Research stocktake to inform design of a plant production accreditation scheme

Report information sheet

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Executive Summary

The problem

Biosecurity is a significant issue for the plant production sector. Pests and pathogens may reduce production and increase cost. The sector does not want to be responsible for the spread of new pathogens or pests nor be subject to unjustified restriction of trade.

Client initiatives

In August 2017, the Myrtle Rust Governance Group agreed in principle on a project to develop a plant production biosecurity accreditation scheme (PPBAS) to enhance long-term management of myrtle rust through effective management of the domestic plant trade. A Plant Production Biosecurity Accreditation Scheme was identified as a key approach to reducing such risk.

The plant production industry has existing nursery best-practice schemes (although not for biosecurity); the "Nursery Production Farm Management System" (comprising of Nursery Industry Accreditation Scheme Australia (NIASA) - focused on business productivity and nursery best practices, and "EcoHort" - an environmental management system, http://nzppi.co.nz/fms) Several existing sector-specific plant production biosecurity schemes already exist in New Zealand, developed to different levels. These include:

- The New Zealand Winegrowers (2016) - Grafted Grapevine Standard (http://ormondnurseries.co.nz/uploads/pdf/GGS%202016-%20version%203.0.pdf)
- The Kiwifruit Vine Health (2016) – The Kiwifruit Plant Certification Scheme (http://www.kvh.org.nz/vdb/document/102513)
- The New Zealand Avocado Growers Association (NZAGA) (2017) - High Health Scheme (avocados) (https://industry.nzavocado.co.nz/industry/biosecurity.csn)
- The strawberry industry's high health programme for viruses. (Langford, 2015)

The New Zealand Plant Production Biosecurity Scheme will work to align with such existing schemes to achieve efficiency and effectiveness gains for both plant producers and the sectors they supply for the benefit of New Zealand.

In December 2018, Scion and Plant & Food Research were contracted to prepare a stocktake of information that will be used by those who develop the Biosecurity Accreditation Scheme.

This project

This stocktake aims to provide guidance and material to assist with the design and development of a science-based standard for a plant production accreditation scheme, and to inform the PPBAS with knowledge of recent science outputs that will assist this process.

Key results

There is a real need to a plant producers' biosecurity accreditation scheme. Nursery stock is a well-recognised pathway for the long distance dispersal of plant pests and pathogens, both overseas and in New Zealand. This puts the industry and New Zealand's primary sector at high risk from damage, production loss and constraint of trade.

A systems approach to plant producers' biosecurity accreditation shows promise but will not cover all risks or eventualities. There is no "silver bullet" for reducing risk to an acceptable level.

Biosecurity risk can be managed in a nursery system by a 'layering' of protection – i.e. increasing biosecurity awareness; improving hygiene of nursery premises, production facilities, growing media and other material; diagnostic tools and inspection to establish baseline data and detect new threats, and protocols for movement of material.

Education and awareness of all involved in plant production from germplasm to end market is critical to success.

Many general and specific crop-focussed biosecurity accreditation schemes exist overseas and there are some specific schemes in New Zealand. Winegrowers, strawberry, avocado, and kiwifruit all have biosecurity accreditation schemes. There is ample information available from which to develop a general cross-sector biosecurity accreditation scheme for all plant producers in New Zealand.

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1. Introduction

A research team, led by Lindsay Bulman and Mark Bullians to coordinate, undertook the stocktake. The team carried out targeted literature searches and used their national and international networks.

They were given considerable support by two Knowledge Navigators (Sierra De La Croix (Scion) and Michele Napier (Plant & Food Research) who did initial literature searches and compiled shared EndNote databases.

Team member	Organisation	Area of expertise
Lindsay Bulman	Scion	Pathologist, forestry
Mark Bullians	PFR	Horticulture
Ed Morgan	PFR	Horticulture
Robin MacDiarmid	PFR	Virology, grapevines
Melanie Davidson	PFR	Entomologist
Andrew Pitman	PFR	Pathologist,
Mette Nielson	PFR	Entomologist
David Logan	PFR	Entomologist
Jessica Dohmen-Vereijssen	PFR	Entomologist
Sandra Visnovsky	PFR	Plant Pathologist
Craig Ford	Scion	Nursery Research Scientist Nursery
Paul Keech		Operations Leader, forestry
Rebecca McDougal	Scion	Molecular Pathologist, forestry
Beccy Ganley	Scion	Pathologist, forestry
Peter Scott	Scion	Pathologist, Phytophthora
Nari Williams	Scion	Pathologist, Phytophthora
Judy Gardner	Scion	Pathologist, forestry
Nick Waipara	PFR	Pathologist
Karyn Froud	Consultant	Biosecurity

Stocktake coverage

The stocktake included general information on nursery biosecurity plus some generic high-impact organisms to cover a range of organisms that represent most of the risks posed to New Zealand nursery, horticultural, forestry, conservation and amenity sectors. These organisms were used as case studies to highlight points made when describing best practices for each of the areas listed in the stocktake structure below.

2. Methods

The high impact organisms below were covered by the research stocktake.

High impact organism	Affected sector(s)
Myrtle rust, *Austropuccinia psidii*	Nursery, manuka / kanuka, conservation estate
Pierce's disease, *Xylella fastidiosa*	Nursery, grapevine, olives, conservation estate
Pine pitch canker, *Fusarium circinatum*	Nursery, forestry
Ceratocystis fimbriata	Nursery, kiwifruit, conservation estate
Sudden oak death, *Phytophthora ramorum*	Nursery, forestry
Kauri dieback, *Phytophthora agathidicida*	Nursery, forestry, conservation estate
Exotic mites and thrips	Nursery
Dothistroma septosporum	Nursery, forestry
Nematodes	Nursery, forestry

The stocktake considered the full range of nursery production systems – indoor-outdoor, container (of all types), in-ground, tissue culture, and product groups – trees, shrubs, potted colour, bedding plant, perennials, vines, etc.

Stocktake structure

It is not possible to completely separate the information developed for one section from that written in other sections. There is some overlap between sections in terms of information presented.

1. Nursery production biosecurity hazards and threats

2. Nursery essentials
   - Nursery details, staff management and responsibilities including staff, high school and hort/forestry student biosecurity training, signage including biosecurity awareness, audit

3. Internal quarantine disciplines and biosecurity critical control points
   - Pest-free place of production
   - Site requirements, including visitor registration
   - Hygiene, waste disposal
   - Growing media and soil treatment systems
   - Field production
   - Propagation and plant husbandry (including crop protection programme)
   - Nursery surveillance, monitoring & recording
   - Transport and dispatch
   - Nursery records and product identification, traceability

4. Diagnostics and biosecurity risk
   - Cost-effective diagnostic tools for assessing plant health status and detecting target organisms
   - Ramifications of discovering a new organism or DNA of a new organism
   - Implications of new organism or DNA discovery in water, soil, plants, shelter crops or neighbouring properties
   - Molecular technologies – risk and impact

5. Modules
   - *Austropuccinia psidii*
   - *Xylella fastidiosa*
   - *Fusarium circinatum*
   - *Ceratocystis fimbriata*
   - *Phytophthora ramorum*
   - *Phytophthora agathidicida*
   - Exotic thrips and mites
   - *Dothistroma septosporum*
   - Nematodes

3. Results

Research Stocktake data

Over 600 references are recorded in the EndNote library. The following steps were taken to reach that point.

- PPBAS EndNote Library was created and shared with Scion and PFR staff.
- Scion peer-reviewed keyword search was done and put into groups in the EndNote library (duplicates and irrelevant results were deleted).
- PFR peer-reviewed keyword search was done and entered into the PPBAS EndNote library.
- Scion non-peer-reviewed search was done and sent as a list to Scion staff and entered into the PPBAS EndNote library.
- PFR non-peer-reviewed search was done and sent as a list to PFR staff and entered into the PPBAS EndNote library.

Reference items were classified in terms of relevance and usefulness using the following criteria:

0 not at all relevant
1 not relevant but possibly of general interest to the PPBAS
2 slightly relevant, low value
3 relevant but either covered better elsewhere or limited in scope
4 relevant, particularly to one or two components of the review
5 broadly relevant to most components of the review or highly relevant to a key aspect of the review.

Research Stocktake findings

1. Nursery production biosecurity hazards and threats

Invasive plant pathogens are a serious threat to plants worldwide. They are associated with movement of live plants and plant trade. Spread of pests and pathogens through the movement of live plants has been recognised as a threat for a long time (Brasier, 2008). Of the over 125 taxa listed in the European State Forest Association's (Eustafor) European Database of the Invasive Forest Pathogens (IFPs) (https://www.eustafor.eu/eu-projects/isefor/) 43% are likely to have been introduced through this pathway. Liebhold, et al. (2012) estimated that 70% of all pest and pathogen establishments between 1860 and 2006 in the US likely entered on live plants. They comment specifically on four important forest pests in the US that have moved on this pathway (white pine blister rust (*Cronartium ribicola* J.C.Fisch.), *Phytophthora ramorum*, citrus longhorned beetle (*Anoplophora chinensis*; Coleoptera: Cerambycidae) and *Epiphyas postvittana* (light brown apple moth; Lepidoptera: Tortricidae). *Phytophthora cinnamomi* is causing root rot, dieback and mortality in many nurseries and ecosystems worldwide. Its spread is attributed to movement of nursery stock and soil. Other notable examples of serious diseases resulting from pathogens being introduced to new regions via live nursery plants include chestnut blight, fire blight, Chrysanthemum white rust, sudden oak death and horse chestnut bleeding canker.

Within nurseries, pests and pathogens lower productivity, marketability and price. Control costs increase as biosecurity issues increase. These issues, inadvertent pest spread and profit loss, are important drivers to ensure all nurseries manage biosecurity as well as possible.

Biosecurity risk is changing. New cultivars or genotypes that are either developed domestically or imported open up the opportunity for completely unexpected pest-host associations. For instance, a first record of *Phomopsis* on Limonium was recorded in New Zealand on a Limonium hybrid (Harvey, et al., 2000). The pathogen, which caused foliage discolouration and stem cankers, was described as a new species.

New Zealand is recognised as having the strictest border biosecurity in the world but internal movement of plants is less well managed, with the exception of restrictions on the propagation and movement of notified or unwanted organisms. *Dothistroma* and other pathogens have been moved around the country on nursery stock. The recent arrival of the myrtle rust pathogen has raised concerns about internal

biosecurity and the long distance dispersal of this pathogen through movement of nursery stock. This has created logistical problems for some nurseries and in some cases threatened trade or stock.

There are examples overseas of systems developed to certify nursery stock as pest-free. The USA-based U.S. Nursery Certification Program (USNCP) https://www.aphis.usda.gov/aphis/ourfocus/planthealth/SA_Export/SA_ACNS/CT_Certification, Grower Assisted Inspection Program (GAIP) http://www.oregon.gov/ODA/PROGRAMS/NURSERYCHRISTMASTREE/Pages/GAIP.aspx and the shipping point inspection (SPI) programmes https://digital.osl.state.or.us/islandora/object/osl%3A1547/datastream/OBJ/view or https://www.cdfa.ca.gov/is/i_&_c/spi.html were studied to evaluate their efficacy against Phytophthora root rot, Phytophthora foliar blight, bittercress, snails and slugs, and root weevils (Osterbauer, et al., 2014). No one programme stood out as most effective against all five pests. The study concluded that the systems approach has promise, but more has to be done to be effective against multiple pests.

The above highlights a real need for the plant producer industry to develop and adopt a biosecurity accreditation system that will help protect New Zealand's plants and the industry itself. Based on the (Osterbauer, et al., 2014) study such a system may be possible, but more work has to be done to make it fool-proof.

Brasier, C. M. (2008). The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathol, 57*. doi:10.1111/j.1365-3059.2008.01886.x

Harvey, I. C., Morgan, E. R., & Burge, G. K. (2000b). A canker of Limonium sp caused by Phomopsis limonii sp nov. *New Zealand Journal of Crop and Horticultural Science, 28*(1), 73-77. doi:10.1080/01140671.2000.9514125

Liebhold, A. M., Brockerhoff, E. G., Garrett, L. J., Parke, J. L., & Britton, K. O. (2012). Live plant imports: The major pathway for forest insect and pathogen invasions of the US. *Frontiers in Ecology and the Environment, 10*(3), 135-143. doi:10.1890/110198

[1]Osterbauer, N. K., Lujan, M., McAninch, G., Lane, S., & Trippe, A. (2014). Evaluating the efficacy of the systems approach at mitigating five common pests in Oregon nurseries. *Journal of Environmental Horticulture, 32*(1), 1-7.

2. Nursery essentials

2.1 Nursery details, staff management and responsibilities including staff training and high school and horticultural/forestry student biosecurity training, signage including biosecurity awareness information, audit.

A key requirement for efficient and sustainable nursery operation, especially when considering biosecurity, is the establishment of best-practice standards and guides and their subsequent communication to those in the industry. A biosecurity plan for the plant producer industry is an important means of coordinating biosecurity activities and investments. It provides a mechanism for industry, governments and stakeholders to better prepare for, and respond to, incursions of pests and diseases that could have significant impacts on the nursery industry (Plant Health Australia, 2013). This plan, and its supporting documents, should speak to the biosecurity risks for producers and provide a clear mechanism of identifying and dealing with pest and disease incursions.

Various biosecurity schemes within specific industries - Grafted Grapevine Standard (New Zealand Winegrowers, 2017), The Kiwifruit Plant Certification Scheme (Kiwifruit Vine Health, 2016), High Health Scheme (avocados) (New Zealand Avocado Growers Association, 2017), The strawberry industry's high health programme for viruses has been implemented in New Zealand, which could cumulatively inform a reasonable general framework for New Zealand nursery biosecurity. The Australian, South African and American nursery industries, however, have already implemented multiple cross-industry biosecurity plans and manuals - Biosecurity manual for the nursery production industry (Plant Health Australia, 2010), Industry biosecurity plan for the nursery industry (Plant Health Australia, 2013), BioSecure HACCP: Guidelines for managing biosecurity in nursery production

[1] Key references are in bold

(Nursery & Garden Industry Australia, 2016), Best management practice guidelines (Nursery Industry Accreditation Scheme Australia (NIASA), 2016), Systems approach to nursery certification program (SANC) (National Plant Board, 2016), Nursery certification scheme (Seedling Growers Association of South Africa, 2017) which would be valuable resources to those considering the same scheme and resources for the New Zealand plant producers. Further accreditation and certification schemes also exist in other countries e.g. the United States of America (National Plant Board, 2016) and South Africa (Seedling Growers Association of South Africa, 2017).

Many of these documents identify critical areas of control for biosecurity in nurseries:

2.1.1 Details of the nursery - Careful consideration of crop types, growing media, propagating material, production inputs, water management, nursery waste, cleaning and storage facilities, the movement of machinery and vehicles, and the incursion risks that each of these impose on the nursery, is a vital part of establishing an individual biosecurity management plan for each nursery. A biosecurity plan should address the likely risks from each of these areas in the industry. Pests and diseases can be introduced via nursery inputs like water, growing media, plant containers, fertiliser, plant material and contamination from waste. A biosecurity manual should advise on: how to ensure propagation material is pest and disease free and how, where possible, to use only certified production nursery inputs; how to implement good hygiene during harvesting, sowing, potting, growing and dispatch; as well as hygiene and maintenance of tools, equipment and machinery, limiting the transfer of disease.

2.1.2 **Staff Management and responsibilities** – Staff should all be able to demonstrate biosecurity awareness and hence be provided with adequate training (even available online), supporting information and documentation. Training must be provided to management and employees on a regular basis so that they understand their roles and responsibilities. A list of available national training programmes and training materials, as well as contact and sourcing details, should be provided within the biosecurity manual supplied. Posters and other media provide valuable mechanisms for keep staff aware of high priority pests and diseases and assist in keeping staff vigilant. Staff should also be made aware of tracking their own movements within the nursery, hygiene of their own equipment and their roles in enforcing movement control of plant material, media, equipment, vehicles and outside visitors.

2.1.3 **Signage and registers** – Biosecurity information and requirements should be clearly communicated by means of well-designed signage on entering the nursery grounds. Biosecurity signage should be placed at the main gate, external entrances, visitor parking areas and wash-down facilities. These signs should highlight the potential biosecurity impact staff and visitors could have on the nursery, and refer to hygiene, safety requirements and auditable systems in place. Signs at entrances or near storage facilities should also provide contact details for the nursery manager, directing them to that person before entering the nursery. All staff should undergo and sign an induction on biosecurity and all visitors should formally register their presence before entering any production areas and then undergo an induction too.

2.2 **Audits** – Audits and accreditation/certification provide a valuable means of monitoring and thereby also maintaining biosecurity measures implemented within a nursery and also across the industry.

