Identifying the plant health risks associated with plant waste disposal and peat-free growing media and developing best practice guidance for waste disposal and composting across sectors

Project Final Report

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Content

1 Executive Summary

This research report focusses on two areas of biosecurity that provide significant risk to the plant businesses and the wider environment in Scotland, i) plant waste management, and ii) the constituents of reduced-peat and peat-free growing media. We engaged with stakeholders in plant production (horticulture, agriculture, and forestry), park and garden management and managers of the natural environment via workshops, and conducted a review of policy and related literature, to increase our understanding of current practices and identify barriers to change for these aspects of biosecurity. Diagnostic work was also undertaken to provide evidence of the biosecurity risks posed by *Phytophthora* spp. in plant waste heaps and constituents of reduced-peat and peat-free growing media.
Specific conclusions and resulting actions:

Plant waste management

- Plant waste management practices are varied with an ad-hoc approach to waste management being adopted in the absence of clear sector-wide advice.
- There is widespread acknowledgement of the biosecurity risk across sectors in Scotland but uncertainty about what to do about it.
- *Phytophthora* spp. were identified in plant waste heaps, including two quarantine-regulated species, *P. ramorum* and *P. austrocedri*. This highlights the risk posed by plant dumps on plant production sites and in parks and gardens.
- The missing part of the waste management circle is getting the waste to a point where it is safe to be used again, either as a component of a potting medium or for a mulch or soil improver.
- Action: This project provides specific, clear, evidence-led advice on the effective management of plant waste so it can be reused or safely disposed of. This guidance can be used by managers to assess risk and explore options to address this biosecurity threat.
- Action: An additional guidance document has been produced for the Plant Health Management Standard so that horticultural trade organisations and businesses that are applying to become Plant Healthy Certified can see exactly what is required to raise their biosecurity standards. The advice is potentially transferrable to other sectors such as agriculture (e.g., Scottish Quality Crops) and forestry (e.g., UK Forestry Standard).

Reduced-peat and peat-free growing media

- Uncertainty surrounding the provenance and safety of growing media constituents, along with the other challenges of changing to reduced-peat and peat-free growing media, is causing particular concern in both the nursery and growing media production industries, and is also of concern to other sectors such as forestry and agriculture.
- This project could not find previous research that identified the risks associated with the specific constituents used in peat-free growing medias. We therefore conclude that this work has not yet been carried out.
- The concurrent 'in kind' diagnostic study of *Phytophthora* in peat-free growing media detected DNA of a number of *Phytophthora* spp. in constituents of peat-free media (chopped bark, coir and composted green waste). A coir sample was also found to contain DNA closely matching *Peronosclerospora,* a genus of tropical downy mildew pathogens.
- Action: A recommendation that a thorough assessment of the potential plant health risks posed by each of the major constituents used in peat-free growing media (namely bark, wood fibre, coir and composted green waste) is required. This should include detailed information on product source, processing treatments, transportation, and storage methods.

2 Introduction

The movement of plant pests and pathogens into new regions via the international trade in plants and plant products continues to be a challenge for plant health across the globe (Hulme, 2014; Brasier, 2008). In the UK, there has been a significant increase in the number of novel plant pest and pathogen species introduced over the last 30 years. Examples include a number of damaging *Phytophthora* spp. (fungal-like plant pathogens), ash dieback (caused by the fungus *Hymenoscyphus fraxineus*) and oak processionary moth (*Thaumetopoea processionea*) (Webber, et al., 2010; Green, et al., 2015; Bakys, et al., 2009; Townsend, 2013). These particular species have caused significant economic, cultural and environmental damage to forests and woodlands across the UK. There are further impacts to agriculture due to introduced crop pests and pathogens (Esker, et al., 2021).

In addition to pest and pathogen species that have already become established in the UK, there are a significant number that are present in Europe, and other parts of the world, that would have a profound impact if they were to be inadvertently introduced into the country. For example, the UK Plant Health Risk Register (Defra, 2022) currently lists details of 1,400 species (as of 31st Aug 2022). This includes several *Agrilus* spp. (bark boring beetles such as the emerald ash borer (*Agrilus planipennis*) and bronze birch borer (*Agrilus anxius*)), new species of *Phytophthora*, *Xylella fastidiosa* (a pathogenic bacterium) and pine processionary moth (*Thaumetopoea pityocampa*).

Until recently, the presence and spread of plant pathogens in spent growing media and waste plant material has seldom been considered as a management priority in plant nurseries. Heaps of this material can build up on nurseries and become a source from which many pathogenic species can spread onto nearby plants, both in the nursery and the surrounding natural environment (Figure 1). Clear evidence for this has been provided by the recent Phyto-threats project (Forest Research, 2019; Green et al. 2021), which surveyed British nurseries for *Phytophthora* pathogens over a three-year period and found that plant disposal was clearly an issue across nurseries, with most disposal areas or 'dumps' containing *Phytophthora*-infected material which could be a source of inoculum. Therefore, the development of guidance on safe disposal of industrially-produced plant/soil/growing media waste is considered a top priority for the UK's new Plant Healthy Certification Scheme (Plant Healthy, 2022). This scheme requires certified nurseries to comply with a set of management requirements to help tackle the increasing risks from invasive plant pests and diseases being spread via the commercial nursery trade.

Figure 1. *Plant waste dump at a plant production nursery*

One of the major hurdles to improving nursery waste management is the limited number of options perceived as being available to nursery managers. One widely recognised standard within the UK organics recycling sector is BSI PAS100 (Publicly Available Specification for Composted Materials) (BSI, 2018). This PAS specifies the requirements for the process of composting, the selection of input materials, the minimum quality of composted materials and the storage, labelling and traceability of compost products. It aims to ensure that the resulting product is safe and reliable.

However, most plant production nurseries, large parks, and gardens do not produce enough waste to justify investing in a PAS100 system for their waste. If organisations and businesses are not going down the PAS100 route, what other options are available? Burning plant material is not possible in many locations close to populated areas. Some nurseries dispose of plant waste through their local authority green waste composting systems, but it is not clear how widespread this practice is or whether any pests or pathogens that might be present in it are effectively destroyed. Nurseries are not currently set up with the required infrastructure for effective composting, and there is no clear guidance to help nursery managers, garden centres and plant retailers develop such infrastructure. There is also a question as to how to deal with spent growing media which does not rot down and cannot easily be composted. Clearly, an evidence-gathering exercise is needed to understand: i) the rationale behind current nursery plant waste management practices, ii) the best options for improved nursery plant waste management, and iii) growers' perceptions of the feasibility of each 'best practice' option so that plant waste management guidance can be developed with the greatest chance of being taken up.

Closely related to the issue of safe disposal and recycling of nursery waste is the phasing out of peat-based growing media. Sales of amateur growing media containing peat are due to be banned in England from 2024, with sales of such media to commercial growers likely to follow shortly after (Carrington, 2021). In future, growing media will be made entirely from alternative constituents, including bark and wood products, coconut fibre [coir] and commercially produced compost, with the latter comprising unknown quantities of domestic and commercial landscaping wastes. There is potential for some growing media constituents, in particular composted bark and commercially-produced compost, to contain plant pathogens but there has been very little work done to determine the nature and level of risk posed to plants being grown in peat-free growing media.

Therefore, through a combination of stakeholder workshops, literature review and diagnostic sampling of nursery waste and growing media, this project aimed to:

- Provide those working in horticulture, agriculture, forestry and the natural environment with information on practical and effective options for safer management of commercially-produced waste and spent growing media, and safer strategies for their use as constituents of growing media and soil improvers.
- Provide evidence for the Plant Health Management Standard so that waste plant material management/disposal can become an auditable requirement for scheme members.
- Clarify the biosecurity risks associated with the constituent parts of peat-free compost and identify how those might be mitigated.

3 Methods

3.1 Workshops

To improve our understanding of current practices and perceptions of alternative 'best practice' options we held two virtual workshops with stakeholders in February 2022:

- Workshop 1 – Exploration of current nursery waste management practices with the aim of improving understanding of the issues that the sectors face when managing waste material (plant production nurseries, forestry and agriculture). Participants targeted included growers of ornamental plants, and forest trees as well as representatives from agriculture.
- Workshop 2 – Understanding the growing media sector and the associated biosecurity risks of using reduced-peat and peat-free growing media. Participants targeted included growing media producers and selected professional growers of nursery stock including trees and shrubs.

Potential attendees were approached by members of the project team from their extensive networks. Eventbrite (https://www.eventbrite.co.uk/) was used to send out invitations and communicate with attendees.

The workshops were held online using Zoom (https://zoom.us/). A set of prepared questions was put to participants who could respond using the Slido website (https://www.slido.com/). A number of stakeholders attended both workshops whilst some specialists only attended one. The data were captured by the software and made available for our analysis.

Considerations when analysing the data:

- The data only captured the views of those who participated in the workshops; we recognise that there were people who did not or could not engage.
- The results analysed are those received from respondents. With minor exceptions where there were obvious discrepancies (e.g., spelling mistakes), no attempt was made to verify data reported.

