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Plant Health and the Natural Environment

Fellowship Final Report

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The James Hutton Institute

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Content

1 Executive summary

1.1 Introduction

The Natural Environment sector underpins Scotland's landscapes, biodiversity, rural industries and recreational activities, but the growing number of plant pest and pathogens (termed pests throughout) pose a significant threat to this sector and the rural economy. There is growing awareness of the importance of plant health (defined as a decline in plant fitness due to the consequences of biotic agents, i.e. pests and pathogens) but this is largely within the agricultural, horticultural and forestry sectors. This Plant Health Centre Fellowship, joint with NatureScot, aimed to assess people's awareness of plant health in the natural environment and likely risks associated with it.

Specifically, this fellowship aimed:

1. To gain a better understanding of stakeholders' awareness of the plant health risks associated with the natural environment, particularly with respect to habitat restoration and creation.
2. To identify the plant pests that threaten Scottish moorlands, as a system in its own right and as an example of a non-woodland/forest habitat to highlight the risks to other habitats.
3. To develop a framework for assessing risks to plant health in the natural environment and guiding the implementation of appropriate responses following pest outbreaks.

1.2 Stakeholders' perceptions of plant pests and the natural environment in relation to habitat creation and restoration.

- Stakeholders perceive that their neighbours' activities rather than their own are the most likely source of pests establishing.
- There is a misconception by stakeholders that seeds are as likely as mature plants to introduce pests.
- Woodlands and wetlands are perceived as the habitats being at greatest risk from pests despite evidence showing that other habitats, such as moorlands, also have a large number of pests that could impact them.
- Stakeholders did not think that plant pests were a greater driver of biodiversity loss than any other drivers of biodiversity loss.
- Stakeholders did not distinguish between the risk of a pest establishing in a habitat and the potential cascading indirect impact of plant pests on other biodiversity.
- Stakeholder awareness of future plant pests was heavily influenced by those currently present.
- More stakeholders had biosecurity protocols in place than biosecurity risk assessments. Such an approach assumes that the biosecurity protocols cover all the relevant risks. Many organisations do not check that biosecurity protocols are followed, and in many cases, there is no one within their organisation responsible for biosecurity.

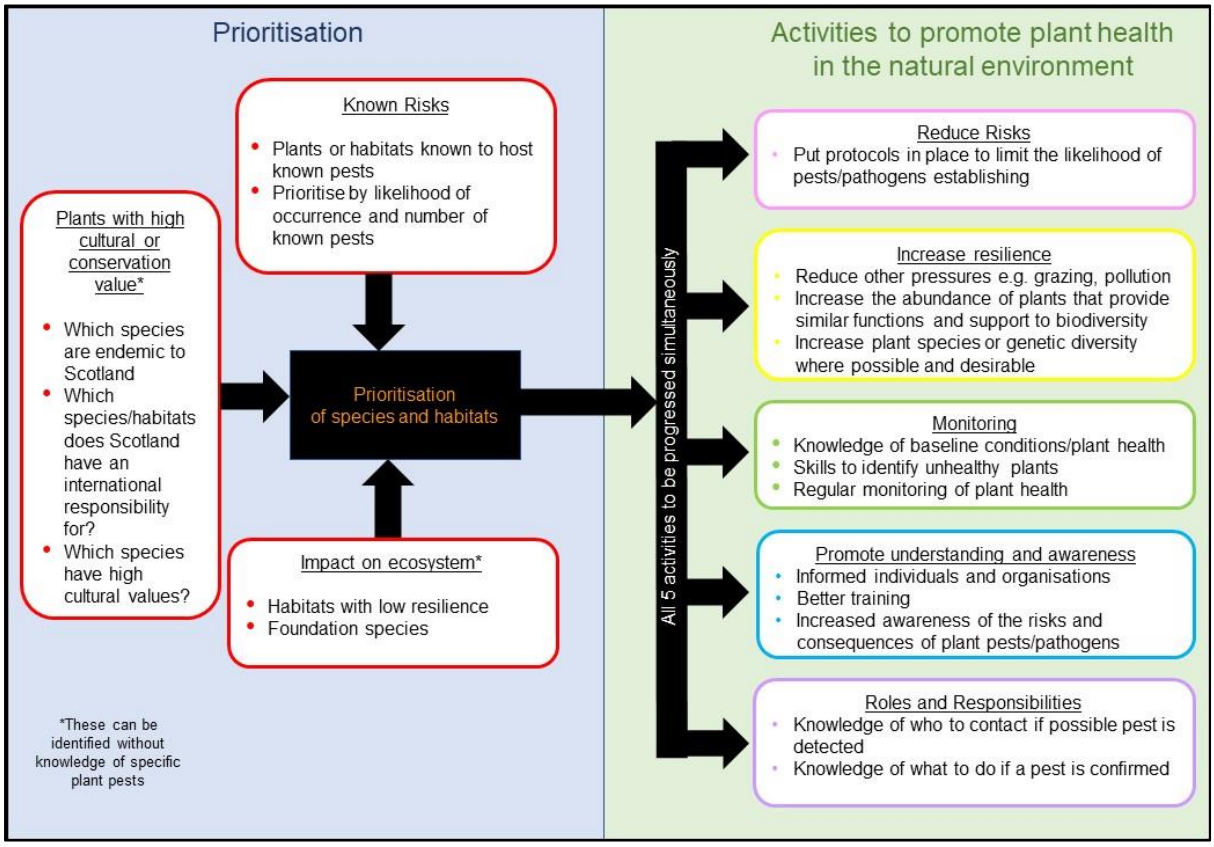
1.3 Risks to Scottish moorlands

- The Plant Health Risk Register lists 161 pests hosted by vascular plants occurring at an abundance of more than 25% cover on Scottish moorlands.
- 38 of these 161 pests are already present in the UK.

- There are 29 pests listed in the PHRR with a mitigated likelihood of establishment of 4 or 5 (the highest two levels) that are hosted by 12 plant genera (occurring at more than 25% cover) on Scottish moorlands: *Arctostaphylos, Calluna, Dactylis, Erica, Festuca, Genista, Juncus, Juniperus, Plantago, Pteridium, Salix, Vaccinium*.
- The most likely pathway for these pests to establish in the UK is via movement of plants, excluding seeds, tubers and bulbs.
- Eighty-eight of the 161 pests have some form of European Public Protection Office (EPPO) or EU regulation.
- Eighty-nine of the 161 pests occur in at least one other European country than the UK. Italy, France, Spain and Germany were the European countries with the greatest number and therefore could be considered the highest risk countries, all having over 40 of the pests.
- 142 pests that were not listed in the UK Plant Health Risk Register, but which could attack plant genera occurring at more than 25% on Scottish moorlands, were found through a literature search.

1.4 Overarching framework

In discussion with stakeholders a framework was developed to a) help prioritise plants/habitats for monitoring of plant health and b) provide activities to promote plant health in the natural environment. The framework, shown below, allows actions to be taken to reduce the risks of, and increase resilience to, plant pests without identification of specific plant pests.



1.5 Roles and responsibilities

- It is unclear who has responsibility for plant health in the natural environment and currently there are no agreed procedures for reporting suspected plant pests in the natural environment.
- The Chief Plant Health Officer for Scotland (CPHOS) has powers to remove plants infected with quarantine pests in the natural environment and to limit access to reduce the risk of quarantine pests spreading.
- There is a lack of diagnostic resources (e.g. labs) for identifying plant pests in the natural environment.
- If NatureScot become the responsible organisation for plant health in the natural environment, they lack the necessary resources.

1.6 Recommendations

1 **Roles and responsibility for plant health in the natural environment need to be clarified**.

- There needs to be clear lines of responsibility and communication for plant health in the natural environment.
- A standard operating procedure for identification of, and response to, plant pests in the environment is required.

2 **A procedure for monitoring plant health in the natural environment should be established.**

- Plant health in the natural environment should be monitored regularly, e.g. it could be included during habitat condition surveys and/or monitoring of habitat restoration/creation success.
- The development of something similar to TreeAlert for non-tree plants would enable the general public to report unhealthy plants in the natural environment.

3 **Habitat restoration and creation projects should include risk assessments for plant pests and biosecurity protocols.**

- All habitat restoration and creation activities should be required to have an assessment of the risk of accidently introducing plant pests and biosecurity guidance/best practice to mitigate the identified risks.
- Organisations involved in habitat creation/restoration should check that their staff/contractors follow the agreed biosecurity protocols and have a named individual responsible for biosecurity.
- Further advice on developing risk assessments and biosecurity protocols for plant pest is required by stakeholders within the natural environment sector.

4 **There needs to be greater awareness of the risks to natural environment from plant pests.**

- The example of numbers of potential pests that could impact Scottish moorlands, collated in this report, could be used as an awareness raising exercise to highlight the risks.

5 **Modification of the Plant Health Risk Register (PHRR) would enable it to be of greater use to stakeholders**.

- If the PHRR and the associated datafile were fully searchable by host rather than pest and included a greater range of native plant hosts in addition to those within in the horticulture, agriculture and forestry sectors it would be of greater use to stakeholders within the natural environment sector. Currently the website allows only restricted and limited searching by host and the associated datafile needs considerable modification to allow searching by host.

1.7 Next steps.

To progress the discussions on roles and responsibilities for plant health in the natural environment that started during this fellowship the following next steps were agreed:

- A paper on wild plant health presented to NatureScot Science Advisory Committee in March 2023.
- Agree protocols for the flow of information if a suspected pest is discovered.
- Trial the protocols on a small subset of species.
- The Plant Health Centre could lead work on mapping roles and responsibilities for plant health in the natural environment.
- The Plant Health Centre could lead work on identifying a few (e.g. 10) foundation species that could be used in a trial for testing protocols and plant health monitoring in the wider environment.

2 Introduction

Plant health is defined in this report as the consequences of biotic agents such as bacteria, fungi, insects, mites, nematodes, oomycetes, phytoplasma, viruses and viroids. Throughout this report they are collectively referred to as pests. Within this report we are not referring to impacts of poor management, vertebrate herbivores, poor soils, or the direct impact of changes in climate on plant health (although climate change will impact pest severity/distribution) (see Table 1 for definitions).

Global trade, land-use change, international travel, habitat fragmentation, and climate change are all contributing factors to an increase in the diversity and impacts of plant pests. Plant pests have wide reaching detrimental impacts, with outbreaks and losses spanning multiple sectors including agriculture, forestry, horticulture and the natural environment. The natural environment sector underpins Scotland's landscapes, biodiversity, rural industries and recreational activities, but the growing number of plant pests pose a significant threat to this sector and the rural economy. There is growing awareness of the importance of plant health, but this is largely within the agricultural, horticultural and forestry sections. This report aims to assess the awareness of plant health in the natural environment and likely risks.

As plants are fundamental building blocks for ecosystem functioning, the impacts of a decline in plant health in the natural environment may cascade far beyond the direct impact of a pest on the plant. Plant pests rarely cause the total extinction of a plant species but do cause their functional extinction, reducing their abundance to such an extent that, while they may still be present, they no-longer have a functional role influencing community composition and processes (Ellison et al. 2005). Ecological theory suggests that if a foundation species is lost, or becomes functionally extinct, this will have cascading impacts on associated species, processes and services. Associated species are those that depend on that plant species for part of their life cycle e.g. breeding (birds and bats) including living space such as epiphytic mosses and lichens, food (herbivores). Therefore, our understanding of plant pest impacts needs to include not only the direct impacts on plant health but also the indirect impacts (Figures 1 and 2).

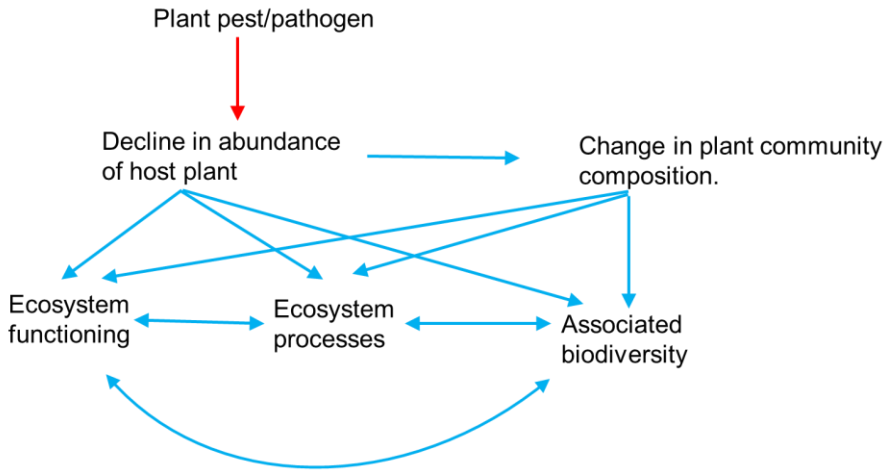


Figure 1 – The direct (red) and indirect (blue) impacts of a decline in plant health on the natural environment.

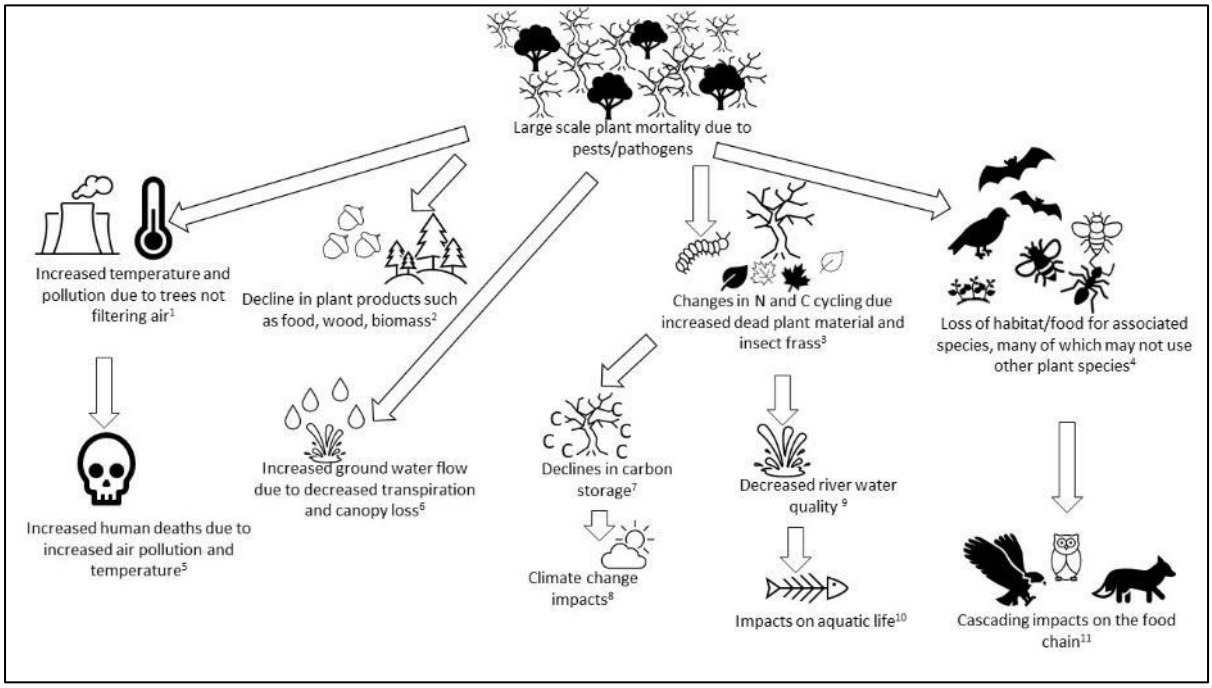


Figure 2 – Examples from the literature of the cascading effects within the natural environment of large scale plant mortality due to pests. [1] Macpherson et al. 2017; Willis & Petrokofsky 2017. [2] Aukema et al. 2011. [3] Frost & Hunter 2004; Gandhi & Herms 2010a; I-M-Arnold et al. 2016; Jenkins, Aber & Canham 1999; I-M-Arnold et al. 2016. [4] Lohmus and Runnel 2014; Rabenold et al. 1998; Tingley et al. 2002; Cahill et al. 2008. [5] Donovan et al. 2013. [6] Embrey, Remais & Hess 2012; Bearup et al. 2014. [7] Hicke et al. 2012; Flower, Knight & Gonzalez-Meler 2013 . [8] Reay 2013; Kurz et al. 2008. [9] Edburg et al. 2012; Brouillard et al. 2016; Eshleman et al. 1998; Cessna & Nielsen 2012; Embrey, Remais & Hess 2012. [10] Webb et al. 1995; Snyder et al. 2002; Gandhi & Herms 2010b; Cessna & Nielsen 2012. [11] Storer et al. 2005; Koenig et al. 2013; Flower et al. 2014; Koenig & Liebhold 2017.

Table 1 – Description of terms used

Term	Description
Biosecurity guidance/best practice	Describe actions or procedures on the ground (e.g. at restoration sites or in propagation facilities for growth of plant material used in restoration projects) that should limit the risks of plant pests spreading (e.g. cleaning of footwear and equipment). These may or may not be compulsory to follow
Foundation species	A single species that defines much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing, fundamental ecosystem processes.
Functional extinction	A reduction in the abundance of a species to such an extent that while they may still be present, they no-longer have a functional role influencing community composition and processes
Functional redundancy	A characteristic of species within an ecosystem where certain species contribute in equivalent ways to an ecosystem function, such that one species may substitute for another.
Habitat creation	The creation of a new habitat which may include the translocation of plants
Habitat restoration	Management to restore an area of land to more favourable ecological status, which may include the translocation of plants.
Pests	Used in this report to include both pests (invertebrates that cause damage to a plant, either by direct action or by acting as a disease vector, e.g. insects and nematodes) and pathogens (a virus, bacteria, fungus or fungus-like organism that causes disease). Refers to both native and non-native pests and includes both those pests already present within the UK and those that might establish in the future.
Plant health	Plant health can be influenced by both biotic and abiotic factors, and their interactions. Here we focus on a decline in plant health due to the consequences of biotic agents (i.e. pests and pathogens). We do not include abiotic drivers of plant fitness (unfavourable growing conditions such as weather and soil), non-infectious diseases, damage by vertebrate herbivores, stress caused to the plant by unfavourable management practices or the relationship between genetic diversity and plant health.
Natural environment	Semi-natural habitats
Risk assessment	An assessment made before an activity is carried out to identify and assess the potential impacts and risks of that activity. In relation to plant health this would include assessments of where staff/equipment/plants to be translocated may come into contact with plant pests and how the proposed activity may result in the plant pests being transported/introduced to a new location.
Translocation	The movement of plants at any stage of their life cycle (seeds, cuttings, adult plants), including both vascular plants and bryophytes

The awareness of both the potential direct and indirect impacts of plant health on the natural environment is limited. This project has five aims:

1. To gain a better understanding of stakeholders' awareness of the plant health risks associated with the natural environment, particularly with respect to habitat restoration and creation.
2. To identify the threats to Scottish moorlands. Currently most of the work on the plant health risks to the natural environment have focussed on woodlands. We use moorlands (also termed dwarf shrub heaths, moors, heaths, or heathlands) as an example of a non-woodland/forest habitat.
3. To conduct a case study on the plant health risks associated with augmenting rare wild plant populations.
4. To develop a framework for assessing the risk to plant health in the natural environment.
5. To initiate a discussion on the roles and responsibilities for plant health in the natural environment.

The overall objective of this work is the start of an awareness raising process within the natural environmental sector of the potential impacts of a decline in plant health.

3 Stakeholders' understandings of the plant health risks associated with habitat restoration and creation

3.1 Introduction

The most effective way to limit the risk of new pests impacting our natural environment is to stop their establishment. Most new pests establish through human aided processes, such as transport on soil within equipment or on translocated plants. It is therefore key that the people involved in the management of our natural environment are aware of the potential risks and have protocols in place to limit any accidental introductions. However, our knowledge of the awareness of stakeholders about the risks that plant health poses to the natural environment is limited. We specifically focused on habitat restoration and habitat creation as these were seen as two potentially high-risk operations within the natural environment when plant pests could establish.

3.2 Method

A questionnaire was designed to better understand:

- The awareness of those involved in habitat restoration and habitat creation of plant health biosecurity risks.
- What risk assessments and biosecurity guidance/best practice are currently used with respect to plant health during habitat restoration and habitat creation.
- What, if any, new guidance is required.

The questionnaire had 19 questions (Appendix 1) and was approved by the James Hutton Institute's ethics committee prior to circulation. The questionnaire was sent to 245 individuals and 88 organisations. The individuals were known to be involved in habitat creation and/or restoration. For the organisations we requested that they circulated the questionnaire to appropriate staff members, those involved in habitat creation and restoration. The organisations included Countryside Managers Association, CIEEM, NE Scotland Biodiversity group, SELINK, National Trust for Scotland, National Trust, Plant life, all the county wildlife trusts, Scottish Countryside Rangers Association, Natural England, NatureScot, Action Oak, and Defra.

The survey ran from 29th September till 30th November 2021.

3.2.1 Data analysis

All data analysis was carried out in R software version 3.6.2 (R Core Team 2018). Ordinal data, i.e. data that is ordered categorical data, such as when participants were asked to score something from 1 low to 5 high, were analysed by the ordinal package in R using a cumulative link model (clmm) (Christensen 2019). Within the analysis, participant was included as a random effect. Tukey's pair-wise comparisons were used to determine differences between pairs of options within any one question (such as differences between habitats) using the package emmeans, and P values were adjusted using the Tukey correction method for multiple tests (Lenth 2019). The emmean values were used to rank the options, for example which habitats were most at risk from pests or which sources of pests were the highest risk. The scores from participants were used to calculate the median value. Spearman rank correlations were used to test the correlation between two categorical variables.

Binominal data, questions with a yes/no response, were analysed using generalized linear models (GLM) with a binomial distribution using the lme4 package (Bates et al. 2015). Once again differences between pairs were assessed using Tukey's pair-wise comparisons as described above.

3.3 Results

There were 224 responses to the questionnaire, although not all participants answered all questions.

Most of the participants carried out habitat restoration and creation work in England (125 participants) and Scotland (87 participants), with 14 participants working in Northern Ireland and 24 in Wales. Participants could select more than one country in which they worked, hence more responses than participants.

Most participants had moderate knowledge of biosecurity and habitat restoration, although the majority said they only had basic knowledge about risk assessments and either basic or moderate knowledge about plant pests (Figure 3).

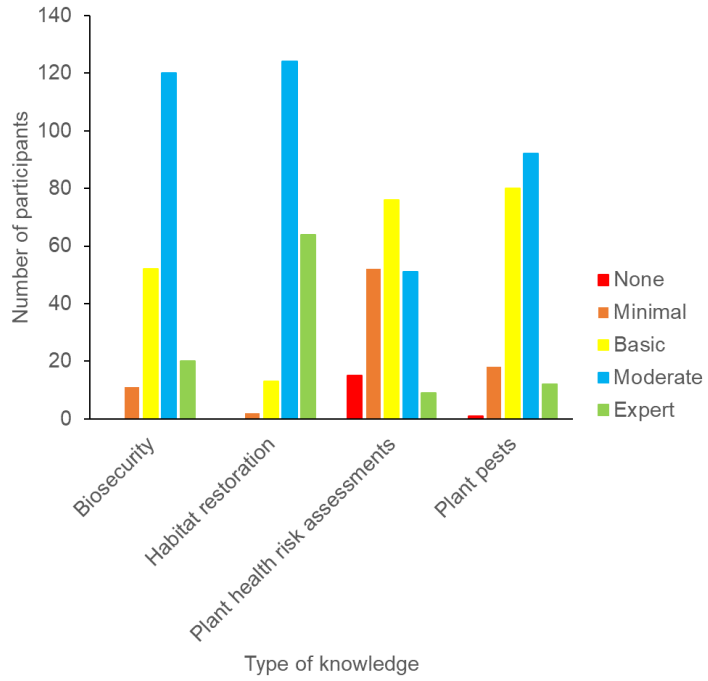


Figure 3 – How participants ranked their knowledge about biosecurity, habitat restoration, plant health risk assessments and plant pests.

Most of the participants were involved in habitat creation and restoration through providing advice, doing the practical work on the ground and/or planning and designing the restoration/creation work. Some participants were also involved through policy, as the landowner or agent or in other aspects (Figure 4a). They largely worked for environmental NGOs or government agencies, but some were self-employed, landowners, contractors or working for consultancies (Figure 4b). Most of the participants worked on habitat creation/restoration in woodlands, hedges and trees outside woodlands (TOW), grassland and freshwater habitats (Figure 4c).

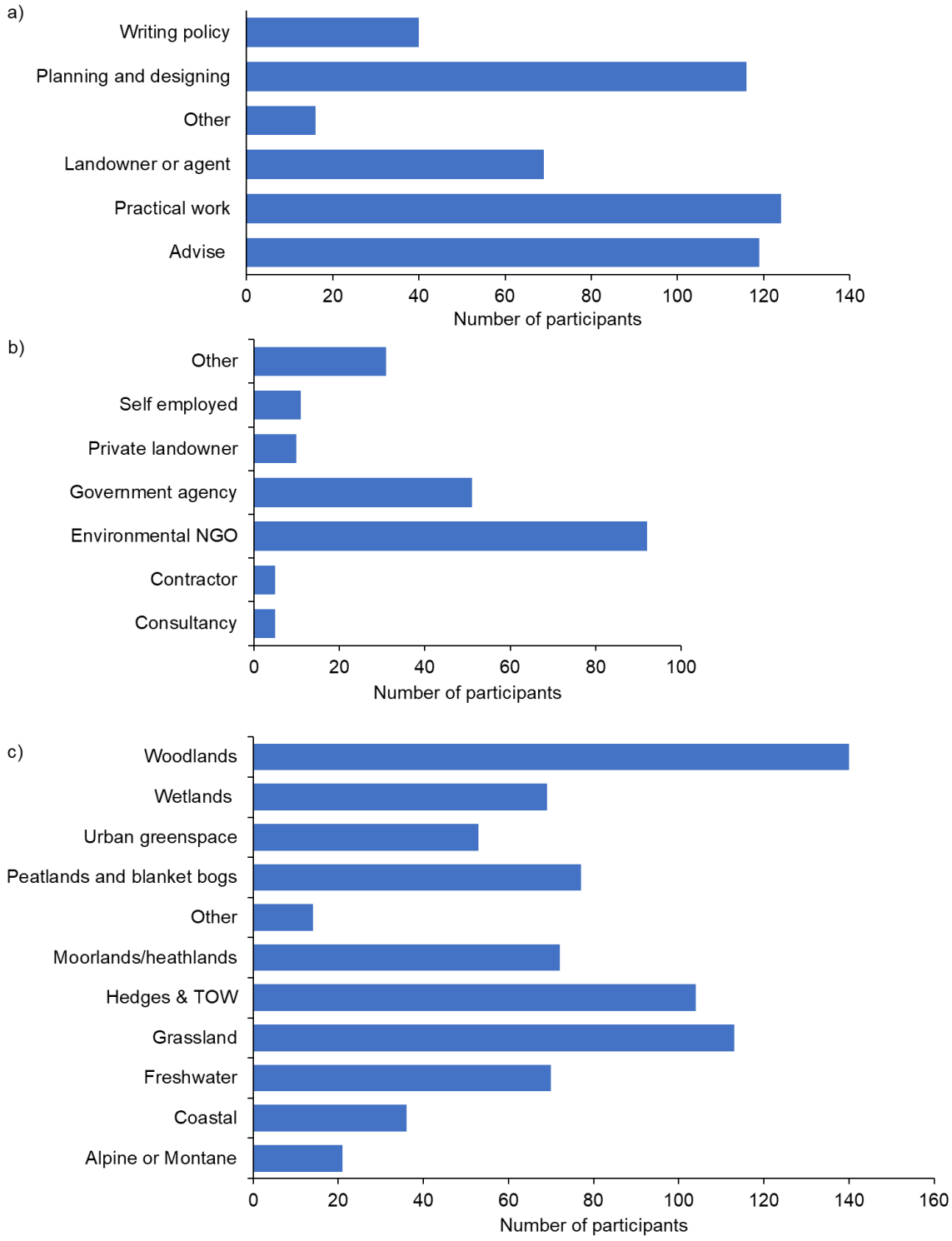


Figure 4 – How the participants of the questionnaire were involved in habitat creation/restoration a) The type of work they did; b) Their employer, c) The habitats they worked on.

3.3.1 The establishment of plant pests

Participants assessed the likelihood of pests establishing at sites they were involved with via 10 different routes:

- Introduction of seed
- Introduction of plants
- Land management operations other than habitat creation/restoration
- Movement of machinery for habit
- Movement of soil during habitat
- Spread by deer and other animals
- Spread from neighbouring sites
- Walkers/Recreation

There was a significant difference ($\chi 2(7, N=159) = 185$ $p<0.001$) between the sources in how they were ranked. Spread from neighbouring sites was ranked highest risk whereas the introduction of seed was ranked lowest (Figure 5). Calculating the median likelihood for each source showed that spread from neighbouring sites, movement of machinery, walkers and recreation, and movement of soil were all ranked as high risk. Spread by deer and other animals, other land management operations, introduction and mature plants and seed were all classed as medium risk.

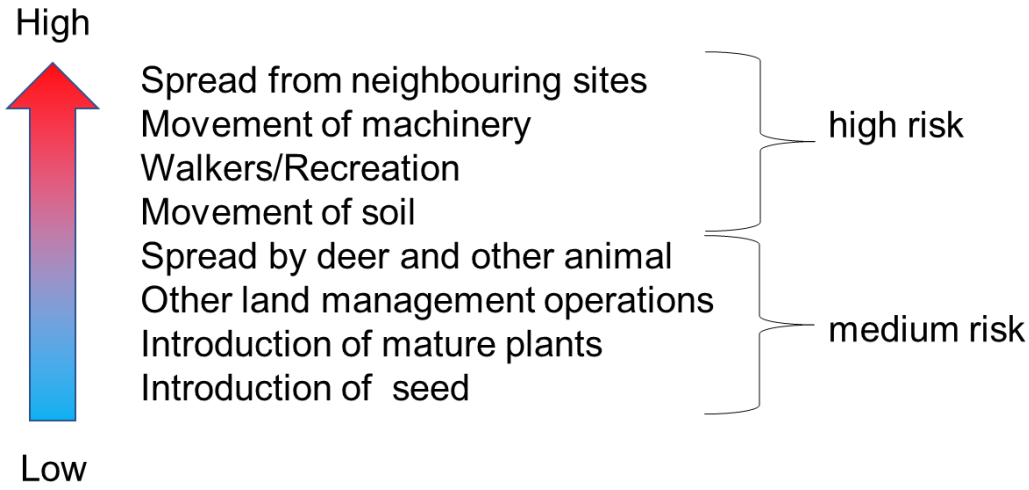


Figure 5 – How the participants assessed the risk of plant pests establishing via different sources. Ranking based on emmeans scores from clmm analysis. The high risk and the medium risk show the median score given the sources.