Kiwifruit Vine Health. *The Kiwifruit Plant Certification Scheme*. Retrieved 01 March, 2018, from http://www.kvh.org.nz/vdb/document/102513

Langford, G. (2015). Running a high-health and trueness-to-type programme. *Acta horticulturae, 1085*, 27-28. doi:10.17660/ActaHortic.2015.1085.5

New Zealand Avocado Growers Association. *NZAGA High health scheme: New Zealand Avocado biosecurity plan*. Retrieved 01 March, 2018, from https://industry.nzavocado.co.nz/industry/biosecurity.csn

New Zealand Winegrowers. *Grafted grapevine standard. Version 3.1.* Retrieved 01 March, 2018, from http://ormondnurseries.co.nz/cms/uploads/pdf/GGS_2017.pdf?v0.1

Nursery & Garden Industry Australia. (2016). BioSecure HACCP: Guidelines for managing biosecurity in nursery production (2nd ed.). Sydney, NSW: Nursery & Garden Industry Australia.

Nursery Industry Accreditation Scheme Australia (NIASA). (2016). *Best management practice guidelines* (6th ed.). Retrieved 01 March, 2018, from http://nurseryproductionfms.com.au/niasa-accreditation/.

National Plant Board. *Systems approach to nursery certification program (SANC)*. Retrieved 01 March, 2018, from http://sanc.nationalplantboard.org/wp-content/uploads/2014/05/SANC-Standard-4-14-14.pdf

Plant Health Australia. *Biosecurity manual for the nursery production industry: Reducing the risk of pests entering and becoming established in your production nursery. Version 1.0.* Retrieved 01 March, 2018, from http://www.planthealthaustralia.com.au/industries/production-nurseries/

Plant Health Australia. *Industry biosecurity plan for the nursery industry. Version 3.0.* Retrieved 01 March, 2018, from https://www.ngia.com.au/Category?Action=View&Category_id=503

Seedling Growers Association of South Africa. *Nursery certification scheme*. Retrieved 01 March, 2018, from http://www.seedlinggrowers.co.za/about/certification

3. Internal quarantine disciplines and biosecurity critical control points

3.1 Pest-free place of production

Nursery environments have historically been shown to aid the propagation of pests and pathogens, including many species that are significant biosecurity concern.

Containerized seedling production provides increased opportunities for improved media sterilisation and hygiene; however, wide-scale nursery surveys throughout Europe suggest many containerised nurseries have similar contamination rates to field-produced plants (Jung, et al., 2016).

Nursery practices contributing to high population densities of *Phytophthora* species include:

- Overly dense plantings;
- The proximity of various plant species enabling cross-infections;
- Reuse of green waste, mulch, compost or plastic containers without sterilization;
- Use of unfiltered surface water or recirculation of irrigation water without filtering or sterilization;
- Storing containerised nursery stock on poorly drained surfaces or even on the ground; and
- Collection of dead plants and plant debris near the production area that can harbour and/or facilitates pests and pathogens.

Jung, T., Orlikowski, L., Henricot, B., Abad-Campos, P., Aday, A., Aguín Casal, O., Bakonyi, J., Cacciola, S., Cech, T., & Chavarriaga, D. (2016). Widespread Phytophthora infestations in European nurseries put forest, semi-natural and horticultural ecosystems at high risk of Phytophthora diseases. *Forest Pathology, 46*(2), 134-163.

3.2 Site requirements, including visitor registration

Accreditation schemes are based on a sound understanding of the biology of the pathogen, and the role of soil and water in its dissemination (Guest, 2004; Pegg, 1978).

Key elements are:

- Preventing the exposure of pots, plants, tools and irrigation hoses to contaminated soil by paving all walkways and surfaces and suppressing dust;
- Placing pots and containers on raised benches, preferably made from galvanised wire mesh;
- Sterilising all pots, containers, and tools, and storing them where there is no chance of contamination by soil or water;

- Using a soil-free or pasteurised growth medium;
- Regularly testing irrigation water sources;
- Regularly inspecting, roguing, containing and destroying diseased plants;
- Quarantining newly acquired propagating material;
- Removal of all weed/pest plants within the nursery site, including along boundary fences to avoid weed seed contamination/alternate host sources;
- Restricting access to all nursery areas to prevent the introduction of contaminated soil, plant materials (e.g. seeds) or water;
- Developing standard operating procedures (SOPs) that outline biosecure hygiene measures;
- Training nursery workers in hygienic practices, including refraining from eating, drinking or smoking in the quarantine area.

Guest, D. I. (2004). *7.2 Nursery Practices and Orchard Management Diversity and Management of Phytophthora in Southeast Asia*. Retrieved 01 March, 2018 https://core.ac.uk/download/pdf/6693118.pdf#page=160.

Pegg, K. (1978). Disease-free avocado nursery trees. *Queensland Agricultural Journal, 104*(2), 134-136.

3.3 Hygiene, waste disposal

A range of international nurseries have been shown to have abundant populations of diverse *Phytophthora* species (Jung, et al., 2005). Planting stock may only be produced according to a 'code-of good-practice' in containers with thermo-sterilized soil and watering material, hygiene practices throughout the production system, and in the absence of all chemical control agents that may suppress pathogen expression.

A wide range of soil-borne plant pathogens, including *Phytophthora* species, are spread globally on healthy looking plants when suppressed by fungicides and fungistatic chemicals, or on non-symptomatic host plants, or as passive hitchhikers on non-host plants (Brasier, 2008). *Phytophthora* may then easily spread into surrounding environments from asymptomatic hosts and infected growing media. Chemically suppressed inoculum may easily enter the surrounding environment where it may be easily diluted, resulting in the activation of previously inactive resting spores (Pérez-Sierra, et al., 2013).

Hygiene enforcement should not prohibit uptake of beneficial procedures. Simple, easy to follow guidelines have been outlined to for managing the threat of *Phytophthora* within developing countries in Southeast Asia (Drenth, et al., 2004). Here researchers have demonstrated the financial benefit of managing *Phytophthora* diseases in nurseries through proper hygiene, compared with disease management with expensive chemicals that may have detrimental impacts on health and safety and the surrounding environment.

Brasier, C. M. (2008). The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathology, 57*(5), 792-808. doi:10.1111/j.1365-3059.2008.01886.x

Drenth, A., & Guest, D. (2004). Phytophthora in the tropics. In Drenth, A. & Guest, D. (Eds.), *Diversity and management of Phytophthora in Southeast Asia.* (pp. 30-41). Canberra, ACT: Australian Centre for International Agricultural Research (ACIAR)

Jung, T., Hudler, G. W., Jensen-Tracy, S. L., Griffiths, H. M., Fleischmann, F., & Osswald, W. (2005). Involvement of *Phytophthora* species in the decline of European beech in Europe and the USA. *Mycologist, 19*(4), 159-166. doi:https://doi.org/10.1017/S0269-915X(05)00405-2

Pérez-Sierra, A., & Jung, T. (2013). Phytophthora in woody ornamental nurseries. In Lamour, K. (Ed.), *Phytophthora: A global perspective* (pp. 166-177). Knoxville, TN: CABI

3.4 Growing media and soil treatment systems

Treatment systems for growing media and soil are not impediments to production. Growing media including soil, water, containers, benches and transporting surfaces should be routinely sterilised, adequately quarantined to prevent recontamination and routinely (statistically representatively) tested for the presence of contamination as per Pegg (1978) and Guest (2004). Consistent hygiene

procedures may require auditing of training procedures and uptake, especially within long-established nurseries that are adapting to new processes.

Adequate heat treatment of soil may follow the procedures outlined in Griesbach, et al. (2012). Soil solarisation can efficiently deactivate inoculum; however, this may be impractical throughout many parts of New Zealand and will require more intensive confirmation of inoculum deactivation (Stapleton, et al., 1986).

Griesbach, J. A., Parke, J. L., Chastagner, G. A., Grünwald, N. J., & Aguirre, J. (2012). Safe Procurement and Production Manual. *Oregon Association of Nurseries, Wilsonville*.

Guest, D. I. (2004). 7.2 Nursery Practices and Orchard Management. *Diversity and Management of Phytophthora in Southeast Asia*, 161.

Pegg, K. (1978). Disease-free avocado nursery trees. *Queensland Agricultural Journal, 104*(2), 134-136.

Stapleton, J., & DeVay, J. (1986). Soil solarization: a non-chemical approach for management of plant pathogens and pests. *Crop protection, 5*(3), 190-198.

3.5 Field production

Nursery plants are recognised as important long-distance vectors of pathogens. It is key that nurseries are able and equipped to prevent introduction of pathogens and to detect pathogens at early stage. Management of pathogens at the nursery is important, as control at grower and wholesaler levels provides the most efficient method for reducing entry of infected plant material into the retail network (Nelson, et al., 2015).

Ideally a nursery will be propagating and growing from pathogen-free or resistant plant material, although this is not always possible. Although plant material can be provided from certified production schemes, these schemes should not be considered to deliver 100% freedom because of factors such as sampling error, test sensitivities, and re-introduction of the pathogen. The most efficient control can be expected through a combination of accredited plant material and good cultivation practice, including strict hygiene (Janse, et al., 2002).

Detection of pathogens can be problematic with infected but asymptomatic plants, root infections and infected pots or media remaining undetected with visual inspection. Detection of, for instance, nematodes in nursery-produced trees must follow strict sampling procedures (Lorrain, 2000). Deliberate scouting for pests and diseases and use of tools to monitor pest populations provide earlier visual detection, allowing greater flexibility in management options (LeBude, et al., 2012), Scouting is time consuming, so sampling strategies are required to provide the needed reliability and efficiency (Bout, et al., 2010) and to provide early information to growers on how crop husbandry practices may contribute to the spread of the disease, e.g. along agronomic rows from previously infected material (Gigot, et al., 2017).

In addition to the movement of plants, pots and media are also transported. The risks of accidentally spreading pests and pathogens in soil and plant samples, including to testing laboratories, have been identified, with testing laboratories encouraged both to implement Hazard Analysis & Critical Control Point (HACCP) practices for sample handling from receipt to disposal and to provide training to staff in pest and disease recognition (Rayment, 2006).

The propagation and growing of new genotypes creates opportunity for previously unknown pathogens e.g. a previously unknown *Phomopsis* species being identified on a new cultivar of a genus in which *Phomopsis* had not previously been reported (Harvey, et al., 2000). Education and training about pests and disease is important as symptoms may not be recognised if growers are not familiar with the disease (Wright, et al., 2016); this survey of grain producers in Australia found growers while aware of endemic pathogens may not be sufficiently aware of (high risk) pests/pathogens they had not previously encountered .

The value of the HACCP approach was demonstrated in work to identify sources of *Phytophthora* infection in nurseries (Parke, et al., 2010; Parke, et al., 2012). Observations from most of the case

studies described by Parke, et al. (2012) were not unexpected, e.g. contamination from previous crops, and easily managed.

Bout, A., Boll, R., Mailleret, L., & Poncet, C. (2010). Realistic Global Scouting for Pests and Diseases on Cut Rose Crops. *Journal of Economic Entomology, 103*(6), 2242-2248.

Gigot, C., Turechek, W., & McRoberts, N. (2017). Analysis of the Spatial Pattern of Strawberry Angular Leaf Spot in California Nursery Production. *Phytopathology, 107*(10), 1243-1255.

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3.6 Propagation and plant husbandry (including crop protection programme)

Biosecurity disciplines are closely coupled to traceability and many nursery accreditation schemes also focus on trueness-to-type. Quarantine issues should be managed not only by producers but by consumers using benchmarking systems in place to help them to recognise that what they are purchasing has been produced to a specification that they can know and recognise. A key element of both requirements is traceability of plants back to original mother plants, through production systems with the necessary information passed to or available to next users (e.g. growers or propagators).

In vitro propagation is generally considered to produce high health plants. Although it offers the opportunity to produce and maintain plants in isolation there is increasing awareness that tissue culture media are designed to grow plants and may not support growth of bacteria endogenous to the plant (Orlikowska, et al., 2017). In at least some cases addenda to the media, e.g., peptone, will support growth of bacteria, allowing repeated non-destructive screening of *in vitro* plants for specific bacteria such as *Pseudomonas syringae* pv. *actinidiae* (Tyson, et al., 2017).

Propagation from good quality planting material, approprate management, excellent sanitation and good record keeping are essential for successful propagation. Good nursery practices then maintain or even enhance the quality of cuttings, but even the best propagation material can be devalued by poor nursery practices. In a review of grapevine propagation (Waite, et al., 2015) identified sanitation and minimisation of stress to plant material as critical to successful propagation. Also important are clearly defined, documented, standardised standard operating procedures that are consistently applied. Although nursery and vine accreditation schemes have been developed, they may lack detail in key areas (Waite, et al., 2015), thus practices can differ between nurseries. Accreditation schemes have or are being developed for a range of crops in a range of jurisdictions, e.g, *Rubus* (USA) (Gergerich, et al., 2016), *Vaccinium* (Tzanetakis, et al., 2016), *Fragaria* (strawberry); (Tzanetakis, 2016). A consistent message is that the development of systems-based approaches is needed to ensure propagation of accredited plants.

Crop protection solutions may not be available for all crops because of lack of authorised agrichemicals, the regular introduction of new crops (or new cultivars), climate change, and other factors. Limitations in the range of chemicals with different modes of action available to growers increase risks of resistance developing when growers can apply only a narrow range of pesticides. Although major crops benefit from access to a diversity of agrichemicals, this is not the situation for smaller, frequently high value, crops.

Uptake of integrated pest management practices (IPM) in the USA has had mixed success (Hoover, et al., 2004). A survey in 2000 was conducted to assess the monitoring and control practices for arthropod pests by the nursery industry. Respondents were typically responsible for the monitoring and pest management decisions for the firm. Most respondents identified the specific insect or mite when monitoring; their ability to do this increased with their level of formal education. Few nurseries kept permanent records of pest problems, although record keeping improved as total sales for the business increased. Cultural control practices included isolating plants for treatment, growing plants hardy to the area, and selling resistant cultivars.

In the EU plant species which may host quarantine pests and diseases require a **plant passport (**https://www.gov.uk/guidance/issuing-plant-passports-to-trade-plants-in-the-eu or https://www.naktuinbouw.com/floriculture/inspections/inspection/plant-passport**).**There are no border controls between member states so emphasis is placed on controls at place of production or at entry to the EU. Plants certified at the place of production are free to move through the EU. A plant passport identifying the grower, and that the plant is eligible to move within the EU, must accompany certain plants.

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3.7 Nursery surveillance, monitoring & recording

Nurseries are strongly implicated in the spread of disease, both to other nurseries and out in the wider environment: within a country and across borders (Gardner, et al., 2006); therefore, careful monitoring by people with the correct knowledge and the ability to exchange knowledge between nurseries and the other related organizations is essential. The support of an efficient diagnostic service that can deliver results rapidly and accurately is also needed.

The need for a coordinated approach among all interested groups is crucial to effective monitoring and surveillance. In Australia the economics of an Area-Wide Management (AWM) system were compared with the 'reliance on the uncoordinated control decisions of farmers' in studies of crop pests, in particular the fruit fly in Queensland, Australia. The AWM, a coordinated approach, was more efficient than increased surveillance (Florec, et al., 2013). Hall (2011) identified that challenges arise with pests and diseases when there is insufficient information on biology and epidemiology, or no effective management.

Nursery staff need to be aware of the diseases that are present in the country and of overseas threats. In an Australian trial when nursery staff were tested on their ability to identify three endemic diseases and four biosecurity threats, it was found that that the ability to identify some of the diseases was dependent on the education of the those doing the surveying (Wright, et al., 2016). Also, establishing a baseline and becoming familiar with symptoms already present is considered important and has been carried out in a number of instances; for example, Knaus, et al. (2015) carried out a survey of Oregon nurseries to characterize the *Phytophthora* species present and in New Zealand a survey was made in Northland sub-tropical nurseries of fungi (Braithwaite, et al., 2006).

Nursery surveys were found to be most effective and efficient when carried out by nursery staff and not independent surveyors (Gardner, et al., 2006) In that study the optimal pest detection method involving surveying and sampling in forest nurseries was determined. A surveyor visited three *Pinus radiata* nurseries once a month and used a shortened 'Forest Nursery and Greenhouse Inspection Protocol'. There were some impediments to relying on surveyors to find symptoms that indicate the presence of pests or pathogens. They were:

- Infected plants may be removed by nursery staff as a sanitation measure to reduce inoculum loading. This will reduce the probability of a surveyor being alerted to the presence of an infected or infested area;
- Chemical application may reduce pest numbers or disease severity and thus mask symptoms but not eliminate the pest or pathogen.

