsurprisingly, of those that answered the question at this event, 100% actively seek knowledge on plant health. Of those who provided additional comments, this took the form of books on pathogens and pests, horizon scanning to keep track of pests, reading articles and academic papers, and through their agronomists, company websites and applications. Some respondents provided a rationale, which included keeping abreast of the latest developments in the industry, being able to pass on advice to farmers and growers and overcoming garden issues. One respondent cited the AHDB website as a source of knowledge and information.

The fifth question asked respondents to rank the knowledge sources that they most trust from 1 (most trusted) to 8 (least trusted). Four respondents omitted this question. As displayed in Table 5, Academic Papers were the most trusted source, followed by Professional Workshops and Conferences. Twitter was the least trusted source of knowledge and information, followed by Websites, Email Bulletins, and Informal with Peers. With a median of 8 and a low standard deviation, Twitter was, quite overwhelmingly, the least trusted source of knowledge and information. Moreover, one-quarter of those that answered the question felt that Twitter was not relevant. With a median of 5.5 and a large standard deviation, Informal with Peers was a rather mixed category in terms of its perceived trustworthiness. Additional comments highlighted that Academic Papers are most trusted because they are peer-reviewed. Furthermore, one respondent indicted that the level of trust invested in Informal with Peers depends entirely on who they are communicating with. The survey also included a question asking participants to rank the sources of knowledge that *others* most trust. However, with a very low response rate (33%), and some respondents expressing concerns over difficulties in estimating others' trust, it was decided to omit this question from the analysis.

Table 4: Form of knowledge exchange used, and to whom

Source	*Percentage of those with a role in communication that use*	*To Whom?*
Academic Papers	17.56%	'Academia and Scientific Audience'
Conferences	64.71%	'Agronomists', 'Colleagues', 'Farm Traders', 'Growers', 'Industry Representatives' and 'Stakeholders'
Professional Workshops	52.94%	'Academics', 'Agronomists', 'Colleagues', 'Farm Traders', 'Growers', 'Seed Growers', 'Industry Representatives', 'Schools (Primary and Secondary)' and 'Stakeholders'
Professional Magazines	29.41%	'Growers' and 'Farming Industry'
Informal with Peers	100.00%	'Agronomists', 'Colleagues', 'Customers', 'Growers', 'Staff', 'CPD', 'Within Association of Independent Crop Consultants' and 'Within Business'
Email Bulletins	64.71%	'Agronomists', 'Colleagues', 'Growers', 'Within Business', and 'With Partners'
Twitter	41.18%	'Colleagues', 'Growers', 'Stakeholders' and 'Whoever Follows Me'
Websites	41.18%	'Colleagues', 'Growers', 'Stakeholders', 'To anyone who will look' and 'Shop Window for my Business and Products'

The sixth question asked respondents which knowledge sources and formats tend to change their policy and/or practices, and to provide examples where possible. There were a range of answers, including: academic papers, campaigns, conferences, email updates, group discussions, industry meetings, listening to academics and scientists, overseas visits to other plant health and policy meetings, practical demonstrations and research, published work disseminated at conferences and/or workshops, seminars, talks and websites. More specifically, one respondent cited plant health science from organisations like SASA, DEFRA, APHA amongst other academic and research institutes. Other, more specific responses included the Scottish Agronomy Newsletter, SRUC, Farm Demos like *AHDB's Spot Farm*, the

AHDB Conference, Seed Potato Events and Technical Workshops like *Potatoes in Practice*, and European Trade Events like *Fruit Logistica*. Another respondent cited discussions with their peers in the independent crop consultancy sector, and another believed that company Websites and Applications from BASE, BAYER and Syngenta were influential.

Table 5: Level of trust in each form ranked from 1: most trusted to 8: least trusted

Source	*Maximum*	*Minimum*	*Median*	*Standard Deviation*	*Average*
Academic Papers	4	1	1	1.13	1.97
Conferences	5	1	3	1.36	3.03
Professional Workshops	6	1	2.75	1.54	2.92
Professional Magazines	7	2	4	1.35	4.18
Informal with Peers	8	1	5.5	2.27	4.97
Email Bulletins	7	2	5.5	1.63	5.28
Twitter	8	4	8	1.24	7.30
Websites	8	2	6.25	1.77	5.69

The seventh question asked respondents how knowledge exchange could be improved. Again, there were a range of more general responses, including: engaging with as many as possible, improving the efficiency of knowledge exchange, making knowledge more easily available, and putting information over a number of platforms. To do this, a number of respondents cited on-farm events such as 'Spot Farm' and 'Farm Example', in addition to other ideas like having more conferences and collaboration on areas of common interest, greater use of leaflets, social media and websites, a conference specifically for plant health in Scotland, constant updating of the SASA and Levy board, presentations for scientists and professionals, and using email databases to greater effect. One respondent believed that combining farm demos, conferences and technical workshops with digital information transfer - perhaps using applications and emails to target information – would be key. Furthermore, there was a suggestion that there should be fewer groups disseminating knowledge and that "year of the…" promotions by government on an important topic will help to cement the issue(s) in people's minds.

The eighth and final question provided respondents with the opportunity to tell us what they would like in terms of knowledge provision. Here, there was a concern that plant health policy needs to be periodically reviewed to ensure it is fit for purpose, and that internet sources tend to be rather questionable and are in need of further scrutiny by acknowledged experts before a particular respondent would make conclusions and act. One respondent indicated

the usefulness of open day events like this one, particularly in combining academia with commercial business. Finally, another respondent simply asked us to keep trying!

The sources that actors trust are not necessarily the ones that they use most frequently, and vice versa. For instance, Academic Papers are the most trusted source of knowledge and information yet are used very infrequently. On the other hand, Informal with Peers is used relatively frequently but has a relatively low level of trust. Moreover, it is interesting to note that Twitter is both least trusted and least frequently used. Finally, it is worth noting that this survey was undertaken as a case study example; the overall number of respondents (24) was low and they were drawn from one area within the agricultural sector and probably represented seriously engaged individuals. More widespread surveys need to be undertaken to reach across sectors, areas and degrees of engagement.

Plant nursery knowledge sources

A project is underway by one of the researchers on this project (MM) to better understand how the horticultural trade is managing plant health threats. The results from this project will be forthcoming and reported elsewhere, but it was felt useful to extract and summaries some of the relevant information in this report. Semi-structured interviews were held with various businesses in the tree/plant trade, who labelled themselves as either "landscape contractor", "landscape architect", "nursery" or "garden centre". They were asked?

"Who do you look to for information on tree/plant pests and diseases? Please select all that apply"

The options for information sources included:

- Others in the tree/plant trade
- Royal Horticultural Society
- Horticultural Trade Association
- Agriculture and Horticulture Development Board (formerly HDC)
- Universities and research agencies
- Environmental charities and trusts (e.g. Woodland Trust)
- Forestry Commission
- Other government departments and agencies (e.g. DEFRA, FERA, APHA, SASA)
- Celebrity gardeners including TV and radio personalities
- Other (please specify)
- British Association of Landscape Industries (BALI) ***not asked to nurseries or garden centres***
- Landscape Institute ***not asked to nurseries or garden centres***

It can be seen that the most commonly used sources of knowledge varied slightly across groups, but that most knowledge was acquired from government departments and a few

trusted sources such as RHS, FC and relevant professional associations (Table 6). Academic knowledge (direct from research institutes) and celebrities were the least used sources.

Table 6: Summary of knowledge sources cited by businesses in the plant nursery and horticultural trade.