Participants perceived the likelihood of pests establishing to significantly differ between habitats ($\chi 2(9, N=168) = 537$ $p<0.001$) (Figure 6). Woodlands were ranked as being at significantly greater risk than all the other habitats except freshwater habitats. Alpine/montane habitats were ranked as being of lower risk then all other habitats. The likelihood score of a pest establishing in a habitat was not influenced by whether the participant worked in that habitat or not.

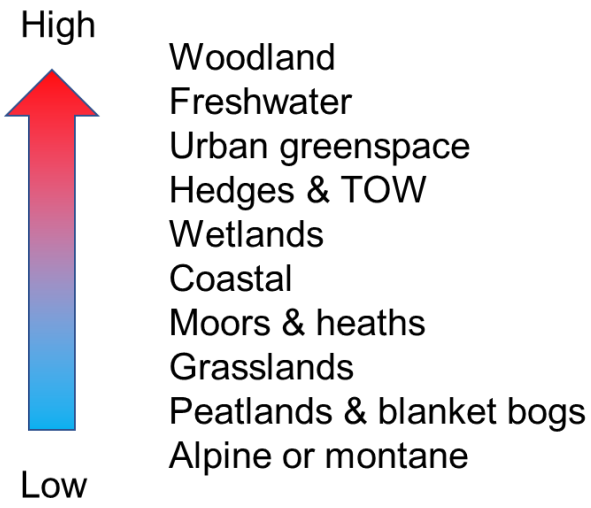


Figure 6 – How the participants ranked the likelihood of plant pests establishing in different habitats. TOW = Trees outside woodlands. Ranking based on emmeans scores from clmm analysis.

Seventy-seven percent of participants were aware of problematic plant pests already present at, or near, sites they were involved with. Fifteen percent were not aware of any problematic plant pests at or near sites they were involved with, and six percent didn't know. When asked to name current problematic plant pests, ash dieback and *Phytophthora* species were most mentioned, followed by oak processionary moth, Dothistroma and Acute oak decline (Figure 7a). Over half the participants (59%) didn't know whether there were plant pests at, or nearby sites they work at, which are not currently problematic but that could become so with changes in climate or land management. Thirty-two percent of participants were aware of such pests with ash dieback and *Phytophthora* species, again the top two diseases mentioned (Figure 7b), although the proportion of participants mentioning ash dieback had declined and those mentioning *Phytophthora* species had increased. Oak processionary moth and heather beetle were mentioned by a greater proportion of participants as future pests they were concerned about compared to current pests. *Xylella* was mentioned as a future pest of concern by one participant.

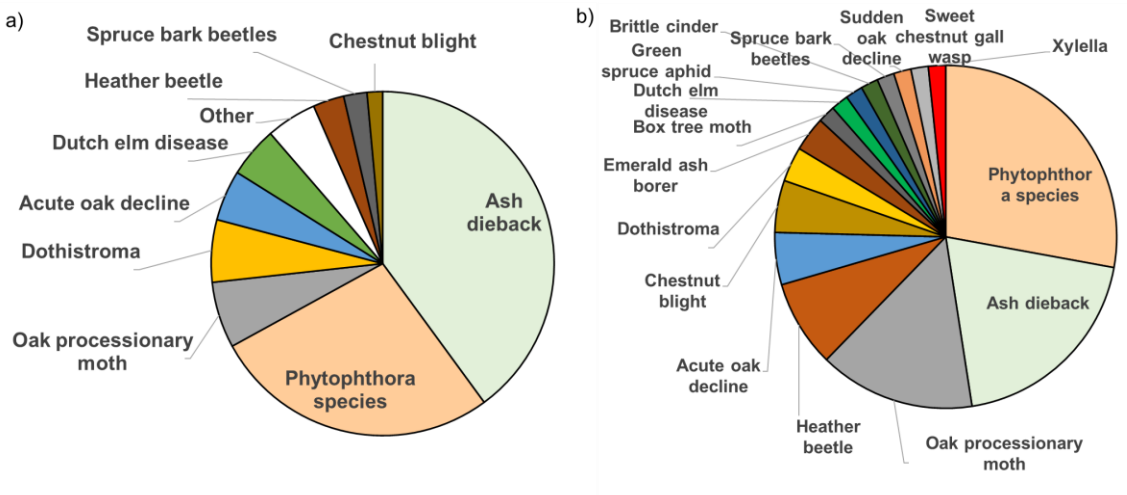


Figure 7 – The proportion of participants listing different plant pests as either a) current or b) of future concern at, or nearby, the sites they manage.

3.3.2 *The impact of plant pests on biodiversity*

While plant pests are known to have cascading effects on associated biodiversity (Chapter 2), they are only one of many potential drivers of a decline in biodiversity. Calculation of the median score showed that participants ranked the establishment of plant diseases as a lower threat to biodiversity (i.e. the potential to cause a decline in biodiversity) than agricultural practices, habitat loss and land management. Plant pests were perceived to be about the same level of threat to biodiversity as climate change, grazing by wild herbivores, other invasive non-native species, nitrogen pollution, sulphur pollution and urban development. Plant pests were not viewed as a greater threat to biodiversity than any of these other drivers of biodiversity loss.

The potential impact of plant pests on biodiversity was perceived by participants to differ significantly between habitats ($\chi 2(9, N=156) = 335$ $p<0.001$, Figure 8). The impact of plant pests on biodiversity in woodlands were ranked significantly higher than the impact on biodiversity in all other habitats and the impact on alpine/montane habitats was ranked significantly lower than all other habitats. How participants perceived the potential impact on biodiversity was not influenced by which habitats they worked on. There was a significant correlation (Spearman's rank correlation $p<0.001$) between the participants perceptions of the likelihood of a pest establishing in a habitat and the potential impact it might have on biodiversity.

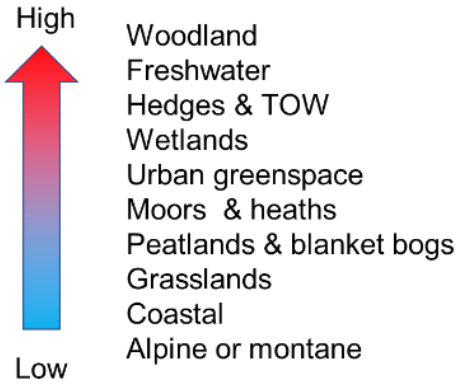


Figure 8 – How the participants ranked the potential impact of plant pests on biodiversity in different habitats. TOW = Trees outside woodlands. Ranking based on emmeans scores from clmm analysis.

3.3.3 *Monitoring of plant health following habitat creation/restoration*

Thirty-six percent of participants monitored the habitat creation/restoration for plant pests following the completion of the work (Figure 9a). Thirty-seven percent did no monitoring and the remaining 27% selected the "other" option (Figure 9a). After all the questionnaires were complete the free text in the "other" box was used to categorise these responses (Figure 9b). Of the 40 participants that selected the "other" box 42% of them said that while they didn't do any specific monitoring for pests, they thought they would be picked up in general habitat condition surveys. Other reasons for selecting the other box were that the participants said monitoring for pests did occur, but they didn't know over what time period (20%), or it wasn't their organisation's responsibility to do any post construction monitoring (15%), or that they didn't know if any monitoring was done (22%).

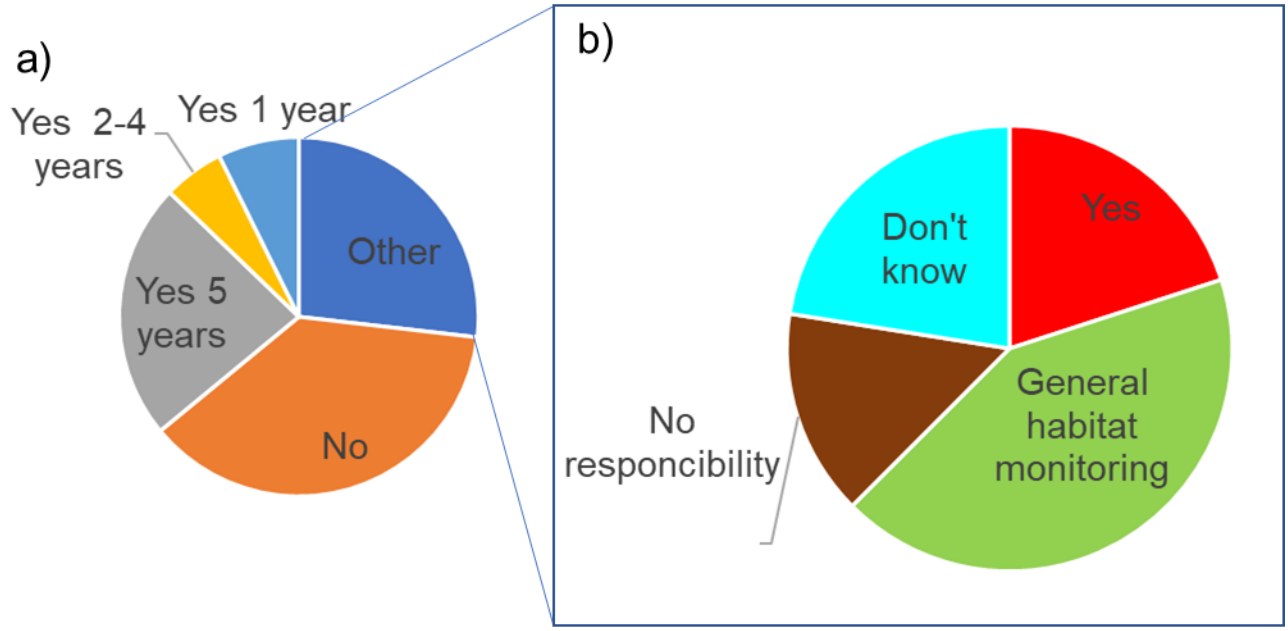


Figure 9 – Whether participants monitor the habitat creation/restoration after completion for plant pests. a) results from the survey with No = monitoring is not carried out; Yes = yes monitoring is carried out and the time frame indicating for how long after completion the monitoring is carried out. b) uses the free text box of the "other" category in a) to identify why the participants selected other. Yes = monitoring was carried out but they didn't know for how long; General habitat monitoring = no specific monitoring for plant pests occurring but the participants thought that any plant pests would be picked up in general habitat monitoring; No responsibility = the participant stated that post completion monitoring was not the responsibility of their organisation; Don't know = the participant didn't know if post completion monitoring for plant pests occurred.

3.3.4 Risk assessments and biosecurity guidance

Fifty-one percent of participants either didn't know if they had or didn't have a risk assessment for plant pests when carrying out habitat creation/restoration (Figure 10a). Who the participants were employed by (consultancy, contractor, environmental NGO, government agency, private landowner, self -employed, other) had no significant impact on whether the participates knew if they had a risk assessment. More of the participants (70%) had biosecurity guidance/best practice for habitat creation/restoration (Figure 10b). However, of those participants that had biosecurity guidance/best practice, 22% didn't check if this guidance was followed. Again, who the participants were employed by had no significant impact on whether the participates knew if they had a biosecurity guidance/best practice. Also, there were no differences between employers in whether checks were made that the biosecurity guidance/best practice was followed. Forty percent of the participants either didn't know or weren't sure if there was anyone responsible for biosecurity within their organisation. Nineteen percent of participants said that no-one was responsible for biosecurity in their organisation and 40% of participants knew that there was someone in their organisation who had responsibility for biosecurity during habitat restoration/creation. Who the participant was employed by had no significant impact on whether the participates knew if they had a someone responsible for biosecurity within their organisation or whether they did have someone responsible.

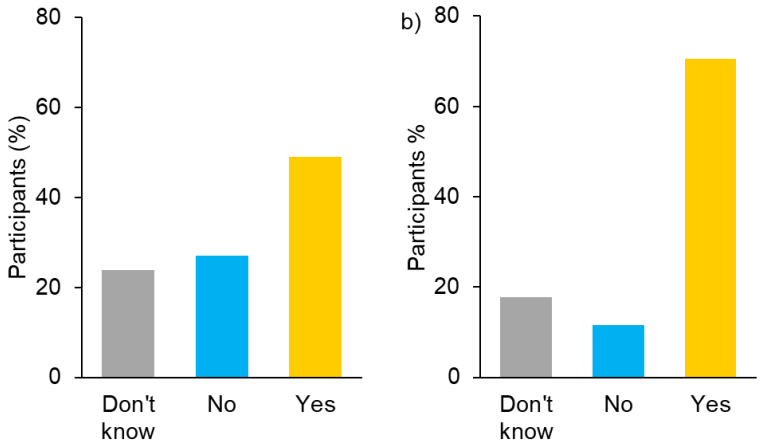


Figure 10 – The proportion of participants who either don't know, don't have (No) or have (Yes) a) a risk assessment and b) biosecurity guidance/best practice for plant pests when doing habitat creation/restoration.

3.3.5 Sources of information and further guidance

Just over a quarter of participants (26%) felt that the guidance they had access to about the plant health risks associated with habitat restoration and habitat creation was sufficient. Thirty-seven percent thought it was insufficient and 36% didn't know (Figure 11).

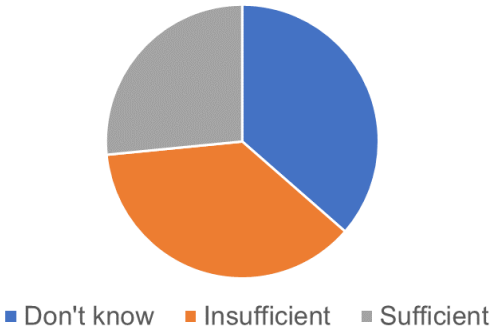


Figure 11 – The proportion of participants who felt that the guidance they had access to, about the plant health risks associated with habitat restoration and habitat creation was sufficient, insufficient or didn't know.

Participants got most of their information about plant health risks from colleagues, followed by government bodies, websites and professional newsletters/magazines (Figure 12). Few participants obtained such information via social media.

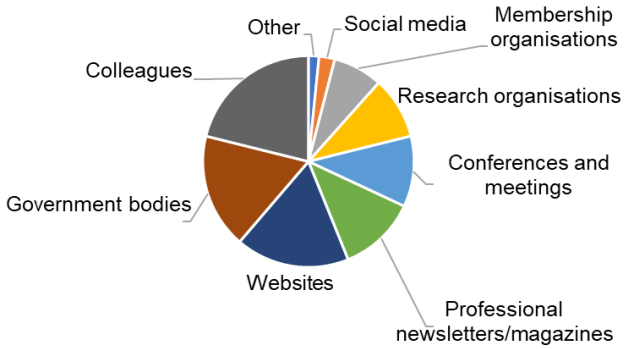


Figure 12 – Where the participants obtain information about the risks of plant pests.

When asked what further guidance participants would like, with respect to plant health, between 78-100 participants wanted guidance on nine of the ten different options provided (Table 2). While biosecurity for staff and contractors was the top request (100), this was followed closely by more information on the current legislation on plant pests and movement of plants/soil/equipment (90 requests) and biosecurity for the general public (87 requests). Overall guidance on propagating plants free of pests was the only type of guidance for which there was not high demand (Table 2).

Table 2 – The number of participates requesting further guidance on a range of different aspects related to plant health.

Further guidance on:	Number of participants
What biosecurity to put in place for staff/contractors	100
The current legislation on plant pests/pathogens and movement of plants/soil/equipment	90
What biosecurity to put in place for the general public that may access land you work on/own	87
Biosecurity risks associated with movement of plants and how to minimize them	86
Biosecurity risks associated with movement of equipment and how to minimize them	84
Sourcing plants free of pests	83
Biosecurity risks associated with movement of soil and how to minimize them	78
How to develop risk assessments	77
Further guidance on where to find information about plant health and disease	76
Propagating plants free of pests	47

3.4 Discussion and conclusions

3.4.1 Perceptions of risk related to biosecurity

3.4.1.1 Neighbours perceived as the most likely source of pest establishment

If neighbours are perceived as the most likely source of infection of pests rather than any activity carried out by the participants, this questions how much participants are prepared to alter their own activities. For example, they may feel it is not worth changing their activities to reduce the risk, if the greatest risk is from their neighbours. However, movement of pests, in the wider sense, on footwear, clothing, equipment etc between neighbouring sites can be very impactful and there are actions with respect to biosecurity that land owners can take to reduce these risks.

3.4.1.2 Mature plants seen as the same level of risk as seed

Contrary to the views of the participants in this survey, the literature suggests that use of seed in habitat creation/restoration is considered intrinsically lower risk than translocations involving living vegetative tissue, as many (but not all) plant pathogens are not transmitted by seed (Anderson et al., 2004). When mature plants are moved, a "biological package" (Davidson & Nettles 1992) is moved that contains not only the plant but also any organisms that are on that plant or in the soil surrounding the plant. These organisms may include species considered as pests.

When mature plants are translocated during habitat creation/restoration and this involves the movement of soil, it is very difficult to know what is in the soil with respect to pests, and this may provide a route for pests to establish during creation/restoration work (Migliorini et al. 2015). An example of this occurred in North American nurseries growing native plants for conservation translocation. *Phytophthora tentaculate* was detected for the first time in the USA in native plant nurseries in four California counties and in restoration sites (Rooney-Latham et al. 2015). Following this discovery, a wider survey found that *Phytophthora* species were common on nursery stock grown for restoration and revegetation purposes in California (Rooney-Latham et al. 2019), and that 25 new *Phytophthora* species had been unintentionally but extensively introduced into restoration sites (Garbelotto et al. 2018). This led to an extensive response to coordinate efforts to reduce their spread (Frankel et al. 2018). It is also difficult to fully check the above-ground parts of plants for pests particularly for large plants. Signs of pests may easily be mistaken for signs of stress due, for example, to over or under watering, and therefore ignored. Mature plants for creation/restoration are often sourced from plant nurseries, which can be a major source of plant pests (Osterbauer et al. 2013).

3.4.2 Knowledge

3.4.2.1 Habitats at risk

The participants assessment of the habitats most at risk appeared to be related to those habitats about which there had been greatest publicity. Woodlands were scored as having the greatest likelihood of pests establishing in them followed by freshwater habitats. These two habitats have had a lot of publicity around them recently. In particular, there has been a lot of publicity about the impact of tree pests. While this study cannot prove a direct link between publicity and the participants assessments, it is suggested as likely.

If there is a link between publicity and participants assessment of risk, this is positive in as much as it shows that the publicity was successful. However, it also highlights the lack of knowledge of most participants about the potential risks in other habitats (See Chapter 4).

3.4.2.2 No distinction between habitats at risk and biodiversity at risk

The significant correlation between how participants assessed which habitat was most at risk and how they assessed the potential impact of plant pests on biodiversity, suggests that they

are unable to distinguish between the two. There could be a habitat that might be a low risk of pests establishing, but if a pest did establish it would have huge consequences for biodiversity. For example, if a pest established in a habitat dominated by one plant species, such as moorland dominated by *Calluna vulgaris*.

3.4.2.3 Lack of knowledge about future pests

The list of pests that participants thought could be of concern in the future was very similar to the list of pests and pathogens they were currently concerned about. This implies a lack of forward thinking and horizon scanning about what could be of concern in the future. For example, only one participant listed *Xylella*.

3.4.2.4 Sources of knowledge

As participants gained most of their knowledge from colleagues, it is important that those carrying out habitat restoration/creation are educated about the risks to plant health from pests so that they can pass this knowledge onto their colleagues. After colleagues, Government bodies, websites and professional newsletters were the most common sources of knowledge. Therefore, targeting these sources to alert practitioners to the potential risks is recommended.

The survey showed that more guidance about the plant health risks associated with habitat restoration and habitat creation is required, and that the required guidance needs to cover a wide range of topics (Table 1). This may provide future topics of work for the Plant Health Centre.

3.4.3 Risk assessments and biosecurity procedures

The results from the questionnaire highlight several potentially serious shortcomings with respect to risk assessments and biosecurity protocols. Firstly, the majority of participants either didn't have or didn't know if they had a risk assessment for plant pest. While the fact that over 70% of participants did have best practice guidance in place that might be expected to reduce the risks of pests establishing, if a risk assessment has not been carried out first then it is not clear that the biosecurity protocols in place were appropriate for the risks. Secondly, nearly a quarter of participants didn't check if the biosecurity protocols were followed. Thirdly, most of them didn't know or didn't have someone responsible for biosecurity in their organisation. Filling these three gaps would be a quick win in terms of improving biosecurity in the habitat creation/restoration. The problem of no-one being responsible for biosecurity within an organisation has been raised in other sectors, such as the horticultural sector (Marzano 2021). This means that biosecurity is likely to fall down the gap, with everyone thinking that someone else is dealing with it.

4 The plant health risks associated with Scottish moorlands

4.1 Introduction

In the natural environment plant health risks are rarely discussed in relation to habitats other than trees and woods and forests. Scotland's moorlands (also called dwarf shrub heaths, heathlands, moors, heaths) cover around 38% of Scotland (3 million hectares). Yet the potential of plant pests to damage this habitat has rarely been considered. This chapter aims to explore what information there is about plant pests that could impact plants within these moorland communities.

Specifically, it aims to:

- Identify which pest are hosted by plant species that occur at more than 25% cover on Scottish moorlands.
- Identify a short list of pests that could impact Scottish moorlands.
- Assess the usefulness of the Defra plant health risk register for identifying pests that would impact the natural environment.
- Using a literature review, identify if there are other pests hosted by plants on Scottish moorlands that are not listed in the risk register.

4.2 Method

4.2.1 Plant health risk register

The Plant Health Risk Register (PHRR) from Defra https://planthealthportal.defra.gov.uk/pests-and-diseases/uk-plant-health-risk-register/ was downloaded on the 20th July 2021. This risk register allows one to search by pest and provides a list of hosts (Baker et al. 2014). For each pest the list of hosts is contained as one data entry point (cell) in the spreadsheet. The data was manipulated to provide a separate record for each pest/host combination, allowing one to search by host and obtain a list of all pests on that host. The host name was further sub-divided into host genera and host species to allow searches to be made at either genera or species level. This data was then linked to the UK National Vegetation Classification (NVC) in an MS Access database. The link was made at the genera level as a) it is unlikely that many native UK plant species will be included in the risk register, rather their commercial varieties are more likely to be included (Defra pers comm); b) this takes account of pests establishing on new hosts within the same genera.

We focussed on moorland communities found in Scotland (H7, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22) (Rodwell 1991) and searched the risk register for any pest hosted by any genera found on Scottish moorlands. We then refined the list to include any genera found at more than 25% cover on Scottish moorlands. This enabled us to focus on species that might be considered foundation species within the community: a species that defines much of the structure of a community by creating locally stable conditions for other species, and by modulating and stabilizing fundamental ecosystem processes (Dayton 1972). We confined our search to vascular plants as, although many bryophytes and lichens occur at more than 25% cover on Scottish moorlands, they are not included in the PHRR.

We extracted from the PHRR the likelihood scores with and without mitigation. The calculation of the likelihood score differs depending on whether the pest is already present in parts of the UK. If the pest is absent from all parts of the UK, then the likelihood score is composed of two sub-scores; those of entry into and establishment within the UK. The PHRR uses the lower of the two scores of entry and establishment. This is because both entry and establishment are necessary for a pest to be introduced. The limiting step for introduction of a pest is therefore whichever component is least likely. The UK PHRR usually only includes

pests which are present in limited areas of the UK, not those that are present nationwide. For these pests already present in the UK, the likelihood score is based on how likely the pest is to spread to maximum extend in the next five years. The PHRR provides likelihood scores both with and without mitigation. We did not use the impact assessment from the risk register as the impact assessment was largely based on the impact on commercial operations not the natural environment.

4.2.2 Literature search

It is acknowledged that the UK plant health risk register is not complete. In order to identify other pests that could impact Scottish moorlands but that are not listed in the PHRR, a literature search was conducted. Between August and November 2021, Web of Science was searched for pests occurring on the genera found at more than 25% cover on Scottish moorlands. Search term Genera AND (pest* OR pathogen*). If the search provided information for a pest not listed for that genera by the risk register, then we noted whether:

- this pest was included in the risk register but this plant genera not listed as host.
- other species in this pest genera are listed in the risk register which do include this plant genera as host.
- other species in this pest genera are listed in the risk register, but none include this plant genera as host.
- the plant pest is not listed in the risk register and does not fall within any of the above groups.

Once one reference to a particular pest on a host genera was found, further references for that combination of host/pest were not read. A pest was not included if only the genera of the species not the entire species was named.

4.3 Results

4.3.1 Plant health risk register

4.3.1.1 Pest of vascular plants occurring at more than 25% cover on Scottish moorlands.

The PHRR identified 357 pests found on 58 plant genera that occur on Scottish moorlands. When refined to only include plant genera that occurred at more than 25% cover, 161 pests (Appendix 2) were identified hosted by 20 plant genera that occur on Scottish moorlands. The 20 genera include *Scirpus*, which is the old name for *Tricophorum*, so this genus was used instead.

Eleven genera, which can occur at more than 25% cover on Scottish moorlands, had no pests listed in the PHRR: *Alchemilla, Anthyllis, Danthonia, Empetrum, Loiseleuria, Luzula, Molinia, Nardus, Potentilla, Succisa* and *Ulex.*

4.3.1.2 Pests of vascular plants occurring at more than 25% cover on Scottish Dwarf shrub moorlands already present in the UK.

Thirty eight of the 161 pests hosted by vascular plants occurring at more than 25% cover on Scottish moorlands are already present in the UK, although generally not widespread. *Vaccinium* and *Salix* were the genera with the greatest number of pests already present (17 and 9 respectively). *Juniperus* was ranked third, hosting five pests that are already present. All other genera only hosted one or two pests (Figure 13a).

Arctostaphylos, Calluna, Plantago, Salix and *Vaccinium* all hosted pests with the highest likelihood score of five (how likely the pest is to spread to maximum extend in the next five

years) (Figure 13a). *Juncus, Juniperus, Plantago, Pteridium, Salix* and *Vaccinium*, all hosted pests with a likelihood score of 4, the second highest. Following mitigation, the likelihood scores were reduced with no genera hosting pests with a likelihood score of five and *Arctostaphylos, Calluna, Juncus, Juniperus, Plantago, Pteridium, Salix* and Vaccinium hosting pests with a score of four (Figure 13c).

4.3.1.3 Pest of vascular plants occurring at more than 25% cover on Scottish moorlands not currently present in the UK.

Of the 123 pests not currently present in the UK, *Salix* and *Vaccinium* hosted the greatest number (48 and 39 respectively) followed by *Juniperus* with 20 (Figure 13b). All other genera hosted five or less pests.

Erica, Juniperus, Plantago, Salix, Thymus and *Vaccinium* all hosted pests with a likelihood score (the lowest of the two scores for entry and establishment) of five (the highest score) (Figure 13b). *Calluna, Dactylis, Festuca, Genista, Juniperus, Plantago, Salix, Thymus* and *Vaccinium* all hosted one or more pests with a likelihood score of four (the second highest). Following mitigation *Erica, Juniperus* and *Plantago* were the only genera hosting pests with a likelihood score of five (Figure 13d).

Eleven genera were identified as hosting pests identified with a likelihood (mitigated) score of 4, the second highest likelihood. Between them they hosted 26 different pests. Of particular concern are the pests hosted by *Arctostaphylos*, *Calluna, Erica*, and *Vaccinium,* as these genera often form the dominant component of moorland communities.

4.3.1.4 Pests of vascular plants occurring at more than 25% cover on Scottish moorlands.

In total, across those present and not already present in the UK, the PHRR lists 29 pests with a likelihood (mitigated) score of 4 or 5 that are hosted by 12 genera occurring at more than 25% on Scottish moorlands: *Arctostaphylos, Calluna, Dactylis, Erica, Festuca, Genista, Juncus, Juniperus, Plantago, Pteridium, Salix, Vaccinium* (Table 3). These 29 pests should be seen as of greatest concern with respect to moorlands, particularly those which are hosted by *Arctostaphylos, Calluna, Erica* and *Vaccinium,* as these genera can form considerably more than 25% cover.