At the time of writing the report it was found that there was high awareness amongst members of the New Zealand Forest Nursery Growers Association of nursery problems and of course, it is in their best interest to report and send in samples of unusual symptoms. It was concluded that surveyors will not be more likely to notice suspect symptoms than nursery staff. For example surveyors missed the relatively subtle change in foliage colour that signals severe root rot. Formal identifications at the Scion diagnostic laboratory are recorded in the 'Forest Health Database' and this provides a valuable record of finds in both the nursery and the forests.

Braithwaite, M., Hill, C. F., Ganev, S., Pay, J. M., Pearson, H. G., & Alexander, B. J. R. (2006). A survey of sub-tropical nursery plants for fungal diseases in Northland. *New Zealand Plant Protection, 59*, 132-136.

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3.8 Transport and Dispatch

Nursery transport and dispatching provides a key control point in the management of pest and disease incursion. Understanding the transport of materials, products and waste to and from the nursery and how to manage these to minimise the risk of an incursion, or spread, is critical. Vehicles and nursery equipment can harbour and transfer pests and diseases, especially through contaminated growing media and plant material. It is therefore imperative that, as part of a biosecurity system, there is a mechanism implemented controlling the movement and sanitation of vehicles and equipment to and from, and within, a nursery. Good sanitation and hygiene practices should be supplied as part of a biosecurity system and should include:

- Vehicle inspections (including crop, media, materials, and cleanliness) before entering the nursery. Checking for the presence of pests, diseased plants, growing media or other soils and foreign plant material. Records of inspections and finds should be maintained;
- Vehicle cleaning (floors and tyres especially), with a disinfecting agent, of dirt which could harbour pests or diseases;
- Washing and disinfecting machinery in a designated zone before moving between areas.
- Not unnecessarily allowing outside vehicles onto the nursery property;
- Keeping nursery vehicle movement to a minimum, especially on wet soil, and sticking to designated pathways;
- Second-hand equipment and machinery being cleaned and disinfected before moving them into a nursery.

3.9 Nursery records and product identification, traceability

An integral part of good nursery biosecurity practice, and a significant component of any management or auditing system, is the maintenance of detailed nursery records. These systems facilitate good hygiene, pest monitoring and traceability. A good record and document control system provides the facility to maintain records for:

- Materials traceability (plant, media, chemicals, waste) – from suppliers through to customer or waste;
- Internal and external audit findings;
- *Ad hoc* pest and disease inspection details and findings;
- Training registers.

This biosecurity traceability allows for the trace-back of infected plant material and other nursery inputs to their source, and also the trace-forward of infected products. In the event of an incursion, these records of surveillance and pest management practices undertaken on the property provide valuable information on how the pest or disease might have entered and also provides evidence that the nursery has taken all necessary steps to try and avoid the incursion.

Records are generally maintained for 2 or more years, and positions responsible for maintaining each record should be assigned to individual staff. An accreditation scheme should provide a list of documents which can be used to meet the traceability standard.

4. Diagnostics and biosecurity risk

4.1 Cost-effective diagnostic tools for assessing plant health status and detecting specific target organisms

The ability to rapidly determine the cause of an observed plant disorder is essential for improved biosecurity and disease management. Diagnostic tools range from commercially available kits that nursery personnel can use, to high-tech diagnostics requiring specific expertise and laboratory-based equipment.

4.1.1 Tools for on-site nursery diagnostics are available (little to some expertise required)

a. Some companies (e.g. Agdia® . https://orders.agdia.com/products or Pocket Diagnostic https://www.pocketdiagnostic.com/) design and supply detection kits specific to organisms of interest including viruses & viroids, bacteria, oomycetes and fungi (e.g. *Phytophthora*, *Fusarium*) and insect. Kits are also available to test plant health status by detection of the plant stress hormone, abscisic acid (ABA). These are useful for simple, field- or nursery- based detection, with no specific expertise required. False-positives can be an issue with some kits, and these types of kits work well with plant material but not with soil. Per sample cost is expensive (approximately $20-30USD per sample). This company can help users to design specific assays for organisms of interest

b. Portable diagnostic systems including portable Polymerase Chain Reaction (PCR) (e.g. recombinase polymerase amplification; RPA) and Loop-mediated isothermal amplification (LAMP)-based systems are designed for in field detection, require increased expertise and specific equipment, which can be costly. For portable PCR and LAMP, assay reagents can obtained in dried pellet form for rehydration and use in the field, making these systems more user-friendly for non-experts. For a comparison of RPA and LAMP using *Phytophthora infestans* -potato pathosystem see Si Ammour, et al. (2017).

Si Ammour, M., Bilodeau, G. J., Tremblay, D. M., Van der Heyden, H., Yaseen, T., Varvaro, L., & Carisse, O. (2017). Development of Real-Time Isothermal Amplification Assays for On-Site Detection of Phytophthora infestans in Potato Leaves. *Plant Disease, 101*(7), 1269-1277. doi:10.1094/PDIS-12-16-1780-RE

4.1.2 Tools for laboratory-based diagnostics (diagnostic expertise required)

Traditional, laboratory-based tools for detecting and identifying microorganisms are typically used in concert with molecular analyses. Traditional methods require typical laboratory and microscopy facilities, access to reference collections (e.g. microorganism and plant), databases and taxonomic expertise. This will be beyond the scope of all but the largest plant producers and therefore has not been considered further. Regardless of the analysis methods used, sound sampling methods are critical. Clear sampling protocols should be provided by diagnostics providers, and these protocols should be adhered to by nursery personnel, to prevent sample degradation and to ensure efficient and accurate outcomes from the diagnostic process.

4.1.2.1 Molecular tools

Molecular tools can facilitate rapid identification of microorganisms present in environmental samples, including soils and plant material. DNA-based data are needed to differentiate species of microorganisms because visual inspections alone are not sufficient for biosecurity (Crous, et al., 2016). There are a number of molecular techniques available, and these are discussed below.

- Extraction and purification of nucleic acids (e.g. DNA or RNA) can be performed in multiple ways including sample collection and extraction from FTA cards, using commercially available kit-based extractions, specific instruments such as PDQeX (https://zygem.com/products/plant-and-agricultural/) or automated systems, such as using in-house automated systems or an external provider for automated processes. The type of sample and molecular tool that will be utilised will dictate the type of extraction procedure used.

- PCR is are the most commonly used technique for species-level identification, quantification, providing a rapid and high-throughput system. PCR targets specific DNA sequences and amplifies (or copies) that piece of DNA to produce millions of pieces, and allowing detection or DNA sequencing. There are different

types of PCR that can be used for different purposes, and these have been reviewed in Porter, et al. (2018).

- Conventional PCR is the traditional end-point PCR method where PCR products, of an expected length, are detected by agarose gel electrophoresis. An example of a conventional PCR is the assay for *Neonectria fuckeliana* (Langrell, 2005).

- Real-time (or quantitative) PCR (qPCR) can be performed using fluorescent dyes or probes (for which multiple types exist). Positive detection of the target is confirmed by detection of florescence at a stage in the reaction (a cycle number) predetermined to be appropriate for that organism and PCR assay, and usually earlier than 30-35 cycles. Examples of qPCR assays commonly used include those for many forest pathogens (Chettri, et al., 2012; Gonthier, et al., 2015; Hunter, et al., 2016; Ioos, et al., 2010; Mulholland, et al., 2015; Schena, et al., 2006; Than, et al., 2013) . Many challenges exist for qPCR-based diagnostics, including clear understanding of the limits of detection for different assays using different instruments and DNA extraction methods, all of which can contribute to variable results. Specific guidelines are available for users in designing and using real-time PCR (Bustin, et al., 2009) and for determining limits of detection (Grosdidier, et al., 2017; Hunter, et al., 2017). A good review of qPCR for detection of fungal and oomycete plant pathogens has been written by Schena, et al. (2013).

- High Resolution Melting (HRM) can differentiate species and strains of a group of organisms based on the melting temperature of DNA fragments amplified using real-time PCR. This method show a great deal of promise for rapid and high-throughput species identification (Zambounis, et al., 2015).

- Methods are available for detecting and simultaneously determining viability (live vs dead) using PCR (Chimento, et al., 2012), which should be considered an essential component to determining risk of new pathogen-host associations.

- Digital droplet PCR (ddPCR) is being used increasingly in a clinical diagnostic setting and its value is now starting to be recognised in diagnostics for biosecurity. Advantages over qPCR include detection of target organisms at very low amounts (single copy) of DNA, and accurate absolute quantification (Gutiérrez-Aguirre, et al., 2015). Guidelines for development and use of ddPCR assays are also available (Huggett, et al., 2013). ddPCR has the potential to contribute to viability testing (Emerson, et al., 2017) and for validation of metabarcoding detected taxa (see below) (Hunter, et al., 2017), but these are yet to be realised.

- DNA sequencing (of amplified PCR products) and the use of DNA-sequence databases for identification are central to any diagnostics programme. DNA sequencing services are available commercially throughout New Zealand and some research institutions also have their own sequencing instruments used in-house. DNA sequences obtained require expertise to critique and analyse and compare with available databases, many of which are free and online and can provide useful information on tentative identifications.

- DNA barcoding uses short DNA sequences of conserved genetic regions for species identification by comparison with a reference sequence. Several case studies demonstrating successful application of DNA barcoding for biosecurity, together with potential limitations, have been described by Hodgetts et al. (Hodgetts, et al., 2016). DNA barcoding has been recently performed for myrtaceous plants in New Zealand (Buys, et al., 2016).

- Genomics-based molecular methods for biodiversity and biomonitoring are now being considered for diagnostics, i.e. high throughput sequencing (HTS)

with environmental DNA or RNA (eDNA or eRNA). These methods allow the simultaneous detection of large numbers of organisms from single samples. Challenges include the large amount of data obtained and processing of this (bioinformatics) to achieve realistic biosecurity outcomes, and confidence in taxonomic assignments. These techniques are reviewed in Porter, et al. (2018).

- Metabarcoding and metagenomics involve the characterisation of microbes present in a given sample using HTS. They have been used for virus and viroid detection (MacDiarmid, et al., 2013), detection of latent or unculturable pathogens (Català, et al., 2016), and surveys for invasive species at ports (Borrell, et al., 2017). Unlike with qPCR, only relative abundance of organisms can be determined. Other reviews of interest include (Abdelfattah, et al., 2017; Pochon, et al., 2017). Metabarcoding has been used to analyse nursery samples (Eberhart, et al., 2017; Prigigallo, et al., 2016).

- Standardised methods for sample extraction, storage amplification and sequencing from environmental samples have been reviewed to overcome potential biases and to ensure comparative analysis is possible between different studies (Lear, et al., 2018).

- To overcome the bioinformatics challenge of specific detection of pathogens from NGS data, the use of E-probes has been proposed (Stobbe, et al., 2013).

- NGS data can aid the development of new diagnostics tests e.g. for *Pseudoperonospora cubensis*, the Cucurbit Downy Mildew Pathogen (Withers, et al., 2016) and an uncultured *Phytophthora* sp. (Català, et al., 2016).

- Luminex technology allows the simultaneous detection of many species of *Phytophthora*, and also to strain level for some species. It can be used for multiple detections from a single environmental sample and does require bioinformatic analysis (Kostov, et al., 2015).

- Broader-screening tools for early characterisation of types of pathogens, e.g. microarrays with genus- and species-specific probes, have been developed for *Phytophthora* plant pathogens (Chen, et al., 2012). These are likely to be superseded by HTS-based methods. A review of microarrays can be found within Porter, et al. (2018).

- Whole-genome sequencing of pathogens, especially using portable devices such as the MinION, are rapidly becoming cheaper and easier to perform and analyse. This work is already underway in human health diagnostics and epidemic situations (Quick, et al., 2017; Quick, et al., 2016) and for in-field plant identifications (Parker, et al., 2017).

All molecular results need to be considered in concert with other diagnostic results such as any culturing or microscopy results and metadata (e.g. host material and symptoms, location) to provide confidence in the results.

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4.2 Ramifications of discovering a new organism or DNA of a new organism

Large volumes of data on an organism's presence can be obtained using several of the molecular tools described above. This often results in the discovery of taxa not previously seen. Understanding the baseline level of biodiversity can be very beneficial in a diagnostic context (i.e. what taxa are already present), but also presents the risk of identifying organisms not previously known to be present, and could cause a degree of caution because of risk to the business of plant producer companies. The ramifications of this situation would range in severity depending on the organism found and the risk associated with that particular detection, but could include requirement for hygiene protocols to be applied, or worst-case scenario market access restrictions, including nursery closure.

Every person is under a general duty (*Biosecurity Act 1993* s. 44) to inform the Ministry for Primary Industries (MPI), as soon as practicable in the circumstances, of the presence of what appears to be an organism not normally seen or otherwise detected in New Zealand. This does not indicate the need to understand or report the risk associated with such detections, nor does it stipulate any differentiation of living, dead, or DNA/RNA-based detection of new organisms. Common sense would dictate that, using the biosecurity knowledge of experts in plant pathology, they could make a judgment call on what is and is not appropriate to report, and to communicate with MPI in situations where there was uncertainty. In practice the surveillance system involves all New Zealanders who have a responsibility to report suspected new pests and diseases. Skill and capability levels range

from those with little to no knowledge of pests and diseases to scientists and industry agronomists with specialist knowledge. Several plant-based industries are signatories to the Government Industry Agreement GIA Deed (http://www.gia.org.nz/About-GIA/The-Act-and-Deed) and run their own awareness programmes.

Upon notification of a suspect exotic pest or disease, MPI will undertake an investigation to rule-in or rule-out the presence of an unwanted organism (*Biosecurity Act 1993*). Incursion Investigators will contact the property owners, or managers, and may in some instances contact the industry body first to establish correct lines of communication, and notification under Government Industry Agreements. Site visits by MPI officers may be arranged to collect samples to confirm identification. Depending on the differential diagnosis (i.e., a list of likely organisms for which the notification may result in a positive identification), pre-emptive measures may be placed on nurseries to prevent potential spread of an unwanted organism (e.g., Restricted Place notice or Direction notice). In most cases, movement controls are not used until diagnostic confirmation is completed by the Plant Health and Environment Laboratory; alternatively, if the notification is from a reputable scientist or laboratory where a true positive is highly likely, movement controls or treatments may be implemented.

Once an Unwanted Organism is confirmed, MPI and the NZPPI will work together to establish the best course of action using the GIA Response Guide (http://www.gia.org.nz/Portals/79/Content/Documents/xHandbookx/GIA%20Response%20Guide%20-%20Interim%20Policy%20-%20December%202014.pdf?ver=2014-12-18-110749-077).
Factors for decision makers include:

- The impact of the Unwanted Organism e.g., high impact pest
- The distribution and hosts of the Unwanted Organism
- The size and throughput of the nursery or nurseries involved
- Availability of suitable tools for detection and treatment of the Unwanted Organism
- Cost:benefit decisions on movement control, and plant and pest / disease treatment
- Regulatory approvals that may be required for treatment and movement control
- Community and stakeholder awareness, consultation, and acceptance.

In some cases the presence of an unwanted organism may not be clear cut, with the investigation into the presence of an Unwanted Organism taking time to clarify the situation. An example is the presence of *'Candidatus* Liberibacter solanacearum' (Lso) in tomatoes in 2008, where glasshouse tomato growers were reporting new and unusual symptoms. Initial investigations identified a bacteria-like organism, and it took some months to determine that a new-to-science species of Liberibacter was being transmitted by the tomato potato psyllid (TPP) and causing poor tomato production as well as affecting potatoes and tamarillo amongst many other potential hosts. This finding was quite rapid compared with the determination of Lso as the causative agent of Zebra Chip potato disease in the United States, which had been grappling with the issue for several years.

New technologies for the detection of high-impact pest DNA are providing the opportunity to detect pests and diseases earlier. However, here the same principles apply as above, where suspect reports of high-pest DNA sequences will lead to investigations to rule-in or rule-out the presence of the pest. For new-to-science pests such as Lso, the degree of risk mitigation is likely to be dependent on the same factors outlined. Are symptoms resulting in production losses, making the plant unsaleable, or do trade issues apply? If yes, then investigations into what is causing the symptoms will need to be undertaken rapidly.

For the nurseries involved, presence of an Unwanted Organism can result in the loss of infected or susceptible hosts. A recent example is the incursion of myrtle rust, which resulted in the destruction of infected hosts. Provisions are available for compensation under s.162A of the *Biosecurity Act 1993* and apply when:

a. Powers under the Act are exercised for the purpose of eradicating or managing an organism; and
b. The powers are not exercised to implement a pest management plan or pathway management plan; and
c. The exercise of the powers causes loss to a person as a result of:
    i. damage to or destruction of the person's property; or

ii. restrictions imposed under [2]Part 6 or [3]7 on the movement or disposal of the person's goods; and

d. There is no agreement under Part 5A[4] that applies to the loss and whose provisions on compensation are expressed to take priority over this section.