3.2 Diagnostic study of nursery waste

- In order to provide evidence for the level of risk from discarded nursery waste, focusing on *Phytophthora* as a genus of plant pathogens well known to be spread via the plant trade, a study was undertaken at Forest Research to identify *Phytophthora* spp. present in nursery waste heaps (Schiffer-Forsyth, 2022).
- Water, root and spent growing media samples were collected in January and February 2022 from plant dumps at three plant nurseries located in the central belt of Scotland operating different management practices (Table 1). These nurseries are identified (using codes from previous projects) as N003, N009 and N016 (Table 1).

Table 1. *Details of the nurseries sampled*

Nursery code	Size/annual turnover	Water source	Percentage of stock				Green and growing media waste disposal method
			Propagated on site	**Brought in from within UK**	**Imported from within EU**	**Imported from outside EU**	
N003	4 ha, non-commercial specialist grower of stock for botanic gardens	Mains	99	1	0	0	Composted on site in sealed concrete holding area
N009	2 ha, £70,000-£80,000	Mains stored in open tank	0	72	28	0	Dumped at back of nursery site
N016	2 ha, £1.5 million	Stream water in pond	50	10	40	1	Dumped at back of nursery site

3.2.1 Sampling methodology

At each nursery, samples of spent growing media (also containing plant debris) of approximately 500 g, comprising three pooled subsamples, were collected from the outer edge of the following horizons within the waste piles; A) upper surface of waste pile, B) mid-way down the waste pile, C) base of waste pile. The pooled subsamples from each horizon were bagged separately. Root samples (up to six per nursery) were also collected from plants dumped on the waste piles which could be identified to genus level.

Four water samples (varying in volume due to puddle sizes but up to 5 l) were also collected per nursery. These included the water used for irrigating stock, as well as samples collected from puddles surrounding the waste piles, from any streams running within 10 m of the waste pile or using a water flow-through method (Green et al. 2021) whereby plant and growing media material was sampled from the waste pile, placed into pots which were then placed into trays, watered to run off and left for a minimum of 30 min to allow any *Phytophthora* propagules to percolate into the trays. The water which collected into the bottom of the trays was then sampled for both baiting and metabarcoding analyses. For baiting analyses, water samples (1 l) were collected into sterile bottles and brought back to the lab for baiting. For metabarcoding analyses, water samples were filtered on site using a knapsack sprayer and hose method known to capture *Phytophthora* propagules (Scibetta et al. 2012) and applied successfully during the Phyto-threats project (Forest Research, 2019; Green et al. 2021). Three filters per sample were placed into tubes containing buffer onsite. Prior to each nursery visit, lab blank water samples were taken by filtering lab tap water through the filtration equipment as a check for DNA contamination of the knapsack sprayer. These lab blank filters were processed for metabarcoding along with the nursery samples.

3.2.2 Downstream sample processing

3.2.2.1 Baiting

Water samples were placed into plastic tubs and bait leaves (rhododendron, hebe and other species collected from each nursery as available) were placed to float on the water surface. Samples of spent growing media were also placed into plastic tubs which were then filled to double the level with distilled water and bait leaves floated on top. Controls were set up in which the baiting test was replicated using the same volume of sterile distilled water. Bait leaves were examined carefully every 2 days for lesion development. Tissue from lesion margins was plated onto *Phytophthora*-selective medium and incubated at 16-20°C. Developing colonies of individual *Phytophthora* isolates were subcultured onto V8 agar and DNA extracted from any *Phytophthora*-like isolates (based on hyphal morphology and the formation of sporangia when cultures were flooded with pond water). Isolate DNA was then subject to PCR of the full ITS region and PCR products Sanger sequenced. ITS sequences from *Phytophthora* isolates obtained in this study were analysed by BLAST into GenBank to identify the isolate to species level based on a 100% or 99% match to a GenBank sequence. Isolate identifications were based on GenBank sequences derived from type strains or voucher specimens, or those published in peer reviewed taxonomic papers.

3.2.2.2 Metabarcoding

Water filter, root and spent growing media from waste piles were also processed for metabarcoding using an Illumina metabarcoding method developed as part of the Phyto-threats project which identifies *Phytophthora* spp. present based on their DNA signatures (Green et al. 2021). This involves DNA extraction from samples, oomycete-specific nested PCR and Illumina library preparation of PCR-positive samples followed by Illumina MiSeq sequencing (carried out at the James Hutton Institute) and sequence analysis using a *Phytophthora* classifier (THAPBI-PICT) developed as part of the Phyto-threats project THAPBI Phytophthora ITS1 Classifier Tool (PICT) — THAPBI PICT 0.10.1 documentation (thapbi-pict.readthedocs.io).

3.3 'In kind' Phytophthora diagnostics of peat-free growing media

As an additional 'in kind' contribution to this project, a concurrent Defra-funded study investigated *Phytophthora* diversity in fourteen samples of peat-free growing media and various individual constituents using similar baiting and metabarcoding methods described in section 3.2. Green and Frederickson-Matika (2022) describes the study in full.

4 Results

4.1 *Literature review*

This section reviews currently available codes of practice (4.1.1) as well as conducting a literature review to present current evidence on effective composting processes and biosecurity concerns with peat-free media constituents (4.1.2 and 4.1.3).

4.1.1 *Current guidance on waste management*

4.1.1.1 *FERA Code of Practice*

The Code of Practice for the Management of Agricultural and Horticultural Waste in Great Britain was introduced in 2008 by the Food and Environment Research Agency (FERA). This voluntary code describes measures for minimising plant health risks from management of residues and associated waste from commercial handling of certain types of plant produce with the aim of protecting human health and the environment (Defra, 2008).

These controls include Part II of the Environmental Protection Act 1990 which makes provision for the improved control of pollution arising from certain industrial and other processes (available from legislation.gov.uk). Amongst other things, they provide for the licensing of waste disposal and waste recovery operations (which include the storage and treatment of waste).

In Scotland, processes that compost biowastes must apply to SEPA for a Waste Management Licence (WML) or register an exemption from licensing (SEPA, 2022). For facilities treating Category 3 Animal By-Products, a Pollution, Prevention and Control Permit (PPC) may be required.

It is important to realise that this code does not replace statutory plant health measures under the Plant Health (Great Britain) Order 1993, which include:

- provisions against the spread of quarantine plant pests and diseases within the European Community;
- conditions for the planting, movement and disposal of certain plants and plant products;
- provision for inspectors to take action to deal with likely or actual outbreaks of quarantine plant pests and diseases.

The underlying policy for this code of practice is based on the principle of reduce, re-use and disposal. The code recommends:

- **Reduction** – Leave as much waste as possible at source by:
    - cleaning root crops on the farm or, preferably, in the field to minimise the amount of soil adhering to them. When loading dirty sugar beet from a clamp, for example, use a cleaner-loader and return soil to the field of origin.
    - wherever possible, carrying out trimming and grading operations in the field, leaving the excess behind to be grazed by livestock or ploughed in afterwards. Alternatively, these operations can be carried out elsewhere on the farm and the waste returned to the field of origin. However, caution is required because this may not be advisable at some times of the year for crops grown in Nitrate Vulnerable Zones (because of risks of nitrate leaching) or those affected by common pests and diseases such as *Phytophthora, Fusarium* or *Verticillium* spp., or stem and bulb nematode. If in doubt, operators are strongly recommended to take professional advice;
    - specifying low levels of waste in contract conditions of purchase, especially for imported produce.

- **Re-use** – Provided that proper consideration is given to risks of spreading serious plant pests and diseases and, if appropriate, special treatments are undertaken to eliminate them, operators are urged to re-use surplus material wherever possible. This can be done by:
    - recirculating washing water after appropriate treatment;
    - re-using solid waste for horticultural or agricultural purposes, for example as growing media, mulch, soil improver, green fertiliser or animal feed;
    - If material has been assessed as low risk it may be suitable for composting or mesophilic anaerobic digestion before re-use. Where the risk is high, however, one of the more effective heat treatments (specified within the code), or higher temperature (thermophilic) aerobic digestion (also specified within the code), should be used. If these precautions are not available, or cannot be undertaken cost-effectively, the operator should consider disposal.

- **Disposal** – Where disposal of solids is unavoidable, either because they are of particularly high risk or because there are no cost-effective alternatives, operators should consider the following options:
    - disposal at a landfill site with an appropriate licence from the relevant environment agency. Operators should give the waste producers sufficient information about the waste to ensure that they can treat and dispose of it properly (e.g. high risk soil should be buried at a minimum depth of 2 metres, not used for capping);
    - disposal in an incinerator authorised under the Environmental Protection Act 1990.

The code states that high risk plant waste which is still viable (i.e., capable of regrowth) should be adequately heat treated or disposed of by one of the above methods. However, it also recognises that there may be circumstances where disposal is impractical, especially regarding operations which generate large quantities of surplus soil (such as sugar beet processing). In these circumstances, operators are urged to consider disposal to land which presents no significant risk of spreading plant pathogens. For example, the code suggests that infill on construction sites, landscaping or road embankments are likely generally to be of low risk, although care may be needed where these are close to arable land to avoid contamination. It may also be possible to use non-arable agricultural or horticultural sites or non-productive land on arable or horticultural premises, providing operators consider the risks carefully. If operators are in any doubt, it is suggested that they avoid such sites entirely.