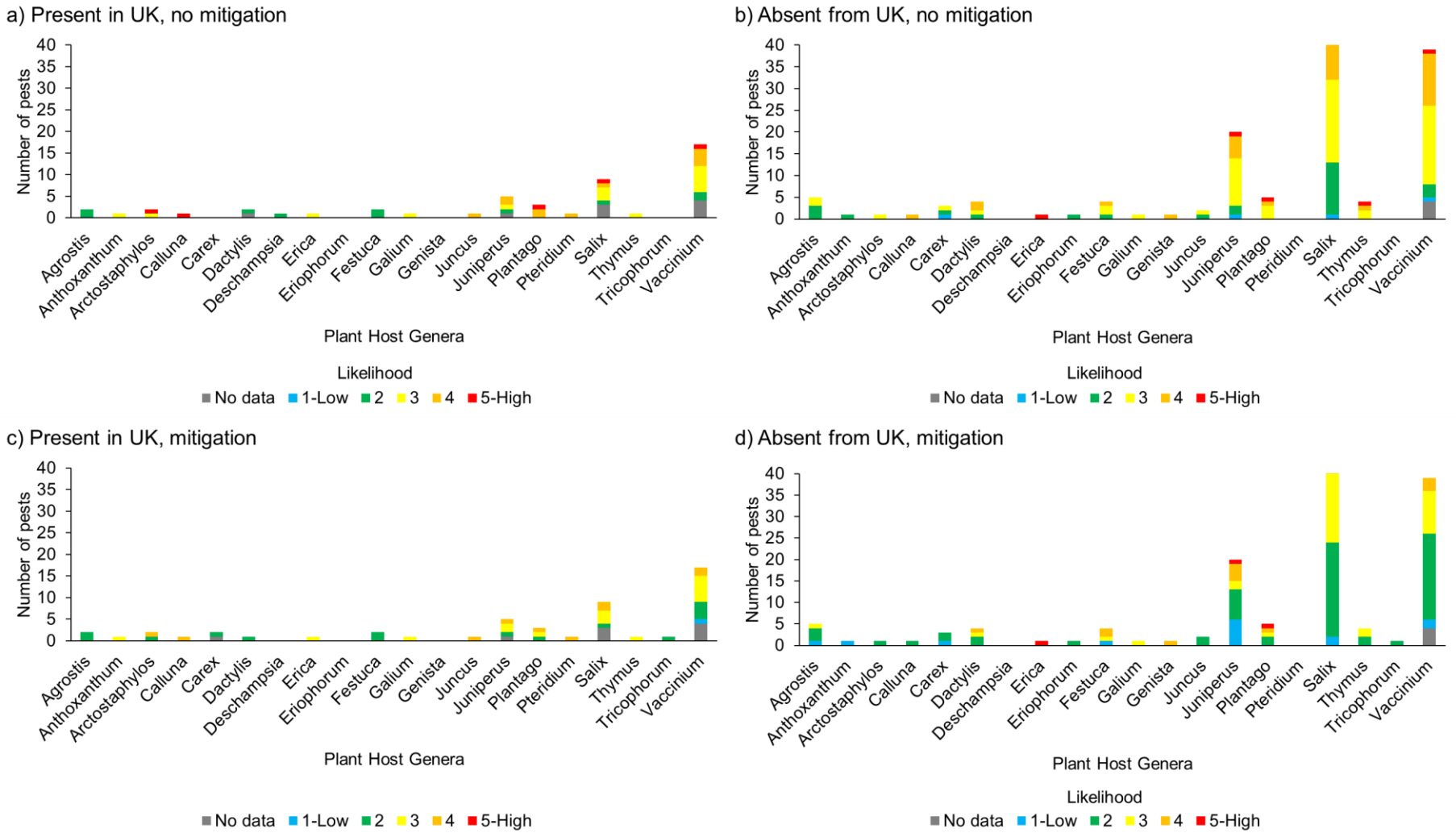


Figure 13 – Plant genera that occur at > 25% cover on Scottish moorlands and the number (total 161) of pests hosted by them, as listed in the PHRR. a) and c) those already present in the UK, b) and d) those currently absent from the UK. The likelihood scores are shown. For pests present this is the likelihood of them spreading to their maximum extent for those absent is the lowest of the establishment or arrival scores. a) and b) unmitigated likelihood scores, c) and d) mitigated likelihood scores. Note 11 Plant genera were that occur at > 25% cover on Scottish moorlands were not listed in the PHRR.

Table 3 – The plant pests listed with a likelihood (mitigated) score of 4 or 5 in the UK (as listed by the UK plant health risk register), that are hosted by genera that occur at more than 25% cover on Scottish moorlands. 1 = pest hosted by that genus.

Pest	Type of pest	Likelihood mitigated	Plant host genera											
			Arctostaphylos	*Calluna*	*Dactylis*	*Erica*	*Festuca*	*Genista*	*Juncus*	*Juniperus*	*Plantago*	*Pteridium*	*Salix*	*Vaccinium*
Currently present in UK														
Cinara curvipes	Insect	4								1				
Duponchelia fovealis	Insect	4									1			
Musotima nitidalis	Insect	4										1		
Phytophthora ramorum	Oomycete	4	1	1									1	1
Rhopalosiphum nymphaeae	Insect	4							1					
Tobacco ringspot virus	Virus or Viroid	4												1
Xylosandrus germanus	Insect	4											1	
Absent in UK														
Agrilus fleischeri	Insect	4											1	
Blueberry shoestring sobemovirus	Virus or Viroid	4												1
Calamobius filum	Insect	4			1									
Callidiellum rufipenne	Insect	4								1				
Cathaica Fasciola	Other	4											1	
Ceroplastes japonicus	Insect	4											1	
Euzophera bigella	Insect	4											1	

Pest	Type of pest	Likelihood mitigated	Plant host genera											
			Arctostaphylos	*Calluna*	*Dactylis*	*Erica*	*Festuca*	*Genista*	*Juncus*	*Juniperus*	*Plantago*	*Pteridium*	*Salix*	*Vaccinium*
Gymnosporangium tremelloides	Fungus	4								1				
Halyomorpha halys	Insect	4											1	
Lamprodila festiva	Insect	5								1				
Luperomorpha xanthodera	Insect	4						1						
Neofusicoccum luteum	Fungus	5				1								
Phenacoccus solani	Insect	4					1							
Planococcus vovae	Insect	4								1				
Plantago asiatica mosaic virus	Virus or Viroid	5									1			
Platynota idaeusalis	Insect	4											1	1
Popillia japonica	Insect	4											1	
Pratylenchus scribneri	Nematode	4					1							
Siphonatrophia cupressi	Insect	4								1				
Takahashia japonica	Insect	4											1	
Thekopsora minima	Fungus	4												1
Tomato chlorosis virus	Virus or Viroid	4									1			

4.3.1.5 Types of pest

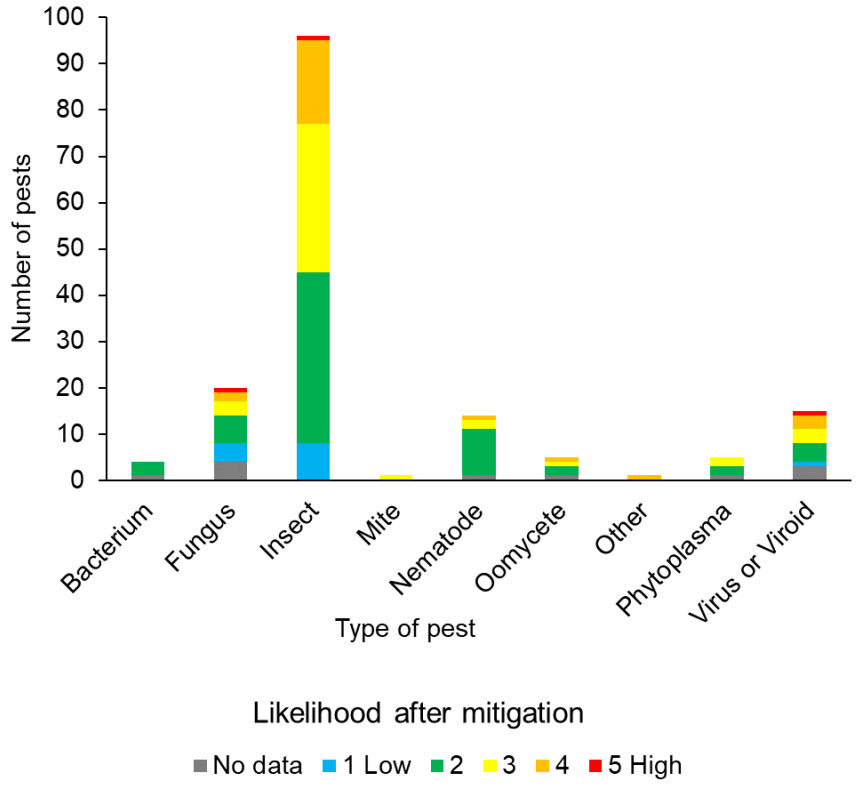


Figure 14 – The different types of pests hosted by plant genera that occur at > 25% cover on Scottish moorlands. The likelihood of establishment in the UK after mitigation is also shown.

Of the 161 pests listed as being hosted by plants occurring at more than 25% cover on Scottish moorlands, the majority of them were insects (96), followed by fungi (20) and viruses or viroids (15) (Figure 14).

4.3.1.6 Pathways

The most common pathway for the 161 pests to establish in the UK is via plants for planting, excluding seeds, bulbs and tubers, with 135 of the pests potentially able to establish via this route (Figure 15). Far fewer pests were likely to establish via seed, bulbs and tubers (10 via seed, 4 via bulbs/tubers). Between 20 and 41 of the 161 pests were able to establish via each of the following routes: cut flowers or branches, fruit and vegetables, non-squared wood, soil/growing media, wood packaging material and hitchhiking. Squared wood, natural spread and seeds were all listed as possible pathways of entry for 10-13 of the pests. Other routes (Figure 15) were possible routes of entry for less for 10 pests.

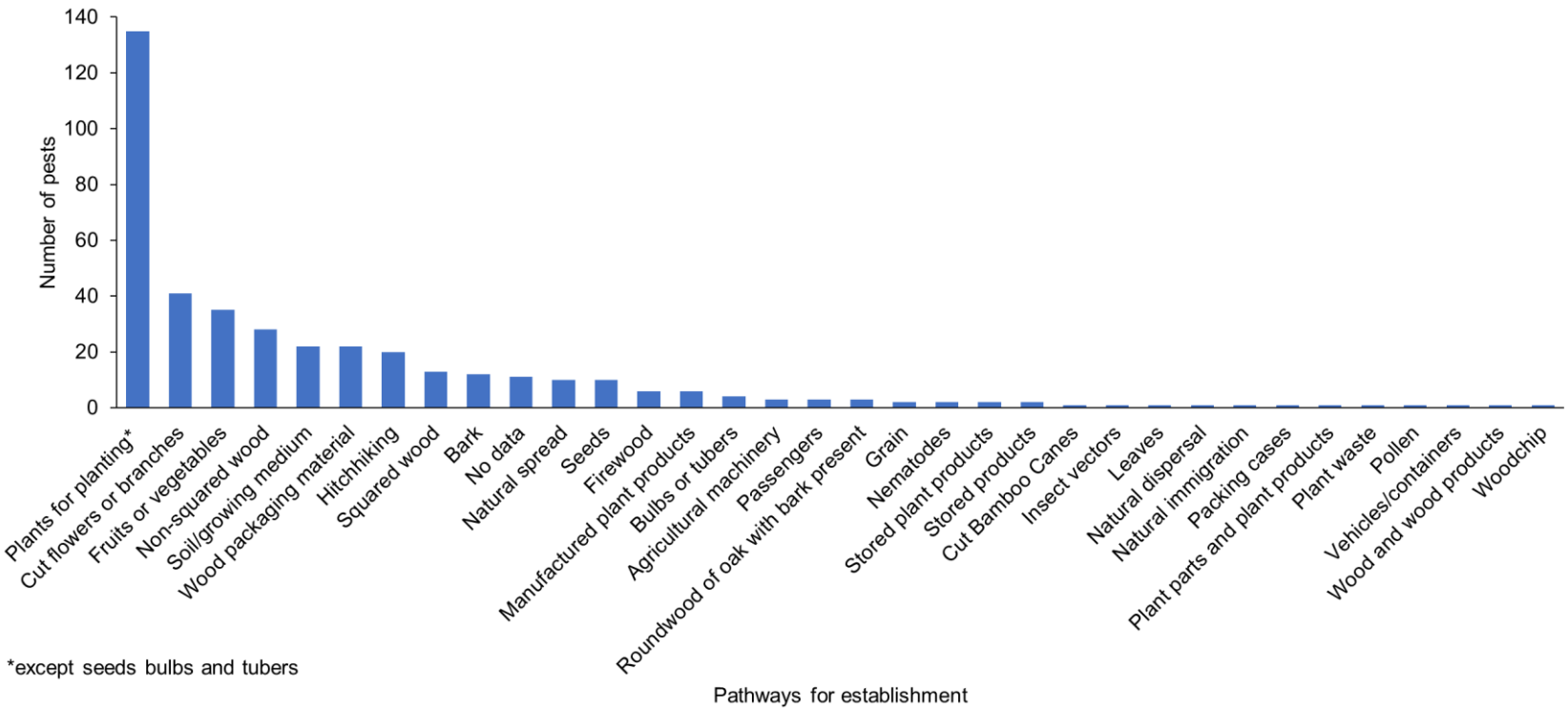


Figure 15 - The pathways for establishment of the 161 pests that are hosted by the genera of plants occurring at more than 25% cover on Scottish moorlands, as listed by the PHRR. No data = there was no information about pathways in the PHRR

4.3.1.7 Regulation

Eighty-eight of the 161 pests have some form of European Public Protection Office (EPPO) or EU regulation (Figure 16). EPPO A1 pests are absent from the EPPO region and the EPPO recommends to its member countries to regulate the pests listed as A1 pests, as quarantine pests. EPPO A2 pests are pests that are locally present in the EPPO region.

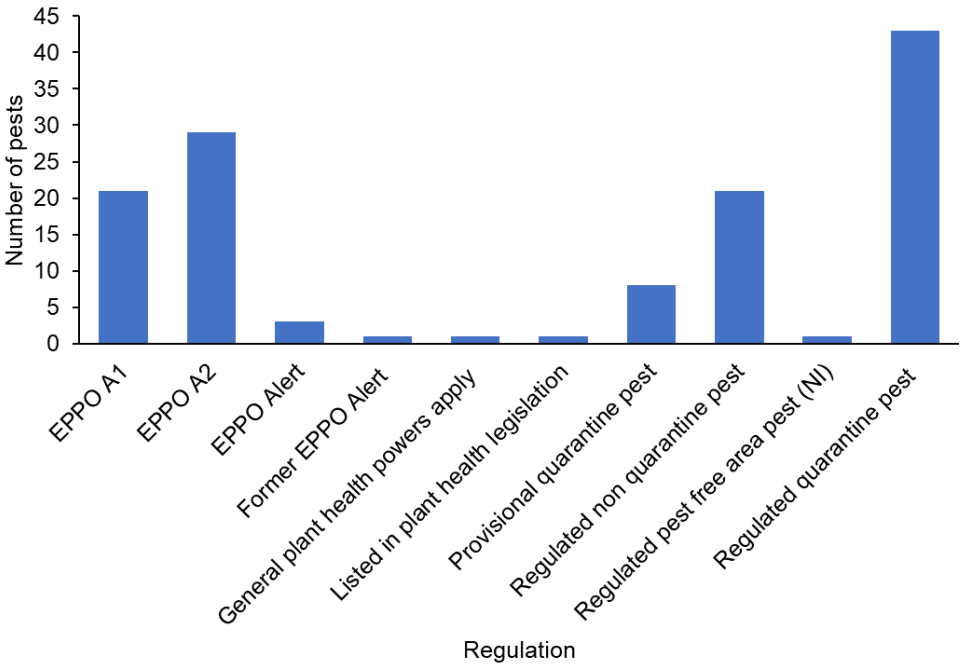


Figure 16 - The number of pests listed in the PHRR that could be hosted by plant genera occurring on Scottish moorlands at more than 25% cover and that have some form of regulation. Note 73 pests have no form of regulation.

4.3.1.8 Current distribution

Most (123) of the 161 pests are currently absent from the UK. With only 9 of them currently known to be widespread in the UK (Figure 17). Eighty-nine of the pests occur in at least one country in Europe. Italy, France, Spain and Germany were the European countries with the greatest number of the 161 pests, and therefore could be considered the highest risk countries, all having over 40 of the pests (Figure 18). Outside of Europe the United States, China, South Korea and Japan all have over 40 of these pests (Appendix 3). For both the Europe and global distribution, it was unclear whether the blank cells in the PHRR indicated not present in Europe or distribution unknown, therefore all blank cells were recorded as no data.

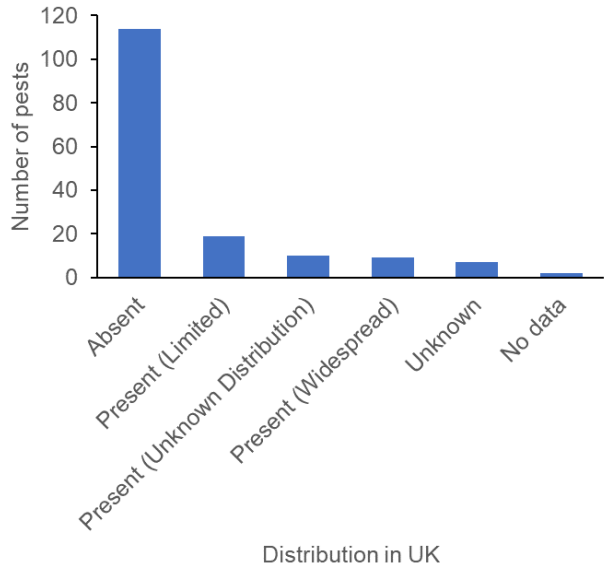


Figure 17 - The distribution in the UK of the 161 pests listed in the PHRR as hosted by genera that occur at more than 25% cover on Scottish moorlands. No data = no information in PHRR

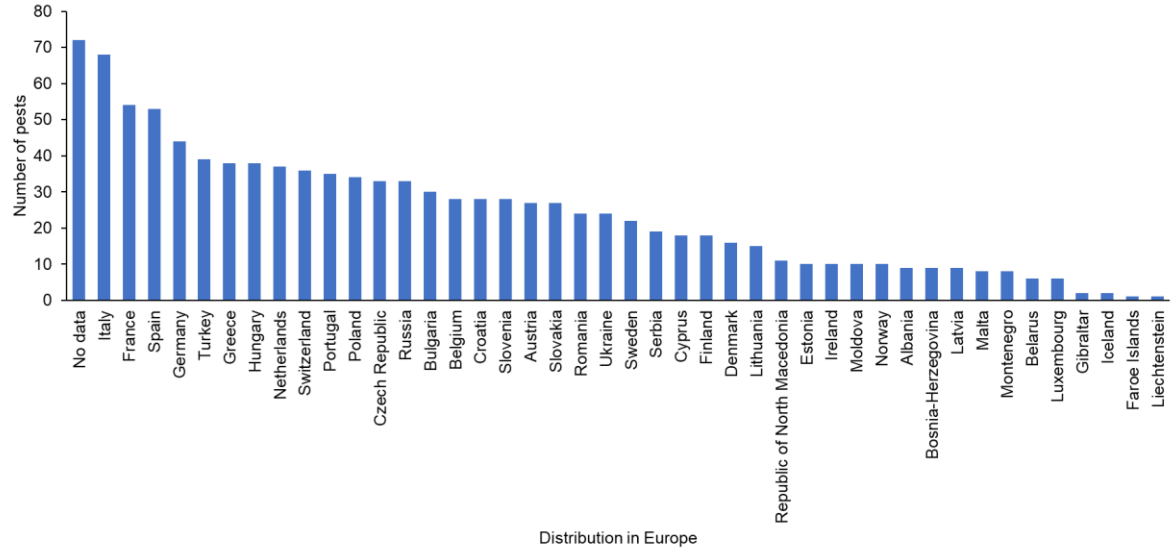


Figure 18 - The distribution in Europe (outside UK) of the 161 pests listed in the PHRR as hosted by genera that occur at more than 25% cover on Scottish moorlands. No data = no information in PHRR

4.3.2 Literature review

A total of 142 pests hosted by plant genera occurring at more than 25% on Scottish moorlands were found through a literature search that were not listed in the UK PHRR (Appendix 4). Most of these were not listed at all, but some of them were listed but not with that specific host. Sometimes other pests in the same genera as the one found by the literature search were listed in the PHRR. Those pests may or may not have included the hosted searched for (Figure 19). Most of the additional pests found were fungi (82) and insects (47) (Figure 20 and 21).

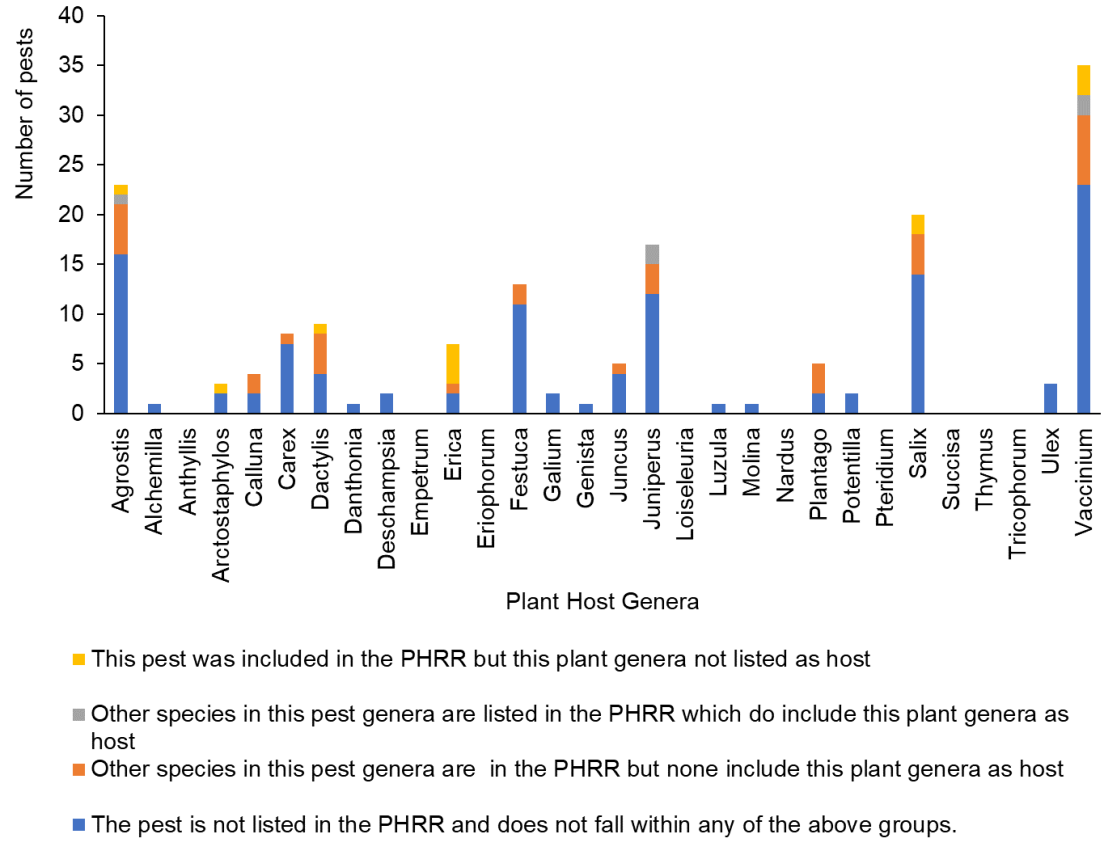


Figure 19 – Plant genera that occur at > 25% cover on Scottish moorlands and the number (total 142) of pests hosted by them, that are not listed in the PHRR. Blanks indicate no additional pests found.

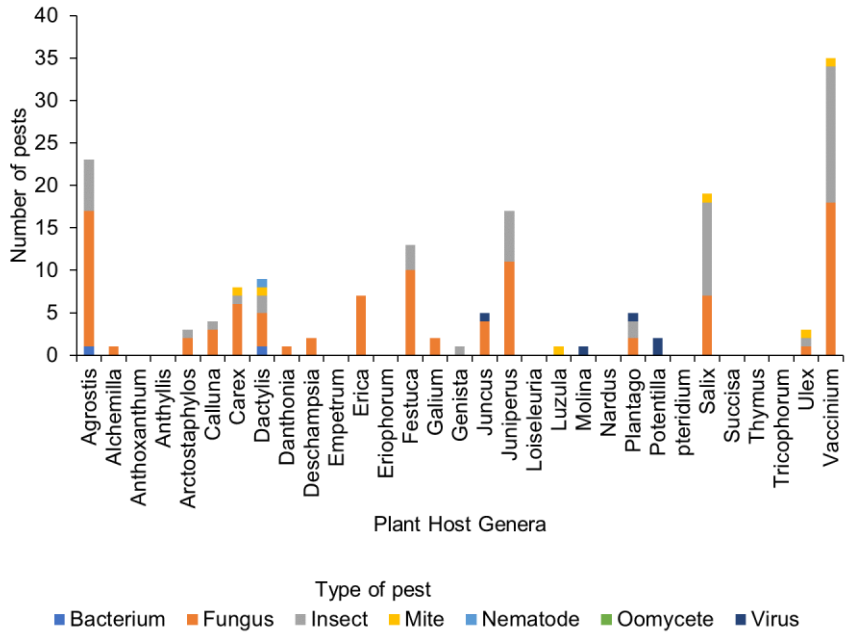


Figure 20 – Plant genera that occur at > 25% cover on Scottish moorlands and the number (total 142 and type of pests hosted by them, that are not listed in the PHRR. Blanks indicate no additional pests found.

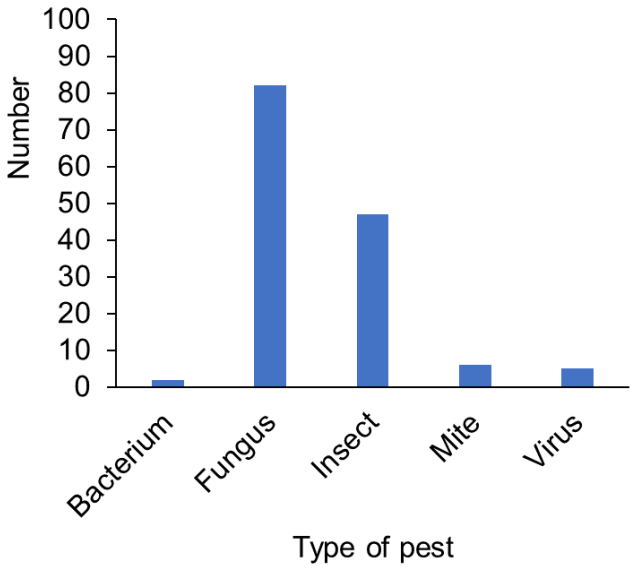


Figure 21 – The 142 pests hosted by plant genera that occur at > 25% cover on Scottish moorlands that are not listed in the PHRR and whether they are bacterium, fungus, insect, mite, nematode or virus.

4.4 Discussion

4.4.1 Key messages from PHRR

The PHRR highlighted the large number of pests, the majority not currently present in the UK, that are hosted by genera occurring on Scottish moorlands at more than 25% cover. If any of these pests did establish in the UK, or those already present in the UK spread to their maximum extent, this could significantly impact the plant community composition of Scottish moorlands with potential cascading effects on ecosystem function and associated species. *Salix, Vaccinium* and *Juniperus* were the genera with the greatest number of pests associated with them, but this could be due to biases in the database – see below. This work showed that it is not possible to identify a "top 10", or a short list of potential pests, for which land-managers should be alert to. At best, it identified a "top 29" which is too many to expect stakeholders to be aware of and know the symptoms for. However, the use of the PHRR is a useful exercise in raising awareness of the pests that could impact semi-natural habitats other than woodlands.

Planting of mature plants (not seeds, bulbs, tubers) was shown as the most likely route of establishment for the majority of the pests listed. In addition, most of the pests listed are insects and so highly mobile. This suggests that a key recommendation to limit spread into the natural environment is tight controls on the movement and plantings of mature plants, not just directly into natural environment but also more widely, such as landscape plantings from which pests could spread.

4.4.2 The limitations of the Plant health risk register

The PHRR provides a useful starting place to explore the number of pests hosted by genera that compose a significant part of plant communities in our natural environment, and hence to start to assess the risk to our natural environment posed by pests. However, the PHRR does have a number of limitations, and as such the lists extracted should not be treated as a comprehensive list of all the pests that could impact the natural environment.

The PHRR focusses on pests of agriculture/horticultural/forestry importance. Therefore, the results from the PHRR are biased towards genera of agriculture/horticultural/forestry importance. The high number of pests listed for *Salix*, *Vaccinium* and *Juniper* may not indicate that these genera are more at risk than other genera, but rather that there are

commercial varieties of these genera, meaning the pests associated with them are more likely to have been included in the risk register.

A further limitation of the PHRR is that it does not include all pests already established in this country, whose distribution or impact could change as a result of climate change.

The PHRR acknowledges that it is not complete in the list of hosts for each pest, there being a limit on the number of hosts that it is possible to enter (Defra 2021). The PHRR states that it aims to include one example from each plant family. Therefore, the list of pests may also be an under-representation for this reason. For example, for the genera in Figure 13, *Xylella* is only included as a pest for *Plantago* and *Vaccinium* yet we know *Calluna* is also a potential host for *Xylella (Chapman et al. 2022)*.

The severity of the impact of the pests hosted by plants in the natural environment is largely unknown and is not taken into account in this assessment. For example, a pest could have an economic impact, e.g. discolouration of leaves, which may not have a severe ecological impact.

The PHRR does include an impact score and a risk rating. The impact score is an indication of the damage expected in the UK for a host plant or industry sector should the pest arrive. It does not take account of the size or value of the host industry; this is rated separately. Economic, social and environmental impacts are scored separately and the largest of these is used for the overall impact score (Defra 2021). For the assessment of the environmental impact the guidance states that "These scores are set using expert judgement and are informed by many of the same factors used in scoring economic impacts." (Defra 2021). The economic impacts are based on:

- Impacts in regions of the world where the pest currently occurs.
- The expected impacts on major hosts in the UK (e.g. cooler summers in the UK could lead to lower levels of damage).
- How easily the pest can be controlled by plant protection products.
- How fast the pest population might be capable of growing and spreading.
- Vulnerability of the host to damage.
- The number of major hosts affected.
- Whether the species can vector other plant pests.

None of the above provide an assessment of the ecological impacts as defined in this report:

- Changes in plant community composition.
- Associated biodiversity that use the host plant to complete part of its life cycle.
- Ecosystem functioning.

Therefore, it was not considered that the PHRR considered the wider impact of these pests on the environment.

The PHRR includes a "likelihood x impact" score which it states can be used for comparing the relative risks of the pests whose hosts are very different. However, as it was felt that the impact score did not really include the impact on the wider environment, instead very much focussing on the impacts to the host, this score was not used. For similar reasons the UK unmitigated risk rating calculated as "likelihood score x impact score x value at risk" was not used in this report. The value at risk score aims to identify the relative importance of different hosts to the UK and is largely based on market values. However, for trees, Defra (2021) states that this does include a value for ecosystem services. There appears to be no value for ecosystem services provided for non-tree genera, hence why this score was not used in this report.