The person is entitled to compensation under this section for loss that:

a. Is verifiable; and
b. Is loss that the person has been unable to mitigate by taking every step that is reasonable in the circumstances."

Where a loss is incurred but falls outside what can be compensated under s.162A of the *Biosecurity Act 1993*, the Crown may consider providing an *ex gratia* payment. These are decided on a case-by-case basis (MPI Compensation Brochure https://www.mpi.govt.nz/law-and-policy/legal-overviews/biosecurity/biosecurity-act-compensation/).

One of the reasons for the 162A provisions is to encourage reporting of suspect pests and diseases to MPI.

4.3 Implications of a new organism or DNA discovery in water, soil, plants, shelter crops or neighbouring properties

The discovery of a new organism or DNA can have a range of consequences for the owner or operators from minimal to catastrophic. Under an incursion response scenario as outlined in Section 4.2 they may have to destroy or restrict the movement of plants, soil and / or water, depending on the nature of the pest. For pests that become established, the presence of a new pest or pathogen can affect the types of plant that can be grown through production losses, increased costs through treatment, and loss of integrated pest management programmes. Consequences for the detection of new organisms can result in the imposition of financial and emotional tolls on owners, growers, families and communities.

Support services are available through the (NZPPI), Rural Support Trust (0800 787 254), and through MPI's Adverse events service (https://www.mpi.govt.nz/protection-and-response/responding/adverse-events/) that helps people recover from biosecurity incursions and other adverse events.

MPI's catch-phrase for building resilience is **Prepare – plan – build resilience – work together**, and urges growers to take responsibility to be prepared for adverse events. Further advice includes considering the risks faced from adverse events and to develop strategies to protect family, business, and community. Rural community members need to work together to manage emergencies.

4.4 Molecular technologies – risk and impact

The use of molecular techniques for plant pathogen diagnostics, without a representative culture, or without taxonomic reference isolates and/or DNA, has the potential to identify potential pathogens incorrectly and cause unnecessary alarm. It is of vital importance that methods used are appropriately validated, and used with the correct reference cultures and/or sequences to ensure robust identifications. Techniques can be applied to reduce the error and risk of false identifications (Ficetola, et al., 2015; Vettraino, et al., 2012), and these should be considered in method development (Roenhorst, et al., 2018). In addition, the use of scientific names (including formal descriptions for new species) and molecular data for those reference specimens will also aid biosecurity (Schoch, et al., 2014).

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2 http://www.legislation.govt.nz/act/public/1993/0095/latest/DLM316048.html?search=ts_act%40bill%40regulation%40deemedreg_biosecurity_resel_25_a&p=1#DLM316048

3 http://www.legislation.govt.nz/act/public/1993/0095/latest/DLM316393.html?search=ts_act%40bill%40regulation%40deemedreg_biosecurity_resel_25_a&p=1#DLM316393

4 http://www.legislation.govt.nz/act/public/1993/0095/latest/DLM4758162.html?search=ts_act%40bill%40regulation%40deemedreg_biosecurity_resel_25_a&p=1#DLM4758162

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5. High Risk Pest Modules

5.1 Austropuccinia psidii

Background

Myrtle rust is caused by the pathogen *Austropuccinia psidii*. Originating in South America, this pathogen is now geographically widespread, most recently being reported in New Zealand in 2017. *A. psidii* is an unusual rust, in that it has an extremely wide host range on hundreds of species of Myrtaceae (Pegg, et al., 2014). Host-specificity testing, along with recent molecular population analyses showed that isolates of *A. psidii* grouped into several distinct host-specific lineages (termed biotypes) (Graça, et al., 2013; MacLachlan, 1938). The “Pandemic biotype” has a wide host range on naïve species of Myrtaceae and is now geographically widespread. It is the biotype present in New Zealand. This biotype has caused significant damage in natural and managed systems in Australia where it threatens ecosystems and the local industries that rely on them, such as eucalypt oil, honey, nurseries and gardens, and forestry (Carnegie, et al., 2011; Hood, 2016). A Scopus search suggests that not much research has been done on *A. psidii* in nurseries.

Spread

Wind dispersal of uredinia (asexual spores) is important for the spread of this disease – making containment difficult. However, the movement of nursery plants is also an important pathway, being implicated in its spread from Florida to California, and on to Hawaii (Hood, 2016). Initial spread in Australia was also thought to be due to the unregulated movement of infected nursery plants (before subsequent quarantine and treatment of plants in nurseries (Carnegie, et al., 2011).

Restrictions on the importation of Myrtaceae plant material has been shown to be economically beneficial in Hawaii (Burnett, et al., 2012), even though myrtle rust is already present, as it will lower the chance of the introduction of other strains (Carnegie, et al., 2011; Loope, et al., 2012).

In Australia, quarantine areas were identified where “nursery businesses could choose to have each consignment certified by a Government Regulatory Inspector, or become accredited under the Certification Assurance (CA) arrangement offered by Industry & Investment NSW” (Carnegie, et al., 2011).

Detection
Molecular diagnosis protocols have been developed, which may assist with the detection of symptomless infections (Langrell, et al., 2008).

Other considerations
Other lessons from Australia (Carnegie, et al., 2011):
- They traced nursery stock from infected nurseries – tracing system important
- Destruction of infected batches
- Engagement – specific advice for target groups e.g. nursery industry – eyes on the ground
- Criticism of the emergency response by members of the nursery sector.

It is found in nurseries and amenity plantings in Victoria and Tasmania, but not in native areas (Hood, 2016). Consideration for regeneration of native areas – produce plants on site? Or from seed?

Highly susceptible mature *Syzygium jambos* growing near nursery acted as an inoculum source for infections in the nursery (Soewarto, et al., 2017). Remove susceptible plants from around nurseries?

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5.2 Xylella fastidiosa

Background
Xylella fastidiosa is a xylem-limited phytopathogenic bacterium. It has a broad host range that includes ornamental, ecological and agricultural plants belonging to over 300 different species in 63 different families (Rapicavoli, et al., 2017). To date, *X. fastidiosa* has been found to be pathogenic in over 100 plant species. It is believed to be responsible for disrupting the passage of water and

nutrients, causing symptoms similar to water stress. These symptoms include leaf scorching, wilting, defoliation, chlorosis, and drying, resulting in plant death (De La Fuente, et al., 2013). Additional symptoms of infection include defoliation, dieback and hardening of fruits. Once infected, vine death usually occurs between 1 and 5 years after the plant becomes diseased (Tumber, et al., 2012). *Xylella fastidiosa* can also establish non-symptomatic associations with many plants, residing as a harmless endophyte (Rapicavoli, et al., 2017). Most *X. fastidiosa* strains do not move systemically in symptomless hosts (Hill, et al., 1995b; Purcell, et al., 1999), but these plants might still serve as sources of inoculum (Hill, et al., 1997).

Xylella fastidiosa is transmitted by about 50 species of Auchenorrhyncha belonging to the families Cercopidae (froghoppers), Aphrophoridae (spittlebugs), Cicadellidae (leafhoppers) and Membracidae (treehoppers) (Redak, et al., 2004). After acquisition of *X. fastidiosa* from a source plant, the bacterium persists in the vector (Severin, 1949) and can multiply in the foregut (Brlansky, et al., 1983; Hill, et al., 1995a). Leafhoppers are particularly efficient vectors of *X. fastidiosa*, and the Glassy Winged Sharpshooter (GWSS) is considered the primary vector of *X. fastidiosa* on grapevines. A recent outbreak of the pathogen that has devastated olive groves in Southern Italy, however, has highlighted that *X. fastidiosa* can be vectored by a broad range of insects, leading the European and Mediterranean Plant Protection Organization (EPPO) to note that "all xylem fluid-feeding insects must be considered as potential vectors" (European Food Safety Authority, 2015). In Italy, the spittlebug species *Philaenus spumarius* is the principal vector in olive groves.

Historically, *X. fastidiosa* was limited to the Americas. Indeed, the first report of disease associated with *X. fastidiosa* dates back to the end of the nineteenth century, when 'California vine disease' destroyed about 14,000 ha of grapevines in the Los Angeles area of California in the United States (Pierce, 1892). It wasn't until 1973, however, that the pathogen was identified as the causative agent of the disease (Goheen, et al., 1973; Hopkins, et al., 1973). California vine disease was subsequently renamed Pierce's disease, and shown to span the North American continent. In more recent years, the global spread of *X. fastidiosa* has been dramatic and it has now established throughout Asia and Europe. Indeed, The New Zealand Ministry for Primary Industries (MPI) no longer recognises any countries in Europe, the Americas or the Caribbean, as well as India, Iran, and Taiwan, to be free of *X. fastidiosa.* The spread of *X. fastidiosa* and its associated diseases has been attributed primarily to human activity which introduced infected plant material, or effective insect vectors, to a new region (Almeida, et al., 2015) .

Xylella fastidiosa has a marked capacity to engage in inter-strain recombination that can effectively result in new strains with different host ranges from the original parent strains (Nunney, et al., 2014). At least five different subspecies of *X. fastidiosa* have been reported and classified: *fastidiosa*, *multiplex*, *pauca*, *sandyi*, and *tashket* (Janse, et al., 2010; Randall, et al., 2009; Schaad, et al., 2004). A sixth subspecies (*morus*) has also been proposed (Nunney, et al., 2014), although the existence of yet other subspecies cannot be ruled out as they may have remained hidden, given that most studies of *X. fastidiosa* have focused on cultivated crops of economic importance rather than on less commercially important hosts such as wild grasses, sedges and forest trees (Baldi, et al., 2017)

Nursery impact

The recent spread of *X. fastidiosa* has been attributed largely to the introduction of infected plant material to new regions because of its broad host range and the asymptomatic nature of many interactions between the pathogen and its hosts. Yet the volume of international trade in potential hosts is staggering. For example, *X. fastidiosa* is widespread in Colombia but in 2014 alone, more than 300,000 roses*,* a known host of *X. fastidiosa,* were exported from Colombia (Market Insider, 2015). Recent events in Europe have led the European Food Safety Authority (EFSA) to conclude that focusing on the trade of plants intended for planting and on the presence of infective insects in plant consignments would be the most effective ways of limiting the spread of the bacterium (http://www.efsa.europa.eu/it/press/news/131126)). This has resulted in stringent regulations being enforced across the European Union to restrict movement of plant material into the Union and across its member states. For example, in Southern Italy, no plant material of a known host can be moved out of the demarcated area associated with the olive outbreak, except for grapevine nursery material subjected to hot water treatment. Movement of specified plants out of Corsica and Provence-Alpes-Cote d'Azur (PACA) is currently also not authorised, while the entire territory of Baleares was declared an area under containment on 14 December 2017 and movement of specified plants became prohibited. In June 2016, the German authorities notified an isolated finding of *X. fastidiosa* subspecies *fastidiosa* in a potted plant of oleander located in a greenhouse of a small nursery of Saxony. Since then several other infected potted plants such as rosemary and other hybrid

ornamental plants have been detected in the nursery, leading to all plants from the nursery being destroyed as listed on the latest developments of Xylella fastidiosa in the EU territory put together by the EU (https://ec.europa.eu/food/plant/plant_health_biosecurity/legislation/emergency_measures/xylella-fastidiosa/latest-developments_en).

The risk of introduction through nursery stock has led commercial growers in the United Kingdom to cease buying host plants originating from regions where *X. fastidiosa* is present. At a HTA Ornamentals Management Committee meeting on 13 July 2017, several wholesale nurseries agreed on the following statement: "We have taken the decision not to knowingly purchase any host plants originating from regions where the disease *Xylella* is known to exist. The decision has been taken after detailed consideration as to the potential catastrophic impact the introduction of the disease could have to the UK environment, coupled with the ever increasing number of host plant genera of this disease. This is in line with DEFRA's good practice recommendations" (Appleby, 2017). In future, all professional 'plant operators' in the United Kingdom will require a 'plant passport' to import any known host plant from the EU. Furthermore, if an infection is detected, strict new biosecurity measures will enforce the removal of every known host plant within a 100-metre radius (which could be most of a garden) and even stricter controls on plant movements in the surrounding 10 km zone, which could potentially destroy a local nursery's business and prevent landscaping works on a massive scale.

Uncertainty remains as to the risks associated with cut flowers and tissue culture, as it has yet to be established if X*. fastidiosa* is transferred via tissue culture or whether it can transfer from a cut flower to an insect vector. Nevertheless, according to an article in GrowerNews (http://www.growernews.co.nz/news_article.htm?cat=5&news_id=4404) from 9 March 2017, in New Zealand, imported plants of any known *X. fastidiosa* host derived from tissue culture must enter quarantine for six months over the summer period (i.e. the high growth period) prior to release. Furthermore, one in five [20%] of all plants have to be tested at a cost of $NZ50/plant, meaning that importation of an increasing number of plant species is becoming prohibitively expensive because of this pathogen.

Host range

Xylella fastidiosa's broad host range includes both monocots and dicots (European Food Safety Authority, 2016). Three clades of *X. fastidiosa* have been identified in North America, corresponding to the different subspecies: *X. fastidiosa* ssp. *fastidiosa*, which is found in grapevines, almond and alfalfa; *X. fastidiosa* ssp. *multiplex*, which can be found in almond, peach, plum and oak; and *X. fastidiosa* ssp. *sandyi*, which, thus far, has only been found in oleander. *Xylella fastidiosa* ssp. *pauca* is another subspecies which is primarily found in citrus and coffee in South America (Scally, et al., 2005; Schuenzel, et al., 2005). The strain associated with olive quick decline syndrome (OQDS) in Italy, aptly referred to as the CoDiRo strain (an abbreviation of the Italian name for OQDS), is genetically related to the *pauca* subspecies (Giampetruzzi, et al., 2015; Marcelletti, et al., 2016). Because *X. fastidiosa* causes diseases in economically valuable crops, the occurrence of these epidemics is typically accompanied by substantial economic consequences. The California table, raisin and wine grape industries were valued at $US4.95 billion in 2015 [California Department of Food and Agriculture (CDFA), 2015]. Following the introduction of GWSS into southern California, losses were estimated to be $US37.9 million annually (Siebert, 2001). Citrus Variegated Chlorosis, caused by *X. fastidiosa*, affects all major commercial sweet orange cultivars too (Goncalves et al. 2012). It is considered to be one of the most important diseases affecting the Brazilian citrus industry, which accounts for 30% of sweet orange production and 85% of exports of frozen orange juice concentrate worldwide (Goncalves et al. 2014; Rodrigues et al. 2013). Currently, 40% of citrus plants in Brazil are affected by Citrus Variegated Chlorosis, and economic losses caused by the disease can reach $US120 million annually (Gonçalves, et al., 2012).

Many landscape species such as elms, maples, oaks, oleander and lavender are affected, along with important cropping plants. The known host range of *X. fastidiosa* is expanding rapidly, particularly as the bacterium moves into new areas, where new vectors and plant species are present. Additional information can be found at MPI's http://www.biosecurity.govt.nz/pests/pierces-disease. In New Zealand, *X. fastidiosa* would threaten not only a number of important export food crops and the nursery and ornamental industries, but also a considerable amount of the native flora. The questions remain regarding the susceptibility of the indigenous New Zealand flora (e.g. pōhutukawa, kauri and flax) in addition to important Māori food crops (e.g. sweet potatoes).

Management

Host plants of *X. fastidiosa* can be grouped into three general categories based on the fate of the bacteria within that host: propagative or non-propagative, systemic or non-systemic, and pathological or non-pathological. *Xylella fastidiosa* is able to multiply within a propagative host, move between xylem vessels in systemic hosts, and to cause observable symptoms in a pathological plant host (Purcell, et al., 1999). Nevertheless, at the moment, there is no scientifically validated treatment to cure any plants of the pathogen in 'the field'. Thus, preventing introduction and establishment of *X. fastidiosa* or its vector by regulating importation of potential host material is considered critical to management. With this in mind, a recent risk assessment for *X. fastidiosa* conducted by MPI, identified a number of immediate changes to the nursery stock import health standard (IHS), which were required to strengthen the measures for *X. fastidiosa* on imported host material. These changes led to all consignments with a phytosanitary certificate issued on or after 22 December 2016 requiring an endorsement with a new additional declaration. For consignments already in transit, phytosanitary certificates issued on or before 21 December 2016 were accepted using the previously acceptable additional declaration. For consignments originating in Europe, the America's, Caribbean, Iran, India, or Taiwan, however, the consignment was required to undergo pre-determined testing for *X. fastidiosa* during the Post Entry Quarantine (PEQ) period in New Zealand. These measures were enforced under s. 24B of the *Biosecurity Act 1993*, and required all importers to comply with the new measures.