Business Type	n	Most commonly used	**somewhere in between**	Least commonly used
Nursery	100<200	Government departments & others in the trade (both around 20%)	RHS, HTA and AHDB were all used by just over 10% of respondents	Universities and research agencies and the FC (used by around 5%); Environmental charities and celebrities were used by <4%
Garden Centre	~200	Others in the trade, RHS, HTA and other gov. depts. (just under 20%)	**none**	AHDB, unis & research agencies, charities, FC and celebrities (all <7%)
Landscape Contractor	~40	Others in the trade, RHS, FC (all around 15%)	Other gov. depts. and charities (~7%)	AHDB, HTA, Celebrities, Landscape Institute
Landscape architect	100<200	Others in the trade, RHS, FC, landscape institute, British Association of Landscape Industries, other gov. depts (all 10<15%)	HTA, universities and research agencies, charities (all 5<10%)	AHDB, celebrities (both around 1%)

Chapter summary

In this chapter, we explored contemporary sources of knowledge, perceived knowledge flows and aspects of knowledge sources such as trust, frequency of use and ease of access. Perspectives were gathered using key informant interviews, a survey of potato day participants and summary data emerging from a separate project on the horticultural trade. Results indicated differences between sectors, with two broad categorisations being visible: Agriculture (including some production horticulture) and Tree Health (including forestry and many of the natural environment concerns). In Agriculture, prediction and prevention of pests are common, and chemicals are widely used against anticipated or identified pests. The agronomist is a key knowledge broker for arable farmers in particular, acting as a gatekeeper to academic knowledge and practical doctor in identifying symptoms, causes and solutions of plant pests and pathogens. There was scepticism about the trustworthiness of commercial companies. For potato farmers, we sought to better understand the actual sources of information rather than the flows through key actors. Academic papers were the most trusted source of knowledge and yet were used infrequently. Informal peer to peer discussion was used frequently by all farmers, although the trust in an interaction differed depending on the peer and topic discussed. Trusted knowledge sources included face to

face interactions at conferences or professional workshops. Social media was important for some of the organisations that certain key informants represented, but was less used or trusted by practitioners and even by agronomists and other key actors. 'Younger' farmers are starting to use WhatsApp groups to communicate rapidly about plant health, but older farmers prefer face to face interaction. For those involved in the potato sector, Twitter was both least trusted and least frequently used. In the horticultural sector, government departments and key institutions (e.g. RHS, FC) were important sources of knowledge. Academic research was rarely directly accessed, and popular celebrity endorsement had little impact. These findings suggest that a multi-faceted engagement strategy on plant health is required that offers different forms of engagement, differentiates audiences, targets key knowledge brokers and translates academic research.

Chapter 6

Social Network Analysis

Introduction

This chapter reports the findings from an online analysis of information networks. It includes a theoretical introduction and background on the primary data source, the results and a preliminary discussion of the project policy implications. This aspect of the research thus contributes to the scoping research addressing the research question: **Where do people in Scotland get their information about the plant health?**

In order to address this research question, a novel and cutting- edge approach to data collection was undertaken. A *network jumping* approach was developed for this project to gather data from Twitter's Application Programming Interfaces (API), that is, the URLs that allow you to find tweets that contain a particular word, for example.

Twitter is a social media platform that is comprised of users who share short (280 character) microblogs about a large variety of topics. Twitter users can include virtually any organisation or user, and, indeed, some Twitter users are automated programmes (colloquially known as *bots*) that share information automatically. Since its creation in the early 2000's, Twitter has been widely used in the UK, with about 17 million accounts as of 2018. It has been used in numerous academic studies (see Jackson, & Lilleker 2011; Bollen, Mao & Zeng 2011).

Methods

The network jumping approach works by:

1. pulling data from a set of pre-identified stakeholders (starting-stakeholder group) in the plant health sector;
2. then pulling out the details of the people they are having conversations with; and,
3. lastly, it collects those people's tweets.

All users included in the research have been given a user-classification to ensure their identity is not revealed. The only exception to this is the starting-stakeholders group, which was chosen for the status of these stakeholders in being trusted names in the Scottish plant health sector.

Figure 3, shown below, illustrates the idea of *network jumping*. We begin with a *starting stakeholder*, shown in the top tier, and we pull down their last 25 tweets. We then go through each tweet and pull any mentions of other Twitter users. A user mentions another user by including that user's Twitter handle denoted by '@' in a tweet. Once we have a list

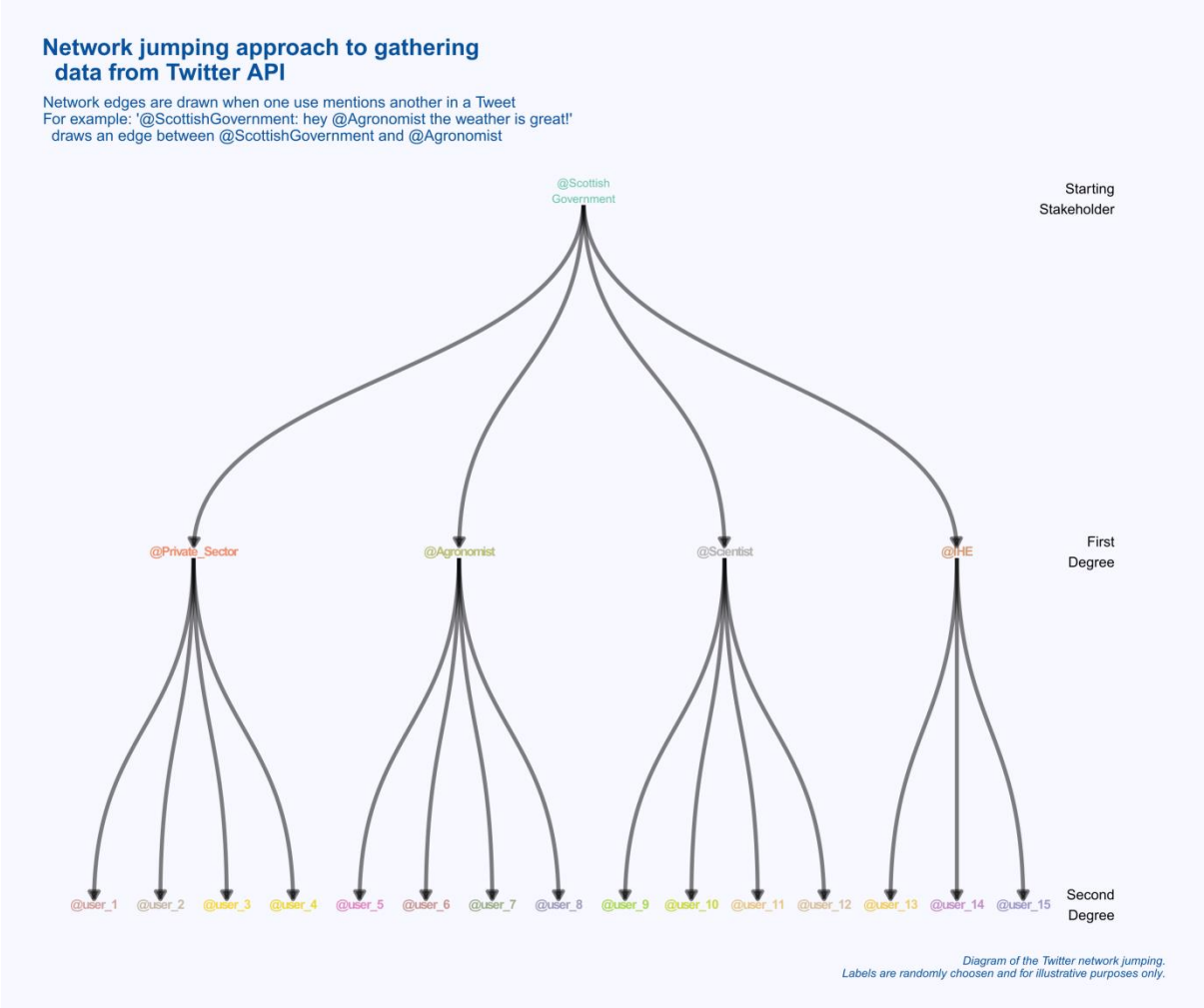


Figure 3: Data gathering methods.

of mentions (shown in the middle tier in Figure 3), we repeat the process by pulling the last 25 tweets of users mentioned.