4.4.3 The limitations of the literature review

The literature review highlighted the limitations of the PHRR, providing an additional 162 pests that were not listed in the PHRR. However, there are also limitations with this literature review:

- Many of the pests may already be present in the UK and co-existing with the hosts in ways that do not cause serious ecological damage.
- The term pest or pathogen might not mean it causes serious damage or potential functional extinction from an ecosystem. However, this could change if climate change were to alter the host-pest relationship.
- The impact of pests on new hosts with which they have not co-evolved is unknown, as shown by the impact of *Hymenoscyphus fraxineus* ash dieback in the UK. *H. fraxineus* co-exists as a pathogen with the native ash trees in Asia but in the UK causes extensive death of ash trees.
- An organism may be considered a pest commercially or economically, particularly when grown in a monoculture and/or when in artificial growing conditions, such as a glasshouse or polytunnel. However, in the natural environment the pest may be held in check by either the environment or competition with other species, such that it does not cause serious damage.

Therefore, one cannot assume that all the pests listed in Appendix 4 would immediately cause a catastrophic decline in a plant host in the natural environment.

As with the PHRR, the literature search found more pests for genera which are also commercially important; *Salix, Vaccinium, Juniperus* and commercially important grasses such as *Agrostis* and *Festuca*. It may be the commercial importance of these species means that more research, and hence literature, is available on the associated pests, not that these genera are actually more at risk than other genera.

4.4.4 Conclusions

This work has shown the large number of pests which could potentially impact dominant plant species that occur on Scottish moorlands. It illustrates that stakeholders' perceptions that heaths and moorlands are low risk (Chapter 2) may not be correct. Similar work could be done for other habitats. The large numbers of pests raises awareness of the potential risks. However, it could also discourage action on the ground to reduce risks if stakeholders think there are too many pests to take action. Instead the results should be used to help encourage the development of habitat-based assessments of the risks (such as Chapter 5) rather than detailed assessments for each pest/host combination. The work also identifies the most likely routes of these pests establishing – via the introduction of live plants. Operations on moorlands or surrounding areas that involve the introduction of live plants, particularly from nurseries or non-local sources, need to be tightly controlled in order to reduce risks.

5 Plant health risks associated with augmenting rare wild plant populations

5.1 Introduction

This chapter documents an example that came to light during the course of this fellowship, where there is a lack of knowledge around plant health and the wider environment. This example is not meant to be seen as exclusively listing all areas where further knowledge about plant health and the wider environment are needed. Rather it provides an insight into a couple of areas and raise questions that could be addressed in the future. In addition, it provides examples of how this fellowship has raised awareness of plant health and the wider environment.

The Royal Botanic Garden at Edinburgh (RBGE) has a project to augment rare wild plant populations in the UK. The plants are Schedule 8 species and native upland species to Scotland. The aim of the project is to collect seed from wild plants, bring them back to the RBGE where they will be grown on and then either planted back out into sites with an existing population or to new suitable sites. Staff at RBGE wanted to produce a risk assessment for this work with respect to plant pests. There are a number of points during this RBGE project at which there are plant health concerns:

- Introduction of plant pests into the wider environment when collecting the plants/seeds.
- Introduction of plant pests from the wider environment into the plant collections at RBGE.
- Contamination of the collected material or the new plants grown on from seed or cuttings with pests from within the glasshouses at RBGE.
- Introduction of plant pests from the glasshouses at RBGE into the wider environment when the plants are planted out.

While conducting their risk assessment, RBGE contacted me concerning the similarities between the issues they were encountering in conducting a risk assessment for their project and the work they knew I was doing on this fellowship.

The following provides a summary of the main gaps in information and knowledge identified during a discussion with the project lead. They are shown here to illustrate the difficulties currently encountered.

5.1.1 Gaps in information and knowledge identified during the project

- The Plant Health Risk Register (PHRR) provides a list of potential pests for some plant species, but it is limited in that you can only search by pest. The database created by this fellowship was used to search by plant species and plant genera.
- The PHRR is biased towards commercial plants and therefore most of the schedule 8 species that RBGE are working on are not listed, in many cases not even the genera is listed.
- Even for common hosts there is a lack of information in the PHRR, e.g. many native plant species that are potential hosts of *Xylella* are not listed.
- The Pest and Disease Index (PDI) lists pests by host so is more user friendly, but it is even more targeted than the PHRR towards those species that are commercial species. In addition, it only lists those pests that are regulated. There are other pests that could cause substantial impacts in the wider environment that are not regulated.

- There is a lack of guidance on what to do once one has a list of potential plant pests for a given host.
- Lack of knowledge about when it would be appropriate to grow plants in a completely separate glass house to reduce risks.
- Many of the potential pests are low risk as the plants concerned are montane plants and the pests are unlikely to survive a Scottish winter, but it is currently unclear how you assess this risk.

5.1.2 What could be improved?

- Plant health risk register searchable by host.
- Guidance as to what to do about the risks once identified.
- Guidance on what is an acceptable risk.
- Plant healthy guidance currently only applied to nurseries but would be useful if it was adapted and applied to sites e.g. SSSI's

6 A framework for assessing plant health risks in the natural environment

6.1 *Introduction*

Chapter 4 illustrated the number of potential pests that could impact just one habitat within Scotland. It serves as an example and similar work could be done for other habitats. Given the large number of potential pests it is unrealistic for practitioners on the ground, within a natural environment context, to a) monitor and b) have detailed risk assessments for all these pests. What is needed is a) a method to help prioritise where plant health monitoring should be focused and b) some overarching activities that can be implemented irrespective of specific pests, which will improve plant health and reduce the risks of plant pests establishing.

6.2 *Development of framework*

Using the existing information such as Scotland's Plant Health Centre Key Principles, Defra's tree health resilience strategy and information from this report, we worked to develop a plant health framework. The draft framework was discussed at a workshop on the 26th May 2022 and the final version is presented below.

6.3 *Framework*

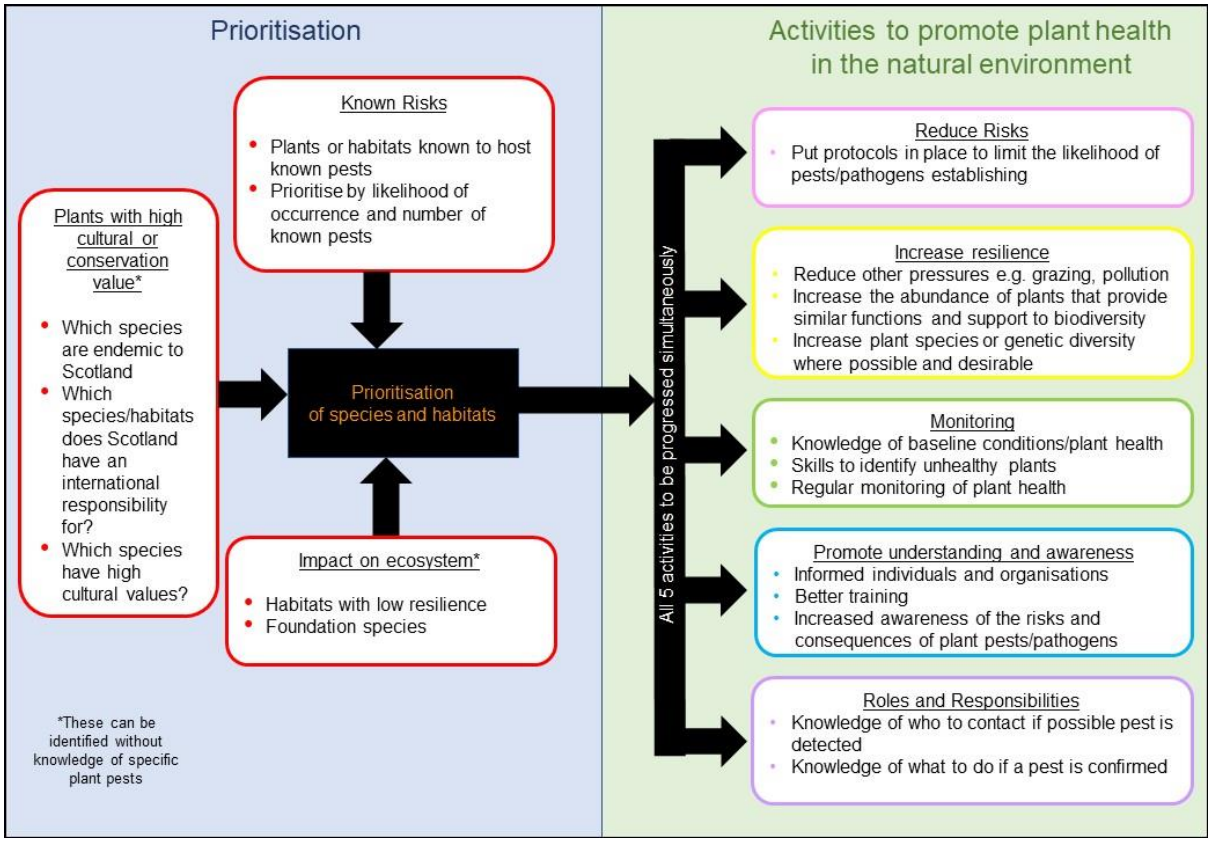


Figure 22 – A framework for assessing and reducing plant health risks in the natural environment.

The framework starts with an assessment of the direct and indirect impacts which, together with knowledge of plants with high cultural or conservation value, aims to aid prioritisation of resources for the implementation of five activities which contribute to promoting plant health in the natural environment (Figure 1). Key points about the framework are:

- It identifies risks at a habitat level in addition to a plant species level.

- It can be implemented at a range of scales.
- Detailed knowledge about individual plant pests is not required to conduct the assessment of indirect impacts and implement the five activities.
- It can be implemented before any pests establish.
- The five activities can be undertaken in any order or parts of the activities undertaken at different times.
- Not all the activities need to be done but the more that are done the greater the reduction in risk and the more resilient a site will be.

6.3.1 Direct Impacts (Known pests)

The assessment of direct impacts prioritises those plants species known to host pests that could cause severe declines in the plant population. However, knowing which pests might impact a given plant species is difficult due to the following reasons:

- Currently the UK Plant Health Risk Register (PHRR) only allows searches by pest not by plant host.
- As highlighted in Chapter 4, the PHRR is focussed on plants with a commercial value and hence may not list hosts that are important in the natural environment. Therefore, identification of hosts probably should be done at the genera level, rather than at the species level.

Defra are working to redesign the PHRR, so it is searchable by host, but until this happens this is a major limitation. An alternative is to use the Pest and Disease Index (PDI) which lists pests by host but as noted in Chapter 6, it is even more targeted than the PHRR towards commercial species. In addition, it only lists those pests that are regulated. There are other pests that could cause substantial impacts in the wider environment that are not regulated. Obviously, it is not possible to search for pests hosted by all the plant species in any habitat; prioritisation should be given to those species that are dominant within a habitat, see 7.3.2.2.

If pests hosted by plant species present within the habitat or site assessed are identified, then the PHRR should be used to assess:

- The potential severity of the pest: i) Is the pest likely to cause a serve impact on the plant, e.g. death or large decline in abundance or ii) Is the impact likely to be smaller e.g. discolouring of leaves that while it might have a large commercial impact, might have limited environmental impact?
- The likelihood of the pest establishing.

In addition, there may be plant species that are prioritised in this section because of known plant pests that are not listed in the PHRR, e.g. heather beetle. Such pests may already be present in the UK, but a changing climate means their severity may increase and as such warrant being prioritised.

6.3.2 Indirect impacts

The indirect impacts (Figure 1) can be identified without knowledge of specific plant pests.

6.3.2.1 Which habitats are at risk?

Ecological theory states that ecosystems with high functional redundancy are expected to maintain stability as species are lost, because other species are present within the system that fulfil similar functions (Rosenfeld 2002; Laliberte et al. 2010; Pillar et al. 2013). Ecosystems dominated by a few foundation species, i.e.: “a single species that defines much of the structure of a community by creating locally stable conditions for other species, and by modulating and

stabilizing, fundamental ecosystem processes" (Dayton 1972), are most at risk from a lack of functional redundancy (Walker 1992; Walker 1995). Thus, those habitats or sites that lack functional redundancy will be at greatest risk from perturbations, in this context the impact of pests.

As an initial starting point in implementing this concept in practical habitat management, those habitats that are dominated by a few plant species are most risk. This is because if a pest was to impact that dominant plant species it would have a huge impact across the whole system as there would be few other species present to replace that plant species. Obviously, this is a simplistic implementation of this theory, but it provides a starting point for site managers to identify those habitats most at risk when resources are limited.

6.3.2.2 Loss of which plant species would have the greatest impact on associated biodiversity and ecosystem functioning?

This is the assessment of the indirect impacts of plant pests on the wider environment (Figure 1). Assessments of the indirect impacts can be carried out without knowledge of the pest. Rather they can focus on an assessment of what the impact would be if a plant species was lost from the community or at least becomes functionally extinct: a reduction in their abundance to such an extent that, while they may still be present, they no-longer have a functional role influencing community composition and processes (Ellison et al. 2005).

If foundation species are impacted by pests, this will have a greater impact on ecosystem functioning than if species with more minor roles within the ecosystem are impacted. Full assessments of the indirect impacts of plant pests on the natural environment, via the loss of foundation species, are complex and time consuming (Figure 2). Indeed complete assessments have never been done, but even assessments such as the impact on biodiversity of a loss of ash or oak trees requires considerable resources (Mitchell et al. 2014; Mitchell et al. 2016; Mitchell et al. 2017; Mitchell et al. 2019; Mitchell et al. 2022). However, even a limited assessment based on current knowledge of how the system would be impacted by the loss of a foundation species would start the thought process and may highlight species of conservation importance that are highly dependent on that foundation species.

The assessment of the indirect impacts should not be limited to impacts on associated species but also include an assessment of how the ecosystem functioning might change. Again, all the information for a complete quantitative assessment is unlikely to be available but even an initial 'brain storming' of potential impacts is likely to be beneficial e.g.

- Changes in decomposition rates – particularly if other species replace the dominant species whose leaf litter breaks down faster/slower than the original dominant species.
- Increase water run off due to loss of vegetation cover.
- Soil erosion due to loss of vegetation cover.
- Establishment of undesirable species, e.g. non-natives due to sudden death of native species.
- Changes in carbon storage.

Within a plant community foundation species are often the dominant species, e.g. oak trees in an oak wood, Phragmites in a reedbed, and Calluna on a heather moorland. Therefore, prioritising the assessment/monitoring of these dominant species within a system is recommended. It is acknowledged that simply identifying the most abundant species is a simplistic implementation of ecological theory. However, loss or decline of species occurring at high abundance, e.g. more than 75% cover, will have a major impact on community composition even if they may not strictly be defined as foundation species. This provides a pragmatic approach to help managers identify what might be considered foundation species

and was thought likely to reduce the number of candidate species for monitoring to a manageable number.

To illustrate how abundance may be used to identify species to prioritize monitoring for plant health, plant species occurring at more than 75% cover in any plant community in the UK NVC were extracted. Two hundred and seventy-three species were identified that occur at more than 75% cover in plant communities across the UK. The data was grouped under 12 broad habitat types: Aquatic communities; Calcicolous grasslands; Heathlands; Mires; Maritime cliff communities; Mesotrophic grasslands; Open habitats; Swamps and tall-herb fens; Shingle, strandline and sand-dune communities; Salt Marsh; Calcifugous grasslands and montane communities; Woodlands, reflecting the grouping of the communities within published documents. The number of species suggested for monitoring for any one habitat was considerably lower than 273, ranging from 71 in woodlands to 11 in Calcicolous grasslands (Appendix 5). The list could be further refined if the data was extracted at the level of NVC community.

6.3.3 Prioritisation of species and habitats

We do not have sufficient information to develop a numerically based prioritisation list for which habitats and plant species should be prioritised for the five activities within the framework. Rather based on the discussion above we recommend the following be used for used to aid prioritisation:

- Based on the direct impacts the five activities should be prioritised towards plant species that host pests that would result in the species becoming functionally extinct and where the pest has a high likelihood of establishment (see PHRR). It is acknowledged that in some cases there may be no knowledge of direct impacts and prioritisation will be based on the two points below.
- Based on the indirect impacts the five activities should be prioritised towards
    - Habitats dominated by a single species. Thus, one would prioritise habitats such as *Calluna* dominated moorlands and *Phragmites* dominated reed beds over more species rich grasslands.
    - Species that are known to be foundation species upon which many other species and ecosystem processes depend.
    - Species that are dominate within a habitat and likely to be foundation species. Thus, within *Calluna* moorlands one would prioritise *Calluna vulgaris* over *Arctostaphylos* species.
- There may also be cultural or conservation reasons for prioritising particular species. Plant species that have either high cultural value, are endemic to Scotland or for which Scotland has international conservation responsibilities may also be prioritised, for example the Scottish Primrose.

Once a prioritised list of species and habitats have been established the five activities in the framework should be implemented. These are discussed in more detail in 7.3.4 to 7.3.8.

6.3.4 Monitoring of plant health

Monitoring of plant health in the wider environment, outside of trees, is rarely conducted. This should become part of routine monitoring, e.g. after habitat restoration/creation works and as part of habitat condition assessments. This would help with early detection of new pests to an area.

Greater use could be made of citizen science for plant health monitoring. The TreeAlert app has been set up to gather information about the health of the nation's trees, woodlands and

forests. The app is used to support tree health monitoring and surveillance work, but no equivalent app exists for non-tree plants.

Underpinning any monitoring for plant health requires knowledge of the baseline conditions or health of plants. This is essential if changes in plant health are to be recorded. For example, if there are several reports of unhealthy-looking plants of a certain species, we need the knowledge to understand if such plants are regularly seen in certain conditions, e.g. drought, or if such symptoms are new. Such knowledge may be gained by implementing regular monitoring.

Underpinning monitoring are the skills required to identify unhealthy plants. This may involve the training of staff on the ground. However, it also requires the knowledge of whom to contact if potential pests are detected, and how to get such pests tested – see "Roles and Responsibilities" activity.

6.3.5 Reduce risks

This activity involves putting in place activities, protocols or biosecurity guidance to minimize the likelihood of pests establishing.

Firstly, the routes via which plant pests may establish need to be identified. This is part of a more traditional risk assessment, although Chapter 2 showed that many organisations do not carry this out. For individual pests in the PHRR the routes via which they might establish within the UK are listed. However, potential routes of establishment can also be identified using Tables 4, 5, 6, without any knowledge of specific pests. These tables illustrate how different activities within the natural environment may be graded high to low risk with respect to the introduction of plant pests and could be used to identify potential routes via which pests may establish.

Having identified routes via which pests could establish at a site, any activities shown as high risk in Tables 4, 5, 6 should be changed to low risk where possible or tightly controlled and monitored if the high-risk activity cannot be changed.

Table 4– The risks of introducing plant pests into the natural environment related to the movement of plants and soils.

	Lower risk	Higher risker
Stage of plant life cycle	Seed	Adult
Soil movement	No	Yes
Distance from source to release site	Local, short distance	Long distance
Movement of plants across natural ecological barriers	No	Yes
Number of plants	A few individuals	Lots
Plants held in propagation facilities	No	Yes
Plants held in propagation facilities that also grow a wide range of other plants, often from many sources	No	Yes
Plants held in propagation facilities with good biosecurity practices.	Yes	No
Species susceptible to pests which lead to high rates of mortality and/or damage	No	Yes
Species susceptible to pests which also impact on a broad range of host species	No	Yes

Table 5 – The risks of introducing plant pests into the natural environment related to the movement of machinery and equipment used for managing the site.

	Lower risk	Higher risker
Closeness of site to existing road/tack	Close	Long distance
Movement of equipment across large areas of land, often crossing estate/ownership boundaries	No	Yes
Local contractors/machinery	Yes	No
Machinery/equipment cleaned prior to use	Yes	No
Staff aware of and following biosecurity guidance	Yes	No

Table 6 – The risks of introducing plant pests into the natural environment related to other beyond site staff accessing the site.

	Lower risk	Higher risker
Contractors following biosecurity guidance	Yes	No
Checks on whether biosecurity guidance is followed	No	Yes
Recreational equipment cleaned (boots, prams, bikes, fishing gear etc)	Yes	No

6.3.6 Increased resilience

There are two main activities that would increase the resilience of a system to plant pests: reduction in other pressures and an increase in functional redundancy.

6.3.6.1 Reduction in other pressures

Plant pests are only one of many pressures such as pollution, climate change, and over-grazing that may increase the plant stress. Stressed plants will be less able to with stand attack from pests. A reduction in these other pressures will therefore increase the resilience of the system and reduce any the impact of plant pests.

6.3.6.2 Increase diversity and functional redundancy

Diverse communities are generally more resilient. While acknowledging that some semi-natural communities are naturally species poor, the diversity of others has been reduced by human activities: e.g. many of our woodlands and grasslands. Ecological theory suggests that more diverse communities will be more resilient as there is greater functional redundancy. Thus, where possible increasing species diversity would increase resilience. Increased genetic diversity is also beneficial with respect to increasing the likelihood of resilience against pests, as has been shown for tree species although there is less evidence of this for non-tree plants.

Ideally, increasing the abundance of species that provide similar functions and support to those species identified as foundation species (7.3.2.1) should be prioritised. If there are multiple species that provide similar ecosystem functioning and similar support to biodiversity, then the system is more resilient – has greater functional redundancy. We acknowledge that in some habitats identification of species than can partially replace each other ecologically may not be possible.

6.3.7 Promote understanding and awareness

Chapter 2 showed the lack of awareness of the plant health risks in the natural environment. Participants scored those habitats which had received recent publicity about pests as at greater risk (woods and fresh water). This illustrates that publicity does work but more is needed with respect to other habitats. In addition, participants in the Chapter 2 survey indicated that they gain most of their knowledge about plant pests from colleagues so promoting understanding at grass roots level is important. This activity links closely with the fifth key principle promoted by the Scottish Plant Health Centre of "promoting widespread understanding and awareness of plant health threats".

Stakeholders working in the natural environment often lack the skills to identify if unhealthy plants should be of concern. For example, is a plant unhealthy due to drought or due to a pest? If due to a pest, should one be concerned? Pests are part of natural systems and not all pests will cause disruption to ecological systems. A lack of identification skills was identified as a knowledge gap by the EU project Global Warning – they produced a Field guide for the

identification of damage on woody sentinel plants. The guide is intended as an aid for managers of sentinel plantings, botanical gardens or arboreta, as well as phytosanitary inspectors, who may have knowledge of common pests and diseases of woody plants but may not know the likely cause of damage that they have not encountered before. It aims to provide a tentative identification of relatively broad groups of organisms and not definitive identification of the causal agents. Similar guides for those working in the natural environment might be beneficial.

6.3.8 Roles and responsibilities

If unhealthy plants are found in the wider environment and the cause might be due to plant outbreaks of plant pests (either native or non-native) the following is needed:

- Knowledge of who to report unhealthy plants to.
- Appropriate mechanisms for identifying if the unhealthy plant is the result of a plant pest of concern.
- Appropriate mechanisms for implementing any containment of plant pests in the natural environment.

During the development of this framework, it became clear that the roles and responsibilities for these three bullet points, and the responsibility for plant health in the natural environment, was unclear. This resulted in discussions with the Chief Plant Health Officer for Scotland and a half day workshop on this subject, which are summarized in Chapter 7.

7 Roles and responsibilities for identifying, containing, and reducing spread of new plant pests within the natural environment.

7.1 Introduction

While developing the framework in Chapter 6, it became clear that the procedures were unclear for identifying and reporting plant pests in the natural environment in non-woodland habitats. This led to two activities being undertaken.

Firstly, a meeting was arranged with Chief Plant Health Officer for Scotland (CPHOS) to clarify the following points:

1. Who does one report a suspected plant pest to if found in the natural environment outside of woodlands, e.g. on Vaccinium or heather or an aquatic plant?
2. Who has the power to access land to check on reported infected plants?
3. Who has other powers to take action, e.g. remove plants?
4. Who has powers to limit access to land to stop disease spreading?
5. What facilities are there to test potentially diseased plants and identify pests?
6. Do 1-5 exist but no-one knows – is it a case of lack of communication or don't they exist?
7. What should we do about it?
8. What is the way forward?

Secondly, an afternoon workshop was arranged with NatureScot and a range of attendees involved in plant health to discuss wild plant health, the roles and responsibilities and to raise awareness.

7.2 Discussion with Chief Plant Health Officer for Scotland (CPHOS)

7.2.1 Who does one report a suspected plant pest to if found in the natural environment outside of woodlands, e.g. on Vaccinium or heather or an aquatic plant?

Who one reports a suspected plant pest to depends on the identification of the pest. For a quarantine organism, the CPHOS needs to be informed, who will then report it to Defra. When the UK was in the EU, the UK would also have had to inform the commission of the presence of quarantine pests, currently this latter action remains unclear.

The process before reporting a suspected plant pest is still unclear, i.e who to report an unhealthy group of plants to, before the identification of the pest is known. There are lots of potential "eyes on the ground" out there that could report unhealthy plants, e.g. NatureScot staff, Landowers, CONFOR, ICF. The CPHOS assumed that the most likely route would be that NatureScot would be made aware of a suspect plant. However, a) it is unclear if the "eyes on the ground" are aware that they should report suspected plant diseases in the natural environment to NatureScot; b) NatureScot as an organisation are generally not currently aware of i) the risks posed by plant pests and ii) aware of any responsibility with respect to plant health and the natural environment. The CPHOS acknowledged that it would be useful to have a Standard Operating Procedure to which NatureScot could refer.

7.2.2 Who has the power to access land to check on reported infected plants?

The CPHOS licences people under various powers written into legislation to conduct inspections. They can access land anywhere in Scotland if they think a pest is present. Anyone can be licenced in this way if they can prove competency in the area (plant pathology,

entomology etc) to access land. They are granted something along the lines of a warrant card. This power to licence anyone as an inspector presumably covers NatureScot. However, currently NatureScot is a) unaware that this power could be given to them and b) don't have the resources or expertise.

7.2.3 Who has other powers to take action e.g. remove plants

A statuary plant health notice puts obligation on a landowner to destroy infected plants. CPHOS believes that this covers any plant, including those in the natural environment.

7.2.4 Who has powers to limit access to land to stop disease spreading

Scottish ministers do have the power to limit access to land to stop the spread of a disease. However, this needs to be done sensitively and, in the past (e.g. woodland situations), this has been done in cooperation with landowner, rather than through legislation. CPHOS can issue Stop Notices, but it is currently unclear how this would work to limit access. A combination of SASA and Scottish Forestry issuing stop notices could be used to limit access.

7.2.5 What facilities are there to test potentially diseased plants and identify pests

Testing for plant pests is currently informal. The first port of call would be contacting and sending samples to SASA, who then might have to pull in others e.g., Forest Research. Official diagnostic labs work cooperatively, when SASA don't have capacity/ ability to do certain tests, the work is outsourced to Fera (York).

NatureScot could utilise the facilities of SASA, but it was agreed that these procedures are perhaps not well known as the process has never been tested, i.e. NatureScot has never come to CPHOS with an issue. While one doesn't wish to invest in a lot of resources to come up with a procedure if it will never be used, if there isn't an obvious system in place that can be used if needed, then we are likely to miss early identifications of diseases. Hence, it would be helpful to have an agreed framework.

7.2.6 Communication

The necessary legislation for bullet points 1 to 5 in section 7.1 do exist but the formal understanding of how to use those powers doesn't exist. We need greater clarity on who does what so this information can be passed on to, e.g. area managers, and so that observations don't just get dropped. It appears there is current a communication void.

7.2.7 What should we do about it?/Way forward

The overall conclusion from the meeting was that while Scottish ministers have powers to remove plants infected with quarantine pests in the natural environment, and to limit access to reduce the risk of quarantine pests spreading, there is a lack of knowledge and agreed procedures as to whom a suspected plant pest in the natural environment should be reported to. There is also a lack of both diagnostic resources (labs for testing for pests, if current lab facilities are also to be used for the pests in the natural environment) and capacity within NatureScot, if NatureScot are agreed to be the responsible organisation for collating potential records of plant pests in the natural environment. There needs to be clear lines of responsibility and communication for plant health in the natural environment and a standard operating procedure for identification of and response to plant pests in the wider environment would enable these responsibilities to be defined.

7.3 Wild plant health workshop

7.3.1 Introduction

On the 23rd February 2023 a half day workshop was held at the Royal Botanic Garden Edinburgh on wild plant health. Present were representative from SASA, NatureScot, Scottish Government, Forestry and Land Scotland and the Plant Health Centre.

The workshop aimed:

- To review and assess the risks to wild plant health from pests, in terrestrial 'nature' settings in a changing climate ('micro-INNS') – especially risks for dominant or foundational species.
    - risks include those to productivity/loss of the plants themselves.
    - there will be consequences for delivery of Scottish Biodiversity Strategy, Climate Change Plan, Adaptation Programme etc.
- to advise on proportionate responses (including uncertainties and consequences)
    - surveillance and monitoring.
    - awareness (who, where, when).
    - inform Draft Plant Health Contingency plan for Scotland.
- to outline roles, responsibilities and resources.

The information from earlier chapters in this report were presented as part of the workshop.

7.3.2 Risks

The workshop participants were presented with a summary of the risks and potential impacts plant health poses to the natural environment (See appendix 5 for slides). Much of the presentation draws on information presented in this report and done as part of the Strategic Research Programme JHI-D4-2, see SEFARI case-study and preprint.

7.3.3 Proportionate responses

The workshop participants were presented with a summary of how different habitats were at risk depending on whether one ranked them by 1) the number of known pests that could be hosted in that habitat; 2) the resilience of the habitat (as measured by species diversity); 3) the foundation species at risk (See appendix 5 for slides). Much of the presentation draws on information presented in this report and done as part of the see Strategic Research Programme JHI-D4-2, see SEFARI case-study and preprint.