Potential insect vectors are also considered most likely to be introduced on plant material. Thus, the risks associated with importation of cut flowers or green foliage is reduced by treatment of the consignments and by an integrated approach in production sites free of *X. fastidiosa.* Extant vectors have also been identified as a risk for establishment or spread of this pathogen, upon introduction into New Zealand. For example, a New Zealand-endemic xylem-feeding spittlebug *Carystoterpa fingens* feeds readily on grape (Cabernet Sauvignon), suggesting that grape is a potential host plant for *C. fingens*, and that it is a potential vector of *X. fastidiosa* in grape (Sandanayaka, et al., 2007).

Finally, given asymptomatic infection of host plants is common, early detection of *X. fastidiosa* will be critical in successful management of this pathogen. Unfortunately, classical immunological methods such as ELISA and immunofluorescence are not always sensitive enough, while molecular-based methods, despite their use at the border, are difficult to implement in the field.

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5.3 Fusarium circinatum

Background

Fusarium circinatum is the causal agent of the pine disease known as pitch canker. Pitch canker infections are characterised by the exudation of copious amounts of resin at the site of infection and can result in mortality of the tree, but most commonly suppress growth. The disease is present in a variety of locations globally and is of serious concern to the New Zealand *Pinus radiata* forestry industry.

Pitch canker disease in pines is characterised by exudation of large amounts of resin in response to an infection. All tissue of susceptible hosts: needles, shoots, branches, male and female strobili, seeds, stems and roots, can be infected by *F. circinatum.*

Identification and diagnoses of *F. circinatum* in nurseries can be problematic, as the symptoms (rot root, wilting, damping-off), either separately or together, of pitch canker in young plants are similar to those caused by other fungal diseases (Gordon, et al., 2001; Viljoen, et al., 1994). *F. circinatum* is a seed-borne pathogen and infection can result in the visible deterioration of the seed; however, infected seed frequently display no symptoms until the seed germinates. In some cases, infected seed can germinate and produce symptomless seedlings from which the fungus can be isolated; it is unknown whether such seedlings would eventually show pitch canker disease symptoms (Storer, et al., 1998). The fungus can be present externally in the seed coat or internally within the seed (Gordon, et al., 2001; Storer, et al., 1998).

Fusarium circinatum can also survive in the soil, thus infected seeds that germinate or seedlings growing in infested soil can develop pitch canker-associated root rot or damping-off (Barnard, et al., 1980; Gordon, et al., 2001; Viljoen, et al., 1994). Root rot is characterised by necrotic and undeveloped roots, and damping-off, by collapsing, withered stems or rotting of the germinating seedling. Both pre- and post-emergence mortality is common. In older seedlings, stem cankers can develop from airborne spores or, at the soil level, from infested soil (Gordon, et al., 2001). Like the cankers that develop in larger trees, these lesions are associated with resin flow (Gordon, et al., 2001). A single basal infection can completely girdle the stem, causing severe wilting and can eventually kill the seedling.

Spread

Spores are produced in sporodochia, usually on the branches of their pine host near the needle fascicle, and are released after rain softens the sporodochia. The spores can be dispersed either by wind or in water splash, and maximum dispersal has been found to occur during rain accompanied by turbulent air (Blakeslee, et al., 1979). *Fusarium circinatum* spores can be recovered from the air throughout the year near infected trees (Correll, et al., 1991; Kratka, et al., 1979; Kuhlman, et al., 1982). The first symptoms of pitch canker can occur at any time of the year.

The exact distance air-borne spores can travel is unknown. One study has shown that spores can be detected just over 280 m from a known inoculum source (Garbelotto, et al., 2008). Based on this distance and the knowledge from other pathogen/disease systems on the distribution of spores from an infection site (Aylor, 1999; Holb, et al., 2004), the maximum distance for *F. circinatum* spore dispersal was modelled. Results from this showed a maximum distance of 1300 m. Although spores could travel longer distances than this, the 1300-m distance was cut at a less than 0.01 probability (Möykkynen, et al., 2015).

In addition to airborne and water splash dispersal, *F. circinatum* spores are capable of surviving in soil, needle litter and wood debris (Gordon, et al., 2001; Viljoen, et al., 1994). Studies have shown that the pathogen can survive for several months in wet soil and at least up to one year in dry soil (T.R. Gordon, personal communication, 2004), although it has been reported that isolates of *F. circinatum* have still been viable after three years in soil under refrigeration (Barrows-Broaddus, et al., 1981).

Fusarium circinatum can also be disseminated by animals or insects. This type of spread is not considered important in a nursery setting but can contribute to the dissemination of the pathogen in plantations.

Detection

Fusarium circinatum can be detected by isolation or direct amplification from infected plant material. It is recommended that any cultures isolated should also be confirmed using *F. circinatum* species-specific primers. There are several different species-specific primer sets available.

Other considerations

Fusarium circinatum has been found to be pathogenic to, or reported on, over 60 species of pine. It has also been identified on *Pseudotsuga menziesii*. *Pseudotsuga menziesii* is the only species outside the pine genus that has been shown to be susceptible to *F. circinatum* both in greenhouse experiments and in the field. Low susceptibility to *F. circinatum* has been observed with pre- and post-emergence of *Cupressus macrocarpa* and *Eucalyptus regnans* seed and seedlings in greenhouse experiments (Dick, et al., 2004) but these trees species are not considered susceptible to *F. circinatum*. Recently corn (*Zea mays*) and several grass species (*Briza maxima, Ehrharta erecta* var. *erecta, Pentameris pallida*) have shown to be asymptomatic hosts of *F. circinatum* (Swett, et al., 2015; Swett, et al., 2014). The role these asymptomatic hosts may play in the transmission of the pathogen is unknown.

Fusarium circinatum causes issues in numerous nurseries overseas in countries that have the pathogens. Nursery methods and protocols to minimize and prevent infection, as well as diagnostic procedures, are well established and documented for many countries.

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5.4 Ceratocystis fimbriata

Background

Ceratocystis fimbriata is a xylem pathogen that causes wilt in a large range of annual and perennial species (Harrington, 2004). It is a species complex, each form/type (or in some cases, species) often having a unique host range and geographic distribution (Harrington, 2004; Oliveira, et al., 2015). It has a wide geographic distribution, which includes New Zealand for the *Ipomoea* (sweet potato) form. Other types (species) threaten a huge range of important woody hosts in New Zealand, such as kiwifruit, pōhutukawa, rata, and species of *Eucalyptus*. A Scopus search suggests that not much work has been done on *C. fimbriata* (or on *Ceratocystis* more generally) in nurseries.

Spread

It has several spore types, which allow different methods of dispersal (Harrington, 2004):

1. Ascospores are sticky and sweet smelling, and are dispersed by insects (nitidulid and ambrosia beetles), which vector the spores to fresh wounds.
2. Aleurioconidia are thick-walled and durable spores:
    a. Can survive insect ingestion - spread in wind-blown insect frass
    b. Survive in soil, and in wood fragments in rivers - spread by movement of soil or water.
3. The pathogen can also spread between individuals through root grafts.
4. Important anthropogenic dispersal routes include in cuttings or germplasm (e.g. storage roots of sweet potato), which can remain symptomless in many host species, despite extensive pathogen growth.
5. It can also spread on machetes or pruning tools, or even in wound dressings. Sanitation of this kind of equipment is therefore very important.
6. It may also spread in wooden packaging (and wood e.g. eucalyptus logs and chips),
7. Or on fruits and seedpods.

Movement on live plants

The kiwifruit form is thought to be native to South America and has caused significant damage in Brazil (Ferreira, et al., 2017). It is genetically similar to strains on eucalyptus. It probably spread between farms in cuttings for grafting and in commercial nursery stock – demonstrating the danger of moving symptomless germplasm.

Evidence for the movement of *C. fimbriata* in international trade of vegetative propagated material of a range of hosts (e.g. eucalypts) comes from several other studies (Ferreira, et al., 2011; Ferreira, et al., 2013; Harrington, et al., 2014).

For these reasons MPI now restricts the import of live plants of several species (Ministry for Primary Industries, 2015). However, MPI still allows the import of seed, despite records of the fungus on fruits and seedpods (Harrington, 2004).

Control

Possible methods of control include chemical fungicides (Harrington, 2004), biofungicides (Suleman, et al., 2002) and plant extracts (Somasekhara, 2011). Sanitation of tools is very important, and helped to stop the spread of *C platani* in the USA in the early 20th Century (Harrington, 2004). Heat treatment of wood products and root storage tissues may also kill the pathogen (Harrington, 2004). Control of the trade of live plants is important.

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5.5 Phytophthora ramorum

Phytophthora ramorum emerged in the mid-1990s nearly simultaneously on woody ornamental plants in Germany and has killed millions of oak and tanoak in California since its first detection in 1995. It is believed to have spread initially from a rhododendron nursery in the San Francisco Bay area (Rizzo, et al., 2005). Currently, infection by *P. ramorum* occurs only in Europe and North America, and three clonal lineages are distinguished: EU1, NA1 and NA2. Ancient divergence of these lineages supports a scenario in which *P. ramorum* originated from reproductively isolated populations and underwent at least four global migration events (Grünwald, et al., 2012).

Phytophthora ramorum was the first major 'aerial' — as opposed to root-infecting — forest *Phytophthora* species to be identified, attacking mainly foliage and stems, as does the potato blight,

P. infestans (Brasier, et al., 2010). Subsequently, *P. kernoviae* and *P. pluvialis* were recorded on pine foliage in New Zealand, including on nursery stock for the latter.

Nursery impacts
The Canadian government in the '*Phytophthora ramorum* compensation regulations' (2007) states 'Sudden oak death (*P. ramorum*) has caused great economic hardship for nursery and landscape businesses in those regions where it has become established' (Frankel, 2008).

Host range
Phytophthora ramorum exhibits a remarkably broad range of species, at least in its new invasive behaviour. Outside nurseries, it has infected more than 40 species across 12 families of trees and non-tree hosts in California, and another 40 species in Europe, although only a minority of tree species have proved highly susceptible (Brasier, et al., 2010).

Management
Countries where sudden oak death is not known to occur in forests rely on quarantines and best management practices to prevent introduction. Best management practices and guidelines have been brought together (Frankel, 2008) on the California Oak Mortality Task Force website: http://www.suddenoakdeath.org/diagnosis-and-management/best-management-practices/

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5.6 Phytophthora agathidicida (plus other root *Phytophthora* species – see below)

Kauri is a keystone species within forests of northern New Zealand and a culturally significant taonga species to Maori. Several *Phytophthora* species have been associated with kauri dieback (Horner and Hough 2014), although only *P. cinnamomi* and *P. agathidicida* (Weir, et al., 2015) have been shown to cause tree death directly. Further research is required to determine whether the other species found in the soil beneath kauri contribute to the ill health.

In 1972, a *Phytophthora* species was isolated from an area of dying kauri on Great Barrier Island (Gadgil, 1974). These isolates were identified morphologically as *P. heveae* and were shown to be the causal agent of the observed symptoms using pathogenicity tests. A *Phytophthora* species was isolated from the soil beneath declining kauri in the Waitakere Ranges Regional Park, and Waipoua Forest in the early 2000s, which was identified using molecular phylogenetic analysis as an undescribed species, distinct *from P. heveae*. Re-examination of the Great Barrier isolates using these techniques confirmed the synonymy of the isolates which were termed Phytophthora taxon Agathis (PTA), which was described as *P. agathidicida* in 2015, and which was established as the causal agent of kauri dieback (Weir, et al., 2015).

Spread
Surveillance programmes have recorded tree health and mapped the distribution of kauri dieback and the presence of *P. agathidicida* at multiple locations, particularly within Auckland and Northland. Other *Phytophthora* species were isolated from declining plants, although *P. agathidicida* was the only species isolated from stem cambium (Waipara, et al., 2013). *Phytophthora agathidicida* spread appears to coincide with walking tracks, although further evidence is required to confirm how and where it is spreading through the environment.

Management
Significant work is required to understand the epidemiology of this disease and the impact of environmental factors. Long-term field trials show that chemical treatment with phosphite can manage disease symptoms caused by *P. agathidicida*; however, chemical suppression of symptoms is only temporary, as phosphite is fungistatic and does not directly kill the pathogen at applied rates (Horner, et al., 2013). There are no known procedures to eradicate *P. agathidicida* from infected forests within New Zealand, so prevention of its introduction, including through contaminated plantings, is an important component of the current kauri dieback management protocols as mentioned on the MPI 'Keep Kauir Standing' website (www.kauridieback.co.nz).

Other *Phytophthora* species
Phytophthora species pose significant threats to New Zealand forestry, natural ecosystems, agriculture and horticulture as they:

- Can be quickly dispersed through the soil, water or aerial-borne reproductive structures, or through many human activities (Ristaino, et al., 2000);
- Often have a broad host range infecting exotic and indigenous plant systems, affecting many different species through the deterioration of ecosystems, as observed for *P. cinnamomi* (Hee, et al., 2013);
- Are increasingly being spread internationally through globalisation and plant trade (Scott, et al., 2013);
- Can form new hybrid species within managed and natural ecosystems, which may lead to the rapid generation of new pathogens and diseases (Érsek, et al., 2008);
- Are difficult to identify in asymptomatic host tissues, as observed for *P. ramorum* and *P. kernoviae* (Denman, et al., 2009), or where symptoms have been suppressed with phosphite, as is widely the case with nursery stock (Hardy, et al., 2001).

Denman, S., Kirk, S. A., Moralejo, E., & Webber, J. F. (2009). Phytophthora ramorum and Phytophthora kernoviae on naturally infected asymptomatic foliage. *EPPO Bulletin, 39*(1), 105-111. doi:10.1111/j.1365-2338.2009.02243.x

Érsek, T., & Nagy, Z. (2008). Species hybrids in the genus *Phytophthora* with emphasis on the alder pathogen *Phytophthora alni*: a review. *European Journal of Plant Pathology, 122*(1), 31-39. doi:10.1007/s10658-008-9296-z

Gadgil, P. D. (1974). Phytophthora heveae, a pathogen of kauri. *New Zealand Journal of Forestry Science, 4*.

Hardy, G. E. S. t. J., Barrett, S. R., & Shearer, B. L. (2001). The future of phosphite as a fungicide to control the soilborne plant pathogen *Phytophthora cinnamomi* in natural ecosystems. *Australasian Plant Pathology, 30*, 133-139.

Hee, W., Torreña, P., Blackman, L., Hardham, A., & Lamour, K. (2013). *Phytophthora cinnamomi* in Australia. In Lamour, K. (Ed.), *Phytophthora: A Global Perspective* (pp. 124-134). Oxfordshire, United Kingdom: CAB International.

Horner, I., & Hough, E. (2013). Phosphorous acid for controlling *Phytophthora* taxon Agathis in kauri: glasshouse trials. *New Zealand Plant Protection, 66*, 242-248.

Ristaino, J. B., & Gumpertz, M. L. (2000). New frontiers in the study of dispersal and spatial analysis of epidemics caused by species in the genus *Phytophthora*. *Annual Review of Phytopathology, 38*, 541-576.

Scott, P., Burgess, T., & Hardy, G. (2013). Globalization and Phytophthora. In Lamour, K. (Ed.), *Phytophthora: A Global Perspective* (Vol. 2, pp. 226-232). Oxfordshire, United Kingdom: CABI Plant Protection Series.

Waipara, N., Hill, S., Hill, L., Hough, E., Horner, I., & Zydenbos, S. (2013). Surveillance methods to determine tree health, distribution of kauri dieback disease and associated pathogens. *New Zealand Plant Protection, 66*, 235-241.

Weir, B. S., Paderes, E. P., Anand, N., Uchida, J. Y., Pennycook, S. R., Bellgard, S. E., & Beever, R. E. (2015). A taxonomic revision of phytophthora clade 5 including two new species, phytophthora agathidicida and P. Cocois. *Phytotaxa, 205*(1), 21-38. doi:10.11646/phytotaxa.205.1.2

5.7 Exotic thrips and mites

Thrips (Thysanoptera) are key pests of many greenhouse and outdoor crops worldwide (Lewis, 1997b; Parker, et al., 1995) because of their ability to damage plants directly through feeding and oviposition and indirectly through transmission of plant viruses. Biological attributes such as polyphagy, vagility, rapid reproduction, cryptic behaviour and insecticide resistance make them particularly difficult to manage (Morse, et al., 2006; Mound, et al., 1995).