This approach is semi-supervised, in that it starts with a small number of stakeholders (four are used in this research project), but any Twitter user who is mentioned in a starter-stakeholder's tweets is then included in the database. This process is then repeated daily. This approach has proved to be quite good at gathering topical data on online information networks in the plant health sector in Scotland. Data collection began on 1st January 2019. As of 24th April 2019 there were 36,510 unique tweets and 590 first and second degree users in the database. In total, there are 16,711 unique Twitter users represented in the database. The R package used to gather data is ***rtweets*** (Kearney 2018).

Starting-stakeholders

The *starter-stakeholders* used in this study were:

1. @FASSCot - Official Twitter handle of ***Scotland's Farm Advisory Service***
2. @ScotGovSASA - Official Twitter handle of ***SASA (Science & Advice for Scottish Agriculture)***
3. @PlantHealthScot - Official Twitter handle of ***Scotland's Plant Health Centre***
4. @NFUStweets - Official Twitter handle of ***NFU Scotland (National Farmers Union)***

Whilst data collection will continue indefinitely, this chapter findings and discussion focuses on the three-month period of January 1 through March 31 2019. In the following section we discuss project findings.

Results

It is against Twitter's User Agreement to attempt to link a user's account with a geographical location via external methods (e.g., searching online for location information and attaching it to a user's account). However, Twitter does allow a user's geography to be shared if the user has agreed. Geolocation tags have to be *turned on* by a user, and it is relatively rare for users to do this, except where users are front-facing or institutional accounts. The results of user's locations for those who allowed this information to be known is shown in Table 7.

Table 7: Number of UK Users by Country

Category	England (n =624)	North Ireland (n =3)	Scotland (n =3,203)	Wales (n =14)
Agriculture	9.9%	100%	44.5%	57.1%
Science	39.1%	0.0%	26.1%	42.9%
Policy	48.6%	0.0%	28.9%	0.0%
Other	2.4%	0.0%	0.5%	0.0%

[a] Approximately 3.37% of stakeholders reported their country.

Of the users who have their location data turned on, just over 83% (approximately 3,200) of them are located in Scotland. This suggest that the majority of topics discussed by stakeholders will be likely framed from a Scottish perspective, though there are many

different countries from around the globe represented in the database. Table 7 breaks these users into sub-categories, which is explained in the following section.

Identifying new stakeholders

As the network jumping algorithm is semi-supervised, we collect data on a high number of users - too many to classify by hand. Each Twitter user has the option to include a short biographical description (the longest is 160 characters) about them that is included in the database. In order to better identify users in the database, we developed a classification process that groups users into four main categories as well as an "Other" category. They are:

1. Policy
2. Agriculture
3. Science
4. Other

As the data collection approach is semi-supervised and due to the large amount of data collected, it is difficult to classify all users. For the purposes of this report, we have developed a ***fast and greedy*** (i.e. quick but not necessarily optimal) approach to classifying users in the database. Our approach is to classify key words that appear in the user's Twitter description. Twitter users have the option to include a short biography or description of themselves. The biographical blogs generally provide some indication of the user, though some users chose to be quite vague in their descriptions of themselves. Anecdotally, professional accounts tend to have very useful biographical descriptions.[1]

Table 8: User Classification

User	Description	Policy	Agriculture	Science	Other
User_1	Crops; Girls; Lothiansmonitor; Nfus		x		
User_2	Striving				x
User_3	Scot_business; Scot_heritage; Scotland's; Scotpolitics; Scotsman_arts; Scotsmansport				x
User_4	Crofting; Crofting; Events; Promotes; Regulates; Tweeting		x		
User_5	Aims; Beekeepers; Products; Scio				x
User_6	Scotland's; Tweeting				x
User_7	Islands; Msp; Representing	x			
User_8	Consultancy; Crofters; Expertineveryfield; Farmers		x		
User_9	Generations; Overfishing; Sustainable seafood			x	
User_10	Views				x

Note: User descriptions have had stopwords and parts-of-speech removed.

The approach, shown in Table 8, classifies key words found in user descriptions. First, all stop words (i.e., common words that are not especially unique and not beneficial in identifying unique users)[2] and parts-of-speech are removed from each user's description.

Next, pre-defined classification words are matched against each word in a user's description. Each of the aforementioned categories has a set of unique classification words. Users are assigned to a category when any one of these classification words is matched within a user-description. This approach allows for users to be classified in more than one category. The following section reviews the key findings.

Key Findings

The following steps were taken in order to address the aforementioned research question. First, we looked at the classification of users in the network and discuss the subject matter of their tweets, paying special attention to plant diseases (e.g. Xylella). Then, we used a temporal networking approach to look at the key stakeholders who are providing relevant information within the network; again we will look at this process further over time. Finally, we used machine learning approaches to model the characteristics of those stakeholders who make the largest impacts in the network.

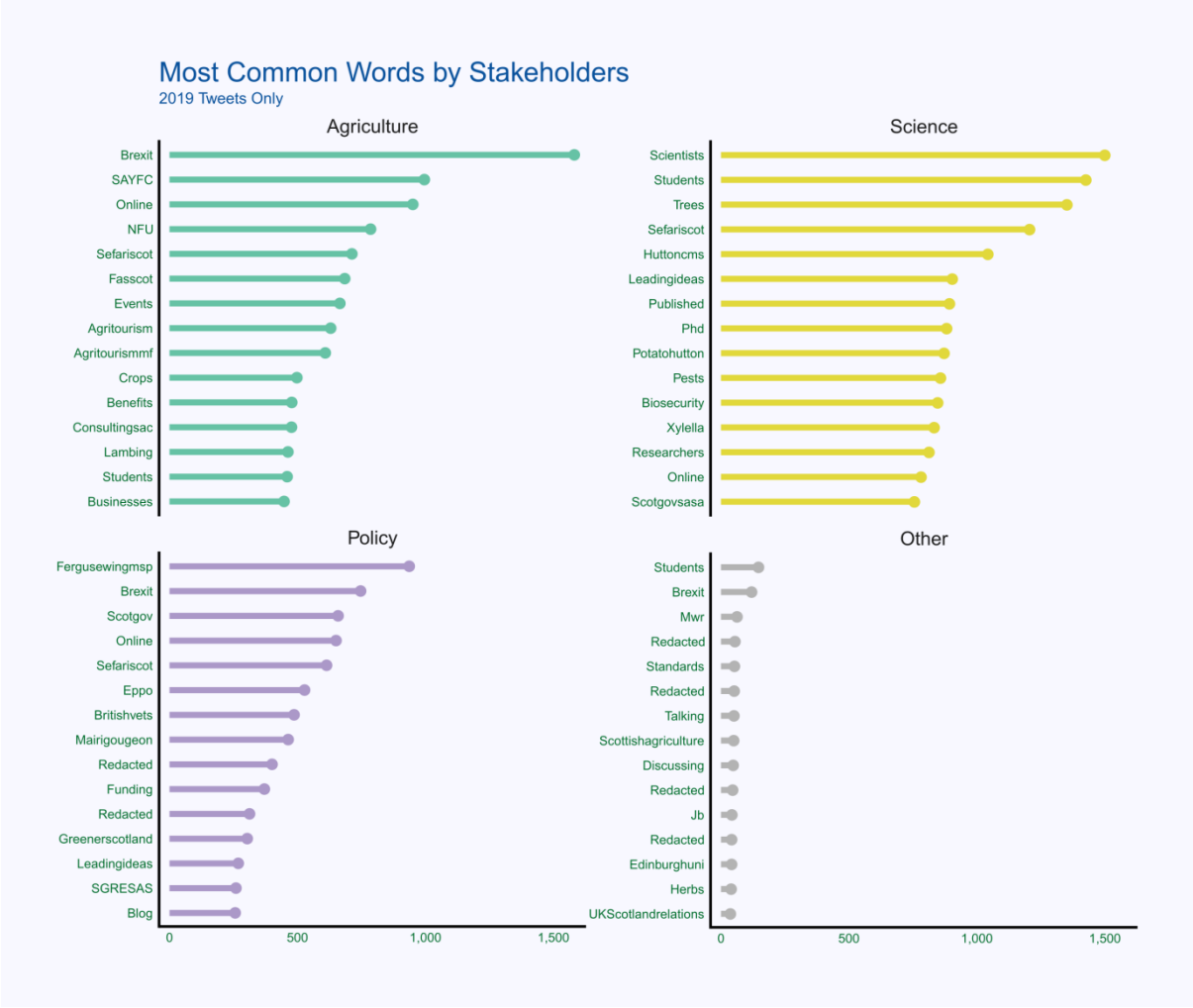


Figure 4: Common words by stakeholder categories. All words – including acronyms – have been made title case to ensure consistency during processing.

