Nursery levy at work: **Building Resilience & Biosecurity Capacity**

General Contingency Plan for Sudden oak death and other diseases caused by Phytophthora ramorum

Queensland Department of Agriculture and Fisheries
Nursery & Garden Industry Australia

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Acknowledgements

This document is an update of the 2010 “Threat Specific Contingency Plan - Sudden Oak Disease caused by *Phytophthora ramorum*”, which was prepared by Plant Health Australia and the Nursery & Garden Industry Australia. Updates to the 2010 document were made by Lindy Coates, Andrew Manners and Fiona Giblin (Department of Agriculture and Fisheries). Thanks go to John McDonald (NGIA) for providing helpful comments that improved this contingency plan significantly.

Disclaimer

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1 Purpose and background of this contingency plan

This contingency plan provides background information on the pest biology and available control measures to assist with preparedness for an incursion into Australia of Sudden oak death or other diseases caused by *Phytophthora ramorum*. It provides guidelines and options for steps to be undertaken and considered when developing a Response Plan to this pest. Any Response Plan developed using information in whole or in part from this Contingency Plan must follow procedures as set out in PLANTPLAN and be endorsed by the National Management Group prior to implementation.

As this contingency plan was developed for the Nursery and Garden Industry Australia (NGIA), it is focussed on production nurseries. Detection of *P. ramorum* outside a nursery would potentially be deemed non-eradicable, with containment a more likely scenario.

In the event of an incursion, operations not covered by the NGIA (e.g. retail nurseries) will not be eligible for Owner Reimbursement Costs, as defined in the Emergency Plant Pest Response Deed (EPPRD), if affected by actions carried out under the Response Plan.

2 Australian nursery industry

The Australian nursery industry is a significant and diverse horticultural sector with total greenlife sales valued at $2.29 billion annually[1]. The industry employs approximately 27,000 people in approximately 1,777 businesses[1]. The industry is located predominantly along the Australian coastline and in major inland regions servicing urban and production horticulture. It is estimated that 1.618 billion plants were sold nationally in the 2015/2016 year and the production area covered 6,229 Ha (outdoor) and 1,273 Ha (indoor)[1].

3 Eradication or containment decision matrix

Eradication of *P. ramorum* will only be technically feasible if the disease is detected while still contained within a very small area. If the initial detection is contained within an area small enough and/or isolated soon enough that eradication is considered feasible, eradication procedures should be implemented immediately.

As *P. ramorum* would potentially have a high environmental impact, the decision should be based solely on technical feasibility. Recommendations for silviculture practices to control *P. ramorum* have not yet been made and knowledge to support a complete program is still limited. The greatest cost of an eradication attempt is likely to be in follow-up surveys, which will be needed to verify the success of the eradication. The time period for suitable weather conditions without detection of the disease is, at this stage unknown before *P. ramorum* free status can be declared.

Overseas, once the pathogen is detected in nurseries, the pathogen is subject to eradication and containment. This same approach would be needed in Australia. Ongoing surveys of nurseries and regulation of nursery stock would be needed to limit spread of the pathogen. A tool to determine the technical feasibility of eradication has been developed by Biosecurity Queensland and will be available through Plant Health Australia.

[1] https://www.ngia.com.au/Attachment?Action=Download&Attachment_id=2170

4 Pest information/status

4.1 Pest details

Common names: Sudden oak death, Phytophthora canker disease of oaks, Ramorum blight, Ramorum shoot dieback, Ramorum twig blight or dieback, Ramorum leaf blight.
Scientific name: *Phytophthora ramorum* Werres, De Cock & Man in't Veld
Synonyms: None
Taxonomic position: Peronosporaceae, Peronosporales, Oomycota, Chromista

4.1.1 Background

Phytophthora ramorum is a major pathogen of ornamental and amenity species where it occurs in the USA and Europe. The pathogen was first described in 2001 when it was associated with a disease that had been known since 1993 and found in *Rhododendron* spp., *Viburnum* spp. and *Pieris* spp. in Germany and the Netherlands (Werres *et al*. 2001). This fungus-like organism caused foliage/shoot/leaf blight, stem canker, dieback and often plant death in a number of species, particularly oaks. It is devastating native forests in the USA and causing significant restrictions to plant movement in the nursery industry of USA and UK. It has a large known host range that continues to increase as the pathogen spreads. It is commonly referred to as Ramorum dieback or Sudden oak death.