In addition to the above, the code recommends that every effort should be made to minimise liquid waste and to recycle washing water wherever it is possible to do so. Where disposal is unavoidable:

- under no circumstances should untreated liquid waste be disposed of on arable or horticultural land;
- water that has been used for peeling or washing vegetables, including potatoes, must not be emptied or allowed to flow into a watercourse (including coastal waters, estuaries, lakes, ponds, rivers, streams, canals, and field ditches) unless operators have written consent to discharge from the appropriate environment agency (for which a charge will be made).

4.1.1.2 EPPO Guidelines

The EPPO (European and Mediterranean Plant Protection Organization) "Guidelines for the management of plant health risks of biowaste of plant origin" were introduced in 2008 (EPPO, 2008). These guidelines describe the requirements for the treatment of biowaste of plant origin to ensure its phytosanitary safety, specifically:

- The requirements for the treatment process to ensure phytosanitary safety of treated biowaste;
- Special requirements for biowaste that may contain quarantine pests or heat-tolerant pests;
- Supervision, test procedures and validation methods to ensure that the treatment process and final product comply with plant health requirements;
- Guidelines for the management of plant health risks of biowaste of plant origin;
- Documentation and labelling requirements during production and exchange of treated biowaste.

For example, in the case of compost, the guidelines suggest that the process should be managed in such a way as to guarantee a thermophilic temperature range that promotes a high level of biological activity over a period of several weeks. This should be achieved under appropriate conditions of humidity and nutrients, as well as by optimum structure and optimum air conduction. The specific conditions suggested by the guidelines are:

- The water content should be at least 40%.
- The entire quantity of materials being treated should be exposed either to a temperature of at least 55°C for a continuous period of 2 weeks, or to a temperature of at least 65°C over a continuous period of 1 week.
- In the case of enclosed composting facilities, at least 60°C for 1 week.
- During the composting process, a minimum number of turnings may be required to ensure that the whole mass is exposed to this temperature.

4.1.1.3 PAS 100

PAS 100 (Publically Available Specification for Composted Materials) is a widely recognised standard within the UK organics recycling sector. BSI PAS 100:2018 is the current version of PAS 100 (BSI, 2018). This PAS:

- Specifies the requirements for the process of composting, the selection of input materials, the minimum quality of composted materials and the storage, labelling and traceability of compost products.
- Specifies requirements for a Quality Management System (QMS) to produce composts that are consistently fit for their intended uses.
- Requires a Safety and Quality Control System, including Hazard Analysis and Critical Control Point (HACCP) assessment, which the composter takes into account when developing, implementing and reviewing the QMS.
- Importantly, there are no legally defined values for key sanitisation parameters for PAS100 composts (time, temperature and moisture content), only recommended parameters (Table 2). Therefore, different PAS100 systems will have different potential to kill pests/pathogens.

Table 2. PAS100 recommended parameters and minimum critical limit (CL) values for eradication of most pathogens during sanitisation[1] (from BSI PAS100:2018)

Temperature	Time[2]	Moisture	Mixing / Turning
65°C	7 Days	51%	Applicable if necessary to expose the whole batch to the recommended minimum conditions[3]. Number of mixes/turns as applicable to the composting system.

[1]Applicable to all composting systems, for all of the human- and animal-pathogens and most of the 60 plant-pathogens and nematode species reviewed by UK studies and subjected to bench- and commercial-scale trials.

[2]The recommended minimum temperature and moisture content should be maintained continuously over a period of 7 consecutive days. However, it is recognized that continuous monitoring and recording of temperature and moisture for 7 consecutive days will not be achieved where the composting process does not have a monitoring system that continuously records such data. It is also recognized that where monitoring procedures are carried out manually by staff who use equipment that takes discrete readings, monitoring is not carried out on any days when such staff do not work on-site (e.g. Sundays). Under those circumstances, proof that minimum temperature and moisture has been maintained continuously over a period of 7 days would not be possible. Thus, the composter should ensure that the CLs set for the sanitization step are clear and appropriate given the nature of the composting and monitoring systems.

[3]In systems where the composting batch remains static, insulation or auxiliary heat might expose the entire composting batch to sanitizing conditions without mixing/turning.

4.1.2 Review of effective methods of composting

Growing media is commonly made using a low nutrient carrier (s), mixed with high nutrient ingredients. Examples are given in table 3.

Table 3. Creating growing media

Low nutrient carriers	High nutrient ingredients
Peat	PAS100 composted green waste
Coire	On-site composted waste (non PAS100)
Bark	Digestate (PAS 100 and non-PAS100)
Loam	
Coarse sand and gravel	
Expanded clay minerals (e.g. perlite, vermiculite, zeolite)	

Composting consists of several phases: a feedstock preparation phase (which usually includes shredding and mixing of materials and may also include addition of water), a high-temperature thermophilic phase (or sanitisation), which usually includes turning or forced aeration in order to ensure that all parts of the feedstock self-heat effectively, a longer and lower temperature phase (stabilisation), often followed by a maturation phase where the compost gradually cools to air-ambient temperatures. Some composts may undergo further preparation prior to use, for example by screening. Many complex microbial interactions may occur throughout these phases, all of which are affected by conditions within the compost, such as the carbon:nitrogen ratio and degree of de-composition of the wastes, the temperature and moisture content (Noble & Roberts, 2004).

According to Bollen (1985), eliminating pathogens during composting is primarily due to: (a) heat generated during the thermophilic phase; (b) the production of toxic compounds such as organic acids and ammonia; (c) lytic activity of enzymes produced in the compost; and (d) microbial antagonism, including the production of antibiotics and parasitism. Of these processes, high temperatures (at appropriate moisture contents) are thought to be the most important for the destruction of pathogens (Ryckeboer 2002; Noble and Roberts 2003; Wichuk, et al., 2011).

In addition to this, temperature is usually the only means of pathogen eradication that can be easily monitored and controlled during composting. This is the reason that time-temperature conditions are generally specified in composting process guidelines and as a means of controlling pathogenic organisms (Wichuk, et al., 2011).

Noble and Roberts (2004) carried out a review of the eradication of plant pathogens and nematodes during composting, testing the effects of time-temperature combinations (and other sanitizing factors such as moisture) on 64 plant pathogenic fungi, plasmodiophoromycetes, oomycetes, bacteria, viruses and nematodes. They found that a peak temperature of 64–70°C for 21 days was sufficient to reduce numbers of most pathogens to below the detection limits of the tests used. This included 33 out of the 38 fungal and oomycete pathogens tested, all seven bacterial pathogens, all nine nematodes, and three out of nine plant viruses.

Given the importance of temperature and moisture to the composting process, it is crucial that all materials in the heap are exposed to the required conditions which may require several turnings of the material to move it all through the high-temperature zone (Veijalainen et al 2005; Downer et al. 2008). However, if the temperature gets too high the conditions in the heap may become limiting, therefore a maximum temperature of 70°C is recommended (Suárez-Estrella, et al., 2002).

However, there are a number of particularly hardy pathogens which routinely survive the composting processes described above as well as those used in PAS100. These include mechanically transmissible viruses and viroids (e.g. tobacco mosaic virus and potato spindle tuber viroid) and fungi and fungus-like organisms with resistant/heat tolerant resting spores (e.g. *Fusarium oxysporum* and *Plasmodiophora brassicae* (clubroot) (Wichuk, et al., 2011). This should be taken into account when re-using material that may have been infested by such organisms.

4.1.3 Biosecurity concerns with peat-free constituents

Coir is a natural product which is extracted from the outer husk of coconut (figure 2) and is one if the commonly used constituents of peat-free growing media. India and Sri Lanka produce 90% of the coir produced every year with Sri Lanka being the largest exporter (Banerjee, 2020). Other exporters of coir include Thailand, Vietnam, the Philippines and Indonesia.

Figure 2. *Coir production. Rajesh Ram.*

There has been international concern about the biosecurity risk posed by coir for some time. For example, in 2009, amended import regulations to improve biosecurity measures and address importer concerns about coir were introduced in New Zealand (updated in 2022) (Ministry for Primary Industries, 2022). This was due to the finding of new-to-New Zealand weeds associated with imported coco peat at a horticultural business. This sparked a survey of nurseries around New Zealand which revealed that these weeds were present at several sites. In total, 25 new-to-New Zealand weed species were detected in imported coco peat during this exercise. The nurseries involved undertook weed control on their sites, including weed removal and the application of a pre-emergence herbicide (Ministry for Primary Industries, 2022).

Fortunately, the weed species found in coir in New Zealand are unlikely to become established in that country, due to the environmental conditions typically present there, but it follows that if coir can support weed seeds during transport it could also harbour plant pathogens and pests.

As a result, coir imported into New Zealand must be treated as follows:

- heat treatment by raising the core temperature of the product to a minimum of 85°C for at least 15 hours at approximately 40% relative humidity; or
- autoclaving at 120°C core temperature for 30 minutes at 100 kPa.

Similarly, Australia has legislation in place for the import of products that may be added to soil or potting media (Australian Government, 2019). In the case of coir, recently updated legislation (24th August 2022) (Australian Government, 2022) states that an import permit is required and several conditions met, including:

- A declaration on the phytosanitary certificate that "Based on inspection of representative samples, the coir peat is clean, free from soil, contaminant plant material and other extraneous material."
- The additional declaration "No visible contamination with animal material".
- A Certificate of microbial analysis (from a department approved lab).
- The goods must be clean and free of contaminant seed, soil, animal and plant debris and other biosecurity risk material prior to arrival in Australian territory.