Stakeholder discussions

An analysis of stakeholder discussions is conducted through the use of natural language processing on the tweets. Tweets can be no longer than 280 characters, and they can include a variety of media inputs, including: plain text; images; gifs (Graphics Interchange Format); video and hyperlinks to webpages. This offers a rich dataset. For instance, images included in tweets are saved in a database and can be analysed using image recognition algorithms. Indeed, hyperlinks included in tweets within the project database very often lead users to important information regarding plant health. Whilst this data is quite interesting and is related to the overall aims of the study, it is outwith the project's current capacity. Plain text analysis does provide a rigorous overview of the topics being discussed by users. The following sections review findings from the plain text analysis of word frequencies by stakeholders in general and the frequency of key words of interest over time.

The top 15 words found in tweets for each stakeholder category are shown in Figure 4. There are times when individual Twitter users (not front-facing Twitter handles that represent larger institutions) are present in the top words. As these names can reveal the identities of individual people, they have been redacted and replaced with the word "Redacted". Overall, topics discussed in each stakeholder category are indicative of the stakeholder categories themselves, with each group discussing topics that makes sense within their unique context (i.e. users classified as Policy talk about politicians and political issues). Furthermore, the categories Agriculture, Science and Policy have similar frequencies for their most discussed terms, with top words showing up between about 1,000 and 2,000 times. The Other category stands out as there are no words that dominate the category, with the top word "students" appearing about 250 times.

By far the most common word in the Agriculture category is Brexit. This is not surprising as the Brexit negotiations have dominated the thoughts of farmers leading up to the proposed deadline of the end of March (as previously mentioned data presented in this report is for the first three months of 2019). Users classified as Agriculture also discussed many relevant farming advocacy groups, including the NFU and SAYFC.

Users classified in the Science category mention "Xylella", "Biosecurity", and "Pests" amongst their top 15 most used words. In addition to these key concerns regarding plant health in Scotland, members of the Science category also list several key stakeholder groups including "ScotGovSASA" and "SEFARIScot".

Likewise, users classified in the Policy group tend to mention key politicians related to rural issues. Both "Fergus Ewing" and "Mairi Gougeon" are mentioned quite frequently – both of whom occupy leading roles in rural affairs within the Scottish Parliament. Understandably, the word "Brexit" appears as a top word in the Policy category as well. Interestingly, "Brexit" is the second most frequent word for the Policy group whereas it is the top most frequent word in the Agriculture category.

Key Terms related to plant health in Scotland

Understanding the key terms within the plant health sector in Scotland is critical to understanding where people get their information about plant health. This section looks at several key terms, how they are used by different stakeholder groups and how their use changes overtime. Similar to the method in the previous section, a semi-supervised approach to identifying key terms was taken. The top words across all stakeholder categories were reviewed by project team members and a list of relevant words identified.

For figure readability, the top-six most relevant terms were chosen and plotted overtime and by stakeholder group in Figure 5. The terms are:

1. Ashdieback – Fungus that infects and kills ash trees (for more information see here).
2. Metaldehyde – Molluscicide (pesticide) used in slug management. It was set to be banned for use in 2020 during the period of this study (for more information see here).
3. Molluscicide – Pesticide used for slug management (for more information see here).
4. Phytosanitary – Certificate of inspection used during the import/exportation of plant species. It states that plants and plant material are free from quarantine (and other) pests and that the product conforms to the plant health regulations of the importing country (for more information see here).
5. Psyllid – jumping plant insect that carries Xylella.
6. Xylella – bacterial pathogen that can cause disease in many plant species (for more information see here).

The most frequent terms are “Ashdieback” and “Xylella”, and these terms of most used within the Science category. Interestingly, “Xylella” is mentioned at a very high rate at the beginning of the study period (beginning of January) and consistently falls whilst “Ashdieback” is hardly mentioned at the beginning of January but is the most mentioned word by early March. This could be partly explained by a BBC News report on Ashdieback that was shown on the popular morning show Breakfast around early March 2019.

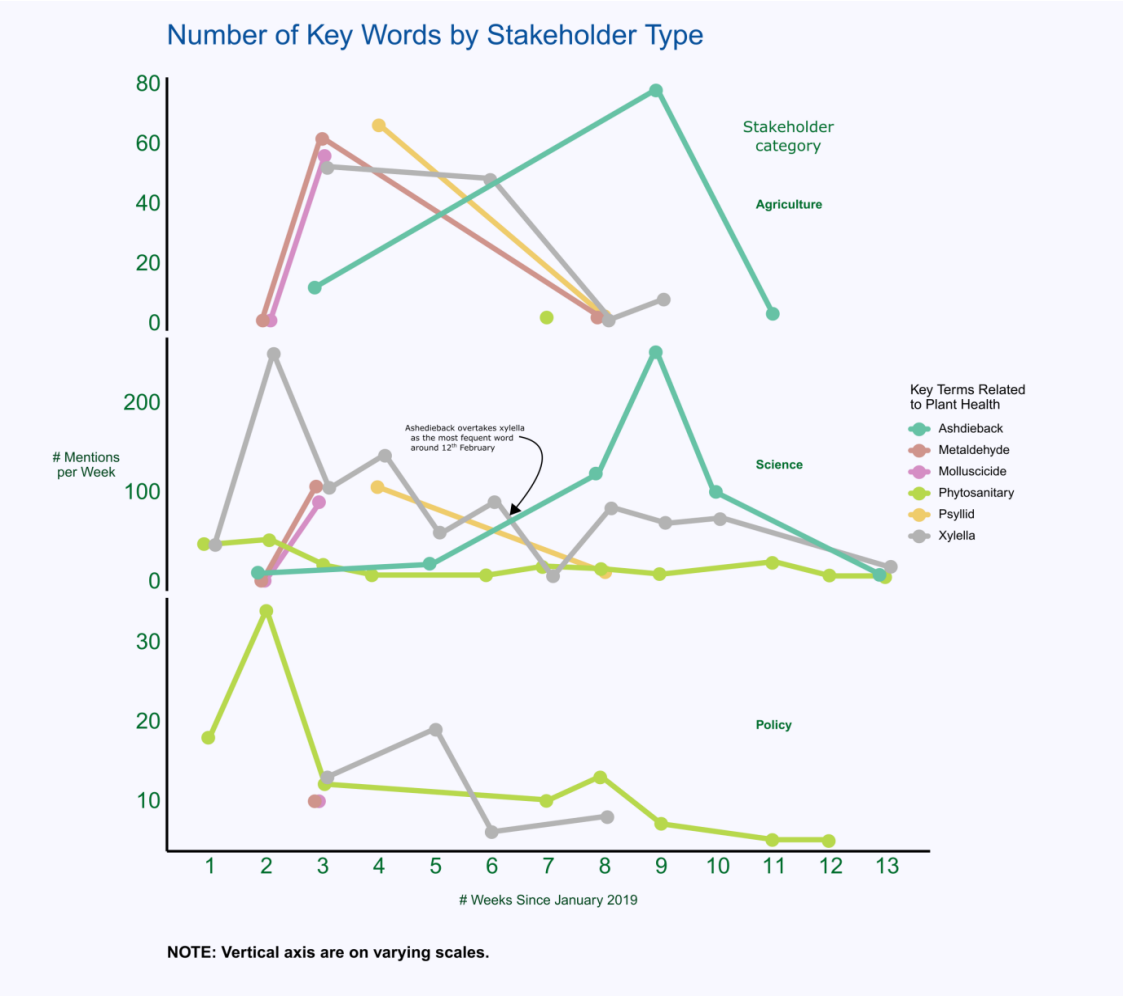


Figure 5: Key terms over time by stakeholder group

The Science category is the most consistently active group of users who mention key terms overtime. "Phytosanitary", which is a plant regulation policy, is mentioned the most frequently by the Policy stakeholder group. The Agriculture group mentions both "Xylella" and "Ashdieback" in similar ways to the Science group (with the same ebbs and flows found in early January and March). Though, the Agriculture group tweets are greatly reduced around mid-March, suggesting that farm-related activities have taken precedent over online discussions.