Thrips are tiny, slender insects with fringed wings belonging to the order Thysanoptera (Mound, 2002). Thrips occur worldwide, with a preponderance of tropical species, numerous temperate species and a few inhabiting cool regions (Lewis, 1997a). While most thrips species are not considered pests, some show all the features (e.g. fast development, extensive host range, rapid development of resistance against pesticides) that predispose them to be major pest species by causing direct feeding damage and by spreading viral diseases to food, fibre and ornamental crops (Brunner, et al., 2010). Several thrips species are the vectors of tospoviruses (Tospoviridae; Bunyvirales), serious plant viruses that can affect a large number of plant species.

Of the 6150 described species of Thysanoptera, fewer than 100 have been recorded as pests around the world. Most of these pest species are localized, but a few are widespread and cause serious crop loss. Some of these species are more serious pests to the nursery industries than others; i.e. they tend to cause greater damage and may feed on a larger number of plant species. In New Zealand, *Thrips tabaci* Lindeman, the polyphagous onion thrips, was the major thrips crop pest for many years. However, the western flower thrips, *Frankliniella occidentalis* (Pergande) from the western USA, was recorded in New Zealand for the first time in 1994 and has become widespread in greenhouses (Teulon, et al., 2005), along with the related European species *Frankliniella intonsa* (Trybom). All three of these species can also cause damage to garden plants and open field crops. While not a pest associated with covered crops in New Zealand, *Heliothrips haemorrhoidalis* (Bouché) is becoming a more common and harmful pest on kiwifruit in New Zealand, especially on smooth-skinned varieties (CABI, 2017; Mckenna, et al., 2009). Serious damage can also occur in other New

Zealand cultivated crops such as avocado and citrus (CABI, 2017) and thrips have also been associated with damage to *Pinus radiata* seedlings (Zondag, 1977).

All the above-mentioned species are introduced into New Zealand. The only native species with any potential as pests are *T. obscuratus* (Crawford), with its very wide host range, and *T. phormiicola* Mound, which was first discovered (but not described) around 1950 during investigations into the future of *Phormium* (native flax) as a fibre crop (Cumber, 1954). *T. obscuratus* is endemic to New Zealand and is an important pest of stonefruit. In spring, feeding by adults and larvae on nectarine ovaries and small fruit results in irregularly shaped blocks of russet, fine scar lines, and fruit distortion. *T. obscuratus* infests nectarines and peaches at harvest, when adults feed and oviposit on the fruit. Feeding damage on mature fruit is usually minor; the main economic concern is contamination of export fruit (Teulon, et al., 1995).

The life cycle of thrips includes an egg, two larval stages that actively feed, followed by two or three non-feeding pupal stages. Eggs are often laid into plant tissue (stems, leaves, flowers or fruits), but some species lay their eggs on the plant surface. Immature thrips (larvae) are similar in appearance to adults, but are generally paler in colour and are always wingless. Many species pupate in soil or leaf litter layers, but some pupate on the plant itself, particularly in flowers and other protected areas on the plant. This has management implications that will be discussed later. The emerging adults are generally winged, but depending on the sex and species, some have short wings and others are wingless. The length of the life cycle depends on environmental conditions and the quality of the food source. In warm conditions, around 30°C, the life cycle can be completed in less than 2 weeks. The same species at 20°C might take 3 weeks to complete the lifecycle.

Identifying thrips in the field is extremely difficult and can only be carried out by an experienced diagnostician with a high-powered microscope; in most cases thrips must be slide-mounted to be identified to species level. Species-level identification is recommended when damage consistently occurs, if management actions fail and occasionally as part of routine monitoring.

Spread

Thysanoptera are limited in their natural ability to spread over a long distance. A number of records, however, show that they are sometimes found far from their original breeding site, after being blown by wind (Lewis, 1973). Thysanoptera are transported with plants over long distances, with cut flowers and propagation material causing the most problems (Vierbergen, 1995). Pest species of thrips can be transported with every green or generative part of a plant and because of their small size and ability to penetrate blooms, they can be extremely difficult to detect without destroying the plant material.

Quarantine measures for Thysanoptera were not considered worldwide until *F. occidentalis* began rapidly dispersing beyond its natural distribution area in the western USA (Vierbergen, 1995). Believed to be predominantly spread via movement of horticultural material, such as cuttings, seedlings and potted plants (Kirk, et al., 2003) this pest spread extensively around the world during the 1980s and 1990s to become a major worldwide pest of agricultural and horticultural crops (Kirk, 2002).
More than half of the 127 thrips species recorded from New Zealand have been introduced from overseas, with many of these are now well established here (Mound, et al., 2017). Eradication of thrips pest post-border is difficult, as they deposit their eggs in the plant tissue and pupate in the soil, making them especially challenging to eradicate (Vierbergen, 1995). However, this is not impossible if they are detected early enough, as shown by the eradication of *Thrips palmi* (Karny) in the United Kingdom in the mid 2000s (Cannon, et al., 2007). Of the thrips species not currently present in New Zealand, a number of them should be considered ‘high risk invaders’ because of their frequent interception in plant material examined at the border or because of the proximity of their established spread to New Zealand. *Thrips palmi* is not currently present in New Zealand, yet its potential introduction represents a continuous threat to glasshouses. *T. palmi* is a polyphagous species, but is best known as a pest of Cucurbitaceae and Solanaceae. Tomato is reported to be a host in the Caribbean, but not in the United States or Japan. Tsai et al. Tsai, et al. (1995) reported that cucurbits were more suitable than eggplant, whereas capsicum was less suitable than eggplant. In Japan, eggplant, cucumber and melon are superior hosts (Kawai, 1990). *Frankliniella schultzei* (Trybom) is another highly polyphagous pest currently not present in New Zealand. *F. schultzei* is known to exploit more than 83 host species belonging to 35 different families of plants (Milne, et al., 2000) and it is one of the major pests of various ornamental and vegetable crops around the globe (Kakkar, et

al., 2012; Palmer, 1990; Vierbergen, et al., 1991). *Thrips palmi* and *F. schultzei* are both also known to transmit a range of tospoviruses. *Frankliniella panamensis* (Hood) is a species frequently intercepted from flowers imported from Colombia into New Zealand, and it is considered a high risk invader. In Colombia it is a pest on greenhouse flowers. Poinsettia thrips, also called impatiens thrips, *Echinothrips americanus*, is another thrips considered to be a high risk invader into New Zealand which can be a risk to greenhouse and nursery-grown plants. It was recently reported from a greenhouse near Auckland, from where it appears to have been eliminated and does not appear to have spread, although affected industries, including plant nurseries, remain vigilant (GrowerNews, 2017). The chilli thrips, *Scirtothrips dorsalis* Hood, is an important pest of various vegetable, ornamental and fruit crops in southern and eastern Asia, Africa, and Oceania (Ananthakrishnan, 1993; CABI/EPPO, 1997) and a potential major pest in vegetable, herb and ornamental production systems in greenhouses. *Scirtothrips dorsalis* also possesses strong viruliferous behaviour for several recorded viruses.

Of the thrips species identified as potential high risk invaders, a number could cause damage to outdoor crops in New Zealand. *Caliothrips fasciatus* (Pergande), was once considered to be a serious pest of a variety of agricultural crops, including alfalfa, beans, cantaloupes, cotton, lettuce, pears, peas and walnuts in California from where it originated (Hoddle, et al., 2006). Another minor pest of leguminous crops overseas and a potential invader is *F. insularis* (Franklin). Highly polyphagous *S. dorsalis* is a pest of economic significance on a number of outdoor-grown crops including citrus, strawberry, grapes, blueberry, and roses. Populations of *S. dorsalis* may show localised specificity. Pinent, et al. (2008) observed *F. schultzei* damaging peach fruit. . Pinent, et al. (2011) recorded *F. schultzei* as the most abundant species on leaves, flowers and fruit of strawberry in Rio Grande do Sul.

In accordance with Ministry for Primary Industries Import Health Standard 155.02.06: Importation of Nursery Stock the following thrips species are regulated (actionable) pests:

AEOLOTHRIPIDAE
Franklinothrips vespiformis [Animals Biosecurity] (Citrus, *Fortunella*, *Poncirus*)

PHLAEOTHRIPIDAE
Haplothrips victoriensis (*Vitis*)

THRIPIDAE
Chaetanaphothrips orchidii (Citrus, *Fortunella*, *Poncirus*)
Caliothrips fasciatus (*Vitis*)
Catinathrips similis (*Vaccinium*)
Catinathrips vaccinicola (*Vaccinium*)
Drepanothrips reuteri (*Vitis*)
Frankliniella bispinosa (*Vaccinium*)
Frankliniella cestrum (*Vitis*)
Frankliniella iridis (*Iris*)
Frankliniella minuta (*Vitis*)
Frankliniella occidentalis [pesticide resistance strain] (*Vitis*)
Frankliniella tritici (*Prunus*, *Vaccinium*)
Frankliniella vaccinii (*Vaccinium*, *Vaccinium macrocarpon*)
Heliothrips sylvanus (*Vitis*)
Leptothrips mali (Citrus, *Fortunella*, *Poncirus*)
Retithrips syriacus (*Persea*)
Rhipiphorothrips cruentatus (*Vitis*)
Scirtothrips aurantii (Citrus, *Fortunella*, *Poncirus*)
Scirtothrips citri (*Poncirus*, *Vitis*)
Scirtothrips dorsalis (Citrus, *Fortunella*, *Fragaria*, *Poncirus*)
Scirtothrips mangiferae (Citrus, *Fortunella*, *Poncirus*)
Scirtothrips ruthveni (*Vaccinium*)
Scolothrips sexmaculatus [Animals Biosecurity] (Citrus, *Fortunella*, *Fragaria*, *Poncirus*, *Vitis*)
Selenothrips rubrocinctus (*Persea*)
Taeniothrips kellyanus (Citrus, *Fortunella*, *Poncirus*)
Taeniothrips vaccinophilus (*Vaccinium*)
Taeniothrips sp. (Citrus, *Fortunella*, *Poncirus*)
Taeniothrips meridionalis (*Prunus*)

Thrips angusticeps (*Prunus*)
Thrips atratus (*Fragaria*)
Thrips coloratus (Citrus, *Fortunella*, *Poncirus*)
Thrips flavus (Citrus, *Fortunella*, *Poncirus*, *Prunus*, *Rubus*)
Thrips major (*Fragaria*)
Thrips palmi (Citrus, *Fortunella*, *Poncirus*)
Thrips tabaci (*Allium*)

While *F. occidentalis* and *T. tabaci* are both established and widely found in New Zealand, they remain regulated (actionable) pests because of the large number of cryptic species within each species complex (Brunner, et al., 2004; Rugman-Jones, et al., 2010). This species complexity, coupled with their ability to harbour and transmit tospoviruses in addition to developing pesticide resistance, makes them a quarantine issue for New Zealand primary sector.

Damage
Thrips feed by rupturing the outer layer of plant cells and sucking up cell contents. This results in scarring, stippling, flecking, russetting or silvering of the leaf surface, scaring of the developing fruit, discolouration and scaring of flowers or distortion of new growth, depending upon where feeding occurs. Faecal droplets, which turn black as mould grows on them, frequently accompany damage. Larvae tend to be more damaging than adults, as they are often in greater numbers and are less mobile than adults. As such, damage is concentrated. Oviposition can also deform developing fruits, e.g. tomatoes. Damage from thrips can also predispose plants to fungal or bacterial infection, allowing a point of entry for the pathogen.

Despite the direct damage that thrips may cause, often the most important economic problem associated with thrips is the ability of a few species to vector tospoviruses (Rotenberg, et al., 2015). Globally, tospoviruses are amongst the most formidable of plant pathogens, causing severe economic losses in a wide range of cultivated crops. Thrips are known to transmit tospoviruses in a persistent propagative manner. Virus acquisition is a developmental stage-dependent phenomenon and only thrips that acquire the virus as larvae are able to transmit the virus. The first instar larval thrips are the most efficient at acquiring the virus, and as they develop, the efficiency of acquisition decreases (Rotenberg, et al., 2015). Adult thrips can acquire tospoviruses, but they do not transmit them. This is presumably because of insufficient multiplication in the midgut, a lack of movement to salivary glands, and a lack of multiplication thereafter (Riley, et al., 2011), all prerequisites for tospovirus transmission (Wijkamp, Van De Wetering, et al., 1996) . In addition, tospoviruses are not transmitted trans-ovarially (Wijkamp, Goldbach, et al., 1996) .

The three known thrips vectors found in New Zealand are associated with the following viruses (* indicates known from New Zealand) (Mound, et al., 2017):

* *Frankliniella occidentalis*: Chrysanthemum stem necrosis virus, Groundnut ringspot virus, Impatiens necrotic spot virus*, Tomato zonate spot virus, Alstroemeria necrotic streak virus, Tomato chlorotic spot virus, and Tomato spotted wilt virus*
* *Frankliniella intonsa*: Chrysanthemum stem necrosis virus, Groundnut ringspot virus, Impatiens necrotic spot virus*, Tomato chlorotic spot virus, and Tomato spotted wilt virus*
* *Thrips tabaci*: Iris yellow spot virus*, Tomato yellow fruit ring virus, and Tomato spotted wilt virus*.

(Prins, et al., 1998) estimated an annual loss worldwide of over $US1 billion from tomato spotted wilt virus alone. Based on 10 years of data from the state of Georgia in the USA, Riley et al. Riley, et al. (2011) estimated annual average losses due to tomato spotted wilt virus to be $12.3 million in peanut, $11.3 million in tobacco, and $9 million in tomato and capsicums, for a total of $326 million from 1996 to 2006. In New Zealand some growers ceased outdoor tomato production because of tomato spotted wilt virus not long after it was first recorded (Chamberlain, 1954). In covered crops producing flowers and in potted plants, tomato spotted wilt virus seems to be almost endemic in some glasshouses, with the main vector being *F. occidentalis* (J. Fletcher, Plant & Food Research, personal communication). In New Zealand, tomato spotted wilt virus is primarily vectored by *T. tabaci* in field tomatoes and peppers, whereas *F. occidentalis* are the primary vector in covered crops producing flowers and potted plants.

Iris yellow spot virus, first reported in New Zealand in 2008 (Ward, et al., 2009), has the potential to significantly affect the horticultural industry in New Zealand. The New Zealand export market of

flowers, plants, seeds and bulbs was ~NZ$100 million in 2003 (Kerr, et al., 2004) and *Zantedeschia* sp., a known host of Iris yellow spot virus, is the country's second largest flower export crop (Elliott, et al., 2009). Iris yellow spot virus is an immediate and serious threat to sustainable and productive onion-cropping systems in the New Zealand, an industry valued at $NZ120 million in 2015 (Statistics New Zealand 2016).

Management

In New Zealand, only a relatively small number of species are considered pests. Of these some are more serious pests to the production nursery industry than others; i.e. they tend to cause greater damage and may feed on a larger number of plant species. Dominate, polyphagous and widespread pest species such as *T. tabaci* and *F. occidentalis* are major concerns to the New Zealand nursery sector.

Plants susceptible to thrips damage should be inspected on a weekly basis for the presence of thrips and data recorded, preferably electronically. The frequency of monitoring should be increased during expected periods of infestation, spring and summer, particularly during periods with strong winds. Frequent monitoring will enable infestations to be spotted while they are still light, and thus easier and cheaper to manage. Methods of monitoring may include visual inspection and yellow sticky traps. A 10-20x hand lens is needed to distinguish the adult thrips from grains of peat moss or other debris. Foliage or flowers can also be tapped over a sheet of white paper to detect adult and larval thrips in the crop. Pest exclusion, or preventing pests from becoming established, is the most important step in avoiding pest problems. It is recommended to put in place as many cultural management practices as possible, such as inspection of thrips on incoming stock, remove and destroy heavily infested stock, control and reduce alternative hosts/weeds (identified through monitoring) in the production area and surrounds. Insect screening on openings such as vents and doors may also reduce the influx of thrips from outside; however, careful design and maintenance is needed to avoid issues in the form of restricted airflow. Tighter weaved screens are necessary to prevent the penetration of thrips. Building a screened foyer to create a double-door entry can partially solve the problems with insects like thrips being blown into the greenhouse. These actions reduce pest pressure passively, reducing the number of thrips that occur in each crop.