- Any packaging used with the consignment must be clean and new.
- On arrival in Australian territory, the goods must be inspected to verify that they are free of live insects, plant or animal debris, soil and other biosecurity risk material.
- Correctly certified full container load (FCL) consignments will be inspected using a partial unpack inspection. The biosecurity officer may order a full unpack inspection dependent on the cleanliness of the shipment.
- If the consignment is not accompanied by an acceptable certificate of analysis from a department approved laboratory the consignment will be secured at an approved arrangement site at the importer's expense whilst microbiological analysis is undertaken (testing is to be conducted by the National Measurement Institute (NMI)).
- If live insects are found during inspection, the consignment will be a) held pending identification by a Department of Agriculture, Fisheries and Forestry entomologist and treated using an appropriate method, b) exported, or c), disposed of.
- If other contaminants such as soil, weed seeds, sticks, or faecal matter are found on inspection, the consignment must be held, and the contaminants must be removed or treated via a method approved by the department, if possible. Alternatively, the goods must be exported or disposed of.

The above approaches significantly reduce the risk of the importation of a novel pest or pathogen on coir and would reduce the risk to the UK if they were introduced here. UK growing media suppliers that subject peat-free constituents to PAS100 will potentially reduce the risk of their products containing new species, but there are no legally defined values for key sanitisation parameters for PAS100 composts (time, temperature and moisture content). Therefore, different systems at different producers will have different potential to kill pests/pathogens. The Australian and New Zealand approaches reduce the risk prior to the product entering the country which applies across the board and is therefore inherently safer.

As of October 2022, there are no import restrictions for coir into the UK, and at the time of writing there are no plans to implement any specific regulations.

4.2 Workshop 1 – Plant waste management

4.2.1 Understanding sector practices and biosecurity risks

This project team held a workshop to gather data on the current knowledge and waste disposal procedures of practitioners across plant production sectors in Scotland. There were 19 attendees, including plant growers, garden managers / landscapers, foresters / arboriculturists, plant retailers, farmers, conservationists, compost producers, sector membership organisations and researchers (Figure 3).

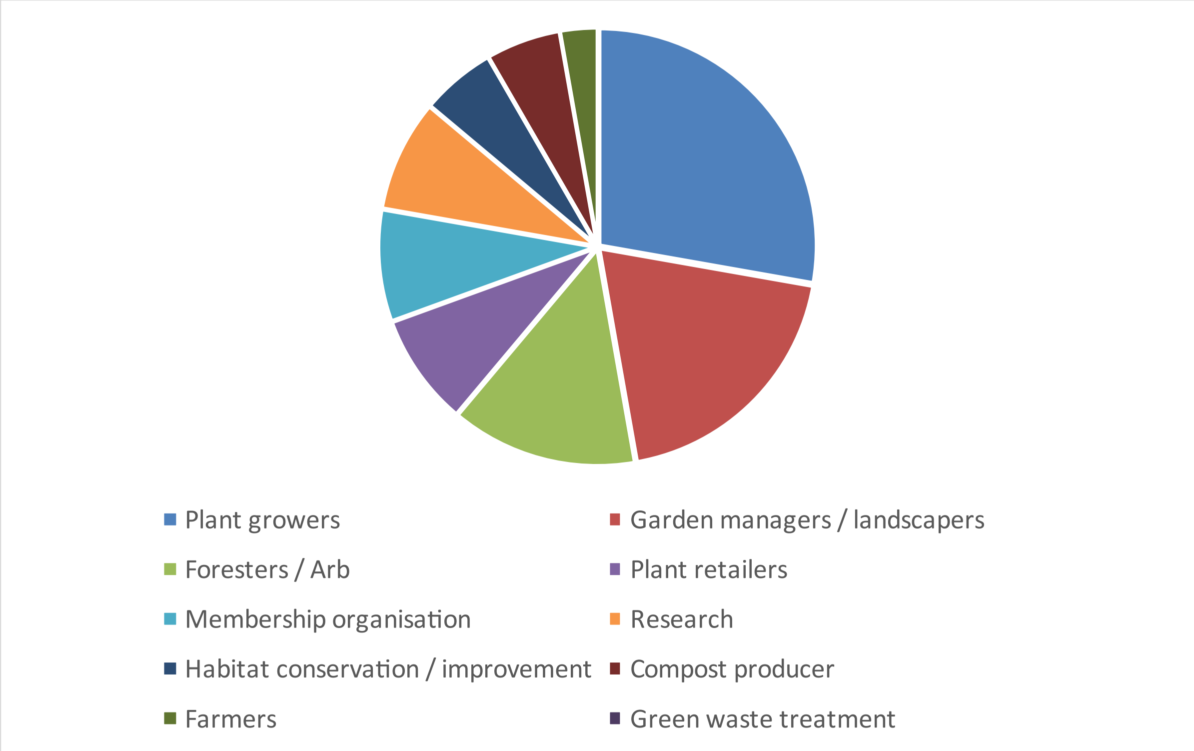

Figure 3. *Sector breakdown of attendees at workshop 1.*

We found that awareness of the biosecurity risks associated with plant waste heaps was high, with 95% of workshop attendees answering yes to the question "Are you aware that some plant diseases are known to be spreading from nursery plant waste heaps into the wider environment?". This is partly due to the attendees being selected to join the workshop due to their plant health knowledge or engagement with previous biosecurity-related research projects, but it also demonstrates the overall trend of increased plant health awareness in plant production nurseries (Yeomans & Tim, 2021). In addition, 78% of respondents had a biosecurity policy in place (where applicable).

When asked "What do you do with your waste plants and plant material?", 41% of workshop attendees said that they have a waste pile on site, 18% send to landfill, 6% responded "other" (which for one respondent was a mix of waste pile but also on-site composting) and 0% removed from site to a PAS compost producer (Figure 4). Resorting to creating a waste pile whilst having a knowledge of the biosecurity risks, as shown in the response above, strongly suggests that practitioners are unsure about what to do with their nursery waste. It is therefore perhaps unsurprising that plant pathogens are routinely found in waste heaps (Jung, et al., 2016).

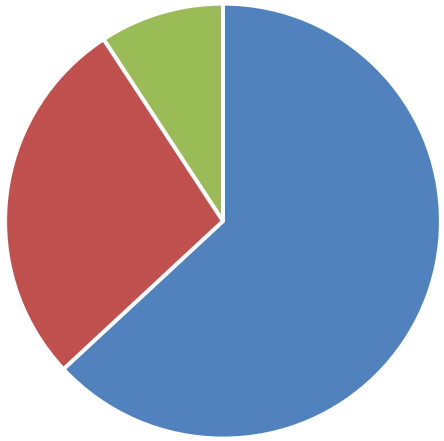

***Figure 4**. Current management practices for plant waste material.*

To demonstrate this further, when asked "What do you do with the waste growing media (which will mainly be associated with waste plants)?" respondents gave a wide range of answers:

- "Compost our green waste but use it for nothing, the pile gets bigger"
- "Waste growing media and plants are added to the compost pile, spent growing media can be sterilised if contaminated"
- "Waste pile, on-site composting, reuse e.g. for planting activities"
- "Compost and spread on woodland"
- "Composted"
- "Compost pile"
- "Landfill"
- "Nothing"

These answers show that not only are waste heaps created but there is a variation in use for the material after it is added to the pile. In some cases, nothing happens to the material so the heap just gets bigger. For those who do have a use, e.g., as a mulch or for future planting, there are obvious biosecurity risks involved with this activity.

A number of respondents said that concern from pest and disease introduction and spread had changed some of their nursery practices. For example, improving their waste material storage to include designated "bins" which can be turned to improve the composting process and kill some of the pathogens. Some have provisionally moved to landfill collection whilst they make arrangements to build more effective composting facilities and others don't allow any waste material on their site at all.

83% of respondents felt that their current nursery waste management practices need improvement. A number of actions were outlined in their responses which include:

- "Could implement better strategies to identify potential sources of disease - focus on training staff, improve the structures around waste disposal so that staff are aware of what they might be looking out for, e.g., when trees are graded out that they get highlighted and disposed of correctly""

- “Waste on site, composted or not, is still a potential bio 'threat'. Rounding the circle, and ensuring waste ends up being useful again and as 'inert' as it can be, would be a better outcome”
- “More sorting and treat in the same way we do with plastics and cardboard to minimise landfill and bio risks”
- “Always looking for ways to improve the safety and also end product of the composting process. Would also like to find more effective ways of killing pathogens and potential spread of them”
- “Compost heap needs more frequent turning and monitoring for temperature and more frequent bait testing”
- “Particularly interested in the compost run-off element (capture, disposal, use). Effective designs, e.g. insulated for additional heat?”
- “Our green waste management is a bit unstructured and dealt with ‘when there’s time’. Needs more structure!”
- “There’s always room for improvement in any operation.”
- “Need to raise temp on compost”

An issue identified during the workshop was the potential lack of availability of reliable information on nursery waste management. Only 20% have been successful in finding information on dealing with plant waste material with a further 60% successful *to some extent* and 20% unable to find any information at all. When asked where information is accessed from, responses included:

- “Internet”
- “Until now I'm not sure we have been actively looking”
- “Government plant health department”
- “Trade body – HTA”
- “Look to peer organisations for information. Most horticulturalists have basic understanding but need source of more sophisticated training and info”

Clearly, the development of guidance on safe disposal of industrially produced plant/soil/growing media waste is needed, and indeed is considered a top priority for the UK’s new Plant Healthy Certification Scheme (Plant Healthy, 2022). This scheme requires accredited nurseries to comply with a set of management standards to help tackle the increasing risks from invasive plant pests and diseases being spread via the commercial nursery trade.