It is important to keep in mind that classifications can include overlap. The four main categories are used in Figure 4 and 5 because of limitations on plot readability. Network graphs are not confined by this restraint and allow for many more categories to be included. In the following section we review findings in network form to better understand how the flow of information occurs within the online plant health community in Scotland.

Network-structure and information flows

A key assumption of the research question stated earlier is that information flows between different stakeholders and users on Twitter, and each time a user engages another user (through mentions in a tweet) a link is made between the two. Network jumping takes these links creates *edges*, links connecting two nodes in social network, between the two users. We therefore capture data on information in its natural form - a network of connected stakeholders who share information, usually regarding plant health (but not always).

A socio-gram, or a network comprised solely of people, is shown in Figure 6. The approach to stakeholder classification is repeated. However, users can now be classified in more than one category. In Figure 6, circles represent Twitter users, and these circles (called nodes or vertices in network terminology) are coloured according to their inclusion in a stakeholder group. The lines (called edges) between the nodes represent an online discussion between the two nodes.

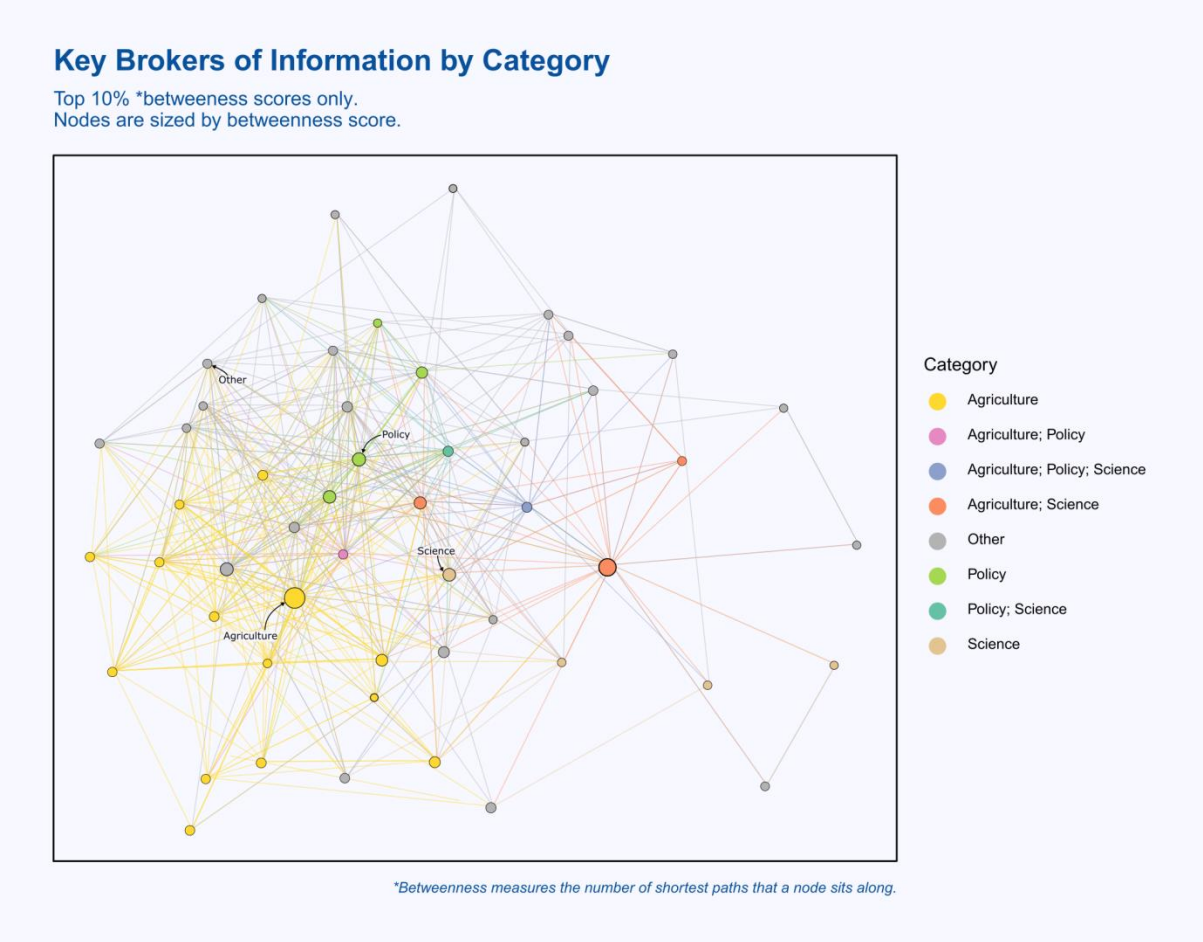


Figure 6: Network graph of the most important brokers of information on Twitter of plant health information in Scotland.

The entire socio-gram is too large to plot. Figure 6 shows the top ten percent of users according to their betweenness score. Betweenness is a measurement of centrality in

networks that counts the number of shortest paths that a node sits on. For the purposes of this study, the higher a user's betweenness score, the more control they have over information that passes within the network. Larger nodes represent higher betweenness scores. In addition to the size of the node, its location within the socio-gram also provides some information on its relative importance. The layout algorithm used in Figure 4 puts nodes which share similar edges close together. The edges have been coloured the same as their node. Several things stand out when looking at Figure 6.

1. The Agriculture category not only comprises a large portion of information in the network, but this group is also very tightly packed. This suggests that users classified as exclusively Agriculture are likely to only communicate with other influential users who are also members of this Agriculture group. It is likely that information is regurgitated between members of this group, which reinforces it, especially for followers of these groups.
2. Users who are classified exclusively in the Science group are not well represented in the most influential positions within the network. It is much more likely that users are classified as a mix of science and policy and agriculture. Still, these classifications are not the most central users in the network.
3. Users classified as exclusively Policy are not well represented in the network. However, users classified as exclusively Policy are better intertwined with the Agriculture users than is the Science group. This suggests Policy users are slightly better situated to influence the information in the network than are users classified in the Science category.

The most influential users regarding plant health on Twitter in Scotland are exclusively related to Agriculture (i.e. farmers or farmer's associations) or classified as Other (i.e. not falling into any of the other three categories or combination thereof). Network influence can be measured using two centrality measures, betweenness and degree. Betweenness measures the number nodes cross it in their shortest paths along the network to other nodes, and degree measures the total number of connections a node has to other nodes in the network. The most influential categories in the network are plotted in Figure 7. Figure 7 shows that three of the four users in the Science category have quite low betweenness and degree score (i.e., not influential) and only one highly influential user.