The CPHOS presented the draft plant health contingency plan for Scotland. These processes show the actions and responsibilities for plant health once a quarantine pest is identified. It is largely applicable to the natural environment. What the contingency plan doesn't identify is how the initial identification of a plant pest of concern in the natural environment is conducted and who is responsible for monitoring plant health in the wider environment.

7.3.4 Roles, responsibilities and resources

The workshop agreed that the roles and responsibilities for plant health in the natural environment were unclear and that current resources for plant health in the natural environment were very limited. The discussion did not finalise roles, responsibilities and resources but the following key points were raised and a plan for future work agreed (summarised in section 7.3.5).

Key points arising from discussion on roles and responsibilities.

- Need to map roles across the interface of plant health and natural environment.
- Need a common way of reporting plant health – there are examples from tree health, can we learn from these?

- Lots of other organisations that could act as the "eyes" to provide alerts of unhealthly plants, e.g. Riverwood partnership for alder, Butterfly conservation for butterfly food plants, Botanical Society of Britain and Ireland currently developing new app for recording – could plant health be included within that app?
- Can we adapt current regimes to include plant health, e.g. site condition monitoring, or habitat restoration programmes?
- Can we learn lessons from Avian flu? The avian flu task force brought together Scottish Government, NGOs, agencies and communications. Is something similar needed for plant health?
- Can a consortium of Scottish Government, NGOs, agencies and communications be built for plant health?
- Need to be clear about the potential impact plant health could have, e.g. ash dieback is estimated to cost the UK £15 billion. We do have detailed analysis of the impacts on biodiversity and ecosystem functioning of a decline in ash and oak trees, but such detailed analyses are rare and costly. However, the lack of detailed analysis of the impacts should not stop us developing standard operating procedures for dealing with the potential risk – much like an insurance policy. The likelihood of a disease impacting some keystone plants in Scotland might be low, but the impact would be high.

Key points arising from discussion on resources

- Need to prioritise which plants to monitor – identify top 10 or so plants as a starting point.
- Need to know what "normal" looks like – so can compared with diseased plants.
- Can we work out what we would do in a worse-case scenario for a small subset of plants, e.g. looking at heather moorlands and saltmarshes, to help develop a protocol?
- A steering group is needed to come up with criteria to help triage plants to identify which plants could be prioritised.
- Routes to fund the prioritisation and mapping work could be via the Plant Health Centre.

7.3.5 Conclusion and way forward

It was acknowledged that this was the first time many involved in plant health had met with those involved in the natural environment. Getting everyone in the room and raising awareness was a good first step. It was agreed further clarification was needed over roles and responsibilities and the following next steps were agreed:

- A paper on wild plant health presented to NatureScot science advisory committee in March 2023 see Appendix 6.
- Meeting in May 2023 to agree on protocols of the flow of information if a suspected pest is discovered.
- Meeting in October 2023 to look at testing the protocols on a small subset of species.
- The Plant Health Centre could lead work on mapping roles and responsibilities for plant health in the natural environment.
- The Plant Health Centre to lead work on identifying a few (e.g. 10) foundation species that could be used in a trail for testing the protocols and plant health monitoring in the wider environment.

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9 Appendix 1: Questionnaire

Plant health and habitat restoration/creation

What is this survey about?
Plant pests and pathogens are increasing in the UK and pose a potential risk to the wider environment and biodiversity.

This questionnaire is being conducted on behalf of Scotland's Plant Health Centre of Expertise and NatureScot to better understand: The awareness of those involved in habitat restoration and habitat creation of plant health biosecurity risks; What risk assessments and biosecurity guidance/best practice is currently used with respect to plant health during habitat restoration and habitat creation; What, if any, new guidance is required

The research is funded by Scotland's Plant Health Centre of Expertise

Who should answer this survey?
Anyone involved in any aspect of habitat creation or restoration

How we will use your data:
This research has received approval from the James Hutton Institute's Research Ethics Committee.

Your survey answers will be anonymous. They will be stored initially with Qualtrics in a password protected electronic format. Data will later be downloaded and stored on a secure server of the James Hutton Institute. In this survey we do not intend to collect any data that could directly or indirectly identify you or your organisation. If you choose to share in free text responses any information that may identify you directly or indirectly, this information will be processed in line with data protection legislation and all reasonable steps will be taken to ensure confidentiality. More information about how the James Hutton Institute processes personal data can be found in its privacy notice. No names or other identifying information will be included in any publications or presentations based on this data, and your responses to this survey will remain confidential.

You do not have to answer all the questions and may exit the survey at any time.

How long will questionnaire take?
There are four sections to this questionnaire, which is mainly multiple-choice questions. In total the questionnaire should take no-longer than 15 minutes to complete.

Thank you for your time.

Further questions?
Please contact Dr Ruth Mitchell from the James Hutton Institute.

I have read the information above regarding how my data will be used and I agree that I am voluntarily taking part in this research and am over 18 years of age.

- ○ Yes (1)
- ○ No (2)

A few definitions relevant to the whole of this questionnaire:

Plant health: a decline in plant health is a decline in plant fitness due to pests and pathogens; it does not include a decline in fitness due to unfavourable growing conditions (such as weather, soil conditions etc), damage by vertebrate herbivores, or stress caused to the plant by unfavourable management practices.

Pathogens: a virus, bacteria, fungus or fungus-like organism that causes disease.

Pests: invertebrates that cause damage to a plant, either by direct action or by acting as a disease vector, e.g. insects and nematodes.

Plant pests and pathogens: include both native and non-native pests and pathogens, and include both those pests and pathogens already present within the UK and those that might establish.

Habitat restoration: any management to restore an area of land to more favourable ecological status, which may include the translocation of plants.

Habitat creation: the creation of a new habitat which may include the translocation of plants.

Translocation: the movement of plants at any stage of their life cycle (seeds, cuttings, adult plants), including both vascular plants and bryophytes.

This section seeks to find out more about your role in habitat restoration and creation and your knowledge of plant health risks

Q1: In which part(s) of the UK do you work?

- [ ] England
- [ ] Wales
- [ ] Scotland
- [ ] Northern Ireland

Q2: How are you involved in habitat restoration/creation? (Select as many answers as you wish.)

- [ ] Advising on habitat restoration/creation work
- [ ] Doing the physical on the ground restoration/creation work
- [ ] Landowner or agent with habitat restoration/creation occurring on land you have an involvement in
- [ ] Planning and designing the restoration/creation work, including potentially sourcing subcontractors to do the work
- [ ] Writing policy for habitat restoration
- [ ] Other (please provide details below)

_____

Q3: Which of the following most accurately describes your employer?

- ○ Consultancy
- ○ Contractor carrying out habitat restoration/creation
- ○ Environmental NGO
- ○ Government agency
- ○ Private landowner
- ○ Self employed
- ○ Other (please provide details below)

_____

Q4: How would you describe your level of knowledge about:

	No knowledge (1)	Minimal knowledge (2)	Basic knowledge (3)	Moderate knowledge (6)	Expert knowledge (7)
Plant pests/pathogens	○	○	○	○	○
Biosecurity	○	○	○	○	○
Habitat restoration	○	○	○	○	○
Plant health risk assessments	○	○	○	○	○

Q5: In which of these habitats are you currently, or have you recently, been conducting habitat restoration and/or creation? (Select as many answers as you wish.)

- ☐ Alpine or Montane
- ☐ Coastal
- ☐ Freshwater (e.g. river/lake/loch/pond)
- ☐ Grassland (e.g. calcareous or acid grassland)
- ☐ Hedges and trees outside woodlands
- ☐ Peatlands and blanket bogs
- ☐ Moorlands/heathlands
- ☐ Urban greenspace
- ☐ Woodlands
- ☐ Wetlands (e.g. fens and reedbeds)
- ☐ Other (please provide details below)

_____

In this section we'd like to know what you think are the greatest risks in relation to plant pests and pathogens

Q6: At the sites you are involved with, how likely do you think it is that plant pests/pathogens could establish by each of the following routes? Where 1 = highly unlikely and 5 = highly likely

	1-Highly unlikely (1)	2 (2)	3 (3)	4 (4)	5-Highly likely (5)	Don't know (6)
Walkers/Recreation - i.e. mud on boots, bikes, prams	○	○	○	○	○	○
Introduction of plants (excluding seed) for habitat restoration/creation purposes	○	○	○	○	○	○
Introduction of seed for habitat restoration/creation purposes	○	○	○	○	○	○
Movement of soil during habitat restoration/creation	○	○	○	○	○	○
Movement of machinery for habitat restoration/creation	○	○	○	○	○	○
Land management operations other than habitat restoration/creation	○	○	○	○	○	○
Spread from neighbouring infected areas	○	○	○	○	○	○
Spread by deer and other animals	○	○	○	○	○	○

Q7: Are you aware of any problematic plant pests/pathogens already present at, or near, sites you are involved with?

- ○ No
- ○ Don't know
- ○ Yes (if so can you name any of them below)

_____

Q8: Are there plant pests/pathogens at, or near sites, you are involved with that are not currently problematic but that could become so, e.g. with a change in climate or land management?

- ○ No
- ○ Don't know
- ○ Yes (if so can you name any of them below?)

_____

Q9: In your view, at the sites you are involved with, how does the establishment of plant diseases rank as a threat to biodiversity (i.e. the potential to cause a decline in biodiversity) relative to:

	Greater (1)	About the same (5)	Lower (2)	Don't know (3)	Not applicable for the sites where I work (4)
Agricultural practices	○	○	○	○	○
Climate change	○	○	○	○	○
Grazing by wild herbivores e.g. deer, rabbits	○	○	○	○	○
Habitat loss	○	○	○	○	○
Invasive non-native species (excluding plant pests/pathogens)	○	○	○	○	○
Land management detriment to biodiversity	○	○	○	○	○
Nitrogen pollution	○	○	○	○	○
Sulphur pollution	○	○	○	○	○
Urban development	○	○	○	○	○

Q10: How likely do you think plant pests/pathogens are to establish in each of the following habitats? Where 1 = low and 4 = high.

	Don't know (1)	Not at risk (2)	1-Low (3)	2 (4)	3 (5)	4-High (6)
Alpine or montane	○	○	○	○	○	○
Coastal	○	○	○	○	○	○
Freshwater (e.g. river/lake/loch/pond)	○	○	○	○	○	○
Hedgerows and trees outside woodlands	○	○	○	○	○	○
Grasslands, e.g. calcareous or acidic	○	○	○	○	○	○
Moorland/heathland	○	○	○	○	○	○
Peatlands and blanket bogs	○	○	○	○	○	○
Urban greenspace	○	○	○	○	○	○
Wetlands (e.g. fens, reedbeds)	○	○	○	○	○	○
Woodland	○	○	○	○	○	○

Q11: How likely do you think plant pests/pathogens are to cause a decline in biodiversity in each of the following habitats? Where 1 = low and 4 = high.

	Don't know (1)	Not at risk (2)	1-Low (3)	2 (4)	3 (5)	4-High (6)
Alpine or montane	○	○	○	○	○	○
Coastal	○	○	○	○	○	○
Freshwater (e.g. river/lake/loch/pond)	○	○	○	○	○	○
Hedgerows and trees outside woodlands	○	○	○	○	○	○
Grasslands, e.g. calcareous or acidic	○	○	○	○	○	○
Moorland/heathland	○	○	○	○	○	○
Peatlands and blanket bogs	○	○	○	○	○	○
Urban greenspace	○	○	○	○	○	○
Wetlands (e.g. fens, reedbeds)	○	○	○	○	○	○
Woodland	○	○	○	○	○	○

Q35 **This section seeks to find out more about the risk assessments and biosecurity guidelines/best practice that you use in relation to plant health**
Risk assessments are defined as an assessment made before an activity is carried out to identify and assess the potential impacts and risks of that activity. In relation to plant health this would include assessments of where staff/equipment/plants to be translocated may come into contact with plant pests and pathogens and how the proposed activity may result in the plant pests and pathogens being transported/introduced to a new location. Biosecurity guidance/best practice describe actions or procedures on the ground (e.g. at restoration sites or in propagation facilities for growth of plant material used in restoration projects) that should limit the risks of plant pests and pathogens spreading (e.g. cleaning of footwear and equipment). These may or may not be compulsory to follow.

Q12: Do you, your organisation or your employer have a risk assessment to assess the risk of transferring plant pests and pathogens during habitat restoration or habitat creation?

- ○ No
- ○ Don't know
- ○ Yes: if possible please provide brief details below about who wrote the risk assessment (e.g. 'in house risk assessment' or 'we follow the risk assessment provided by.....') and what it covers (e.g. plant propagation facilities, soil movement, movement of plants, movement of equipment, cleaning equipment, disturbance in pristine habitats): _____

Q13: Do you, your organisation or your employer have biosecurity guidance/best practice (e.g. covering cleaning equipment, sourcing plant material) for habitat restoration and/or creation?

- ○ No
- ○ Don't know
- ○ Yes: if possible please provide further details below e.g. 'in house guidance' or 'we follow Scottish Forestry guidelines', what the guidance/best practice covers (e.g. cleaning equipment, sourcing plant material, movement of soil), and who is expected to follow the guidelines/best practice: _____

Q14: Do you, your organisation or your employer check to ensure these guidance/best practice are followed during habitat restoration and/or creation?

- ○ No
- ○ Yes
- ○ N/A as no guidelines/best practice

Q15: Does anyone in your organisation have responsibility for biosecurity during habitat restoration/creation?

- ○ No
- ○ Don't know/not sure
- ○ Yes

Q16: Do you, your organisation or your employer monitor the site following completion of restoration/creation to check for the establishment of any plant pests/pathogens?

- ○ No
- ○ Yes for the first year following completion
- ○ Yes for the first 2-4 years following completion
- ○ Yes for 5 years or more following completion
- ○ Other _____

In this section we'd like to know more about the gaps in plant health risk assessments and biosecurity guidance/best practice that you are aware of

Q17: Is the guidance, that you have access to, about the plant health risks associated with habitat restoration and habitat creation:

- ○ Sufficient
- ○ Insufficient
- ○ Don't know

Q18: With respect to plant health would you like further guidance on: (select as many answers as you wish)

- ☐ How to develop risk assessments
- ☐ Biosecurity risks associated with movement of plants and how to minimize them
- ☐ Biosecurity risks associated with movement of soil and how to minimize them
- ☐ Biosecurity risks associated with movement of equipment and how to minimize them (4)
- ☐ What biosecurity to put in place for staff/contractors
- ☐ What biosecurity to put in place for the general public that may access land you work on/own
- ☐ Sourcing plants free of pests and pathogens
- ☐ Propagating plants free of pests and pathogens
- ☐ Further guidance on where to find information about plant health and diseases
- ☐ The current legislation on plant pests/pathogens and movement of plants/soil/equipment
- ☐ Other (please provide details below) _____

Q19: Where do you obtain information about the risks of plant pests and pathogens? (Select as many answers as you wish.)

- ☐ Colleagues
- ☐ Conferences and meetings
- ☐ Government bodies
- ☐ Membership organisations
- ☐ Professional newsletters/magazines
- ☐ Research organisations
- ☐ Social media
- ☐ Websites
- ☐ Other (please provide details below)

_____

Thank you for your time. In early 2022, we will be running an online workshop about plant health and habitat restoration and creation, which will include a presentation of the results from this work. If you would like to receive further details about this please contact Ruth Mitchell at The James Hutton Institute. This email link is in no-way linked to your answers to the survey which will remain anonymous.

10 Appendix 2: The 161 pests listed in the UK PHRR that are hosted by genera found at more than 25% cover on Scottish moorlands.

For type of pest B = Bacterium; F = Fungus; I = Insect; M = Mite; N = Nematode; O = Oomycete;; P= Phytoplasma; V = Virus or Viroid; X = Other

Pest Name	Pest family	Plant Host genera																			
		Type of pest	Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Present in the UK																						
Agrobacterium tumefaciens	Rhizobiaceae	B																	1			1
Argyresthia cupressella	Argyresthiidae	I														1						
Armillaria mellea	Physalacriaceae	F														1			1			
Beet necrotic yellow vein benyvirus		V															1					
Brenneria salicis	Pectobacteriaceae	B																	1			
'Candidatus Phytoplasma asteris' in carrot	Acholeplasmataceae	P																				1
'Candidatus Phytoplasma asteris' in potato	Acholeplasmataceae	P																				1
Chryseococcus arecae	Pseudococcidae	I		1						1												
Chrysolina americana	Chrysomelidae	I																		1		
Cinara curvipes	Aphididae	I														1						
Drosophila suzukii	Drosophilidae	I																				1
Duponchelia fovealis	Pyralidae	I															1					
Godronia cassandrae	Godroniaceae	F																				1
Hemiberlesia rapax	Diaspididae	I																				1
Longidorus elongatus	Longidoridae	N						1														

Pest Name	Pest family	Type of pest	Plant Host genera																			
			Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Lymantria dispar	Lymantriidae	I																	1			
Meloidogyne minor	Meloidogynidae	N	1									1										
Musotima nitidalis	Crambidae	I																1				
Neofusicoccum australe	Botryosphaeriaceae	F																				1
Neofusicoccum parvum	Botryosphaeriaceae	F																				1
Neonectria ditissima	Nectriaceae	F																	1			
Parthenolecanium fletcheri	Coccidae	I														1						
Pepino mosaic virus	Alphaflexiviridae	V															1					
Phyllonorycter pastorella	Gracillariidae	I																	1			
Phytophthora austrocedri	Pythiaceae	O														1						
Phytophthora cinnamomi	Peronosporaceae	F																				1
Phytophthora citrophthora	Peronosporaceae	O																				1
Phytophthora kernoviae	Pythiaceae	O																				1
Phytophthora pseudosyringae	Pythiaceae	O			1																	1
Phytophthora ramorum	Peronosporaceae	O			1	1													1			1
Rhopalosiphum nymphaeae	Aphididae	I													1							
Scirtothrips inermis	Thripidae	I																	1			
Simo hirticornis	Curculionidae	I											1									1
Strawberry latent ringspot virus	Secoviridae	V																				1
Tobacco ringspot virus	Comoviridae	V																				1
Tomato ringspot virus	Comoviridae	V																				1
Urocystis agropyri	Tilletiaceae	F	1					1	1			1										

Pest Name	Pest family	Type of pest	Plant Host genera																	
			Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Xylosandrus germanus	Curculionidae	I																	1			
<u>Absent in the UK</u>																						
Acleris issikii	Tortricidae	I																	1			
Acleris minuta	Tortricidae	I				1													1			1
Acleris senescens	Tortricidae	I																	1			
Aeolesthes sarta	Cerambycidae	I																	1			
Agrilus ater	Buprestidae	I																	1			
Agrilus fleischeri	Buprestidae	I																	1			
Aleuroclava psidii	Aleyrodidae	I																	1			
Anguina pacificae	Anguinidae	N	1																			
Anoplophora chinensis	Cerambycidae	I																	1			1
Anoplophora glabripennis	Cerambycidae	I																	1			
Anthonomus signatus	Curculionidae	I																				1
Apriona germari	Cerambycidae	I																	1			
Apriona rugicollis	Cerambycidae	I																	1			
Aroga trialbamaculella	Gelechiidae	I																				1
Aschistonyx eppoi	Cecidomyiidae	I														1						
Bactra bactrana	Tortricidae	I					1				1				1						1	
Bemisia tabaci European populations	Aleyrodidae	I																		1		
Bemisia tabaci non-European populations	Aleyrodidae	I																		1		
Blueberry leaf mottle virus	Secoviridae	V																				1

Pest Name	Pest family	Type of pest	Plant Host genera																		
			Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Blueberry mosaic associated virus	Aspiviridae	V																				1
Blueberry red ringspot virus	Caulimoviridae	V																				1
Blueberry scorch virus	Betaflexiviridae	V																				1
Blueberry shock virus	Bromoviridae	V																				1
Blueberry shoestring sobemovirus	Unallocated ssRNA+ virus	V																				1
Calamobius filum	Cerambycidae	I						1														
Callidiellum rufipenne	Cerambycidae	I														1						
'Candidatus Phytoplasma pruni'	Acholeplasmataceae	P																				1
'Candidatus Phytoplasma solani'	Acholeplasmataceae	P																				1
Cathaica fasciola	Bradybaenidae	X																	1			
Ceroplastes ceriferus	Coccidae	I																	1			1
Ceroplastes japonicus	Coccidae	I																	1			
Ceroplastes rusci	Coccidae	I																	1			
Ceroplastes sinensis	Coccidae	I																				1
Cherry leaf roll virus	Secoviridae	V																				1
Cherry rasp leaf virus	Comoviridae	V															1					
Chionaspis pinifoliae	Diaspididae	I														1						
Choristoneura fumiferana	Tortricidae	I														1						
Choristoneura parallela	Tortricidae	I																	1			1
Choristoneura rosaceana	Tortricidae	I																	1			1

Pest Name	Pest family	Type of pest	Plant Host genera																	
			Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Chrysobothris femorata	Buprestidae	I																	1			
Chrysodeixis eriosoma	Noctuidae	I																		1		
Chrysomyxa arctostaphyli	Coleosporiaceae	F			1																	
Comstockaspis perniciosa	Diaspididae	I																				1
Coniferiporia weirii	Hymenochaetaceae	F														1						
Conotrachelus nenuphar	Curculionidae	I																				1
Cranberry false blossom phytoplasma		P																				1
Deudorix dinochares	Lycaenidae	I																				1
Elasmopalpus lignosellus	Pyralidae	I														1						
Endoclita excrescens	Hepialidae	I																	1			
Ennomos subsignaria	Geometridae	I																	1			
Eurygaster integriceps	Scutelleridae	I						1				1										
Euwallacea fornicatus	Curculionidae	I																	1			
Euwallacea kuroshio	Curculionidae	I																	1			
Euzophera bigella	Pyralidae	I																	1			
Euzophera semifuneralis	Pyralidae	I																	1			
Grapholita packardi	Tortricidae	I																				1
Gymnosporangium asiaticum	Pucciniaceae	F														1						
Gymnosporangium clavipes	Pucciniaceae	F														1						
Gymnosporangium globosum	Pucciniaceae	F														1						

Pest Name	Pest family	Plant Host genera																				
		Type of pest	Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Gymnosporangium juniperi-virginianae	Pucciniaceae	F														1						
Gymnosporangium monticola	Pucciniaceae	F														1						
Gymnosporangium tremelloides	Pucciniaceae	F														1						
Gymnosporangium yamadae	Pucciniaceae	F														1						
Halyomorpha halys	Pentatomidae	I																	1			
Helicotylenchus dihystera	Hoplolaimidae	N	1																			1
Heterobasidion irregulare	Bondarzewiaceae	F														1						
Hyalesthes obsoletus	Cixiidae	I											1				1					
Hylesia nigricans	Saturniidae	I																	1			
Lamprodila festiva	Buprestidae	I														1						
Lepidosaphes ussuriensis	Diaspididae	I																	1			
Lissorhoptrus oryzophilus	Curculionidae	I	1																			
Listronotus bonariensis	Curculionidae	I	1	1								1										
Longidorus diadecturus	Longidoridae	N																				1
Luperomorpha xanthodera	Chrysomelidae	I												1								
Lymantria mathura	Lymantriidae	I																	1			
Malacosoma parallela	Lasiocampidae	I																	1			
Megaplatypus mutatus	Platypodidae	I																	1			
Monochamus guttulatus	Cerambycidae	I																	1			
Neofusicoccum luteum	Botryosphaeriaceae	F								1												

Pest Name	Pest family	Type of pest	Plant Host genera																		
			Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Neopulvinaria innumerabilis	Coccidae	I																	1			
Oligonychus perditus	Tetranychidae	M														1						
Orgyia thyellina	Lymantriidae	I																	1			
Parabemisia myricae	Aleyrodidae	I																	1			
Phenacoccus solani	Pseudococcidae	I										1										
Phomopsis vaccinii	Diaporthaceae	F																				1
Phytomyza thymi	Agromyzidae	I																		1		
Planococcus vovae	Pseudococcidae	I														1						
Plantago asiatica mosaic virus	Flexiviridae	V															1					
Platynota flavedana	Tortricidae	I																	1			1
Platynota idaeusalis	Tortricidae	I																	1			1
Platynota rostrana	Tortricidae	I																	1			1
Platypus apicalis	Platypodidae	I																	1			
Popillia japonica	Rutelidae	I																	1			
Pratylenchus scribneri	Pratylenchidae	N										1										
Prionoxystus robiniae	Cossidae	I																	1			
Pseudanaphothrips achaetus	Thripidae	I						1														
Pseudococcus meridionalis	Pseudococcidae	I																				1
Puto barberi	Pseudococcidae	I															1					
Rathayibacter toxicus	Microbacteriaceae	B	1																			
Rhagoletis mendax	Tephritidae	I																				1
Ripersiella hibisci	Pseudococcidae	I					1															

Pest Name	Pest family	Type of pest	Plant Host genera																	
			Agrostis	Anthoxanthum	Arctostaphylos	Calluna	Carex	Dactylis	Deschampsia	Erica	Eriophorum	Festuca	Galium	Genista	Juncus	Juniperus	Plantago	Pteridium	Salix	Thymus	Tricophorum	Vaccinium
Rusticoclytus rusticus	Cerambycidae	I																	1			
Scirtothrips citri	Thripidae	I																				1
Siphonatrophia cupressi	Aphididae	I														1						
Stromatium barbatum	Cerambycidae	I																	1			
Takahashia japonica	Coccidae	I																	1			
Thekopsora minima	Pucciniastraceae	F																				1
Tomato chlorosis virus	Closteroviridae	V															1					
Tremex fuscicornis	Siricidae	I																	1			
Trichodorus cedarus	Trichodoridae	N														1						
Trichoferus campestris	Cerambycidae	I																	1			
Wiseana umbraculata	Hepialidae	I					1															
Xiphinema bakeri	Longidoridae	N						1														1
Xiphinema bricolense	Longidoridae	N													1							
Xiphinema californicum	Longidoridae	N														1			1			
Xiphinema incognitum	Longidoridae	N																				1
Xiphinema rivesi (European populations)	Longidoridae	N																				1
Xiphinema rivesi (non-European populations)	Longidoridae	N																				1
Xylosandrus crassiusculus	Curculionidae	I																	1			
Xylotrechus namanganensis	Cerambycidae	I																	1			
Zaprionus indianus	Drosophilidae	I																				1
Paratrichodorus minor	Trichodoridae	N																				1
Xylella fastidiosa	Xanthomonadaceae	B																				1

11 Appendix 3: The global (excluding Europe) distribution of the 161 pests listed in the PHRR that are hosted by plant genera that occur on Scottish moorlands at >25% cover.

The number of pests present in each country is shown.

Country	Number
United States	99
Canada	68
China	62
Japan	59
South Korea	45
Mexico	39
India	35
New Zealand	34
Iran	33
Taiwan	32
Chile	31
Australia	28
Brazil	28
Israel	25
Russia	25
Argentina	24
South Africa	24
Egypt	22
Morocco	21
Pakistan	21
Algeria	18
North Korea	18
Uruguay	18
Venezuela	18
Vietnam	17
Georgia	16
Lebanon	16
Peru	15
Cuba	14
Puerto Rico	14
Syria	14
Thailand	14
Afghanistan	13
Indonesia	13
Iraq	13
Uzbekistan	13
Colombia	12
Malaysia	12
Tajikistan	12
Tunisia	12
Armenia	11
Azerbaijan	11
Kazakhstan	11
Kenya	11
Saudi Arabia	11

Country	Number
Tanzania	11
Congo (Democratic Rep.)	10
Kyrgyzstan	10
Myanmar	10
Nigeria	10
Sri Lanka	10
Costa Rica	9
Cote d'Ivoire	9
French Guiana	9
Guatemala	9
Jamaica	9
Jordan	9
Malawi	9
Papua New Guinea	9
Philippines	9
Turkmenistan	9
Zimbabwe	9
Bangladesh	8
Bolivia	8
Dominican Republic	8
Ecuador	8
Guadeloupe	8
Madagascar	8
Mauritius	8
Nepal	8
No data	8
Panama	8
Mozambique	7
Reunion	7
Seychelles	7
Cameroon	6
Ethiopia	6
Fiji	6
Guyana	6
Haiti	6
Libya	6
Paraguay	6
Senegal	6
Sudan	6
Trinidad and Tobago	6
Uganda	6
Bermuda	5
Cabo Verde	5
El Salvador	5
Ghana	5
Honduras	5
Samoa	5
Tonga	5
Zambia	5
Africa	4

Country	Number
Angola	4
Antigua and Barbuda	4
Barbados	4
Benin	4
Burkina Faso	4
Cambodia	4
Dominica	4
Gambia	4
Grenada	4
Guinea	4
Martinique	4
Mongolia	4
New Caledonia	4
Nicaragua	4
Oman	4
South America	4
Togo	4
Bhutan	3
Brunei	3
Hong Kong	3
Mayotte	3
Palau	3
Saint Kitts and Nevis	3
Saint Lucia	3
Singapore	3
Solomon Islands	3
Somalia	3
Yemen	3
Asia	2
Bahamas	2
Belize	2
Cayman Islands	2
Central African Republic	2
Comoros	2
Equatorial Guinea	2
Eritrea	2
French Polynesia	2
Gabon	2
Laos	2
Marshall Islands	2
Mauritania	2
Niger	2
North America	2
Oceania	2
Rwanda	2
Saint Vincent and the Grenadines	2
Sao Tome and Principe	2
Sierra Leone	2
United Arab Emirates	2
Vanuatu	2

Country	Number
[Kingdom of] eSwatini	1
Bahrain	1
Botswana	1
Burundi	1
Chad	1
Congo (Brazzaville)	1
Falkland Islands	1
Greenland	1
Kazak	1
Kiribati	1
Kuwait	1
Liberia	1
Maldives	1
Micronesia	1
Namibia	1
Nauru	1
South Sudan	1
Suriname	1
Trinid	1
Tuvalu	1

12 Appendix 4: The 142 pests found in the literature that are hosted by genera found on Scottish moorlands at > 25% cover that are not listed in the PHRR.