4.2.2 Changing practices

Perhaps unsurprisingly, 87% of respondents agreed that they have a role to play in helping to reduce the spread of plant diseases and there appears to be an appetite within industry to change practices. For example, 73% of respondents indicated that they would be prepared to implement changes on their nursery in order to improve biosecurity, e.g., preparing and implementing a nursery waste management policy and/or joining a certification scheme.
When asked “Which method do you think works best (or would work best) for you to minimise the risk of disease spreading from plant and growing media waste?”, responses were collected against a number of options:

- A covered or uncovered plant waste heap well away from the production areas and downwind from the nursery (18 % agreed)
- An incinerator based on the nursery (18 % agreed)
- A well-managed shredding and composting system based on the nursery (36 % agreed)
- Collection and disposal to landfill (9 % agreed)
- Collection and PAS100 composting (18 % agreed)
- Collection and commercial incineration (0% agreed)

In order to understand this better, we asked how plant waste management practices could change, the seven responses were:

- “Ideally for nurseries to produce as little as possible in the first place. That perhaps needs to be discussed as part of this? Gardens naturally will produce waste so won't have that as an option”
- “Standards can and should be raised throughout the industry. Improve training for staff and institutions”
- “More information, more training”
- “In general, there should be acknowledged standard practice that is both practical and effective”
- “A central resource/ portal for industry advice and information to help change happen”
- “A standard for nursery composting setting out best practice”
- “We need some authoritative guidelines that can be built into the Plant Healthy Standard over time”

These responses highlight the need for more information and training on plant waste management as well as this aspect of nursery management being included in an official Standard.

4.2.3 Barriers to change

A number of barriers to change were identified by attendees of the workshop, these included:

- “Commercially the incentives to change are low. Better knowledge, understanding and incorporation into standards such as Plant Healthy may help, as would improved connections with commercial composters etc.”
- “Time, space, cost. Perhaps not understanding there might be a problem. A bit of everything”
- “Lack of knowledge and understanding re which courses of action pose greatest risk, and options available”
- “Lack of understanding of the risks, lack of guidelines around doing the job well and lack of legal end uses for a composted product”
- “Funding and existing pressure on staff (staff shortages etc), lack of knowledge”
- “It takes time to sort carefully, and that is a resource issue for most…”
- “Highlighting the risks in the way we have heard today would help push the messages”
- “Behavioural change, weighing up the environmental impact of burning vs composting”
- “Time and resources”
- “Cost and people resources involved”
- “Cost and ignorance”

The clear message from the responses is that knowledge of the correct management of waste material is low and therefore incorporating this element of nursery management into a certification scheme would help improve the situation.

Paying for waste disposal was also discussed. Currently, only 17% of respondents pay for plant waste disposal. For those that do not pay, we asked whether they would be prepared to pay in the future, 38% said yes, 38% maybe and 25% no.

4.2.4 Diagnostic study of nursery waste

Detailed results are presented in Schiffer-Forsyth, 2022, therefore only a brief overview of results is presented here.

4.2.4.1 Baiting analyses

For nursery N003, no sample yielded *Phytophthora* in the baiting analyses.

For nursery N009, *Phytophthora bilorbang* was isolated into live culture from a stream water sample and the following six *Phytophthora* spp. were isolated into live culture from samples collected from the base layer of the waste pile; *P. ramorum, P. hibernalis, P. gonapodyides, P. pseudocryptogea, P. chlamydospora, P. gregata*. *Phytophthora chlamydospora* was also isolated from the top layer of the waste pile.

For nursery N016, *Phytophthora chlamydospora* was isolated from a puddle water sample, *P. gonapodyides, P. chlamydospora* and *P. ramorum* were isolated from the top layer of the waste pile, *P. ramorum, P. megasperma, P. chlamydospora* and *P. gonapodyides* were isolated from the middle layer of the waste pile and *P. ramorum, P. chlamydospora* and *P. gonapodyides* were isolated from the base of the waste pile.

Of the nine *Phytophthora* species identified from the baiting analyses, only two (*P. ramorum* and *P. austrocedri*) have entries on the UK Plant Health Risk Register and only one (*P. ramorum)* is a notifiable plant pest.

4.2.4.2 Metabarcoding analyses

DNA extracts from all samples collected from nursery N003 were negative for *Phytophthora* in the genus-specific PCR thus none were processed for Illumina sequencing. For nurseries N009 and N016, respectively, thirteen and seven *Phytophthora* spp. were detected in total by metabarcoding across water, root and waste pile samples. At nursery N009 this also included detection of the regulated pathogen *Phytophthora austrocedri* in stream and irrigation water samples.

4.3 Workshop 2 – Challenges with reduced-peat and peat-free growing media

4.3.1 Current status of the peat-free sector

Peat has been the base for growing media for over 50 years for several reasons, including the relatively low cost. It has been widely available in sufficient quantities, it has a good stable structure, is typically free from plant pathogens and pests (it is effectively sterile) (Alexander, et al., 2008), it is very consistent (within peat bogs), it is acid and therefore easy to lime to the appropriate pH, it's almost nutrient-free and therefore easy to add bespoke amounts of nutrients to (Holmes & Bain, 2021).

However, peat bogs are of high ecological importance and are the UK's largest form of carbon storage (RSPB, 2021). It is clear that the ongoing extraction of peat is not sustainable. Over the decades this activity has caused significant ecological damage which will take centuries to repair. This has led to the planned phasing out of peat-use in horticulture, with a ban on the retail sale of growing media which contains peat by 2024 (UK Government, 2022). This will only currently apply to bagged compost products for sale in England (as of 27th August 2022), but it is increasingly likely that this will be adopted by the other countries of the UK. In addition, a ban is eventually likely to come into force for commercial growers at some point but the timescale on this is currently unknown.

It is much more difficult to produce reduced-peat and peat-free growing media than peat-based media for several reasons (Litterick, 2022). Firstly, alternative constituents (e.g., coir, wood fibre, composted bark and green compost) are much less consistent than peat from a single location, therefore it is more difficult to quantify the amounts of other materials required to make good quality media. There is also an acute shortage of good quality growing media constituents, which makes manufacturing of volumes of media, sufficient to satisfy demand, extremely challenging (Holmes & Bain, 2021; Litterick, 2022). Growing media manufacturers generally find that it is much more difficult to ensure consistently high quality without peat. There is continuing resistance amongst professional growers to using peat-free media, often due to their own bad experiences (or those of others) or bad press (Litterick, 2022). It is likely that the majority of professional growers will continue to use peat-based media until forced to change to peat-free by either their buyers or due to government bans (Litterick, 2022).

Plant pests and pathogens are a potential concern with some growing media constituents, particularly those based on plant waste material (e.g., coir, composted bark and green compost). Loam can also pose a risk depending on its source and on the methods used to sterilise it. The level of risk from using such constituents in growing media is currently not well understood. Further work is required to better understand these risks and to develop effective strategies to mitigate them (Litterick, 2022).

A workshop was held to gather data on current knowledge and practices regarding peat-free growing media in Scotland. There were 19 attendees from a wide range of sectors including plant growers (nursery stock) and retailers, garden management/landscaping, farming, forestry/arboriculture, research, compost production, sector membership organisations, habitat conservation/improvement and green waste treatment (Figure 5). These data have been combined with the literature to build up a picture of the current situation.