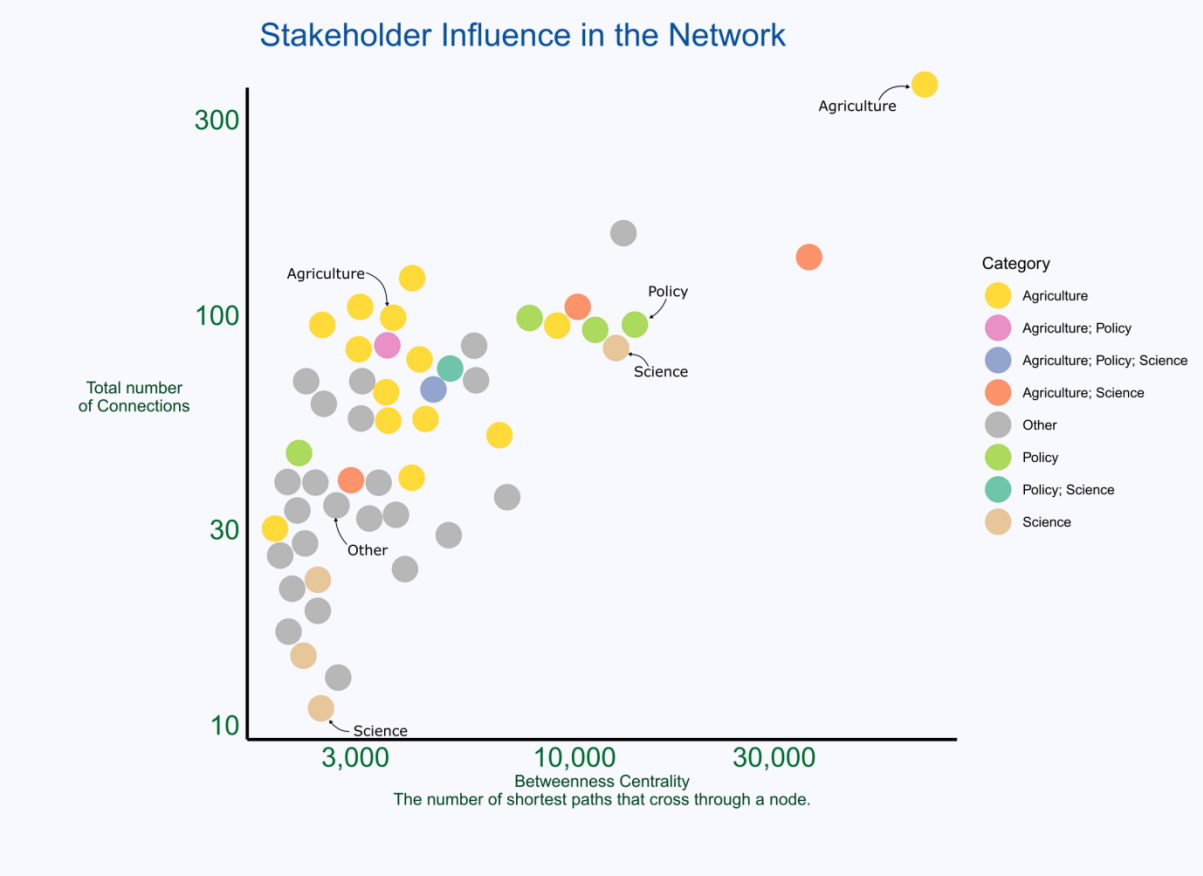


Figure 7: Stakeholder Centrality by Category

In the following section, the network of users discussing "Ashdieback" and "Xylella" are considered. Following this, a discussion of the aggregated results is provided.

Knowledge flows within the network

Based on results presented above, it can now be argued that the key purveyors of general information in the plant health sector on Twitter in Scotland are users classified in Agriculture and those classified as Other. As this project's research aims are to understand the flow of information specifically on plant health topics, we now turn our attention to focus on the flow of information on two pertinent topics in the plant health sector: "Ashdieback" and "Xylella". The results of this are shown in Figure 8.

In order to better understand the flows of information regarding these topics we have filtered the network to only include users who only mention either "Ashdieback" or "Xylella". Edge colour indicates what users are discussing (black for "Ashdieback" and grey for "Xylella". Edge width is determined number of times two users discuss a given topic. This has greatly reduced the number of users in the network, indicating that these two topics are

being discussed over and over by the same users. As the number of users in the network has been reduced, it is feasible to apply a more nuanced classification by reading each user's biography description. Users now fall into four distinct classifications:

1. Advocacy groups – these users are classified as charitable organisations that are doing advocacy or lobbying work within the plant health sector. Examples of users who may fall into this category are the Woodlands Trust, etc.
2. Agriculture; Science – these users are a mix of farmers and scientist. An example of users in this category is individuals working on research farms in Scotland.
3. Individual Researcher – this category is new. Users classified in this category are individuals (not front-facing institutional accounts like @SRUC) who are highly influential within the network. Examples of users in this category could be private accounts of university academics and of botanists working in Scotland.
4. Science – this category is a holdover from the approach used in the previous section. Users in this category may include science departments at universities or within the Scottish Government.

A key take-away from Figure 8 is that Individual Researchers are the most centrally located users in the network – meaning they have a large degree of control. Furthermore, there are relatively fewer Individual Researchers when compared to other groups. This may mean that Individual Researchers voices are stronger because they are unique and not restrained by any formalities that may apply to institutional users. Institution accounts generally have restrictions on what can be posted to social media whereas Individual Researchers can take more personal approach in what they say about a given topic.

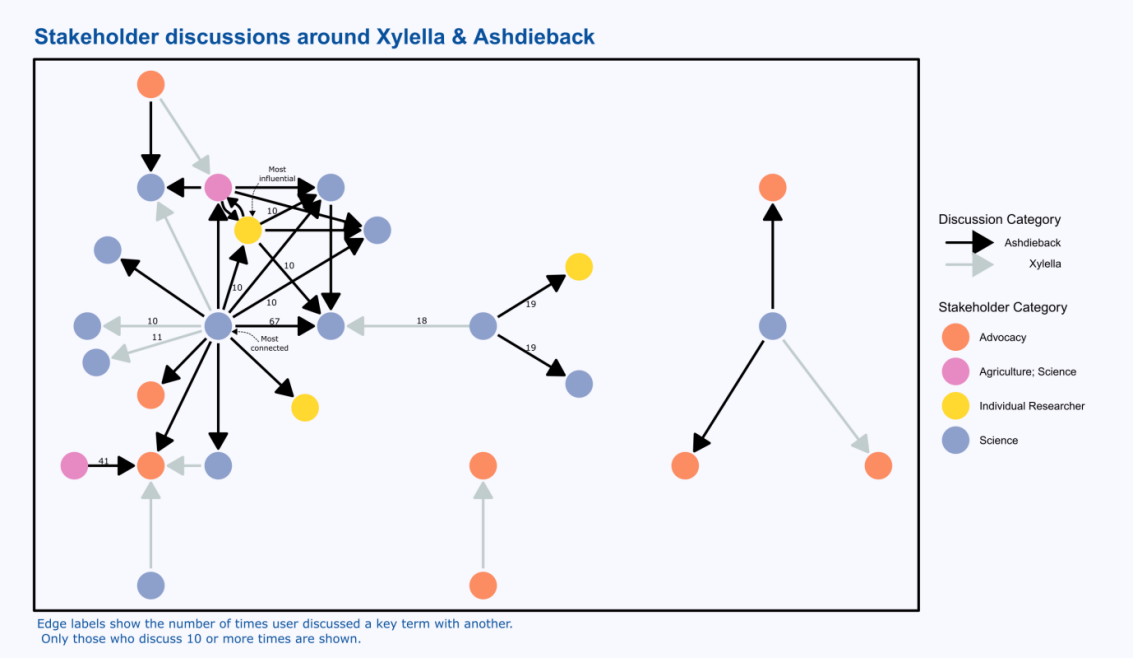


Figure 8: Plant health topics in the network. The results of the filtering process mean that this graph is zoomed in on the node labels 'Science' in Figure 4.