Once a thrips infestation is detected and identified, control options using biological control and pesticides may be needed. Commercially available predatory mites may be a good first option for managing thrips populations, since many thrips species inhabit protected regions of plants, within flowers, growing tips and leaf curl galls and the mites can get into these spaces to prey on thrips. Also, the small protected spaces thrips inhabit on plants create a major problem for the control of thrips with pesticides, since it is very difficult to reach them when they live deep inside flowers and other narrow crevices. For this reason, contact pesticides are likely only to have a strong impact on those species that mostly are on the leaf surface, unprotected. For all other thrips, systemic or translaminar products are required. Populations of some species of thrips can develop pesticide resistance quite rapidly, most notably *T. tabaci* and *F. occidentalis*. For this reason, it is important to rotate between mode-of-action chemical groups and to cease the application of products that have been ineffective. Most products registered against thrips relevant to production nurseries are organophosphates or synthetic pyrethroids (Novachem, http://www.novachem.co.nz/). If thrips are likely to cause economic damage, it is important to apply a product on multiple occasions within a short period of time, i.e. at least weekly for three weeks. This will assist in breaking the lifecycle for those species that pupate in growing media or are otherwise protected from the pesticide application. For *F. occidentalis,* research have shown that three consecutive sprays at 3- to 5-day or 6- to 12-day intervals, depending on temperature, are recommended, then switching to a product with a different mode of action after 2-3 weeks. When using pesticides, read the label carefully and follow instructions to ensure insecticides are used correctly and for maximum efficacy. Do not continue to apply insecticides that are not effective in controlling the thrips population; this will increase insecticide resistance.

Identifying thrips in the field is extremely difficult and can only be carried out by an experienced diagnostician with a high-powered microscope; in most cases thrips must be slide-mounted to be identified to species level. Species-level identification is recommended when damage consistently occurs, if management actions fail, and occasionally as part of routine monitoring. This can allow access to additional information that may be specific to the management of the particular species in the crop, e.g. alternate host plants seasonality and pesticide efficacy.

In regards to using biological control agents for thrips management, only a very small number of products are currently commercially available in New Zealand. There are predators available commercially that feed on thrips on foliage: the predatory pirate bug *Orius vicinus* (Bioforce Limited), and two predatory mite species *Amblydromalus* (Typhlodromalus) *limonicus* (Bioforce Limited, Zonda Biologicals) and *Neoseiulus cucumeris* (formerly *Amblyseius cucumeris*) (Bioforce Limited, Zonda Biologicals) .

As mentioned above, the most important economic problem associated with thrips is the ability of a few species to vector tospoviruses. Plants cannot be cured once infected by a virus. Instead, disease control aims to prevent or delay the infection of plants. No single method is likely to provide good control, and integrating multiple measures will generally be more successful. Based on information published by Nursery and Garden Industry Australia Limited (https://www.ngia.com.au/Attachment?Action=Download&Attachment_id=1844), the methods used to manage virus diseases can be grouped under the following headings:

Exclusion/avoidance

* Quarantine (international and regional)
* Plant virus-free seed
* Grow crops in regions where the disease seldom occurs or during periods when the virus or its vector (i.e. thrips species) are at low numbers
* Grow crops in insect-proof protected structures.

Reduction in virus inoculum levels

* Control weeds and other hosts of viruses and insect vectors in and around crops
* Destroy old crops promptly
* Physical separation of new crops from maturing crops and avoiding overlapping crop.

Nursery impact

The impact of thrips and any viruses they can vector could be quite severe to the nursery industry in New Zealand. In the case of the eradication of *T. palmi* in the United Kingdom, the benefit:cost ratios for eradicating and maintaining exclusion ranged from 4:1 to 19:1 if there was no loss of export, and from 95:1 to 110:1 if significant export losses resulted from *T. palmi* establishment (MacLeod, et al., 2004). Where management of thrips pests relies heavily on insecticides, the limited number registered for thrips pests in nursery crops increases the chances of control failures occurring through insecticide resistance. Alternative strategies that will provide longer-term management are needed, including: a better understanding of how commercially available biological control agents can be integrated into crop management, the development of novel management strategies that exploit behavioural response of thrips to olfactory and visual cues (e.g. push-pull, mass trapping, lure and infect), and the availability of more selective insecticides (i.e. those with reduced impact on the environment and non-target insects) for thrips management.

Exotic mites

Exotic mites include some important pests of economic concern to horticulture and forestry. MPI's Import Health Standard for Nursery Stock list all the regulated pests of concern and requires that all whole plants and cuttings must be treated for insects and mites, unless stated otherwise in the "schedule of special conditions**".**

Manners (2015) provides a good overview of the range of mites that commonly can cause damage to plants, how they can be identified and effectively managed.

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5.8 Dothistroma septosporum

Background

Dothistroma needle blight is caused by *Dothistroma pini* and *D. septosporum*. Only the latter is recorded in New Zealand. It is a serious disease of pines worldwide and it estimated to cause loss of over $NZ20 million per year to the New Zealand forest industry. Spread of *Dothistroma* via nursery stock has been recorded here and overseas. In the mid-1960s *Dothistroma* was found in Esk Forest in Hawke's Bay. The spread was due to planting contaminated seedlings imported from an infected area. In 1966, *Pinus contorta* seedlings infected by *Dothistroma* were exported from a Kaingaroa nursery and planted in a shelterbelt in northern Southland. In April 1967, dothistroma needle blight was detected there and the entire shelterbelt of about 2,000 trees was destroyed and the disease eradicated. *Dothistroma* spp. may spread via natural means, but the plant trade has also had a very significant role in long-distance spread (EFSA Panel on Plant Health, 2013). An outbreak in England in the 1980s was traced back to *P. contorta* and *Pinus nigra* subsp. *laricio* planting stock from a nursery where infection had been found in the 1950s (Murray, et al., 1962);(M. S. Mullett, personal communication, July 10, 2013). Bednářová, et al. (2006) attributed spread of *Dothistroma* in Europe to movement of nursery stock.

Mitigation

Forest nurseries in New Zealand recognise that it is poor practice to produce planting stock with visible dothistroma disease symptoms. Two tactics are used to reduce disease in seedlings: hygiene and chemical control. Whenever possible all old stock is removed to prevent a build-up of inoculum. Close stocking in nursery seedbeds is discouraged because it leads to high infection rates that serve as inoculum sources for nearby healthy seedlings. Copper is applied monthly or every six weeks from October to March.

In Britain and Slovenia, all *Pinus* nursery plants are inspected for dothistroma needle blight during the peak infection period. If found, all affected stock is destroyed and restrictions are placed on the movement of stock from that nursery. In Switzerland, distribution of *Pinus* is banned from an infected nursery until no dothistroma needle blight has been detected for an entire growing season.

Movement restriction

In Scotland, infected seedlings were found in two nurseries in 2010. There was concern that movement of that infected stock would introduce a new genotype into the pathogen population and through recombination result in a more virulent type. This put 5 million seedlings under threat of destruction and the financial viability of the nurseries was also in doubt. After consideration a compromise solution was reached. It was agreed that:

- All seedlings with visible disease would be destroyed
- Seedlings within 550 metres of infected beds would be planted in Scotland only
- Seedlings more than 550 metres away would have no movement restrictions.

Bednářová, M., Palovčíková, D., & Jankovský, L. (2006). The host spectrum of Dothistroma needle blight Mycosphaerella pini E. Rostrup–new hosts of Dothistroma needle blight observed in the Czech Republic. *Journal of Forest Science, 52*(1), 30-36.

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5.9 Nematodes

Nematodes are simple, worm-like, multi-cellular microscopic animals. They feed on other microorganisms and plants and some are serious human and animal pathogens. Plant parasitic nematodes may attack the roots, stem, foliage and flowers of plants.

Nematode attack causes root galls or lesions, excessive branching and/or root stunting. The plant may wilt, yellow or suffer defoliation or leaf stunting..

Parasitic nematodes are readily spread by any physical movement of soil via equipment, tools, or shoes; or birds, insects, and water. Plant movement is an important mode of spread.

Nurseries are often common points for infestation and it is almost impossible to eradicate nematodes from them. However, nematodes can be controlled by a number of methods to reduce loss and spread elsewhere.

- Planting resistant species and cultivars.
- Use nematode-free nursery stock for planting.
- Keep hygiene standards high, i.e. storage and benches clean.
- Crop rotation will inhibit build up of nematode populations, especially single species.
- Soil treatment fumigants or nematicides before planting can be effective.

Nematodes are not recognised as a problem in New Zealand forest nurseries and populations are generally low. Pine wilt nematode causes significant problems in some pine species overseas but on pines that have grown well beyond seedling stage. The nematode also needs an insect vector to introduce it to the host. Varying levels of damage have been recorded in glasshouses and nurseries over the years in New Zealand but systematic surveys have not been conducted. Their biosecurity significance has not been determined and as such will not be considered further in this research stocktake.

6. Other areas of innovation that serve to facilitate plant producer biosecurity risk management.

No innovative biosecurity risk mitigation measures were found.

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Appendix A – Information summary

1. Nursery production biosecurity hazards and threats

Headings	Facts	Key words	Reference
Nursery production risk	Live plants are a key pathway for movement of pathogens and pests	Nursery production, biosecurity, hazards, Phytophthora, pathway risk	Brasier, C. M. (2008). The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathol, 57*. doi:10.1111/j.1365-3059.2008.01886.x
Biosecurity	Risk is dynamic	New disease records	Harvey, I. C., Morgan, E. R., & Burge, G. K. (2000b). A canker of Limonium sp caused by Phomopsis limonii sp nov. *New Zealand Journal of Crop and Horticultural Science, 28*(1), 73-77. doi:10.1080/01140671.2000.9514125
Risk in New Zealand	NZ has an excellent biosecurity system		
	Movement of pathogens still takes place domestically	*Dothistroma* Myrtle rust	Liebhold, A. M., Brockerhoff, E. G., Garrett, L. J., Parke, J. L., & Britton, K. O. (2012). Live plant imports: The major pathway for forest insect and pathogen invasions of the US. *Frontiers in Ecology and the Environment, 10*(3), 135-143. doi:10.1890/110198
Nursery accreditation	There is no systems approach that will eliminate risk	Systems approach, biosecurity inspection	Osterbauer, N. K., Lujan, M., McAninch, G., Lane, S., & Trippe, A. (2014). Evaluating the efficacy of the systems approach at mitigating five common pests in Oregon nurseries. *Journal of Environmental Horticulture, 32*(1), 1-7.

2. Nursery essentials

Headings	Facts	Key words	References
Existing generic accreditation schemes	Most lack detail	Biosecurity accreditation	Plant Health Australia. *Biosecurity manual for the nursery production industry: Reducing the risk of pests entering and becoming established in your production nursery. Version 1.0.* Retrieved 01 March, 2018, from http://www.planthealthaustralia.com.au/industries/production-nurseries/

			Plant Health Australia. *Industry biosecurity plan for the nursery industry. Version 3.0.* Retrieved 01 March, 2018, from https://www.ngia.com.au/Category?Action=View&Category_id=503 Nursery & Garden Industry Australia. (2016). BioSecure HACCP: Guidelines for managing biosecurity in nursery production (2nd ed.). Sydney, NSW: Nursery & Garden Industry Australia. Nursery Industry Accreditation Scheme Australia (NIASA). (2016). *Best management practice guidelines* (6th ed.). Retrieved 01 March, 2018, from http://nurseryproductionfms.com.au/niasa-accreditation/. National Plant Board. *Systems approach to nursery certification program (SANC)*. Retrieved 01 March, 2018, from http://sanc.nationalplantboard.org/wp-content/uploads/2014/05/SANC-Standard-4-14-14.pdf Seedling Growers Association of South Africa. *Nursery certification scheme*. Retrieved 01 March, 2018, from http://www.seedlinggrowers.co.za/about/certification
Existing specific accreditation schemes	Useful for a general framework	Biosecurity accreditation	New Zealand Winegrowers. *Grafted grapevine standard. Version 3.1.* Retrieved 01 March, 2018, from http://ormondnurseries.co.nz/cms/uploads/pdf/GGS_2017.pdf?v0.1 Kiwifruit Vine Health. *The Kiwifruit Plant Certification Scheme*. Retrieved 01 March, 2018, from http://www.kvh.org.nz/vdb/document/102513 New Zealand Avocado Growers Association. *NZAGA High health scheme: New Zealand Avocado biosecurity plan*. Retrieved 01 March, 2018, from https://industry.nzavocado.co.nz/industry/biosecurity.csn

			The Strawberry Industry's high health programme for viruses
Critical areas of control	Nursery details, staff responsibilities, Signage and registers, Audits		New Zealand Winegrowers. *Grafted grapevine standard. Version 3.1.* Retrieved 01 March, 2018, from http://ormondnurseries.co.nz/cms/uploads/pdf/GGS_2017.pdf?v0.1 Kiwifruit Vine Health. *The Kiwifruit Plant Certification Scheme*. Retrieved 01 March, 2018, from http://www.kvh.org.nz/vdb/document/102513 New Zealand Avocado Growers Association. *NZAGA High health scheme: New Zealand Avocado biosecurity plan*. Retrieved 01 March, 2018, from https://industry.nzavocado.co.nz/industry/biosecurity.csn Langford, G. (2015). Running a high-health and trueness-to-type programme©. Acta Hortic. 1085, 27-28. DOI: 10.17660/ActaHortic.2015.1085.5

3. Biosecurity critical control points

Headings	Facts	Key words	References
Pest-free place of production	Containerised nurseries have similar contamination rates to field-produced plants	Pests, pathogens	Jung, T., Orlikowski, L., Henricot, B., Abad-Campos, P., Aday, A., Aguín Casal, O., Bakonyi, J., Cacciola, S., Cech, T., & Chavarriaga, D. (2016). Widespread Phytophthora infestations in European nurseries put forest, semi-natural and horticultural ecosystems at high risk of Phytophthora diseases. *Forest Pathology, 46*(2), 134-163.
Site requirements	Mitigation of spread depends on	*Phytophthora*	Pegg, K. (1978). Disease-free avocado nursery trees. *Queensland Agricultural Journal, 104*(2), 134-136

	understanding the biology of the pest		
	There are many sources of contamination		Guest, D. I. (2004). *7.2 Nursery Practices and Orchard Management Diversity and Management of Phytophthora in Southeast Asia*. Retrieved 01 March, 2018, from https://core.ac.uk/download/pdf/6693118.pdf#page=160.
Hygiene, Waste disposal	Many nurseries have abundant populations of *Phytophthora* species in soil. Simple, easy to follow hygiene guidelines have been documented.	*Phytophthora*, waste, nursery hygiene	Brasier, C. M. (2008). The biosecurity threat to the UK and global environment from international trade in plants. *Plant Pathology, 57*(5), 792-808. doi:10.1111/j.1365-3059.2008.01886.x Drenth, A., & Guest, D. (2004). Phytophthora in the tropics. In Drenth, A. & Guest, D. (Eds.), *Diversity and management of Phytophthora in Southeast Asia.* (pp. 30-41). Canberra, ACT: Australian Centre for International Agricultural Research (ACIAR)
Growing media and soil treatment systems	Media and soil treatment systems for growing may not impede production.	Growing media, soil treatment	Pegg, K. (1978). Disease-free avocado nursery trees. *Queensland Agricultural Journal, 104*(2), 134-136 Guest, D. I. (2004). *7.2 Nursery Practices and Orchard Management Diversity and Management of Phytophthora in Southeast Asia*. Retrieved Retrieved from https://core.ac.uk/download/pdf/6693118.pdf#page=160.
Field production	Well managed, deliberate and planned monitoring/scouting programmes needed for pest and disease management	Pests, pathogens monitoring,	Bout, A., Boll, R., Mailleret, L., & Poncet, C. (2010). Realistic Global Scouting for Pests and Diseases on Cut Rose Crops. *Journal of Economic Entomology, 103*(6), 2242-2248 LeBude, A. V., White, S. A., Fulcher, A. F., Frank, S., Klingeman, W. E., III, Chong, J.-H., Chappell, M. R., Windham, A., Braman, K., Hale, F., Dunwell, W., Williams-Woodward, J., Ivors, K., Adkins, C., & Neal, J. (2012). Assessing the integrated pest management practices of southeastern US ornamental nursery operations. *Pest Management Science, 68*(9), 1278-1288.