For type of pest B = Bacterium; F = Fungus; I = Insect; M = Mite; O = Oomycete;V = Virus

Name of pest	Type of pest	Plant Host Genera																				
		Agrostis	*Alchemilla*	*Arctostaphylo-*	*Calluna*	*Carex*	*Dactylis*	*Danthonia*	*Deschampsia*	*Erica*	*Festuca*	*Galium*	*Genista*	*Juncus*	*Juniperus*	*Luzula*	*Molina*	*Plantain*	*Potentilla*	*Salix*	*Ulex*	*Vaccinium*
Acalitus vaccinii	M																					1
Aceria tosichella	M						1															
Acidovorax avenae subsp. Avenae	B	1																				
Acremonium alternatum	F	1																				
Acremonium rutilum	F	1																				
Acrobasis vaccinii	I																					1
Aegorhinus superciliosus	I																					1
Agrotis ipsilon	I	1																				
Allantophomopsis lycopodina	F																					1
Alternaria alternata	F										1											
Alternaria caricicola sp. nov.	F					1																
Anthonomus musculus	I																					1
Anthracoidea heterospora	F					1																
Anthracoidea pamiroalaica	F					1																
Anthracoidea transberingiana	F					1																
Anthroacoidea limosa	F					1																

Name of pest	Type of pest	Plant Host Genera																					
		Agrostis	*Alchemilla*	*Arctostaphylo-*	*Calluna*	*Carex*	*Dactylis*	*Danthonia*	*Deschampsia*	*Erica*	*Festuca*	*Galium*	*Genista*	*Juncus*	*Juniperus*	*Luzula*	*Molina*	*Plantain*	*Potentilla*	*Salix*	*Ulex*	*Vaccinium*
Ascochyta phleina Sprague	F										1											
Atkinsonella hypoxylon	F							1														
Bipolaris sorokiniana	F										1											
Blissus insularis Barber	I										1											
Botryosphaeria dothidea	F																					1
Botryosphaeria stevensii	F														1							
Botrytis cinerea	F																					1
Brontispa longissima	I					1																
Calonectria pseudonaviculata	F		1	1								1										
Carulaspis juniperi (Bouche)	I														1							
Cherry leaf roll virus	V																	1				
Choristoneura houstonana	I														1							
Cinara cupressi	I														1							
Cintractia junci	F													1								
Clarireedia bennettii	F										1											
Clarireedia homoeocarpa	F										1											
Clarireedia jacksonii	F	1																				
Clarireedia jacksonii	F										1											
Clarireedia monteithiana	F										1											
Colletotrichum cereale	F	1																				
Cryptorhynchus lapathi	I																			1		
Curvularia trifolii	F	1																				
Cyclocephala flavipennis	I						1				1											

Name of pest	Type of pest	Plant Host Genera																					
		Agrostis	*Alchemilla*	*Arctostaphylos*	*Calluna*	*Carex*	*Dactylis*	*Danthonia*	*Deschampsia*	*Erica*	*Festuca*	*Galium*	*Genista*	*Juncus*	*Juniperus*	*Luzula*	*Molina*	*Plantain*	*Potentilla*	*Salix*	*Ulex*	*Vaccinium*
Dasineura oxycoccana	I																					2
Diaporthe adunca	F																	1				
Diaporthe vaccinii	F																					1
Diplodia africana	F														1							
Diplodia sapinea	F														1							
Dorcadion pseudopreissi Breuning	I										1											
Dysmicoccus vaccinii	I																					1
Earias chlorana	I																			1		
Epiphyas postvittana	I			1																		
Epyaxa rosearia	I																	1				
Exobasidium maculosum	F																					1
Frankliniella bispinosa	I																					1
Frommeella tormentillae	V																		1			
Fusarium dactylidis	F						1															
Fusarium graminearum	F	1					1															
Fusarium poae	F	1									1											
Fusarium tumidum	F																				1	
Gelechia senticetella	I														1							
Halyomorpha halys	I																					1
Hypoderma junipericola	F														1							
Isophrictis similiella	I														1							
Lasiodiplodia clavispora	F																					1

Name of pest	Type of pest	Plant Host Genera																					
		Agrostis	*Alchemilla*	*Arctostaphylo-*	*Calluna*	*Carex*	*Dactylis*	*Danthonia*	*Deschampsia*	*Erica*	*Festuca*	*Galium*	*Genista*	*Juncus*	*Juniperus*	*Luzula*	*Molina*	*Plantain*	*Potentilla*	*Salix*	*Ulex*	*Vaccinium*
Lasiodiplodia fujianensis	F																					1
Lasiodiplodia henanica	F																					1
Lasiodiplodia nanpingensis	F																					1
Lasiodiplodia paraphysoides	F																					1
Lasiodiplodia theobromae	F																					2
Leucoptera laburnella	I												1									
Listronotus maculicollis	I	1																				
Lochmaea suturalis	I				1																	
Lophodermium harbinense	F														1							
Lophodermium jianchuanense	F														1							
Lophodermium juniperinum	F														1							
Macrophomina phaseolina	F																					1
Magnaporthiopsis meyeri-festucae	F										1											
Melampsora epitea	F																			1		
Melampsora larici-epitea	F																			1		
Melampsora yezoensis	F																			1		
Microdochium nivale	F	1																				
Microdochium poae	F	1																				
Molinia streak virus	V																1					
Monilinia vaccinii-corymbos	F																					1
Mycocentrospora acerina	F											1										
Myriosclerotinia sulcatula	F					1																

Name of pest	Type of pest	Plant Host Genera																					
		Agrostis	*Alchemilla*	*Arctostaphylos*	*Calluna*	*Carex*	*Dactylis*	*Danthonia*	*Deschampsia*	*Erica*	*Festuca*	*Galium*	*Genista*	*Juncus*	*Juniperus*	*Luzula*	*Molina*	*Plantain*	*Potentilla*	*Salix*	*Ulex*	*Vaccinium*
Nematits salicis	I																			1		
Neofusicoccum eucalyptorum	F																					1
Neomyzus circumflexus	I																			1		
Novophytoptus luzulis	M															1						
Ophiosphaerella agrostis	F	1																				
Pestalotiopsis sydowiana	F				1					1												
Phaeosphaeria deschampsii	F								1													
Phellinus sulphurascens	F														1							
Phloeosinus aubei	I														1							
Phragmidium duchesneae	V																		1			
Phratora vitellinae	I																			1		
Phratora vulgatissima	I																			1		
Phyllodecta vitellinae	I																			1		
Phyllodecta vulgatissima	I																			1		
Phylloscelis rubra	I																					1
Phytophthora cinnamomi	F			1						1												
Phytophthora cryptogea	F				1					1												
Phytophthora lateralis	F														1							
Phytophthora ramorum	F									1												
Phytoptus caricis	M					1																
Podosphaera plantaginis	F																	1				
Popillia japonica	I																					1
Prodiplosis vaccinii	I																					1

Name of pest	Type of pest	Plant Host Genera																				
		Agrostis	*Alchemilla*	*Arctostaphylos*	*Calluna*	*Carex*	*Dactylis*	*Danthonia*	*Deschampsia*	*Erica*	*Festuca*	*Galium*	*Genista*	*Juncus*	*Juniperus*	*Luzula*	*Molina*	*Plantain*	*Potentilla*	*Salix*	*Ulex*	*Vaccinium*
Pseudopyricularia iraniana	F													1								
Puccinia graminis subsp. graminicola	F						1				1											
Pucciniastrum vaccinii	F																					1
Pyrenophora teres f. teres	F								1													
Ramomarthamyces tuku	F													1								
Rhizoctonia blight	F	1																				
Rhizoctonia solani	F	1			1					2												
Rhopobota naevana	I																					1
Rhynchosporium orthosporum	F						1															
Rosellinia desmazieresii	F																			1		
Scaphoideus luteolus	I																			1		
Schizaphis agrostis	I	1																				
Schizaphis holc	I	1																				
Scirtothrips dorsalis	I																					1
Sclerotinia homoeocarpa	F	1																				
Scopula rubraria	I																	1				
Seiridium cardinale	F														1							
Sericothrips staphylinus	I																				1	
Soleella junipericola	F														1							
Sparganothis sulfureana	I																					1
Sphaceloma murrayae	F																			1		
Sphaerulina musiva	F																			1		

Name of pest	Type of pest	Plant Host Genera																						
		Agrostis	*Alchemilla*	*Arctostaphylos*	*Calluna*	*Carex*	*Dactylis*	*Danthonia*	*Deschampsia*	*Erica*	*Festuca*	*Galium*	*Genista*	*Juncus*	*Juniperus*	*Luzula*	*Molina*	*Plantain*	*Potentilla*	*Salix*	*Ulex*	*Vaccinium*
Sphenophorus venatus confluens Chittenden	I						1															
Spodoptera frugiperda	I	1																				
Stenacis triradiatus	M																			1		
Systena frontalis	I																					1
Tetranychus lintearius	M																				1	
Tolype innocens	I																					1
Tuberolachnus salignus	I																			1		
Typhula incarnata	F	1																				
Typhula ishikariensis	F	1																				
Urocystis junci	F													1								
Valdensinia heterodoxa	F																					2
Waitea circinata	F	1																				
Xanthomonas vasicola	B						1															
Yellow dwarf viruses (YDVs)	V													1								

13 Appendix 5: Plant species occurring at more than 75% cover within 12 broad habitat types in the UK that are suggested priorities for plant health monitoring.

Species	Habitat																	
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime communities cliff	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Montane communities	Calcifugous grasslands and	Woodlands
Acer pseudoplatanus													1
Achillea millefolium						1							
Acorus calamus								1					
Agrostis canina				1									
Agrostis capillaris			1		1	1			1			1	1
Agrostis curtisii			1									1	
Agrostis stolonifera				1		1	1	1	1	1			
Allium ursinum													1
Alnus glutinosa													1
Alopecurus geniculatus						1	1						
Ammophila arenaria									1				
Anemone nemorosa													1
Anthoxanthum odoratum									1				
Anthyllis vulneraria					1				1				
Arctium minus							1						
Armeria maritima					1								
Arrhenatherum elatius						1			1				
Artemisia maritima										1			
Arthrocnemon perenne										1			
Aster tripolium										1			

Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Montane communities and grasslands	Calcifugous	Woodlands
Atriplex hastata								1					
Avenula pubescens		1											
Beta vulgaris					1								
Betula pendula													1
Betula pubescens													1
Blysmus rufus										1			
Brachypodium pinnatum		1											
Brachypodium sylvaticum		1											1
Brachythecium rutabulum													1
Briza media		1											
Bromopsis erecta		1											
Bromus hordeaceus							1						
Callitriche hamulata	1												
Callitriche hermaphroditica	1												
Callitriche obtusangula	1												
Callitriche stagnalis	1												
Calluna vulgaris			1	1									1
Carex acutiformis								1					1
Carex aquatilis								1					
Carex arenaria			1						1				
Carex bigelowii			1									1	
Carex curta				1									
Carex demissa				1									

Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Calcifugous grasslands and montane communities	Woodlands
Carex elata								1				
Carex flacca		1										
Carex nigra				1				1	1			
Carex otrubae								1				
Carex paniculata								1				
Carex pseudocyperus								1				
Carex riparia								1				
Carex rostrata				1				1				
Carex saxatilis				1								
Carex vesicaria								1				
Carpinus betulus												1
Castanea sativa												1
Ceratophyllum demersum	1											
Chamerion angustifolium							1					
Chara spp	1											
Chenopodium album							1					
Chrysanthemum segetum							1					
Cladium mariscus								1	1			
Corylus avellana												1
Crataegus monogyna												1
Cytisus scoparius												1
Dactylis glomerata						1						
Deschampsia cespitosa						1					1	1

Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Montane communities	Calcifugous grasslands and	Woodlands		
Deschampsia flexuosa												1	1		
Dryas octopetala		1													
Dryopteris dilatata													1		
Dryopteris filix-mas													1		
Elatine hexandra	1														
Eleocharis palustris	1						1	1							
Eleocharis quinqueflora				1											
Eleocharis uniglumis										1					
Elodea canadensis	1														
Elodea nuttallii	1														
Elymus farctus									1						
Elymus pycnanthus									1	1					
Elymus repens							1			1					
Elytrigia repens							1			1					
Empetrum nigrum			1	1									1		
Epilobium hirsutum							1								
Equisetum fluviatile								1							
Equisetum palustre									1						
Equisetum telmateia													1		
Equisetum variegatum									1						
Erica ciliaris			1												
Erica cinerea			1												
Erica tetralix				1											

Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, sand-dune and strandline communities	Salt Marsh	Montane communities and grasslands	Calcifugous	Woodlands
Eriophorum angustifolium				1				1					
Eriophorum vaginatum				1									
Fagus sylvatica													1
Festuca arundinacea						1				1			
Festuca ovina		1	1		1		1		1			1	
Festuca rubra		1			1	1	1		1	1			
Filaginella uliginosa							1						
Filipendula ulmaria				1		1							
Frangula alnus													1
Fraxinus excelsior													1
Fumaria occidentalis							1						
Funaria hygrometrica							1						
Geranium sylvaticum						1							
Glaux maritima										1			
Glyceria fluitans								1					
Glyceria maxima								1					
Gymnocarpium robertianum							1						
Halimione portulacoides								1		1			
Hedera helix													1
Hippophae rhamnoides									1				
Hippuris vulgaris	1												
Holcus lanatus					1	1							1

Species	Habitat																
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	montane communities	Calcifugous grasslands and	Woodlands
Holcus mollis													1
Hordeum murinum							1						
Hyacinthoides non-scripta					1								1
Hydrocotyle vulgaris								1	1				
Hylocomium splendens													1
Hypericum elodes				1									
Ilex aquifolium													1
Inula crithmoides										1			
Iris pseudacorus				1									
Isoetes lacustris	1												
Isoetes setacea	1												
Juncus acutiflorus				1									
Juncus articulatus									1				
Juncus bulbosus	1												
Juncus effusus				1			1	1					1
Juncus gerardi										1			
Juncus inflexus							1						
Juncus maritimus										1			
Juncus squarrosus												1	
Juncus trifidus												1	
Juniperus communis													1
Lamium album							1						
Larix decidua													1

Species	Habitat															
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	montane communities	Calcifugous grasslands and	Woodlands
Larix spp													1
Lavatera arborea					1								
Lemna gibba	1							1					
Lemna minor	1							1					
Lemna trisulca	1							1					
Leymus arenarius									1				
Limonium vulgare										1			
Limosella aquatica							1						
Littorella uniflora	1												
Lobelia dortmanna	1												
Lolium perenne						1	1						
Lotus corniculatus									1				
Lupinus arboreus									1				
Luronium natans	1												
Luzula sylvatica												1	1
Lythrum salicaria								1					
Matricaria maritima							1						
Melampyrum pratense													1
Menyanthes trifoliata				1				1					
Mercurialis perennis													1
Molinia caerulea			1	1	1			1					1
Myrica gale				1									
Myriophyllum alterniflorum	1												

Species	Habitat															
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Calcifugous grasslands and montane communities	Woodlands
Myriophyllum spicatum	1											
Nardus stricta		1	1								1	
Narthecium ossifragum				1								
Nasturtium officinale								1				
Nitella spp	1											
Nuphar lutea	1											
Nymphaea alba	1											
Oxalis acetosella												1
Oxalis articulata							1					
Oxalis pes-caprae							1					
Parietaria diffusa							1					
Phalaris arundinacea								1				
Phragmites australis								1	1			1
Pinus nigra												1
Pinus sylvestris												1
Plantago maritima					1					1		
Poa annua							1					
Poa pratensis						1						
Poa trivialis												1
Polygonum amphibium	1											
Polygonum aviculare							1					
Polygonum hydropiper							1					
Polygonum lapathifolium							1					

Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Montane communities and grasslands	Calcifugous	Woodlands
Potamogeton alpinus	1												
Potamogeton berchtoldii	1												
Potamogeton compressus	1												
Potamogeton crispus	1												
Potamogeton filiformis	1												
Potamogeton friesii	1												
Potamogeton gramineus	1												
Potamogeton lucens	1												
Potamogeton natans	1							1					
Potamogeton obtusifolius	1												
Potamogeton pectinatus	1												
Potamogeton perfoliatus	1												
Potamogeton polygonifolius	1			1									
Potamogeton pusillus	1												
Potamogeton trichoides	1												
Potamogeton x niten	1												
Potentilla anserina						1			1				
Potentilla palustris				1				1					
Prunella vulgaris									1				
Prunus spinosa													1
Pseudotsuga menziesii													1
Pteridium aquilinum												1	1
Puccinellia maritima										1			

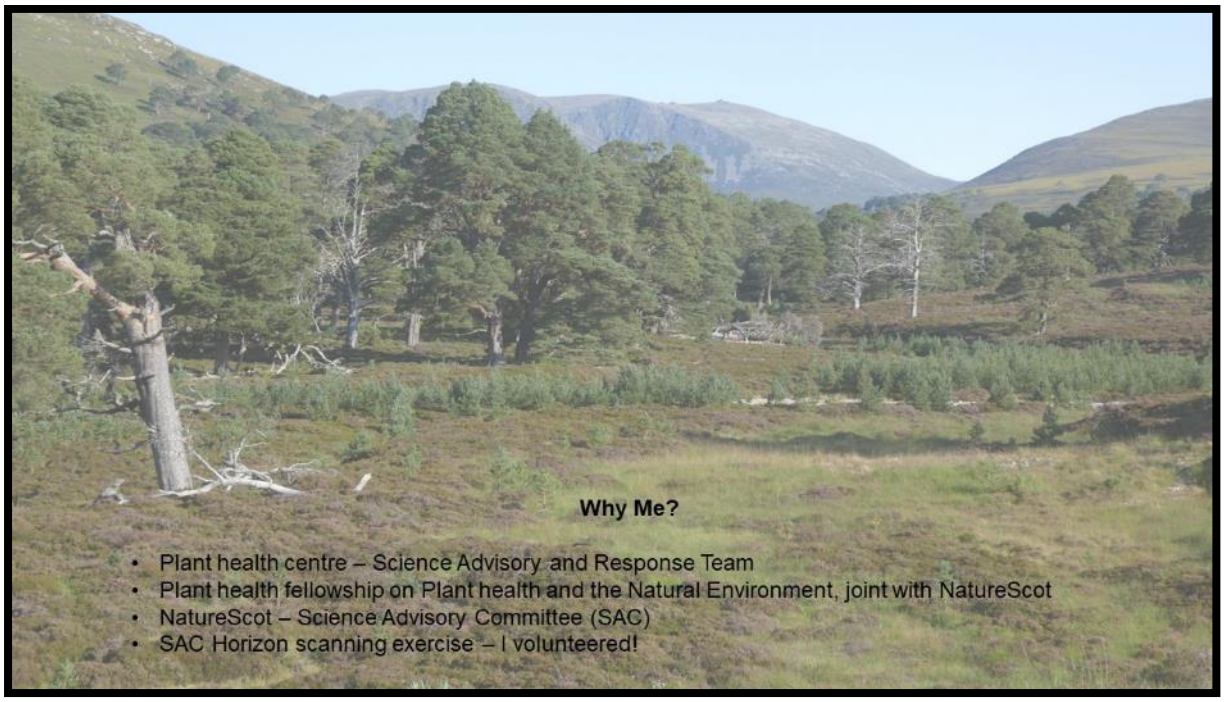
Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Calcifugous grasslands and montane communities	Woodlands
Quercus hybrid												1
Quercus petraea												1
Quercus robur												1
Ranunculus baudotii	1											
Ranunculus circinatus	1											
Ranunculus fluitans	1											
Ranunculus omiophyllus				1								
Ranunculus peltatus	1											
Ranunculus penicillatus	1											
Ranunculus repens						1			1			1
Ranunculus sceleratus							1					
Ranunculus trichophyllus	1											
Riccia fluitans	1											
Rorippa prostrata							1					
Rubus caesius									1			
Rubus chamaemorus				1								
Rubus fruticosus agg												1
Sagittaria sagittifolia								1				
Salicornia agg.										1		
Salix aurita												1
Salix cinerea												1
Salix fragilis												1
Salix lapponum												1

Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Calcifugous grasslands and montane communities	Woodlands
Salix myrsinifolia												1
Salix nigricans												1
Salix pentandra												1
Salix phylicifolia												1
Salix repens									1			
Saxifraga aizoides											1	
Schoenus ferrugineus				1								
Schoenus nigricans				1								
Scirpus fluitans	1											
Scirpus lacustris								1				
Scirpus maritimus								1	1			
Scirpus tabernaemontani								1				
Sedum anglicum					1							
Sesleria albicans		1										
Sparganium angustifolium	1											
Sparganium emersum	1											
Sparganium erectum								1				
Sparganium minimum	1											
Spartina anglica										1		
Spartina maritima										1		
Sphagnum auriculatum	1											
Spirodela polyrhiza	1							1				
Stellaria media							1					

Species	Habitat														
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, sand-dune and strandline communities	Salt Marsh	Montane communities and grasslands	Calcifugous	Woodlands
Suaeda maritima										1			
Taxus baccata													1
Thelypteris limbosperma												1	
Tilia cordata													1
Trichophorum cespitosum				1									
Trifolium pratense							1						
Trifolium repens						1							
Turf fucoids										1			
Typha angustifolia								1					
Typha latifolia								1					
Ulex europaeus			1										1
Ulex gallii			1										1
Ulex minor				1									
Ulmus glabra													1
Ulmus minor													1
Ulmus procera													1
Ulmus spp													1
Urtica dioica							1	1					1
Vaccinium myrtillus			1	1								1	1
Vaccinium vitis-idaea													1
Vulpia bromoides							1						
Zannichellia palustris	1												
Zostera marina									1				

Species	Habitat													
	Aquatic communities	Calcicolous grasslands	Heathlands	Mires	Maritime cliff communities	Mesotrophic grasslands	Open habitats	Swamps and tall-herb fens	Shingle, strandline and sand-dune communities	Salt Marsh	Calcifugous grasslands and montane communities	Woodlands
Zostera noltii									1			

14 Appendix 5: The slides presented at the workshop on wild plant health.



Scottish Government
Riaghaltas na h-Alba
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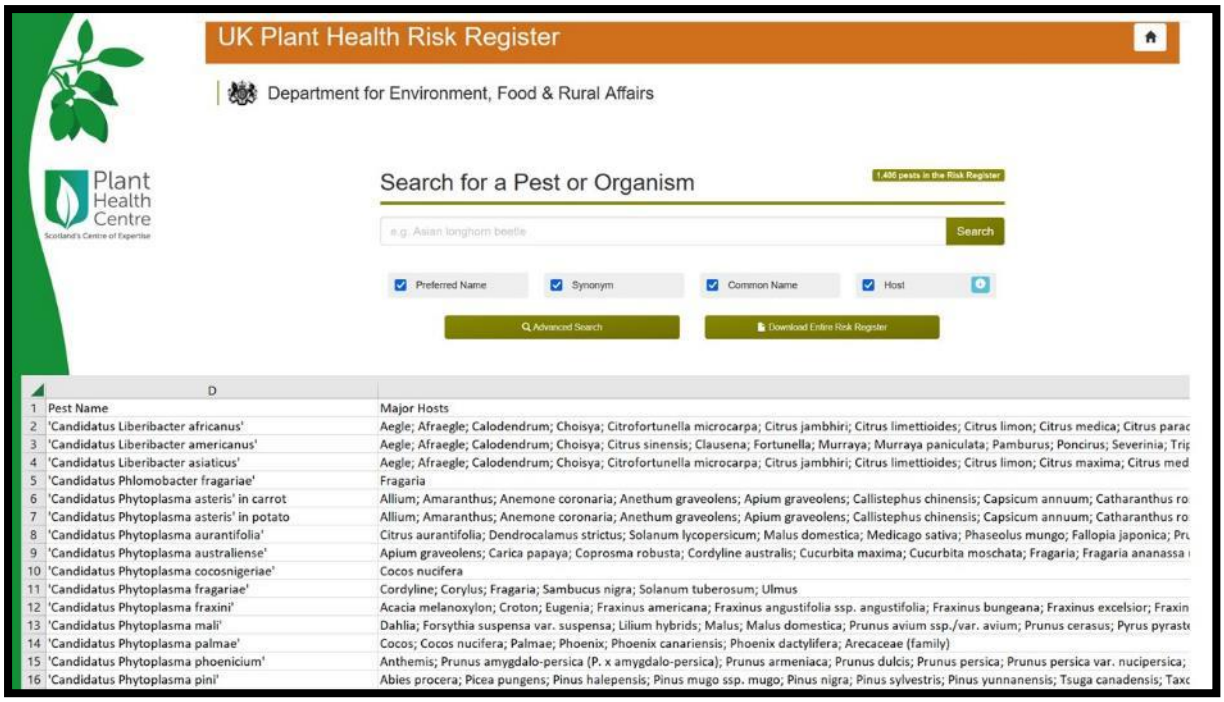
Plant Health Centre
Scotland's Centre of Expertise

What is plant health?
the plant health consequences of biotic agents, i.e. pests and pathogens.

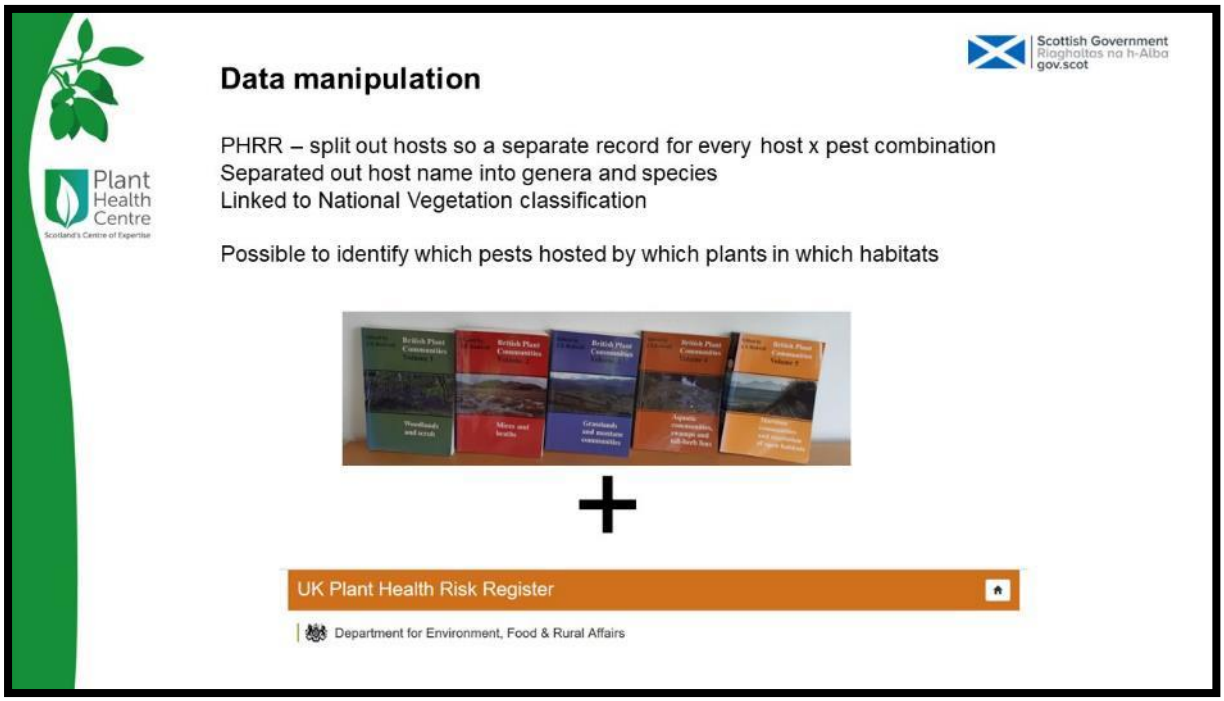
Biotic agents:
- include bacteria, fungi, insects, mites, nematodes, oomycetes, phytoplasma, viruses and viroids,
- collectively referred to throughout as pests

NOT referring to impact of:
- Poor management
- Vertebrate herbivores
- Poor soils
- Direct impact of changes in climate on plants (although climate change will impact pests/pathogens severity/distribution).



	D	
1	Pest Name	Major Hosts
2	'Candidatus Liberibacter africanus'	Aegle; Afraegle; Calodendrum; Choisya; Citrofortunella microcarpa; Citrus jambhiri; Citrus limettioides; Citrus limon; Citrus medica; Citrus parac
3	'Candidatus Liberibacter americanus'	Aegle; Afraegle; Calodendrum; Choisya; Citrus sinensis; Clausena; Fortunella; Murraya; Murraya paniculata; Pamburus; Poncirus; Severinia; Trip
4	'Candidatus Liberibacter asiaticus'	Aegle; Afraegle; Calodendrum; Choisya; Citrofortunella microcarpa; Citrus jambhiri; Citrus limettioides; Citrus limon; Citrus maxima; Citrus med
5	'Candidatus Phlomobacter fragariae'	Fragaria
6	'Candidatus Phytoplasma asteris' in carrot	Allium; Amaranthus; Anemone coronaria; Anethum graveolens; Apium graveolens; Callistephus chinensis; Capsicum annuum; Catharanthus ro
7	'Candidatus Phytoplasma asteris' in potato	Allium; Amaranthus; Anemone coronaria; Anethum graveolens; Apium graveolens; Callistephus chinensis; Capsicum annuum; Catharanthus ro
8	'Candidatus Phytoplasma aurantifolia'	Citrus aurantifolia; Dendrocalamus strictus; Solanum lycopersicum; Malus domestica; Medicago sativa; Phaseolus mungo; Fallopia japonica; Pru
9	'Candidatus Phytoplasma australiense'	Apium graveolens; Carica papaya; Coprosma robusta; Cordyline australis; Cucurbita maxima; Cucurbita moschata; Fragaria; Fragaria ananassa
10	'Candidatus Phytoplasma cocosnigeriae'	Cocos nucifera
11	'Candidatus Phytoplasma fragariae'	Cordyline; Corylus; Fragaria; Sambucus nigra; Solanum tuberosum; Ulmus
12	'Candidatus Phytoplasma fraxini'	Acacia melanoxylon; Croton; Eugenia; Fraxinus americana; Fraxinus angustifolia ssp. angustifolia; Fraxinus bungeana; Fraxinus excelsior; Fraxin
13	'Candidatus Phytoplasma mali'	Dahlia; Forsythia suspensa var. suspensa; Lilium hybrids; Malus; Malus domestica; Prunus avium ssp./var. avium; Prunus cerasus; Pyrus pyrast
14	'Candidatus Phytoplasma palmae'	Cocos; Cocos nucifera; Palmae; Phoenix; Phoenix canariensis; Phoenix dactylifera; Arecaceae (family)
15	'Candidatus Phytoplasma phoenicium'	Anthemis; Prunus amygdalo-persica (P. x amygdalo-persica); Prunus armeniaca; Prunus dulcis; Prunus persica; Prunus persica var. nucipersica;
16	'Candidatus Phytoplasma pini'	Abies procera; Picea pungens; Pinus halepensis; Pinus mugo ssp. mugo; Pinus nigra; Pinus sylvestris; Pinus yunnanensis; Tsuga canadensis; Taxo



Number of potential pests?