Chapter summary

This research addressed the question of where people in Scotland get their information regarding plant health. In order to answer this data was obtained from the Twitter API using an approach called network jumping. Results suggest most Twitter users included in the database get information directly related to plant health from scientists and individual researchers. However, this information does not permeate out into the wider online network. Rather, it is shared and discussed within a select few users.

This is beneficial, in that scientists and researchers are usually correct when it comes to the topic of plant health. However, there are drawbacks to the current network structure. Mainly, the key purveyors of information have limited reach (see Figure 6), and this is due to the structural nature of the network. Users classified as Agriculture and Other make up the majority of users in the network, and those classified as Agriculture are the most influential. According to the results above, the most efficient way to spread useful information regarding plant health in Scotland is to engage directly with those classified as Agriculture. Furthermore, if the assumption that institutional Twitter accounts (e.g. official accounts of university departments) are limited in their ability to quickly engage in candid discussions (i.e. peer-to-peer), then the most efficient way to circulate credible information in the network is for Individual Researchers (Figure 6) to engage directly with influential farmers. This will ensure that accurate information is spread directly to those have the most influence on the most people.

Chapter 7

Discussion, recommendations and conclusions

Introduction

As for most environmental issues (see Mayumi and Giampietro, 2006), Plant Health is typified by spatial and temporal complexity, risk and uncertainty, attaching a premium to understandings of how and where people acquire knowledge on plant health, in addition to how they make decisions based on this. There has been a recent emphasis on the democratisation (Frame and Brown, 2008), integration (Brand and Karvonen, 2007; Jensen *et al.*, 2007; Raymond *et al.*, 2010), and strategic management (Kolleck, 2013; Muñoz-Erickson and Cutts, 2016) of knowledge to overcome the persistent (Schuitmaker, 2012), or wicked (Frame, 2008), nature of environmental problems. Many, such as Cornell *et al.*, (2013), advocate and actively encourage the *opening* of knowledge systems so as to engage more actors, intensify interaction, and integrate and target knowledges and technologies at a specific arena, i.e. Plant Health, or issue, i.e. Cyst Nematodes. In such a context, networks need to be engaged and 'switched-on' to the short and long-term implications of active intervention. In this chapter, we discuss the results of the review and scoping research, draw some conclusions and offer practical recommendations. We structure the discussion against each of the aims highlighted at the beginning of the report.

1) ***To sketch a conceptual framework to illustrate how Plant Health Centre can best support knowledge flows for effective plant health management***

In all forms of sustainability governance, there is a shift towards more participatory forms of knowledge sharing and implementation. The conceptual framework highlighted the need to consider knowledge exchange and not just knowledge transfer; to recognise that knowledge is not absolute but a 'justified true belief'; and to understand that knowledge requirements will vary with pest, context, stakeholder. In this conceptual framework we highlighted how the type of knowledge and knowledge flows required will be affected by:

- **Risk**
- **Stakeholder awareness** and the types of deeper **stakeholder engagement** required to co-design and implement solutions
- **Stage of invasion** – outbreaks occur along a time trajectory and different knowledge focus is required depending on whether a pest is Endemic or an outbreak trajectory demands Specific awareness, Alert awareness or Crisis management.

2) ***To review knowledge flows amongst stakeholders in relation to plant health, with particular relevance to Scotland***

The literature on knowledge flows in relation to plant health was explored and synthesised, with the production of an annotated bibliography that could support future research and decision making. There was a good literature on stakeholders in tree health and on knowledge acquisition in general in agriculture and on how to develop collaborative management and strategies for the natural environment. It was clear that we need multiple knowledge flows and mechanisms.

3) ***To discuss how stakeholder engagement for enhanced knowledge exchange might be implemented***

We developed a good initial stakeholder map (see Appendix 2), listing and categorising stakeholders, but the scope of this study did not permit a full stakeholder analysis by interest and influence or other categories. This map needs to be developed to form a stakeholder engagement plan that takes into account sector, pests, stage of outbreak etc. Further information on how people gain knowledge, what sources are most used and which sources are most trusted, discussed below, is essential to incorporate into a multi-faceted stakeholder engagement plan. A potential suite of actions to address this is offered in the recommendations.

4) ***To empirically scope existing and potential knowledge flows in relation to plant health in stakeholders in Scotland***

The greatest part of the research specifically explored existing knowledge flows across sectors. Rather than utilising only one methodology, the team scoped this question using several approaches: an online analysis of Twitter interactions, key informant interviews, a survey at an agricultural event, summary data from an emerging project on knowledge sources in the horticultural trade. This diverse approach allowed us to offer insights from across sectors, but obviously it is limited because of the scoping nature and the small size of the possible mini projects undertaken.

Individual uses of knowledge sources varied. There is a healthy scepticism regarding some knowledge sources. People are cautious of commercial data and it was not trusted by farmers or individual forest managers. Academic papers were the most trusted source, but since they were not accessed by most stakeholders, people would rely on key knowledge brokers (such as agronomists) or events (such as conferences or professional workshops) to inform them of the latest changes. Hence, the role of the agronomist or the forest consultant and face to face

events are crucial in relaying information and supporting informed decision making and subsequent good plant health behaviours. Trusted sources tended to lead to decision making. Twitter was used only by a small subset of participants over the project.

Sectoral differences were apparent, with clear lines opening up across a binary division of a) Tree health (Forestry, much Natural Environment, some horticulture) and b) Agriculture (with some horticulture). There are known pests and unknown pests; in Agriculture there tends to be a more proactive approach to plant health, with preventative spraying if it is known that some plant pests or pathogens are likely to arise in a particular season. Chemicals may also be applied to treat initial indicators of outbreaks. Farmers thus expect and manage pests all the time and the strong commercial interests in the chemistry industry understand this and try to ensure their products are used. However, in Tree Health, pests are often 'unknown' or 'unexpected'. Knowledge flows in Agriculture are thus more about management but in Tree Health are more about prediction, detection and identification followed by management plans for some pests. Quarantine is used to some extent e.g. in horticulture. Although Agriculture is dependent on chemical control, in Tree health chemicals are used far less frequently. One participant discussed how within the forestry sector, different owners may differ in the ways they want to manage pests e.g. commercial plantation owners are potentially more likely to take a more chemical approach, but in more natural environments there may be an expectation that pests will occur and represent a 'normal' component of dynamic ecological systems. These findings raise questions regarding options for the forestry sector and the organic sector, where the focus in more on prevention than treatment. There are more structural approaches to support plant health through management in forestry e.g. through thinning, diversification of species, genetic source and structure of forest. Crisis management is compulsory felling, with potential quarantine of an area in some cases. Whilst these results go beyond our exploration of knowledge flows, they indicate significant sectoral differences in concerns, priorities and management.

Two interviewees had much to say about engaging with the public – they discussed how to develop more biosecure behaviours. In horticulture or public gardens there is the need for a consistent message, with information indicating why requests are made, encouraging small steps e.g. walking through boot bath. Encouraging more biosecure behaviours among wider publics (e.g. boot and bike cleaning before visiting forests) is a long-term process requiring a "drip feed" approach – consistent communication including small easily-achievable actions.

Networks enable trust, relationships and communication channels to be established. Key network nodes include agronomists and forestry consultants (e.g. Confor, the ICT and RFS)

but informal peer-to-peer learning is also important. Some farmers have established WhatsApp groups. Individual forest landowners and farmers are sometimes hard to reach directly, although articles in agricultural magazines may be effective. Communication with urban and peri-urban public audiences on issues regarding tree health will be more effectively undertaken by NGOs or educational /interest bodies (e.g. RHS).