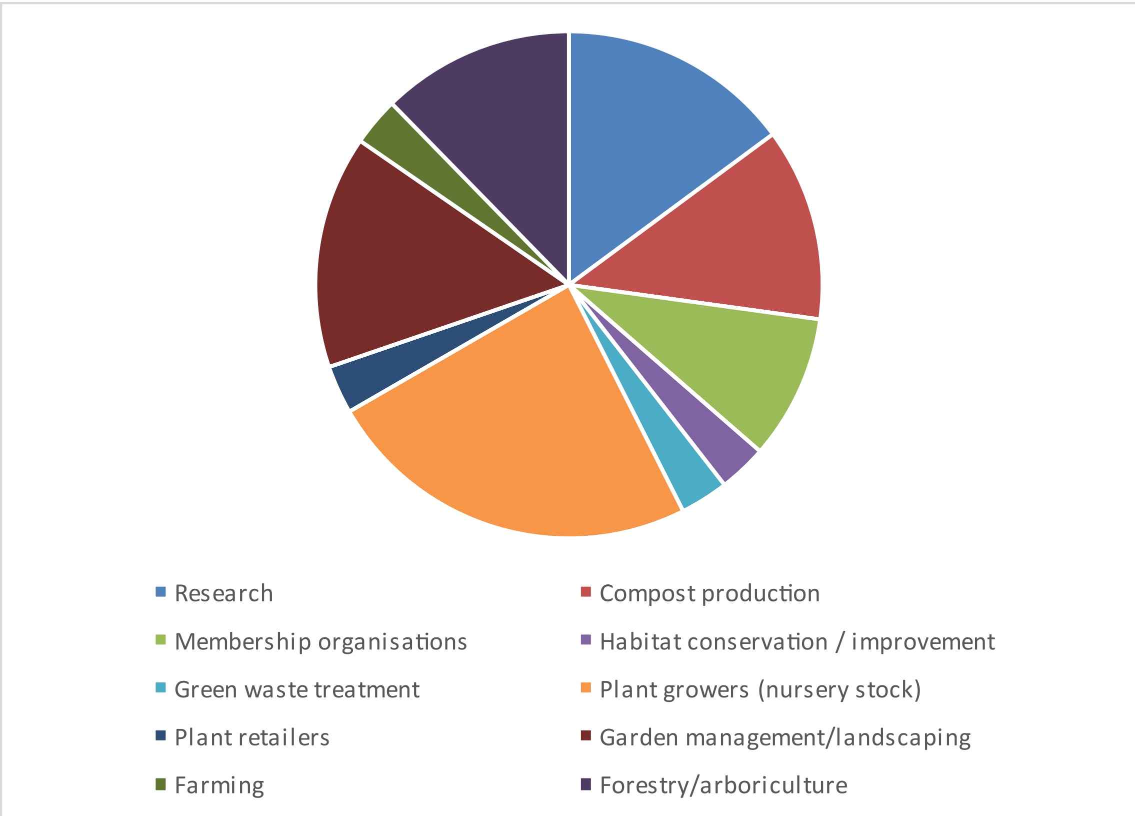

Figure 5. *Sector breakdown of attendees at workshop 2.*

50% of respondents at the workshop used peat-free growing media, 21% used reduced-peat and 14% used peat-based products. For those not using peat-free growing media, when asked why, they responded:

- “We are in the process of testing of peat-free/ reduced-peat media. We are going to move to peat-free media in future”
- “Growing specialist plants that grow much better with the addition of peat in the mix, Protaceae family especially. All other plants are peat-free”

- “We are peat-free for the areas under our control. We cannot reasonably source all nursery stock/ other plants which have been whole-life in peat-free (i.e., the environmental cost of transport etc outweighs the impact of the peat content)”

4.3.2 Pest and disease perceptions and issues with peat-free growing media

When asked if respondents were happy that peat-based growing media products are free from pests and pathogens, 43% replied yes, 43% were unsure and 14% replied no. When asked the same question about peat-free and reduced-peat growing media, 50% were unsure, 7% replied yes and 43% no. This suggests that there is significantly less confidence that peat-free media is free from pests and diseases.

As far as levels of biosecurity risk go, 67% of respondents felt that the risk from peat-free growing media was moderate, 8% thought it was high risk, 8% low risk and 17% didn’t know. This appears to influence respondents’ choice of constituents for inclusion in potting mixes because 91% responded that biosecurity risk is a consideration. The majority of respondents thought that a ban on using peat as a component of growing media increased the biosecurity risk (67%), whilst 25% were unsure and 8% replied no.

In addition, when asked if respondents were concerned about the potential for some of the constituents of peat-free growing media to contain pests and pathogens, 0% replied “not at all”. In fact, 43% were moderately concerned, 29% very concerned and 29% a little concerned. Constituents of concern to respondents in peat-free and reduced-peat growing media were:

- “Composted green waste is the main issue. Coir and bark are thoroughly tested, not routinely but enough to be confident. 3-4 decades of use and information”
- “Main concerns - places of production, are they free from pest and diseases?”
- “I would not use ‘composted green waste’ for anything other than a soil improver”
- “Wood products and the storage before it gets to the end user”
- “Green compost and wood fibre/bark”
- “Thielaviopsis (fungal pathogens of concern in agriculture)”
- “Materials imported from other countries without checks”
- “As we sell compost, I’m concerned that we may pass pests/pathogens into the gardens of our customers”
- “PAS100 compost and reclaimed materials”
- “Green compost and coir”
- “Bark fibre /wood waste”

It should be noted that the terminology associated with growing media constituents and processes is often not clear which can lead to confusion. The phrase “green waste” is often used interchangeably with “green compost” but technically speaking these are different, “waste” has potentially not been treated whereas “compost” could have been. In addition, use of the word “compost” does not necessarily mean that the waste has been exposed to the temperatures required to kill pests and pathogens. These issues with terminology add to the potential risk because there can be confusion among stakeholders about what is being discussed.

As stated earlier, there are no legally defined values for key sanitisation parameters for PAS100 composts (time, temperature and moisture content), therefore there is variation in PAS100 produced composts.

As to where the constituents come from, 50% of respondents lacked confidence that suppliers (including outside the UK) fully understand the biosecurity risks and take effective measures to prevent and control them. A further 29% were moderately confident and 21% had no confidence at all.

In summary, the workshop data showed that there is considerable concern in the industry about the biosecurity risk from peat-free media constituents which will have significant ramifications for the wider take up of peat-free growing media.

4.3.3 Peat-free growing media solutions

When asked how the sourcing and processing of components of peat-free growing media could be improved for better quality and biosafety, responses included:

- "Standards (testing, certification)"
- "Covered production, checking of raw materials"
- "More information needed and standards for all raw materials (as used in The Netherlands with the RHP system?)"
- "Traceability of materials, Regulated standards and certified testing"
- "By a non-business based, independent body?"
- "Recognised industry standard, with regular testing of samples to meet the standard"
- "We simply rely on our suppliers!"

In order to minimise risk and protect themselves from a pest or disease outbreak, we asked workshop attendees what measures are already being taken to protect their businesses:

- "Testing of diseased material for phytophthoras, isolate material coming from other nurseries for a growing season and inspect before release."
- "Certified sourcing and site management"
- "Using premium grade bulk materials and minimum composted bark. Trust in companies' hygiene and sourcing"
- "Buy from large professional supplier and hope they have a plan. Perhaps they could advise what they do to reduce likelihood / severity of issues - currently don't really have that info other than informal chats if we ask"
- "Not so much a process but are using well-known producers of longstanding industry track record. Do still get hiccups in quality!"
- "Occasional bait testing and microscopy"

There is general recognition that peat-free growing media are very different to peat-based. We therefore asked some of the experts at the workshop what advice they would give professional growers as they make the change to peat-free media:

- "Use a good supplier! Adapting the irrigation is needed - often more 'little and often' watering may be needed - and nitrogen nutrition may need adjusting. Trial new media first and monitor the nutrition"
- "Unless the transition is handled well, there is a nightmare waiting to happen. People buying plants that then fail/planting into growing media which are not up to scratch will simply give up and stop gardening"
- "Be prepared to change your way of growing plants, they may need less or more feeding depending on the constituents of the mix, expect more losses of plants until you have settled on the mix you want to use. Add different constituents to it yourself to improve the quality"
- "Talk to your supplier and ask as many questions as you need to. Act early on any concerns. Do not wait to see if something might resolve itself. Be positive about the potential in the change"
- "They need to get to know the new products (difficult if they are too variable) - it will stretch their horticultural skills"
- "You have to use peat-free media asap and not keep them for long at storage"
- "For myself I had no issues and possible benefits. Source the best you can and have trials while reducing the peat volume"
- "Don't use green compost"

- “Need to communicate/share info re successes and failures with different species. Also need to ensure retailers and the general public are aware quite how differently these peat-free composts and the plants being sold/purchased in them, need to be treated”
- “Sustainably sourced, from certified sources”
- “Add a lot of extra feed”
- “That obviously there is an adjustment period so look at a gradual change until they are used to the peat-free medium”

4.3.4 Barriers to change

A significant barrier to uptake is the inconsistency in the quality of peat-free/reduced-peat media, especially for the amateur gardener (who will be forced to change by 2024 through legislation) through retail supplies (professional growers have the option not to phase out peat until 2030). As one highly experienced workshop participant commented” when an amateur gardener has plant failures, they often won’t think to blame the growing media, more often they will blame themselves and give up”. This is obviously detrimental to horticulture and should not be the case. The horticulture industry has pledged to move to entirely peat-free growing media by 2030, depending on what government support is available (Appleby, 2021) to help them cope with the change to peat-free due to inconsistent growing results.

Cost was also mentioned in the workshop as a barrier. In particular, the competition for compostable materials with the biomass sector. The biomass sector can afford to pay more for materials (e.g., wood chip) than a compost producer which leads to a poorer and more inconsistent product and producers struggling to make a profit.

4.3.5 ‘In kind’ Phytophthora diagnostics of peat-free growing media

Of the fourteen samples of peat-free growing media and individual constituents tested, six were positive for *Phytophthora* (or closely related oomycetes) in the nested PCR and were processed for Illumina sequencing. *Phytophthora* DNA was detected in five of the six positive samples. These were: *P. citrophthora* in two samples of chopped pine bark from Scotland and in one sample of peat-free industry mix; *P. bilorbang* in one of the bags of peat-free growing media produced for the amateur market; and *P. crassamura/P. megasperma* (these two closely related species cannot be separated by their ITS1 sequences) in one of the coir samples. A downy mildew matching *Peronosclerospora* spp. was also detected in a second coir sample.