PHRR lists 916 pests that could be hosted by genera that occur in semi-natural habitats at more than 25% cover in the UK

Refine by mitigated likelihood of 4 or 5

91 Pests with a mitigated likelihood of 4 or 5

Terminology

Likelihood
score, 1-low to 5-high.

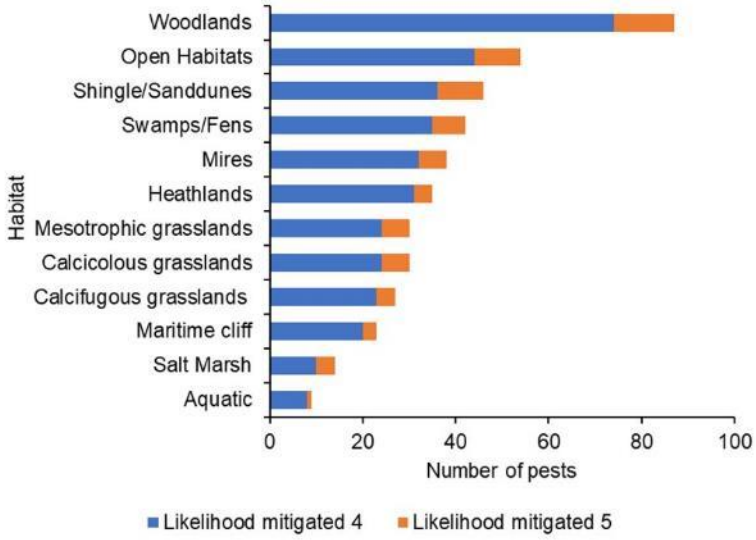
If pest not present
2 sub-scores of entry into and establishment. The lower of the 2 scores used

If pest present in UK
based on how likely the pest is to spread to maximum extent in the next five years.

Mitigation
Likelihood scores with and without mitigation

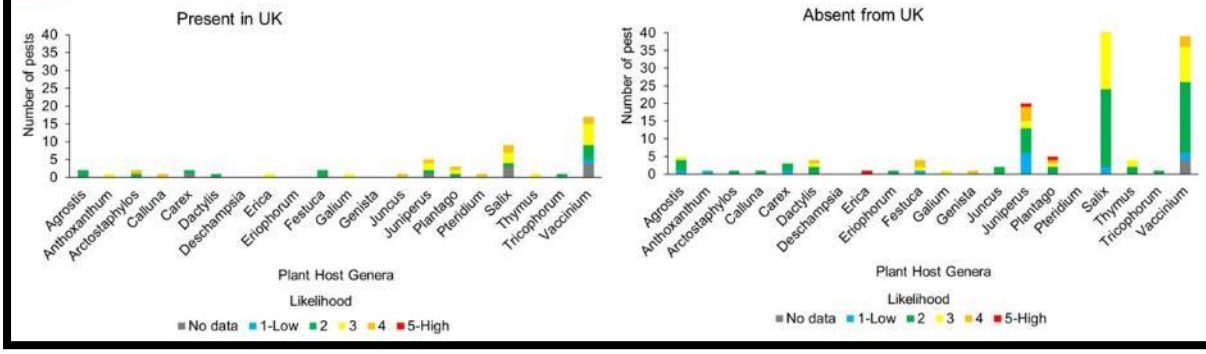
Here used Likelihood with Mitigation assuming that all mitigations, such as import prohibition on the key hosts, had been implemented.

Number pests in PHRR with a likelihood score of 4 or 5 hosted by genera in different habitats

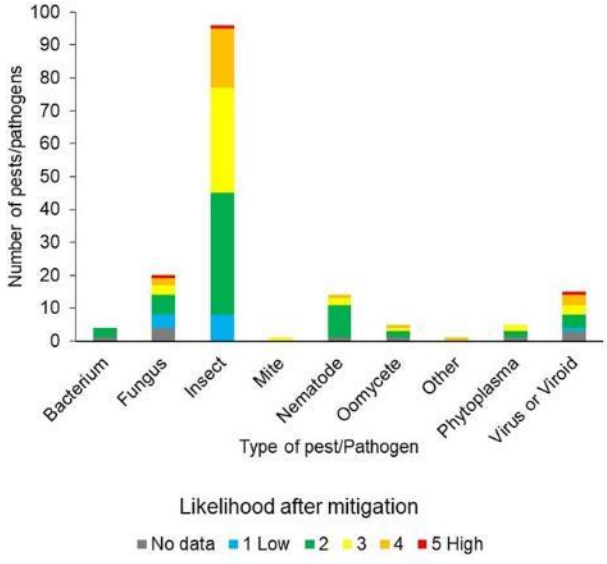


Scottish Heaths

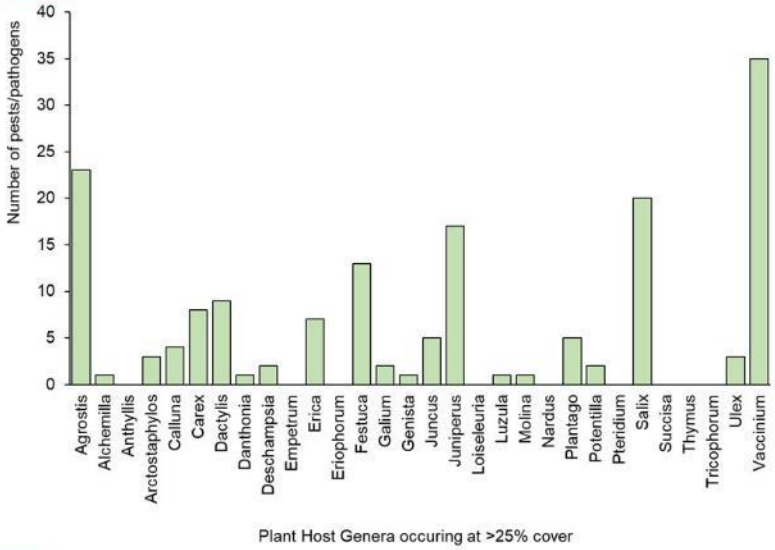
161 pests hosted by vascular plants at >25% cover
38 of these already present in the UK but not wide spread
29 pests with a mitigated likelihood of 4 or 5
Hosted by 12 genera



Scottish Heaths 161 pests – the different types



Scottish Heaths 161 pests plus 142 others……

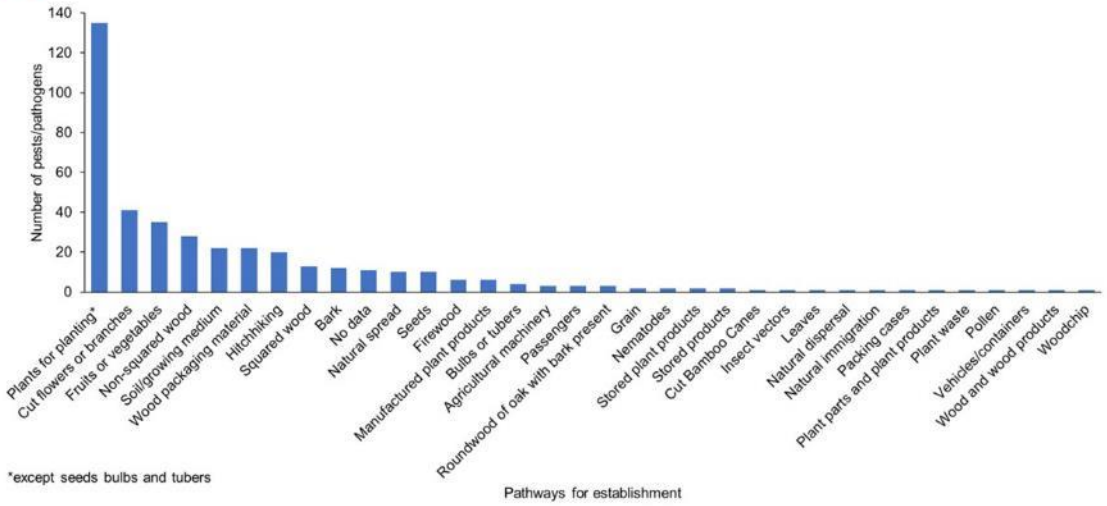


Literature search:

142 pests hosted by plant genera on Scottish heaths that were not included in the PHRR

- Include wide spread hosts already present (e.g. heather beetles)
- Includes some pest listed in the PHRR but not this pest/host combination
- But PHRR is biased towards plant genera used in agriculture, horticulture and forestry

161 heathland pests in PHRR Pathways for establishment



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Stakeholders understanding of challenges posed by plant health threats to the natural environment

Plant Health Centre
Scotland's Centre of Expertise

What is this survey about?

Plant pests and pathogens are increasing in the UK and pose a potential risk to the wider environment and biodiversity.

This questionnaire is being conducted on behalf of Scotland's Plant Health Centre of Expertise and NatureScot to better understand:

1. The awareness of those involved in habitat restoration and habitat creation of plant health biosecurity risks
2. What risk assessments and biosecurity guidance/best practice is currently used with respect to plant health during habitat restoration and habitat creation
3. What, if any, new guidance is required

224 responses from stakeholders involved in habitat creation/restoration

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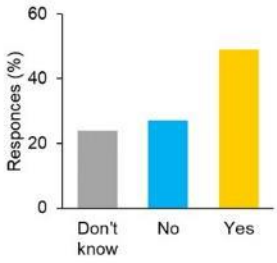
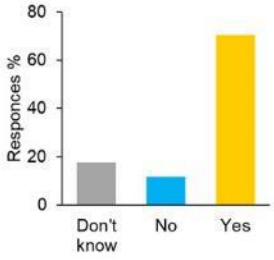
Plant Health Centre
Scotland's Centre of Expertise



Do you have a risk assessment?

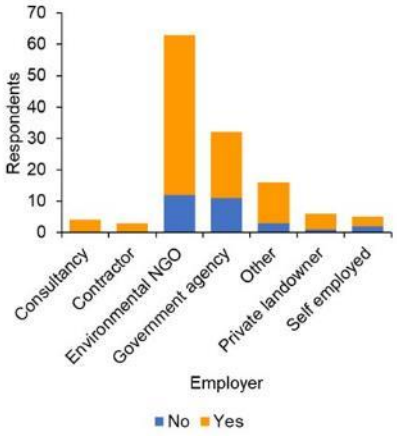
- c. half of respondents either didn't know or didn't have one
- No difference between type of employers



Do you have biosecurity guidance/best practice?

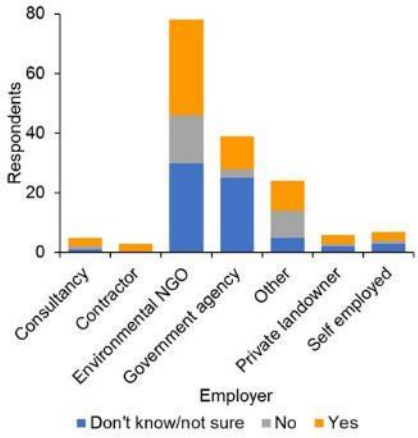
- c70% have best practice guidance
- More respondents have best practice guidance than risk assessments
- But – if no risk assessment is the guidance suitable?

Do you check guidance is followed?



22% didn't check if guidance was followed

Does anyone in your organisation have responsibility for biosecurity?



60% either didn't have or didn't know if anyone was responsible for biosecurity

Risks not just to plant health……..associated species and ecosystem functioning

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Plant Health Centre
Scotland's Centre of Expertise

Loss of

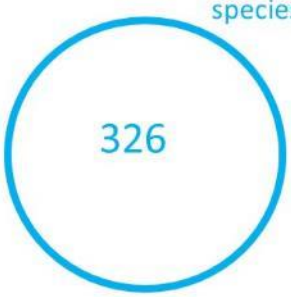
Ash OR **Oak**

955 ash-associated species

2300 oak-associated species

Obligate ash associated species

Obligate oak associated species



Risks not just to plant health……..associated species and ecosystem functioning

Scottish Government
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Plant Health Centre
Scotland's Centre of Expertise

Loss of

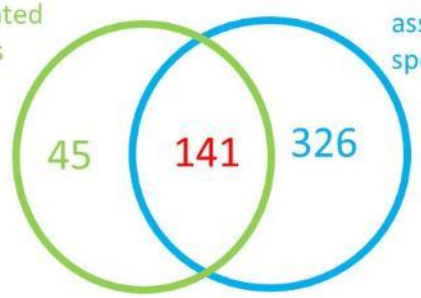
Ash AND **Oak**

955 ash-associated species

955 ash-associated species

Obligate ash associated species

Obligate oak associated species



Species only use oak and ash

512 = 38% increase on the sum

Contribution to the Biodiversity Crisis

Of the 512 species:

- 21% protected
- 404 species at risk with no current protection

What if *Calluna vulgaris* declined????????

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Scotland's Centre of Expertise

Biodiversity

Hen harriers
Red Grouse
Capercaillie
Black Grouse
Merlin
Lesser Tayblade

Heather moors become grass dominated?

Functions and services

Soil erosion
Carbon loss
Water quality
Cultural
Economic
Visual

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- Good evidence there are considerable risks to plant health in ALL semi-natural habitats
- Likelihood might be low in some cases
- Ecological IMPACT could be high

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Wild Plant health Workshop

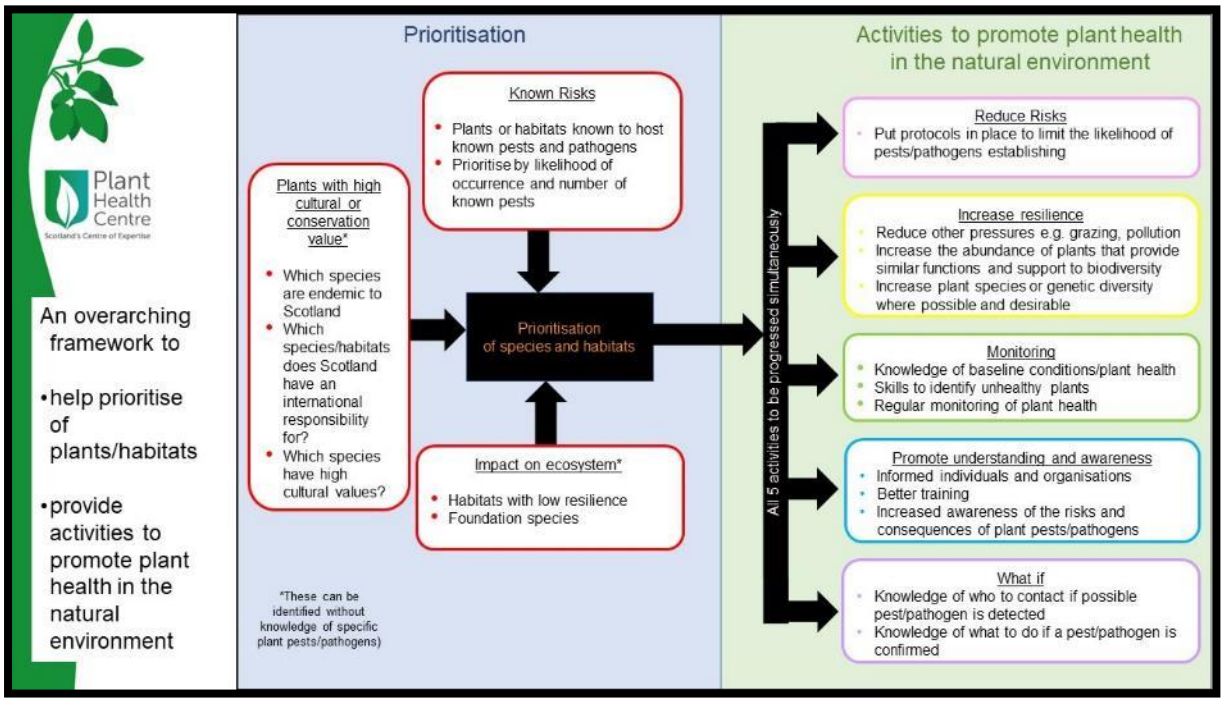
Proportionate responses

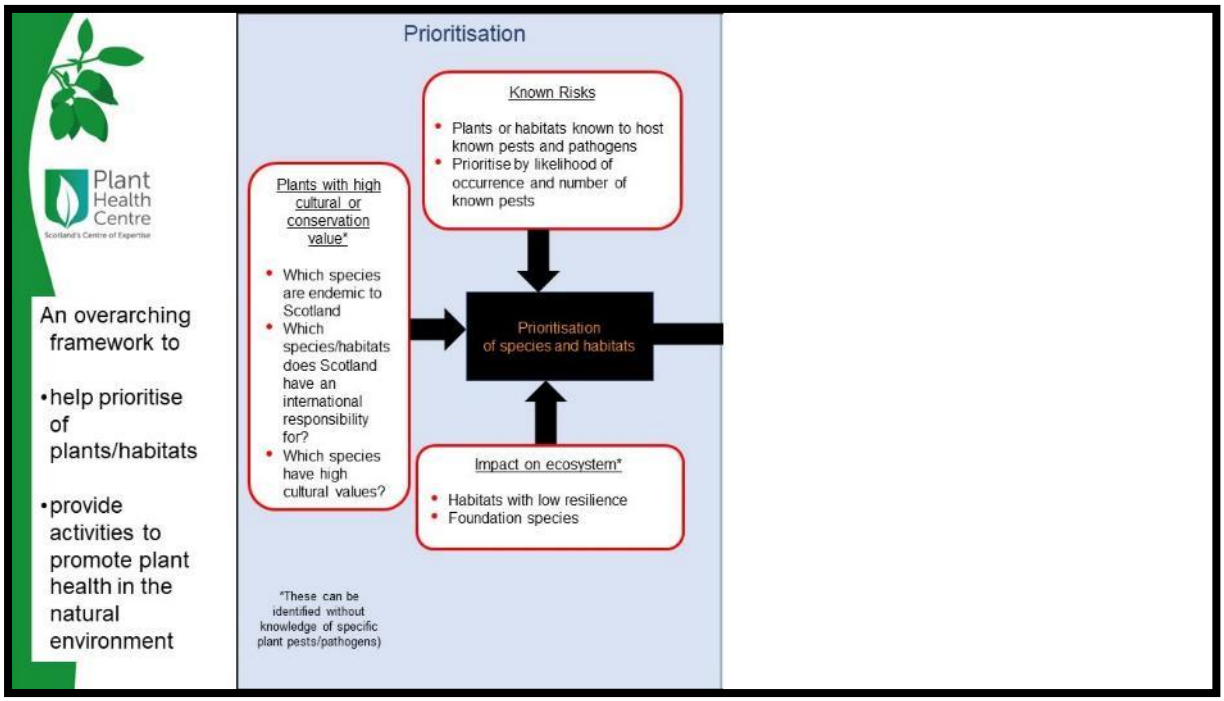
Ruth Mitchell

23rd February 2023

NatureScot Scotland's Nature Agency Buidheann Nàdair na h-Alba

Plant Health Centre
Scotland's Centre of Expertise


Plant Health Centre
Scotland's Centre of Expertise
An overarching framework to
•help prioritise of plants/habitats
•provide activities to promote plant health in the natural environment
Prioritisation
Known Risks
Plants or habitats known to host known pests and pathogens
Prioritise by likelihood of occurrence and number of known pests
Plants with high cultural or conservation value*
Which species are endemic to Scotland
Which species/habitats does Scotland have an international responsibility for?
Which species have high cultural values?
Prioritisation of species and habitats
Impact on ecosystem*
Habitats with low resilience
Foundation species
*These can be identified without knowledge of specific plant pests/pathogens)
Activities to promote plant health in the natural environment
All 5 activities to be progressed simultaneously
Reduce Risks
Put protocols in place to limit the likelihood of pests/pathogens establishing
Increase resilience
Reduce other pressures e.g. grazing, pollution
Increase the abundance of plants that provide similar functions and support to biodiversity
Increase plant species or genetic diversity where possible and desirable
Monitoring
Knowledge of baseline conditions/plant health
Skills to identify unhealthy plants
Regular monitoring of plant health
Promote understanding and awareness
Informed individuals and organisations
Better training
Increased awareness of the risks and consequences of plant pests/pathogens
What if
Knowledge of who to contact if possible pest/pathogen is detected
Knowledge of what to do if a pest/pathogen is confirmed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How you prioritise alters what you prioritise for surveillance

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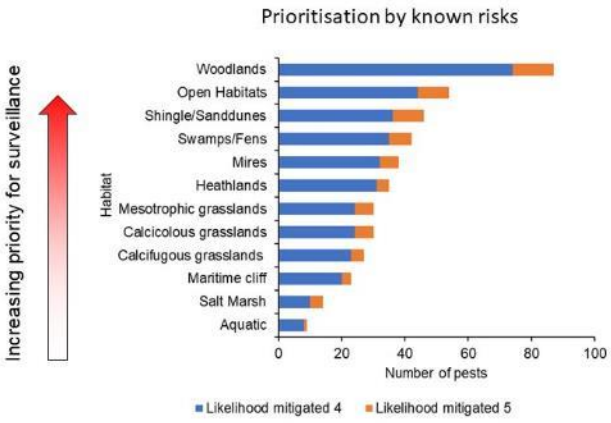

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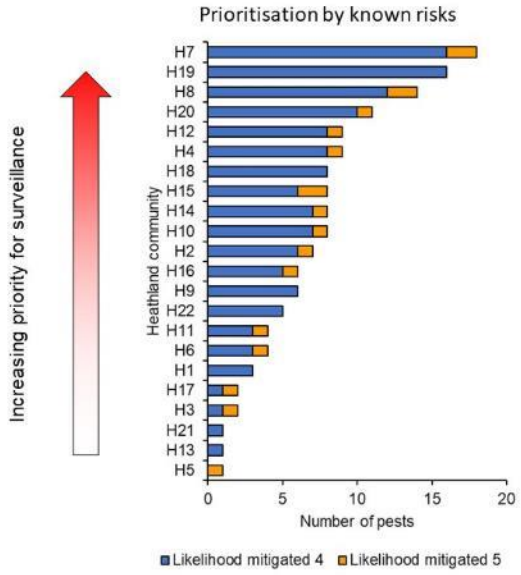
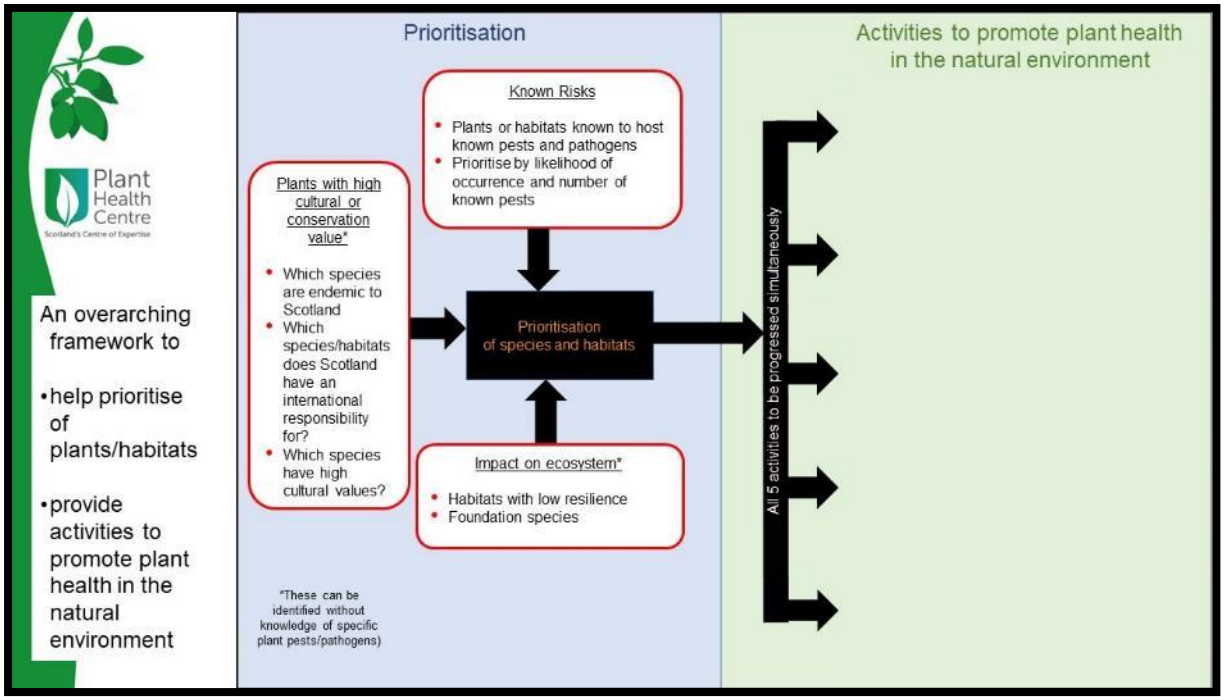
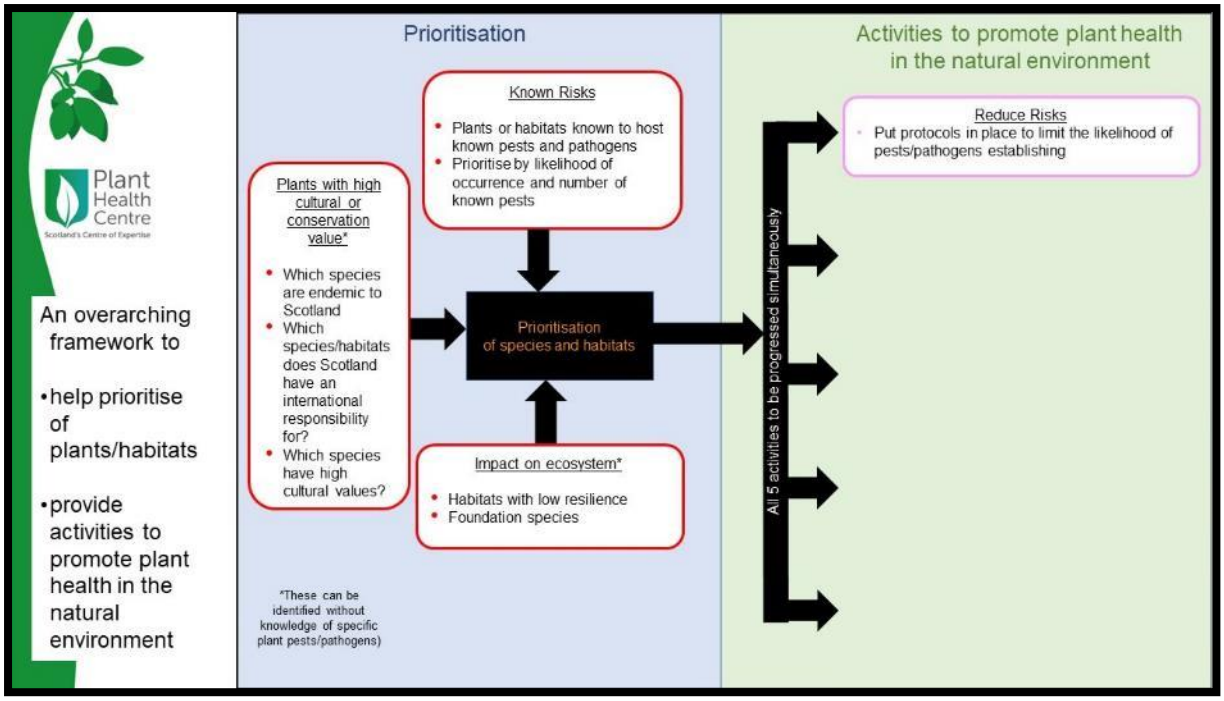


Prioritisation of species

Known Risks	Impact on ecosystem
Genera on heathlands known to host pests with likelihood of 4 or 5	Foundation species on heathlands (>75% cover)
Agrostis	*Agrostis capillaris Agrostis curtisii*
Arctostaphylos	
Calluna	*Calluna vulgaris*
Carex	*Carex arenaria, Carex bigelowii*
Dactylis	
Empetrum	*Empetrum nigrum*
Erica	*Erica ciliaris, Erica cinerea*
Festuca	*Festuca ovina*
Genista	
Juncus	
Juniperus	
Molinia	*Molinia caerulea*
Nardus	*Nardus stricta*
Plantago	
Pteridium	
Rubus	
Salix	
Teucrium	
Ulex	*Ulex europaeus Ulex gallii*
Vaccinium	*Vaccinium myrtillus*