Information gleaned through the survey at the potato event gave more detail and patterns of the knowledge sources in agriculture. This case study survey produced a snapshot of existing knowledge flows, and focusses on how these may be developed in the future. In terms of frequency, respondents, quite overwhelmingly, tended to favour and use forms of knowledge exchange that involve face-to-face, first-person interactivity like Conferences, Informal Chats, and Workshops as opposed to Academic Papers, Social Media and Websites that typically require one to locate and process knowledge in lieu of a more *socialised* dissemination and exchange. More experiential forms of learning and participation also tended to change the policy and practice of respondents more than others and were regarded as the best way to transmit knowledge and information across everyone in the sector. For instance, many respondents cited on-site demonstrations like 'Spot-Farm' or 'Farm Example' as being the most potent force for change, with one respondent calling for greater integration between Conferences, Workshops and these On-Site Demonstrations to build synergies. To fulfil the appetite for making knowledge more accessible, and exchange more efficient and effective, respondents thus attach a premium to inclusive, participatory frameworks that enable forms of knowledge co-production, exchange and implementation. This case study would hence suggest, and support, the idea that experiential and interactive methods, together with long-term frameworks and short-term interventions, are a potent recipe with which to encourage and facilitate effective engagement with UK Plant Health.

The results also suggest that there is a real disconnect between the forms of knowledge that respondents trust, and those they use in practice, particularly with respect to Academic Papers and Informal with Peers. For instance, Academic Papers are, quite significantly, the most trusted source of knowledge, but are used infrequently with some citing difficulties in terms of access (fee), comprehension (complexity), and a lack of traction with agricultural sectors (culture). Here, the Plant Health Centre, and the Academic Community more generally, should focus on making academic study more accessible, comprehensible and welcoming to non-academic audiences. The use of peer-review still provides legitimacy and trust to academics, but efforts should be made to popularise and interpret scientific knowledge within society. There have been several theories explored that may be useful in underpinning a future industry-science-policy interface in plant health e.g. Post-Normal

Science (Funtowicz, 1994; Ravetz, 2004) or Sustainability Science (Bäckstrand, 2004; Kates and Scholar, 2011). Potential solutions might include summarising and disseminating the key findings from Academic Papers at Conferences and Workshops; including stakeholders in the design, implementation and transmission of Academic Studies and Papers; and continuing to develop and integrate more socialised forms of knowledge exchange through issue-driven, participatory events like On-Site Demonstration, in addition to a focus on experiential, practical Conferences and Workshops. Networks, in particular their ability to enhance interaction between people, have also been cited as a means of addressing persistent problems (Cornell *et al.*, 2013). The Plant Health Centre could therefore look to develop a more dialogic culture around the issues faced, with a particular emphasis on strategically managing and targeting informal discussion. Here, explicit attention should be afforded to the authenticity of informal dialogue because, despite being a frequently used form of knowledge exchange, it faces issues in terms of perceived trustworthiness. Top-down campaigns from key industry players encouraging a more active and critical engagement with knowledge, in addition to improved opportunities for informal knowledge-exchange and networking, could be pursued.

A targeted stakeholder engagement strategy is required to integrate knowledge production, exchange and implementation across various levels of participation, such as informing, consulting, involving and empowering, at all stages of invasion, in the short and long term (O'Brien, Marzano and White, 2013). Any potential solution, for instance, will be more appropriate if supported, or even co-designed (Sanders and Stappers, 2008), or co-produced (Muñoz-Erickson, 2014; Polk, 2015), using an *extended peer community* - the knowledge and visions of actors from myriad backgrounds and disciplinary domains - to integrate local and scientific expertise, and thus assure and enrich the creation, review, and implementation of prospective solutions (Frame and Brown, 2008; Cornell *et al.*, 2013).

5) To employ social network analysis to offer detail of particular knowledge flows

The public is increasingly turning to social media for information regarding a variety of sources, including information regarding plant health, although this project showed that not all practitioners are active in this way. A study of online social networks using data from Twitter's API was conducted in this scoping study in order to better determine the key stakeholders regarding plant health information in online sources. Data was pulled daily from Twitter's API using a technique called network jumping. In total, approximately 150,000 tweets were gathered from key stakeholders in the plant health sector and those users with whom they engage. Results suggest that while Twitter allows for information to be transferred quickly and to a large number of people, plant health experts are not well-placed within Twitter networks to ensure that information permeates to those who need it most.

Indeed, some of the sources of plant health information that are available to the public are less trusted than others. Currently, key stakeholders with backgrounds in policy and science are not well placed to control the online-narrative on plant health information. Furthermore, individual researchers are best suited to get accurate information to the largest number of users in the shortest period of time. It is important that the plant health sector develop an engagement strategy that considers and includes social media use.

6) ***To provide conclusions and recommendations to support future practice and research in this area***

It was concluded that knowledge production, exchange and implementation is complex across a wide range of stakeholders in plant health in Scotland. Some key recommendations can be made regarding optimising knowledge flows, including development of a stakeholder engagement strategy that develops networks and collaborations whilst reinforcing existing key knowledge brokers and points whilst developing new knowledge channels and enabling subsequent biosecure behaviours.

Recommendations

1. It is crucial to develop a **stakeholder engagement strategy** – including different knowledge exchange approaches for different stakeholder types and contexts, sectors, pests and stages of outbreak. This should recognise the broad sectoral differences we identified i.e. Tree health and Agriculture. This plan should include support of networks to facilitate knowledge flows for normal management as well as crisis responses over time during invasion periods. The stakeholder engagement strategy may include:

- stakeholder analysis of those with interests and responsibilities in plant health
- information provisions for the public(s), with consideration of different pest and pathogen species and different stages of outbreak
- consultation processes for new practices and policy and as new or stronger risks emerge
- involvement strategies to engage individuals and groups in effective plant health behaviours
- partnerships and collaborations that strengthen the community of those with an interest in or responsibility for plant health, enabling strong knowledge flows
- building networks to support baseline knowledge exchange along with crisis response mechanisms to exchange information rapidly in case of a high risk pest outbreak

A stakeholder engagement strategy that includes (and maintains existing) collaborations and partnerships as well as creating specific knowledge channels is in line with trends in sustainability governance.

2. **Further research is required on knowledge flows in relation to plant health specifically**, in Scotland. To achieve this, it is important to recognise and work with trusted relationships and networks.
3. The scepticism regarding commercial information was high and future knowledge engagement by PHC should **include commercial companies but be careful** to always offer their own synthesis of commercial information. Bayer is a dominant presence on Twitter and practitioners should be reminded of the commercial focus of such bodies.
4. Twitter remains a key potential for knowledge exchange; it will rarely reach individual practitioners (such as farmers or forest owners) directly but is used by certain groups and key individuals. **A more dominant narrative by trusted plant health sources should be established on Twitter**. Future research could be undertaken to classify actors in the Twitter sphere (grounded in stakeholder maps and in field based interviews to understand who and what they are e.g. Bayer and PHC use the same words in descriptors but they are very different in motivation and purpose.
5. The **use of WhatsApp could be expanded** with local, sector specific groups enabling rapid knowledge exchange among trusted peers and a key contact such as an agronomist. This is especially so for younger practitioners.
6. Whilst academic papers were trusted, they were rarely accessed. Maintaining a flow of **regular Policy Briefs, Research In Action notes or some other format** and distributing and discussing these at events would be one way to synthesise, prioritise and collate academic research for laypeople and provide opportunities for key scientists to become familiar and, over time, trusted faces at events.
7. Further research and engagement could **link to other sectors** e.g. animal health – learning and sharing across networks. It would also be interesting to infuse cross sectoral issues e.g. across climate change with plant health; possibly also water quality

In conclusion, we can see that plant health is important across the sectors of forestry, agriculture, horticulture and environment, with some overlapping areas. Much of the recent focus on stakeholders and stakeholder engagement has occurred in 'tree health', which overlaps all of these sectors to some extent. The boundaries across the sectors of interest in plant health are blurred, with literature especially not distinguishing between agriculture and horticulture in many areas. A stakeholder engagement strategy is required for the Plant Health Centre that integrates knowledge production, exchange, implementation and ranges across informing, consulting, involving and empowering forms of engagement. This research

provides information to inform this process and ensure that plant health is optimised across Scotland and beyond.

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