4.4 Best biosecurity practice for safe disposal of plant waste and spent growing media

Research has shown that plant waste and spent growing media can harbour pests and pathogens, including quarantine-regulated species such as *Phytophthora ramorum*. These organisms have the potential to spread from untreated waste piles to stock plants, young plants and the wider environment. This guidance aims to help the horticultural sector understand and mitigate these risks by providing some practical advice on waste management.

Waste and environmental legislation is a devolved issue so please note that if you are using this guidance outside Scotland, the relevant national licencing authorities will need to be contacted.

4.4.1 Minimise waste and risk of infected waste material

The best way to limit waste volumes and to minimise the risk of pests and pathogens proliferating in waste is to ensure that plant stock is sourced and grown to high standards of biosecurity and is monitored frequently to ensure that plants remain visibly healthy/symptom-free. Various types of growing media ingredients and mulches (e.g. pot tops) can also harbour and be sources of pests/pathogens.

Implementing robust risk assessment measures based on the type and provenance of live plant material and associated components required for their cultivation and movement help minimise the risk of plant pests/pathogens arriving onto site.

4.4.2 Waste storage prior to disposal

Waste material must be managed in a way that minimises the risk of spreading pest/pathogens. Any on-site waste storage should be situated on hard standing (e.g. concrete) with clear separation from growing stock, hedgerows, woodlands or water courses. Separate holding areas should be built to accommodate storage of different forms of waste (e.g., plant waste, cardboard, plastic) until they can be properly disposed of. Plant waste heaps should also be covered to prevent water ingress and run-off after rain.

4.4.3 Disposal of waste plant material and spent growing media

Any plant or other material that is suspected of being infested or harbouring a notifiable pest should be reported to SASA in Scotland (APHA in England and Wales, DAERA in Northern Ireland), who will advise on the required treatment.
All other waste material can be managed through the following methods:

- On-site composting
- Incineration with relevant permit in place
- Disposal at a landfill site
- Removal to commercial composting facility by waste management company

4.4.3.1 On site composting

Composting (< 1,000 tonnes at any one time) is permitted in Scotland under a Waste Management Licence Exemption (WMLE) (Paragraph 12). Those wishing to run a composting operation of any scale up to 1,000 tonnes of waste per year must register their operation under this exemption with SEPA. There is no charge where less than 100 t/year is being composted (A charge of around £500/year will be made where > 100 t is composted annually). Registration can be made online on the SEPA website (https://www.sepa.org.uk/regulations/authorisations-and-permits/application-forms/waste-management-exemptions/).

Unless the composting operation is accredited under the UK Compost Certification Scheme to the BSI PAS100 standard, the resulting compost will remain a waste. It can therefore only be used on the premises on which it is made UNLESS an application is made to SEPA to register its use in agriculture, field horticulture, landscaping or land restoration under a WMLE Paragraph 7 or 9.
For composting systems, The EPPO (European and Mediterranean Plant Protection Organization) guidelines recommend:

- The water content should be at least 40%. (Research has shown that a moisture content of 50 to 60% is best in order to ensure effective kill of pathogens when temperatures are also appropriate for pathogen kill.)
- The entire quantity of materials being treated should be exposed either to a temperature of at least 55°C for a continuous period of 2 weeks, or to a temperature of at least 65°C over a continuous period of 1 week.
- In the case of enclosed (in-vessel) composting facilities, temperatures of at least 60°C for 1 week are required in all parts of the waste.
- During the composting process (other than in-vessel systems), a minimum number of turns will be required to ensure that the whole mass of waste is exposed to this temperature.

- Note that pathogens which cause some plant diseases can survive the composting process; for example, Plasmodiophora brassicae (which causes clubroot) and Armillaria mellea (honey fungus).

4.4.3.2 Incineration

Whilst this is a good option in terms of controlling plant pathogens in diseased material, it is only easily feasible for small quantities of relatively dry waste. Burning of other wastes (e.g. cardboard, waste wood or plastic) along with plant waste is not permitted. Controlled burning of plant wastes in an exempt incinerator or plant tissue in the open air is only allowed in certain circumstances and the farmer or grower must register an exemption with SEPA first. Exemptions are considered where the grower demonstrates that the activity will not pollute the environment or harm human health. Where burning is permitted, the grower must register the activity under either a Paragraph 30 exemption or under a Paragraph 29 exemption (at no cost). This can be done online on the SEPA website (https://www.sepa.org.uk/regulations/authorisations-and-permits/application-forms/waste-management-exemptions/).

4.4.3.3 Disposal to landfill

Landfill is still permitted in Scotland, but Scottish Government intend implementing a ban on sending organic waste to landfill in 2025. After that year, woody organic wastes must be treated through alternative means including composting, dry anaerobic digestion or incineration. The gate fees for submission of organic wastes to landfill are currently between around £93 and £187/tonne (considerably more expensive than composting and therefore a less favourable option. The cost of haulage to the nearest landfill site must also be added to the cost of this option).

4.4.3.4 Removal to commercial composting facility

Commercial composting by a facility accredited under the UK Compost Certification Scheme to the BSI PAS100 standard is an effective, environmentally sustainable option for treating plant wastes generated in nurseries and gardens. The gate fees for submission of organic wastes to PAS100-accredited facilities are currently between around £30 and £60/tonne, but the cost of haulage to the nearest site must also be added to the cost of this option. The distribution of suitable composting sites is very patchy in Scotland, with few sites in the less populated areas, thereby making commercial composting a financially realistic option mainly in the central belt.

4.4.4 Uses of treated plant material and growing media

If the risk can be deemed low and the on-site composting procedures above are followed, the compost can be used on site. For example:

- As an additive to soils in ornamental and stock beds to add fertility and improve soil structure
- A surface mulch in ornamental and stock beds
- Where compost is produced by a garden open to the public, then it may be possible to use well composted material as part of potting mixes for plants being grown on for planting in that same garden, but this is tricky and not advised. Note that compost produced in gardens and nurseries remains a waste unless it is accredited under the UK Compost Certification Scheme to the BSI PAS100 standard. Such compost should not therefore be used as a component of growing media used to grow plants which are then sold off the nursery. In any case, it is very difficult to manufacture growing media of sufficient quality when using home-produced compost as one of the main constituents.

4.4.5 Understand your obligations

Follow plant health regulations, e.g. the notification scheme for importing some high-risk plant species, which, along with Plant Passports and Phytosanitary Certificates, aim to protect against the introduction and spread of pests. More details are available at: planthealthportal.defra.gov.uk

5 Evidence gaps

5.1 Plant waste material

One of the concerning areas of uncertainty is around the use of plant waste material after it has been placed in a heap for a period of time. Some respondents mentioned using it as a mulch or as part of a potting mix, but this poses a number of biosecurity risks (Noble & Coventry, 2005). *Phytophthora* spp. have been identified in waste heaps in nurseries and in parks and gardens but it is unclear what the scale of the risk is if such material is re-used, and likely that the risk will vary depending on how well the waste heap has composted and the purpose for which it is used.

The strong message emerging from the workshop was the need for good quality, reliable and clear information on what represents best practice for nursery waste management. Plant producers also need to know the scale of the problem and that they are not alone in struggling to know how best to manage waste. The inclusion of waste management guidance within certification schemes, so that managers know what to aim for, would be one way to lift such information into practice and drive more biosecure waste practices. Advice on best practice should include methods on minimising the generation of waste, as well recommendations on handling and using waste materials. It should also be tailored to different sectors as the risks that pertain to using waste in nurseries will differ to those relating to spreading waste on broad-acre crops or in the forestry sector.

5.2 Reduced-peat and peat-free media

The literature review provides some limited evidence that pathogens, pest and weeds can be contained in products used to substitute for peat in growing media, however, there was a distinct lack of specific evidence for constituents and specific pests and pathogens. Therefore, a thorough assessment of the potential plant health risks posed by each of the major constituents used in peat-free growing media is needed for the main products used to substitute for peat, which are bark, wood fibre, loam, coir, PAS100 produced products and composted green waste. This should include detailed information on product source, processing methods, transportation, and storage methods.

Biosecurity risks also apply when spreading composts and green wastes onto broad-acre crops. Some of this risk can be mitigated by using products produced in a PAS100 system but not all (e.g., clubroot, although the risk of transfer is substantially reduced although not eliminated in a PAS100 system). The use of a non PAS100 product on fields would potentially transfer of all the pathogens of concern for horticulture and the wider environment.

The volumes of peat-alternatives that will need to be sourced are significant and will represent barriers to change. The financial incentives in place to reward sending woody material to biomass need to be reviewed. This policy could be introducing an unfair negative bias into the peat-free media industry as it tries to source good quality wood-based components for a realistic price.

Support also needs to be provided to growers on how best to use different types of media for different purposes.

Similarly, to waste management, it was felt that information on the biosecurity risks related to peat-free growing media and advice on how to minimise such risks was lacking.