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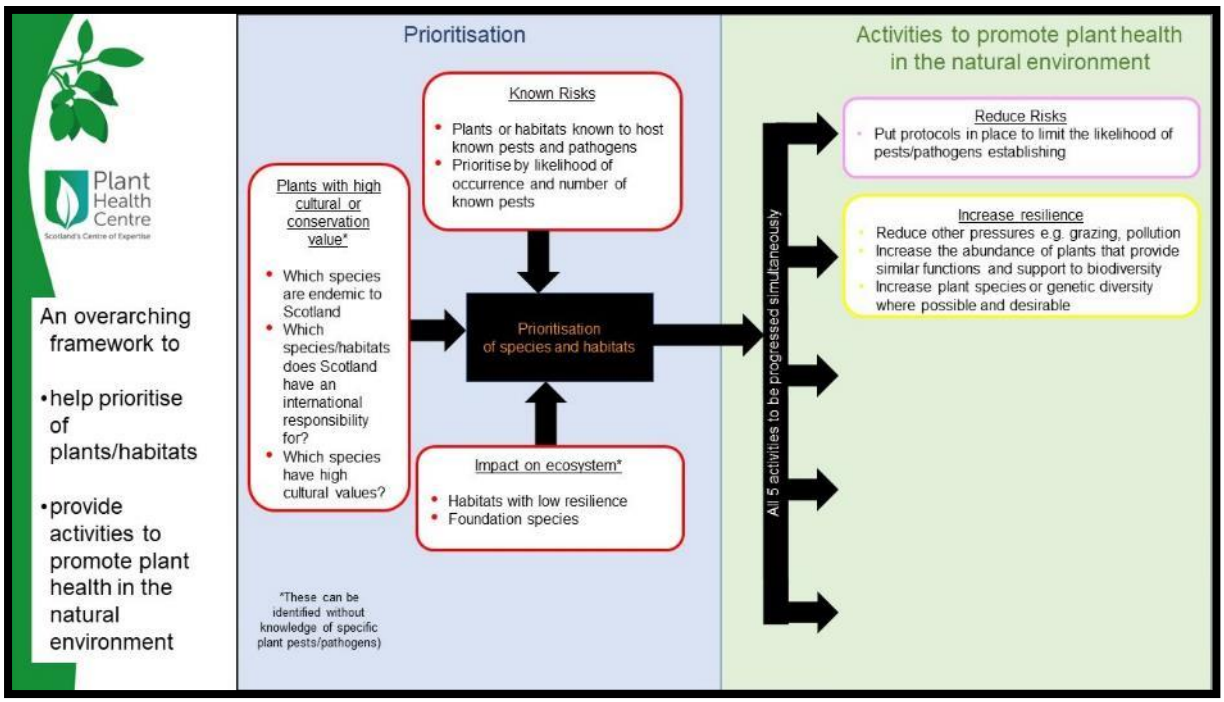
All 5 activities to be progressed simultaneously
Reduce Risks
Put protocols in place to limit the likelihood of pests/pathogens establishing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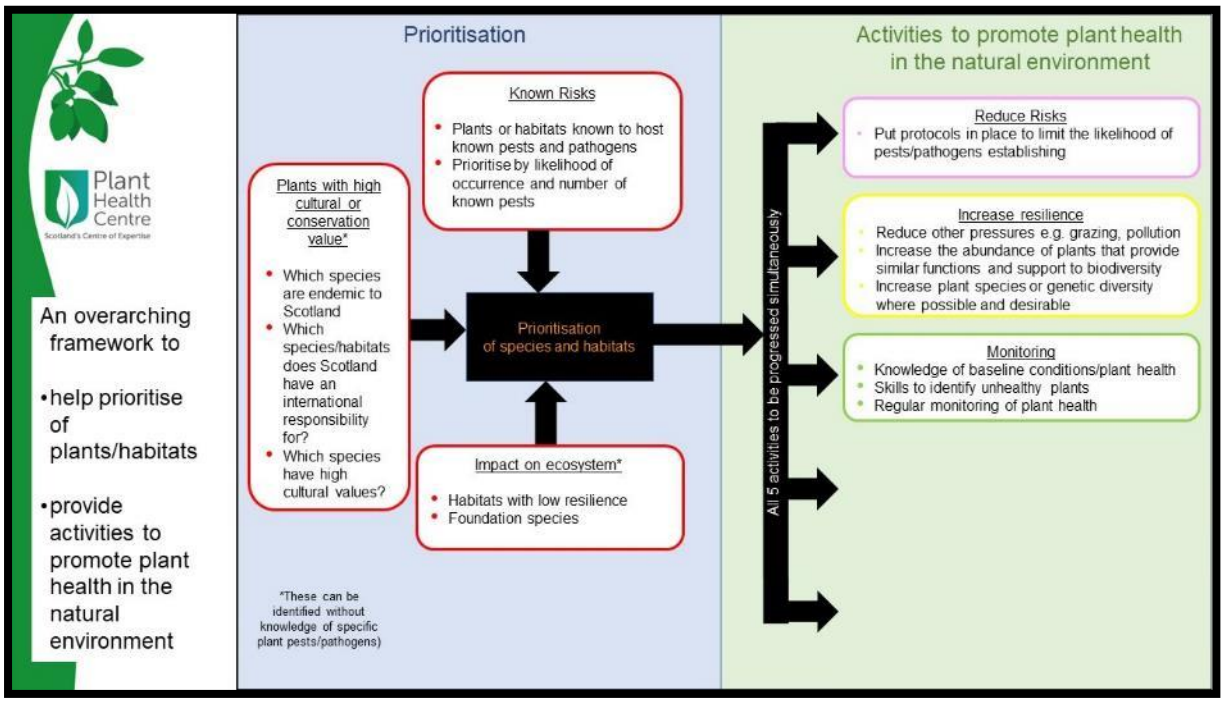
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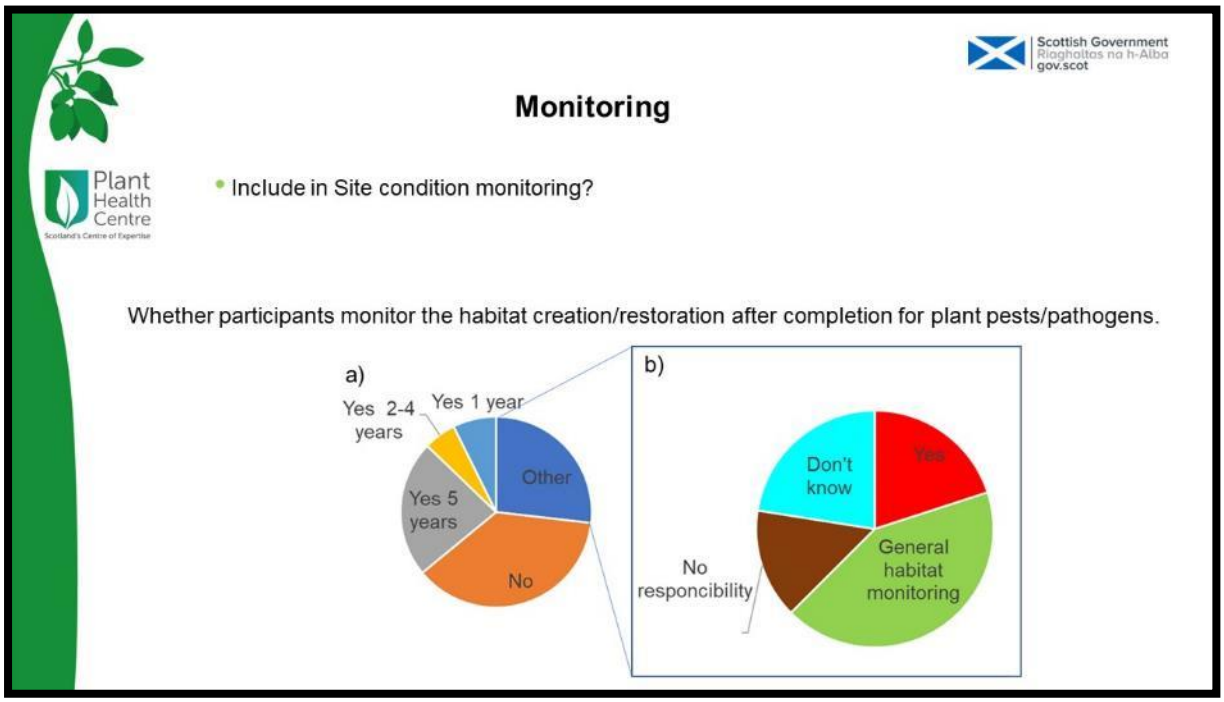
Monitoring
Knowledge of baseline conditions/plant health
Skills to identify unhealthy plants
Regular monitoring of plant health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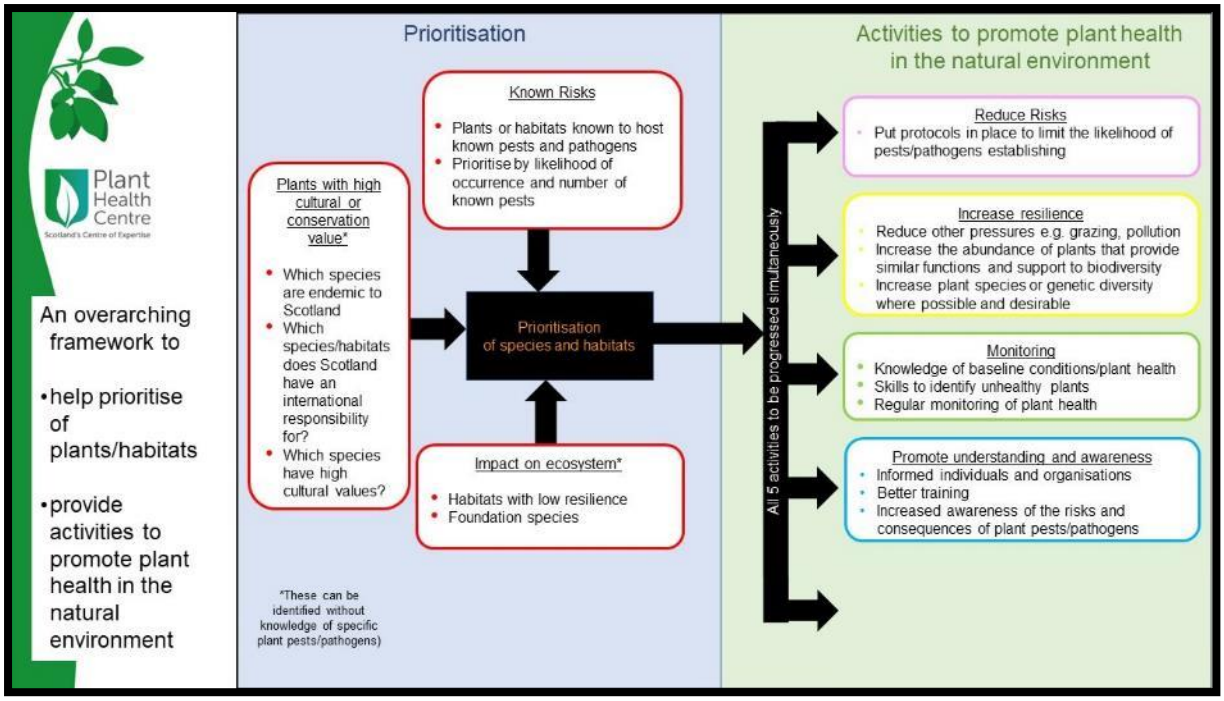
Scotland's Centre of Expertise
Monitoring
Include in Site condition monitoring?
Whether participants monitor the habitat creation/restoration after completion for plant pests/pathogens.
a)
Yes 2-4 years
Yes 1 year
Other
Yes 5 years
No
b)
Don't know
Yes
No responcibility
General habitat monitoring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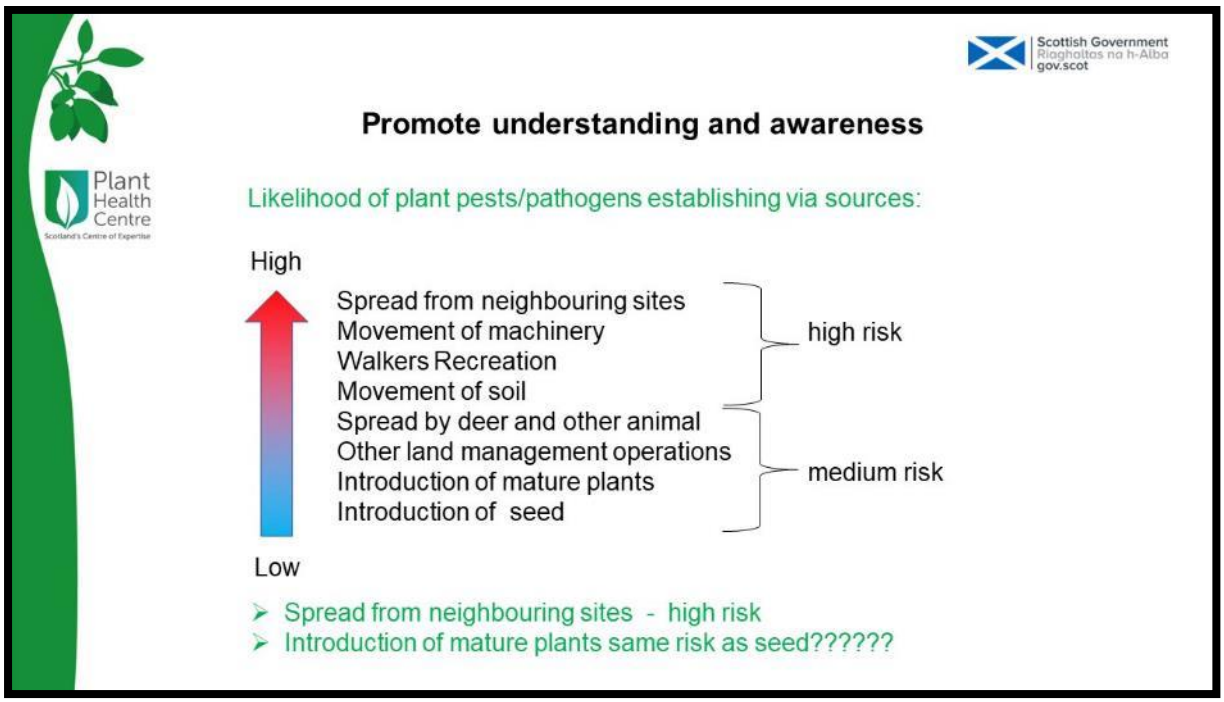
Informed individuals and organisations
Better training
Increased awareness of the risks and consequences of plant pests/pathogens


Plant Health Centre
Scotland's Centre of Expertise
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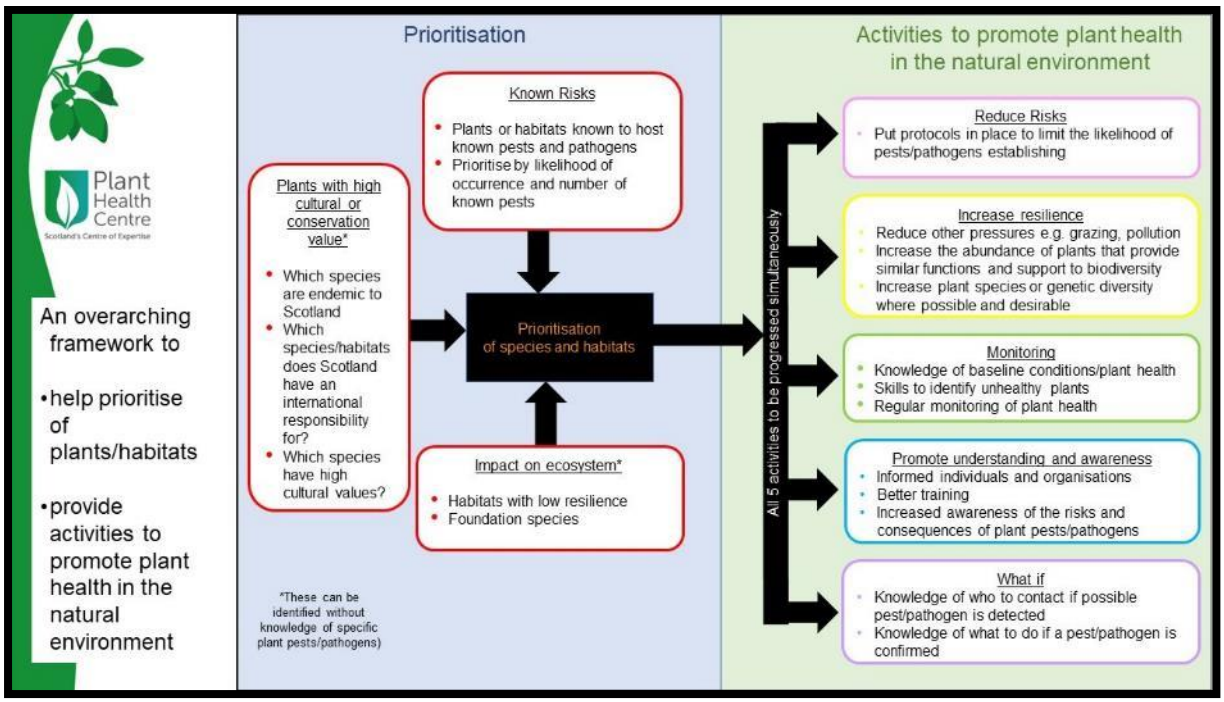
Promote understanding and awareness
Likelihood of plant pests/pathogens establishing via sources:
High
Spread from neighbouring sites
Movement of machinery
Walkers Recreation
Movement of soil
high risk
Spread by deer and other animal
Other land management operations
Introduction of mature plants
Introduction of seed
medium risk
Low
Spread from neighbouring sites - high risk
Introduction of mature plants same risk as seed??????

Promote understanding and awareness

The number of participates requesting further guidance on a range of different aspects related to plant health

Further guidance on:	Number of participants
What biosecurity to put in place for staff/contractors	100
The current legislation on plant pests/pathogens and movement of plants/soil/equipment	90
What biosecurity to put in place for the general public that may access land you work on/own	87
Biosecurity risks associated with movement of plants and how to minimize them	86
Biosecurity risks associated with movement of equipment and how to minimize them	84
Sourcing plants free of pests and pathogens	83
Biosecurity risks associated with movement of soil and how to minimize them	78
How to develop risk assessments	77
Further guidance on where to find information about plant health and disease	76
Propagating plants free of pests and pathogens	47
Other	11



15 Appendix 6: The paper presented to NatureScot Science advisory committee on 27th March 2023.

SCIENTIFIC ADVISORY COMMITTEE

DISCUSSION PAPER

Horizon Scan: Plant Health, March 2023

Purpose

1. Following discussion in November 2022, The SAC requested a deep dive into plant health in semi-natural systems. This paper focuses on the science and evidence: resourcing questions will be raised through other relevant channels (Resourcing Group/SLT).

Action

2. The SAC is asked to note that, and/or comment on:
    - Plant pests and pathogens are currently causing biodiversity declines and losses. Future plant pests and pathogens (non-native; not currently present; those currently present but whose severity may change due to climate change) pose a significant risk to native plants and their associated biodiversity and ecosystem services. Although details of exact impacts, such as number of associated species affected, are unknown in many cases, there are potential risks to plans to enhance carbon removals into biological systems, the management of climate risks and the state of nature, including ecological restoration (paras 4-10)
    - The framework to guide future work (paras 11-13).
    - The responsibilities for plant health in semi-natural habitats is unclear and should be clarified in conjunction with appropriate organisations, especially the Plant Health Centre, initially through a mapping exercise, learning from emergency response protocols in better known areas such as INNS and avian influenza. (para 14-18)
    - Plant health is a large and potentially complex risk to manage. We suggest learning-by-doing, for example: identify business-critical areas for NatureScot (e.g. habitat restoration or creation projects); initial focus on c.10 key foundation plants to target for a trail monitoring of plant health (para 14-18)

Preparation

3. The paper was written by Clive Mitchell based on notes by Ruth Mitchell and Duncan Stone from a Plant Health Workshop held on 23 February. It is sponsored by Eileen Stuart.

Background

4. This paper follows the first meeting/workshop held to discuss plant health issues in more natural vegetation systems and draws on a joint fellowship between NatureScot and Plant Health Centre.
5. Plant health is the plant health consequences of biotic agents, i.e. pests and pathogens (include bacteria, fungi, insects, mites, nematodes, oomycetes, phytoplasma, viruses and viroids) - collectively referred to as pests throughout this paper. The paper excludes the impact of poor management, vertebrate herbivores, poor soils, direct impact of changes in climate on plants (although climate change will impact pests/pathogens severity/distribution).
6. Plant health activities in semi-natural habitats currently focus on woodlands, but there are a range of other habitats that could be impacted e.g. peatlands, moorlands, aquatic habitats.
7. Defra plant health risk register (PHRR) lists the pests currently known that could impact plant health in the UK, but the register is biased towards pests of commercial plants (horticulture, forestry and agricultural).
8. There are 916 pests[1] in the PHRR that could be hosted by plant genera that occur in semi-natural habitats in the UK at more than 25% cover. Of these, 91 have the highest likelihood of occurring (4 or 5 in the risk register). There are other pests and hosts not listed in the PHRR that are relevant to semi-natural habitats (e.g. a literature review revealed 142 additional pests on moorlands not in the PHRR).
9. Plant health affects more than just the host, with cascading effects on the biodiversity associated with that host and acute effects for obligate species[1]. For example, ash trees host 955 species, 45 of which are only found on ash[2]. In addition, declines of multiple host plants due to disease will have cumulative impacts on biodiversity[3]. Plant diseases caused by non-native pests have been described as an insidious, mostly overlooked threat to biodiversity[4] and the cause of extinction cascades[5].
10. Recent work by the Plant Health Centre Fellowship revealed a lack of awareness of plant health risks during habitat creation/restoration. In a survey attracting 224 respondents involved in habitat creation/restoration, half either didn't know or didn't have a risk assessment for biosecurity, 22% didn't check if biosecurity best practise as

[1] Mitchell, R.J., et al. (2019) Collapsing foundations: The ecology of the British oak, implications of its decline and mitigation options. *Biological Conservation* 233, 316-327.
[2] Mitchell, R.J., *et al.* (2014). Ash dieback in the UK: A review of the ecological and conservation implications and potential management options. *Biological Conservation* 175, 95-109.
[3] Mitchell, R.J., *et a*l. (2022) Cumulative impact assessments of multiple host species loss from plant diseases show disproportionate reductions in associated biodiversity. *Journal of Ecology* 110, 221-231.
[4] Jonsson, M.T., Thor, G. (2012) Estimating Coextinction Risks from Epidemic Tree Death: Affiliate Lichen Communities among Diseased Host Tree Populations of Fraxinus excelsior. *Plos One* 7, (9): e45701.
[5] Hultberg, T. *et al.* (2020) Ash dieback risks an extinction cascade. *Biological Conservation* 244, e108516.

followed and 60% either didn't have or didn't know if anyone was responsible for biosecurity in their organisation. This includes peatland restoration.

Framework for promoting plant health

11. The number of pests and hosts precludes monitoring everything. A plant health framework (Figure 1) has been developed to (a) prioritise which plants/habitats to focus on and (b) identify activities to promote plant health (these can be progressed simultaneously). The framework is explained in the following paragraphs.

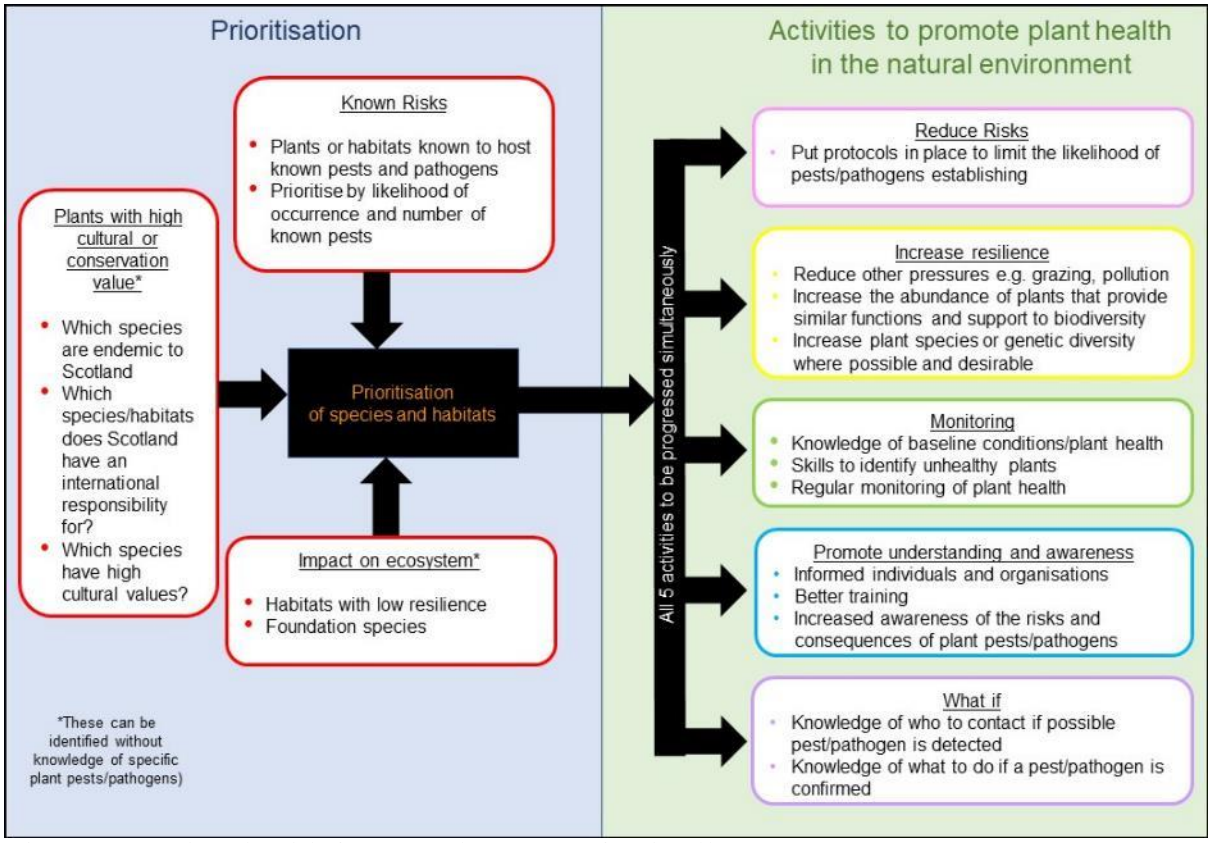


Figure 1. A plant health framework. See text for detail.

12. *Prioritisation*: which plant species or habitats to prioritise for action can be based on: i) plants with high cultural or conservation value, ii) known risks – the plants or habitats known to host the most pests listed in the PHRR or iii) the potential ecological impact (impact on associated species and ecosystem services). Prioritisation via ii) or iii) leads to very different lists as the PHRR is biased towards species of commercial importance. Method ii) does not account for known unknowns, whereas method iii) does. For further information see SEFARI case-study and preprint.

13. *Activities to promote plant health in the natural environment* includes actions grouped into 5 activities:
    - *Reduce risks*: action to reduce risks includes risk assessments and appropriate biosecurity for habitat creation/restoration works, especially those that are publicly funded, to lead by example. Free-trade rules ('most favoured nation status') may make prohibition of imported plants for restoration difficult unless

there are known risks but raising awareness of the benefits of sourcing plants grown in the UK, to reduce risks and associated costs, is encouraged.

- *Increase resilience*: if habitats are more resilient then they are likely to better withstand pest/pathogen attack. Where possible activities to reduce other pressures, would increase resilience to pest/pathogen attack. We can learn from vulnerabilities in commercial (monoculture) systems; and resilience in (more diverse) natural systems.
- *Monitoring*: There is currently no system for monitoring plant health in the wider environment, outside of woodlands. Developing a system requires knowledge of baseline conditions and what a healthy plant looks like and the skills to identify the causes of the plant ill-health, e.g. distinguish between effects of drought and effects of pests/pathogens.
- *Promote understanding and awareness*: awareness of the risks associated with plant health is often lacking, from the potential sources of pests/pathogens to cascading effects on biodiversity. For example, in the Plant Health Centre survey, the 224 participants ranked "neighbouring habitat" as the greatest risk and ranked mature plants and seeds and equal risk, in contrast to the literature[6].
- *What if*: We need to know what to do if a suspected pest/pathogen establishes in the semi-natural habitats outside of woodlands. Roles and responsibilities are currently unknown (workshop findings, including Gerry Saddler, Chief Plant Health Officer). Once a quarantine pest (i.e. of concern) is identified there are procedures and legislation to remove plants/restrict access to land/attempt to eradicate pests. But the route to raise awareness of potentially unhealthy plants and the relevant diagnostic skills and resources for identification is unclear.

Recommendation: moving to a wild plant health monitoring and response system

14. A coherent wild plant health monitoring and response system is likely to involve:
    - **Prioritization** – a small number of plants which are 1) at risk of pest attack, and 2) have characteristics such that pest impact would have negative consequences over large areas or result in a cascade of dire consequences for dependent species.
    - **Field Assessment** – to gather information on plant health from the wider environment, possibly a combination of professionals and Citizen Science. Guidance on how to identify potential pest impacts without generating excessive false positive outcomes needs some work – such as photographic guides of 'normal' and disease/pest appearance. Laboratory resources within FERA/SASA/FR to confirm pest impacts are scarce and expensive and need to be considered in any flow of information on possible pest/disease occurrence.
    - **Outbreak management –** clarity and preparation on roles and responsibilities, probably based on clear contingency planning to allow appropriate action to be taken if pest/disease outbreaks are confirmed.

[6] Mitchell, R.J., *et al.* (2023) Plant Health, Biosecurity, and Conservation Translocations, *In Conservation Translocations*. eds M. Gaywood, J.G. Ewen, P.M. Hollingsworth, A. Moehrenschlager, pp. 241-270. Cambridge University Press, Cambridge.

15. Implementing such a system for a small number of plant species is likely to be most helpful to raise awareness, test elements of the system, and build staff expertise.
16. There are clear connections to our work on animal disease outbreaks, like avian influenza and INNS, and these should inform NatureScot's approach to plant health.
17. The range of species covered by any agency-based health monitoring and response system is likely to be small because of competing demands on our resources. However, we could construct such a system with an open architecture that would allow other organisations - perhaps focused interest on particular habitats - to maintain their own field assessment systems which could feed into the overall plant health monitoring and if necessary, response. For example, the 'Riverwoods' partnership is planning monitoring of riparian woodland, and it would be relatively simple to add a commitment to monitor plant health of key species, such as alder.
18. This approach is likely to be a necessary part of delivery of the Scottish Biodiversity Strategy, especially targets to restore 30% degraded ecosystems by 2030 (COP15, Global Biodiversity Framework). Similarly for activities required to deliver biological sequestration for the Climate Change Plan including peatland restoration which involves a small number of contractors operating over a wide area and moving from place to place.

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