			Lorrain, R. (2000). Nematodes in walnut tree nurseries. Realistic preventive measures are absolutely essential. *Phytoma*(524), 38-39
	Education on identifying pest and disease is needed	education	Wright, D., MacLeod, B., Hammond, N., & Longnecker, N. (2016). Can grain growers and agronomists identify common leaf diseases and biosecurity threats in grain crops? An Australian example. *Crop protection, 2016 v.89*, pp. 78-88. doi:10.1016/j.cropro.2016.07.005
	Systematic processes such as HACCP are important	HACCP	Parke, J. L., & Grünwald, N. J. (2012). A Systems Approach for Management of Pests and Pathogens of Nursery Crops. *Plant disease, 96*(9), pp. 1236-1244. doi:10.1094/pdis-11-11-0986-fe
Propagation and husbandry	Tissue culture is not a guarantee of pathogen-free plants	Tissue culture	Orlikowska, T., Nowak, K., & Reed, B. (2017). Bacteria in the plant tissue culture environment. *Plant Cell Tissue and Organ Culture, 128*(3), 487-508. doi:10.1007/s11240-016-1144-9
	Accreditation schemes may contain insufficient detail	Accreditation	Waite, H., Whitelaw-Weckert, M., & Torley, P. (2015). Grapevine propagation: principles and methods for the production of high-quality grapevine planting material. *New Zealand Journal of Crop and Horticultural Science, 43*(2), 144-161
	Uptake of technologies can be slow, with better resourced nurseries better able to utilise them	IPM	Hoover, K., Sellmer, J. C., & Ostiguy, N. (2004). Survey of the monitoring and control practices for arthropod pests by the nursery industry in Pennsylvania. *Journal of Environmental Horticulture, 22*(1), 5-11.
Nursery surveillance, monitoring & recording	Nursery staff need to know the diseases/pests that are present and key overseas threats. Surveys are most effective and efficient when carried out by	Surveillance, biosecurity, field pest identification	Braithwaite, M., Hill, C. F., Ganev, S., Pay, J. M., Pearson, H. G., & Alexander, B. J. R. (2006). A survey of sub-tropical nursery plants for fungal diseases in Northland. *New Zealand Plant Protection, 59*, 132-136. Florec, V., Sadler, R. J., White, B., & Dominiak, B. C. (2013). Choosing the battles: The economics of area wide pest management for Queensland fruit fly. *Food policy, 2013 v.38*, pp. 203-213. doi:10.1016/j.foodpol.2012.11.007

	nursery staff and not independent surveyors. Often symptoms may be masked by removal of diseased plants or chemical control but low levels of contamination remain.		Hall, B. H. (2011). New challenges for pest and disease management in olive orchards and nurseries *Acta Horticulturae* (pp. 127-135). Knaus, B. J., Fieland, V. J., Graham, K. A., & Gruenwald, N. J. (2015). Diversity of Foliar Phytophthora Species on Rhododendron in Oregon Nurseries. *Plant Disease, 99*(10), 1326-1332. Wright, D., MacLeod, B., Hammond, N., & Longnecker, N. (2016). Can grain growers and agronomists identify common leaf diseases and biosecurity threats in grain crops? An Australian example. *Crop protection, 2016 v.89*, pp. 78-88. doi:10.1016/j.cropro.2016.07.005

4. Diagnostics and biosecurity risk

Headings	Facts	Key words	Reference
Diagnostics (field-based)	Expertise not critical, identifications may be less accurate	Immunostrips, portable diagnostic devices	Si Ammour, M., Bilodeau, G. J., Tremblay, D. M., Van der Heyden, H., Yaseen, T., Varvaro, L., & Carisse, O. (2017). Development of Real-Time Isothermal Amplification Assays for On-Site Detection of Phytophthora infestans in Potato Leaves. *Plant Disease, 101*(7), 1269-1277. doi:10.1094/PDIS-12-16-1780-RE Agdia, Inc., http://www.agdia.com/
Diagnostics (lab-based)	Baseline biota identification, accurate identifications, high-level expertise required, potentially expensive	eDNA, PCR, qPCR, digital PCR	Mumford, R. A., Macarthur, R., & Boonham, N. (2016). The role and challenges of new diagnostic technology in plant biosecurity. *Food Security*. doi:10.1007/s12571-015-0533-y Porter, T. M., & Hajibabaei, M. (2018). Scaling up: A guide to high throughput genomic approaches for biodiversity analysis. *Molecular Ecology*, n/a-n/a. doi:10.1111/mec.14478

Detection of a new organism or DNA of a new organism	General duty (s. 44 *Biosecurity Act 1993*) to inform the Ministry for Primary Industries, as soon as practicable in the circumstances, of the presence of what appears to be an organism not normally seen or otherwise detected in New Zealand Determination of new organism or hazardous substance (s. 26 *Hazardous Substances and New OrganismsAct 1996*)	Duty to notify Unwanted Organism New Organism	*Biosecurity Act 1993* http://www.legislation.govt.nz/act/public/1993/0095/latest/DLM314623.html?search=qs_act%40bill%40regulation%40deemedreg_biosecurity+act_resel_25_h&p=1&sr=1 *Hazardous Substances and New Organisms Act 1996* http://www.legislation.govt.nz/act/public/1996/0030/latest/DLM381222.html?search=qs_act%40bill%40regulation%40deemedreg_hazardous_resel_25_h&p=1&sr=1
Implications of a new organism or DNA of a new organism	Part 6 Administrative provisions and **Powers** (*Biosecurity Act 1993*) 97A Enforcement of Act in respect of new organisms (HZNO Act 1996) (1) The enforcement agency must ensure that the provisions of this Act are enforced in respect of new organisms	Power to give directions Declaration of a restricted place Declaration of controlled area	*Biosecurity Act 1993* http://www.legislation.govt.nz/act/public/1993/0095/latest/DLM314623.html?search=qs_act%40bill%40regulation%40deemedreg_biosecurity+act_resel_25_h&p=1&sr=1 *Hazardous Substances and New Organisms Act 1996* http://www.legislation.govt.nz/act/public/1996/0030/latest/DLM381222.html?search=qs_act%40bill%40regulation%40deemedreg_hazardous_resel_25_h&p=1&sr=1 Government Industry Agreement Response Guide

	(2) For the purpose of complying with subsection (1), the enforcement agency may appoint enforcement officers in accordance with this Act who may exercise also the **powers** of inspectors under the Biosecurity Act 1993 that may be exercised in respect of an unwanted organism, and the provisions of that Act apply with all necessary modifications		http://www.gia.org.nz/Portals/79/Content/Documents/Resource-Library/GIA%20Response%20Guide.pdf?ver=2016-06-27-140714-970

5. High Risk Pest Modules (to be completed)

Headings	Facts	Key words	Reference
Myrtle rust, *Austropuccinia psidii*			Burnett, K., D'Evelyn, S., Loope, L., & Wada, C. A. (2012). An economic approach to assessing import policies designed to prevent the arrival of invasive species: the case of Puccinia psidii in Hawai'i. *Environmental Science & Policy, 19-20*, 158-168. doi:https://doi.org/10.1016/j.envsci.2012.03.006 Carnegie, A. J., & Cooper, K. (2011). Emergency response to the incursion of an exotic myrtaceous rust in Australia. *Australasian*

			Plant Pathology, 40(4), 346-359. doi:10.1007/s13313-011-0066-6 Hood, I. (2016). *Myrtle rust and the New Zealand Forest Industry.* 57365: Scion.
Pierce's disease *Xylella fastidiosa*	*Xylella fastidiosa*, is a xylem-limited phytopathogenic bacterium, transmitted by about 50 species of plant bugs, Introduced via infected plant material to new regions because of its broad host range and lack of symptoms, Preventing introduction and establishment of *X. fastidiosa* or its vector by regulating importation of potential host material is considered critical to management	*Xylella fastidiosa,*	European Food Safety Authority. (2015). Scientific Opinion on the risk to plant health posed by *Xylella fastidiosa* in the EU territory, with the identiication and evaluation of risk reduction options. *EFSA Journal, 13*(1), 3989. **Rapicavoli, J., Ingel, B., Blanco-Ulate, B., Cantu, D., & Roper, C. (2017). Xylella fastidiosa: an examination of a re-emerging plant pathogen. *Molecular Plant Pathology*. doi:10.1111/mpp.12585** **Redak, R. A., Purcell, A. H., Lopes, J. R. S., Blua, M. J., Mizell III, R. F., & Andersen, P. C. (2004). The biology of xylem fluid–feeding insect vectors of *Xylella fastidiosa* and their relation to disease epidemiology. *Annual Review of Entomology, 49*(1), 243-270.**
Pine pitch canker, *Fusarium circinatum*			Gordon, T. R., Storer, A. J., & Wood, D. L. (2001). The pitch canker epidemic in California. *Plant Disease, 85*(11), 1128-1139. doi:10.1094/PDIS.2001.85.11.1128
Ceratocystis fimbriata	*Ceratocystis fimbriata* is a xylem pathogen that causes wilt in a large range of annual and perennial species,	*Ceratocystis fimbriata*	Ferreira MA, Harrington TC, Alfenas AC, Mizubuti ESG 2011. Movement of Genotypes of Ceratocystis fimbriata Within and Among Eucalyptus Plantations in Brazil. Phytopathology 2011 v.101 no.8 (no. 8): pp. 1005-1012. Ferreira MA, Harrington TC, Gongora-Canul CC, Mafia RG, Zauza EAV, Alfenas AC 2013. Spatial–temporal patterns of Ceratocystis wilt

	It has several spore types, which allow different methods of dispersal, Evidence for the movement of *C. fimbriata* in international trade of vegetative propagated material of a range of hosts (e.g. eucalypts) comes from several other studies, Possible methods of control include chemical fungicides, biofungicides and plant extracts		in Eucalyptus plantations in Brazil. Forest Pathology 43(2): 153-164. Suleman P, AL-Musallam A, Menezes CA 2002. The effect of biofungicide Mycostop on *Ceratocystis radicicola*, the causal agent of black scorch on date palm. BioControl 47(2): 207-216. Somasekhara YMYYM 2011. Effect of culture filtrates of vermicompost against pomegranate (*Punica granatum* L.) wilt pathogen, *Ceratocystis fimbriata* Ell. amp; Halst. Research on Crops 12(1): 217-221. Harrington, T. C. *Ceratocystis fimbriata*. Retrieved 07/02/2018, from http://www.public.iastate.edu/~tcharrin/CABIinfo.html Ministry for Primary Industries. *Ceratocystis fimbriata*. Retrieved 08 February, 2018, from mpi.govt.nz/document-vault/10601
Sudden oak death, *Phytophthora ramorum*			Brasier, C., & Webber, J. (2010). Sudden larch death. *Nature, 466*, 824. doi:10.1038/466824a Cunniffe, N. J., Cobb, R. C., Meentemeyer, R. K., Rizzo, D. M., & Gilligan, C. A. (2016). Modeling when, where, and how to manage a forest epidemic, motivated by sudden oak death in California. *Proceedings of the National Academy of Sciences of the United States of America, 113*(20), 5640-5645. doi:10.1073/pnas.1602153113
Kauri dieback, *Phytophthora agathidicida*			Érsek, T., & Nagy, Z. (2008). Species hybrids in the genus *Phytophthora* with emphasis on the alder pathogen *Phytophthora alni*: a review. *European Journal of Plant Pathology, 122*(1), 31-39. doi:10.1007/s10658-008-9296-z Hardy, G. E. S. t. J., Barrett, S. R., & Shearer, B. L. (2001). The future of phosphite as a fungicide to control the soilborne plant

			pathogen *Phytophthora cinnamomi* in natural ecosystems. *Australasian Plant Pathology, 30*, 133-139. Horner, I., & Hough, E. (2013). Phosphorous acid for controlling *Phytophthora* taxon Agathis in kauri: glasshouse trials. *New Zealand Plant Protection, 66*, 242-248. Ristaino, J. B., & Gumpertz, M. L. (2000). New frontiers in the study of dispersal and spatial analysis of epidemics caused by species in the genus *Phytophthora*. *Annual Review of Phytopathology, 38*, 541-576. Scott, P., Burgess, T., & Hardy, G. (2013). Globalization and Phytophthora. In Lamour, K. (Ed.), *Phytophthora: A Global Perspective* (Vol. 2, pp. 226-232). Oxfordshire, United Kingdom: CABI Plant Protection Series. Waipara, N., Hill, S., Hill, L., Hough, E., Horner, I., & Zydenbos, S. (2013). Surveillance methods to determine tree health, distribution of kauri dieback disease and associated pathogens. *New Zealand Plant Protection, 66*, 235-241. Weir, B. S., Paderes, E. P., Anand, N., Uchida, J. Y., Pennycook, S. R., Bellgard, S. E., & Beever, R. E. (2015). A taxonomic revision of phytophthora clade 5 including two new species, phytophthora agathidicida and P. Cocois. *Phytotaxa, 205*(1), 21-38. doi:10.11646/phytotaxa.205.1.2
Exotic thrips and mites	Thrips (Thysanoptera) are key pests of many greenhouse and outdoor crops worldwide, Exclusion/avoidance: * Quarantine (international and regional) * Plant virus-free seed	Exotic thrips and mites	Lewis, T. (1997b). *Thrips as crop pests*. Wallingford, UK.: University Press. Manners, A., Persley, D. Cooke, T. (2014). Protect your nursery from virus diseases. Nursery Production Plant Health & Biosecurity Project, Nursery and Garden Industry Australia. Manners, A. (2015). *Herbivorous mites A pest management plan for production nurseries.* Nursery Production Plant Health & Biosecurity Project, Nursery and Garden Industry Australia.

	* Grow crops in regions where the disease seldom occurs or during periods when the virus or its vector (i.e. thrips species) are at low numbers * Grow crops in insect-proof protected structures. Exotic mites include some important pests of economic concern to horticulture and forestry		Parker, B. L., Skinner, M., & Lewis, T. (1995). *Thrips biology and management*. Life Sciences. New York, USA.: Plenum Press. Zhang, Z.Q. 2003. *Mites of Greenhouses: Identification, biology and Control*. CABI Publishing, Wallingford, Oxford, UK.
Dothistroma septosporum			Bednářová, M., Palovčíková, D., & Jankovský, L. (2006). The host spectrum of Dothistroma needle blight Mycosphaerella pini E. Rostrup–new hosts of Dothistroma needle blight observed in the Czech Republic. *Journal of Forest Science, 52*(1), 30-36. EFSA Panel on Plant Health. (2013). Scientific Opinion on the risk to plant health posed by Dothistroma septosporum (Dorog.) M. Morelet (Mycosphaerella pini E. Rostrup, syn. Scirrhia pini) and Dothistroma pini Hulbary to the EU territory with the identification and evaluation of risk reduction options. *THE EFSA JOURNAL, 11*(1), 1-173. Murray, J., & Batko, S. (1962). Dothistroma pini Hulbary: A new disease on pine in Britain. *Forestry: An International Journal of Forest Research, 34*(1), 57-65.

Appendix B: Mitigations

Hazard/risk	Mitigation	Likelihood of success	Reference
Phytophthora	Thermo-sterilized soil and watering material	High, but expensive	
Pathogens	Fungicides and fungistatic chemicals	Suppress symptoms but may not kill the pathogen	Pérez-Sierra, A., & Jung, T. (2013). Phytophthora in woody ornamental nurseries. In Lamour, K. (Ed.), *Phytophthora: A global perspective* (pp. 166-177). Knoxville, TN: CABI.
General pests/pathogens	Hygiene	Will not produce pest-free status, but could manage risk	Drenth, A., & Guest, D. (2004). Phytophthora in the tropics. In Drenth, A. & Guest, D. (Eds.), *Diversity and management of Phytophthora in Southeast Asia.* (pp. 30-41). Canberra, ACT: Australian Centre for International Agricultural Research (ACIAR)
	Inspection	Moderate, but chemical control suppresses symptoms	
	Diagnostics	Establishes what is present but doesn't remove risk, can be beyond scope of small producers	
	Systems approach	Promising but more work needed	Osterbauer, N. K., Lujan, M., McAninch, G., Lane, S., & Trippe, A. (2014). Evaluating the efficacy of the systems approach at mitigating five common pests in Oregon nurseries. *Journal of Environmental Horticulture, 32*(1), 1-7.
Ground based application methods			Gous, Stefan F 2013. A review of ground based pesticide application methods for usein biosecurity pest eradication programmes. B3 Report.
Containment of Phytophthora cinnamomi			Dunstan, W.A., Rudman, T., Shearer, B.L. et al. Biol Invasions (2010) Containment and spot eradication of a highly destructive, invasive plant pathogen (Phytophthora cinnamomi) in natural ecosystems. 12: 913. https://doi.org/10.1007/s10530-009-9512-6

Plant pathogen eradication			Smith, G.R., Fletcher, J.D., Marroni, V. et al. 2017. Plant pathogen eradication: determinants of successful programs. Australasian Plant Pathol. (2017) 46: 277. https://doi.org/10.1007/s13313-017-0489-9
Arthropod eradication			Tobin PC, Kean JM, Suckling DM, DG MC, Herms DA, Stringer LD (2014) Determinants of successful arthropod eradication programs. Biol Invasions 16:401–414.
Handbook of plant biosecurity			Gordh, Gordon, McKirdy, Simon (Eds.) 2014 The Handbook of Plant Biosecurity: Principles and Practices for the Identification, Containment and Control of Organisms that Threaten Agriculture and the Environment Globally. Pgs 723. ISBN 978-94-007-7365-3