6 Discussion

6.1 Plant waste material management

This project has found that there is widespread recognition across the plant production sectors that plant waste is a biosecurity risk and that current practices need to improve. This risk was further demonstrated by evidence from the diagnostic study where a diverse range of *Phytophthora* spp. were recovered from plant waste heaps. This leads to the conclusion that if *Phytophthora* spp. survive then other pathogens can too.

For example, numerous isolates of the quarantine regulated pathogen *P. ramorum* were obtained from waste heaps. This pathogen has a wide host range and has caused the devastating epidemics on oaks in western USA and larch in the UK. In addition, *P. austrocedri* was detected in stream water and irrigation water. This pathogen is quarantine-regulated in the nursery trade and invasive in the wider environment causing widespread mortality of native juniper (*Juniperus communis*) in Britain.

This clear diagnostic picture shows the risks posed by the dumping of plant waste on-site. This is concerning because the majority of practitioners that engaged with this project dealt with their waste in this way. There is very little commercial incentive to change practices because managing waste incurs a cost. In the nursery sector we found some managers are spreading waste material onto land outside of their sites. This is also a clear potential route for pathogens to spread onto plants in the wider environment. This is a common scenario in the agricultural sector where the use of bulky organic wastes can improve soil health and offset the need for a proportion of the inorganic fertiliser that might be needed but leaves farmers at risk from some of the plant health risks identified in this report.

One clearly positive outcome from the diagnostic study was the complete lack of detection of any *Phytophthora* spp. in the waste piles of a nursery where particularly good practices were noted. This nursery has a proactive approach to biosecurity and management practices including not routinely importing stock and raising plants from seed on site, having a quarantine area for new arrivals and using clean water for irrigation. Importantly, the nursery also has a well-managed composting facility and procedure on site. From the results of this project alone, causation cannot be implied but, combined with the insights of previous work (Forest Research, 2019), it is very likely that there is a strong link between these enhanced biosecurity measures and the lack of *Phytophthora* found in their green waste piles. Such practices have been used to inform the best practice guidance presented in this report.

This project found that stakeholders are becoming increasingly aware of the risks posed by plant waste, particularly those that have engaged with metabarcoding studies such as the one carried out as part of this project. Many nursery businesses can see the biosecurity benefits of managing plant waste properly and have started to deal with their waste more effectively, using separate “bins” for storage of different material for example. This is a positive move forward.

The missing part of the waste management circle is getting the waste to a point where it is safe to be used again, either as a component of a potting medium or for a mulch or soil improver. This may not be applicable to plant producing commercial nurseries who would not reuse treated material, but valuable to large gardens, community gardens, allotment holders, farmers, etc., who may want to use treated wastes again. PAS100 is effective and available for those wishing to invest in the system, but there are no legally defined values for key sanitisation parameters for PAS100 composts (time, temperature and moisture content). Therefore, it should be understood by end users that different systems at different producers will have different potential to kill pests/pathogens.

For those not using PAS100, the best practice guidance produced during this project (section 4.4) outlines how pest and pathogen risk can be reduced as part of a well-managed waste disposal strategy. This guidance will also be used to inform the Plant Health Management Standard which will provide clarity on waste management for those businesses and organisations who engage with the Plant Healthy Certification Scheme. There is potential that some of this best practice advice is transferrable to other sectors and future knowledge exchange should engage with schemes relevant to those sectors such as Scottish Quality Crops and UK Forestry Standard.

This is important because most of the stakeholders that this project connected with indicated that they would prefer to manage their waste on site and reuse it, but they had difficulty in accessing the relevant waste management information. If guidance was available showing clear examples of how to achieve change, then the current barriers such as time and cost can be overcome as managers realise that it is not as onerous as they expected.

An issue identified during this project was that there is confusion around the terminology used when discussing plant waste. The phrase “green waste” is often used interchangeably with “green compost” but technically speaking these are different, “waste” has potentially not been treated whereas “compost” could have been. In addition, use of the word “compost” does not necessarily mean that the waste has been exposed to the temperatures required to kill pests and pathogens. A compost heap may just be a waste pile that has undergone no treatment. These issues with terminology add to the potential risk because there can be confusion among stakeholders about what is being discussed.

6.2 Reduced-peat and peat-free growing media

There is significant uncertainty about biosecurity status of some of the constituents of peat-free and reduced peat products. For example, as part of the ‘in kind’ diagnostic study of *Phytophthora* in peat-free growing media, found DNA matching *P. citrophthora*, *P. crassamura/P. megasperma* and *P. bilorbang* in chopped bark, coir and a peat-free product aimed at the amateur gardening market, respectively. A coir sample was also found to contain DNA closely matching *Peronosclerospora,* a genus of tropical downy mildew pathogens (Green & Frederickson-Matika, 2022).

This project aimed to clarify some of the specific risks associated with the constituents of peat-free growing media, however, we found that there is very little information available. In part, this is due to uncertainty related to the origin of constituents which is concerning. This has been noted in other studies, for example, the diagnostic work carried out by Green & Frederickson-Matika (2022) found that “interpretation of the findings was hampered by a lack of documented information on the source, precise contents and processing methods used for most of the samples”.

Further to this, the uncertainty surrounding the provenance and safety of growing media constituents, along with the other challenges of changing to reduced-peat and peat-free growing media, is causing considerable concern in the growing media production industry. In particular, the inconsistency of plant growth with some reduced-peat and peat-free media can make growing plants financially unviable leading to shortages in supply. In addition, if higher plant losses occur because of new growing medias, more plants need to be produced and therefore more waste is produced. As discussed in 6.1, this increases the plant health risks to the business, organisation and the wider environment in Scotland.

If UK growing media suppliers subject the peat-free constituents they use to a PAS100 system, this will potentially reduce the risk of their products containing new pest or pathogen species. However, as stated earlier, it is important to realise that PAS100 is a voluntary scheme and there are no legally defined values for key sanitisation parameters for PAS100 composts (time, temperature and moisture content). Therefore, there is a variation in PAS100-produced growing media.

The uncertainty described in this study has caused some countries to introduce strict phytosanitary measures on products such as coir. This precautionary approach seems justified given the lack of evidence identified during this project. In terms of risk reduction, the approach taken in Australia and New Zealand reduces the risk prior to the product entering the country which applies across the board and is therefore inherently safer. To date, there are no restrictions on the importation of coir into Scotland.

More evidence on the biosecurity safety of potential media constituents is required. Firstly, in order that a thorough biosecurity risk assessment can occur, the pathways need to be understood. This is far from the case with some of the constituents in question (particularly bark, wood fibre, and coir). The provenance of material and the processes that it may or may not have been subjected to are far from clear. Once this step has occurred, a more in-depth investigation into the potential pests and diseases of concern to Scotland can be carried out.

This information is not only important to protect plant and food production sectors and the natural environment in Scotland, it would also provide confidence in the sector and wider take-up of reduced-peat and peat-free media, thereby reducing the impact of peat extraction and protecting this important natural resource.

7 Conclusions

7.1 Plant waste management

The biosecurity risk from plant waste is high, as shown in the diagnostic testing in this and other projects, as is the awareness of the issue across sectors, however, an ad-hoc approach to plant waste management has developed in Scotland due to an absence of published guidance. The volumes of waste described by stakeholders are also a factor in increasing the biosecurity risk associated with plant waste. This means that the likelihood of a disease outbreak from unmanaged waste is high, and the spread could be rapid.

To improve sustainability, many stakeholders, such as plant production nurseries would like re-use plant waste "in-house" as a component of a potting medium or for a mulch, however, they are concerned about the biosecurity risks. Farmers too should be cautious of spreading waste generated off or on farm. PAS100 is a good way to ensure that waste material has been subjected to a production process that ensures it is to a certain standard, however, the end result can vary depending on the PAS100 system used.

Recommendation: Dissemination of the evidence-led best practice guidance produced by this project to provide clear advice on how to achieve a well-managed waste disposal/re-use strategy. This guidance will become part of the Plant Health Management Standard so that organisations and businesses that are applying to become Plant Healthy Certified can identify what is required to raise their biosecurity standards. The advice is also transferrable to other sectors such as agriculture (e.g., Scottish Quality Crops) and forestry (e.g., UK Forestry Standard).

7.2 Reduced-peat and peat-free growing media

The uncertainty surrounding the provenance and safety of growing media constituents, along with the other challenges of changing to reduced-peat and peat-free growing media, is causing considerable concern in the growing media production industry. Concern is heightened by potential deadlines for a ban on peat use in horticulture. Given the environmental impact of peat extraction, it is important that this uncertainty is reduced so that wider adoption of peat-free growing media can be achieved.

As shown in this project by the 'in kind' diagnostic study of *Phytophthora*, the risk of the inadvertent introduction of a novel pathogen within reduced-peat and peat-free media constituents could be high if the DNA detected is from live propagules. It is the provenance of the material which is concerning because there is very little information on where material originates, where it moves through, and how it is treated. As a result, a number of countries have already introduced pre-emptive legislation to manage this risk (e.g., New Zealand and Australia).

Recommendation: These findings indicate that a thorough assessment of the potential plant health risks posed by each of the major constituents used in peat-free compost (namely bark, wood fibre, coir, loam and composted green waste) is required. This should include detailed information on product source, processing treatments, transportation, and storage methods.

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