Unlike most *Phytophthora* species that infect roots, *P. ramorum* is mainly a foliar pathogen. Multiple types of spores are produced, and those landing on the wet leaves or stems germinate and infect the plant. Young leaves are especially susceptible.

Phytophthora ramorum was first identified in California in nursery stock in 2001 (Santa Cruz County), but the North American nursery industry was not widely impacted by the pathogen until 2003, when it was detected across nurseries in California, Oregon, Washington, and British Columbia. This discovery in nurseries heightened concern that infected nursery crops could move the pathogen long distances to new areas, infecting new hosts. The pathogen has recently been traced from a large southern California nursery on *Camellia* plants shipped to many locations throughout the US. European isolates of the pathogen have also been detected in nurseries in the Pacific Northwest and Canada.

While *P. ramorum* is mainly found in nurseries in the USA, in southern Oregon and northern California it has caused the mortality of oaks (mainly tanoak and coast live oak) in native forests and at the urban-native forest interface in the coastal fog belts (*Figure 1*). *P. ramorum* has also caused twig and foliar diseases in numerous other plant species, including California bay laurel, Douglas-fir and coast redwood (Rizzo *et al*. 2002). The pathogen is currently at epidemic levels in coastal California, however it is subject to an eradication program in Oregon. The recent spread of the pathogen across the USA has been limited to nurseries with no evidence to suggest that it has spread to the native ecosystems in other parts of the USA.

In European countries, the pathogen causes similar symptoms, but has been primarily limited to ornamental nursery crops. However, the pathogen has been tracked moving from infected nursery outplantings, to adjacent shrubs and trees resulting in lethal infections.

Figure 1. Sudden oak death in Marin County (north of San Francisco). (Image Fire Dept Marin County, California, USA (**http://www.suddenoakdeath.org/maps-media/photos/landscape-photos/**)

4.1.2 Genetic diversity

Four distinct clonal lineages of *P. ramorum* have been described to date, namely the North American lineages NA1 and NA2, and the European lineages EU1 and EU2 (Van Poucke *et al*. 2012) (Table 2). All NA1 and NA2 isolates have so far been found to be of mating type 2 (A2), and almost all EU1 and EU2 isolates have been found to be of mating type 1 (A1) (Van Poucke *et al*. 2013). NA1 is predominant in US forests and found in most nurseries, whereas NA2 is confined to nurseries and adjacent waterways. In the US, EU1 has only been detected in a few Pacific Northwest nurseries. In Europe, EU1 is found in gardens, woodlands and nurseries, whereas EU2 has a much more limited distribution in Northern Ireland and western Scotland on four host plants including Japanese larch (Van Poucke *et al*. 2012).

Evidence suggests that these lineages have been introduced into North America and Europe from their native range through the international trade of ornamental plants (Goss *et al*. 2011; Grünwald *et al*. 2012; Mascheretti *et al*. 2012; Prospero *et al*. 2007). The geographic centre of origin for *P. ramorum* is not currently known, although it has been speculated to be somewhere in East Asia. A significant number of samples recently collected in the natural environment of North Vietnam contained *P. ramorum* (Webber & Brasier 2017). These isolates are most likely not from a currently known lineage.

Table 2. Characteristics of currently known *Phytophthora ramorum* clonal lineages (adapted from Grünwald *et al*. 2009 and others)

Clonal lineage	Current distribution	Environment	Mating type
NA1	North America	Forests, nurseries	A2
NA2	North America	Nurseries	A2
EU1	Europe, North America[1]	Nurseries, gardens, forest plantations	A1[2]
EU2	Europe	Mostly *Larix*, but also *Quercus*, *Rhododendron* and *Vaccinium*	A1

[1] EU1 only found in a few US nurseries
[2] Rare A2 mating types of EU1 lineage have been observed in Belgium (Vercauteren *et al*. 2011; Van Poucke *et al*. 2013).

4.1.3 Life cycle

The life cycle of *P. ramorum* is similar to that of other aerial Phytophthora species, such as *P. infestans*, the cause of potato blight and the Irish potato famine of 1845 (*Figure 2* and *Figure 3*).

Phytophthora ramorum, while having many features in common with fungi, is not a true fungus and is technically related to diatoms and brown algae. *Phytophthora* species are oomycetes or “water moulds” and require a moist environment to actively grow and reproduce. The genus *Phytophthora* has over 150 species (Yang *et al*. 2017), many of which are virulent plant pathogens. The fungus consists of thread-like strands (hyphae) collectively called mycelium which develops through leaf, bark and vascular tissue.

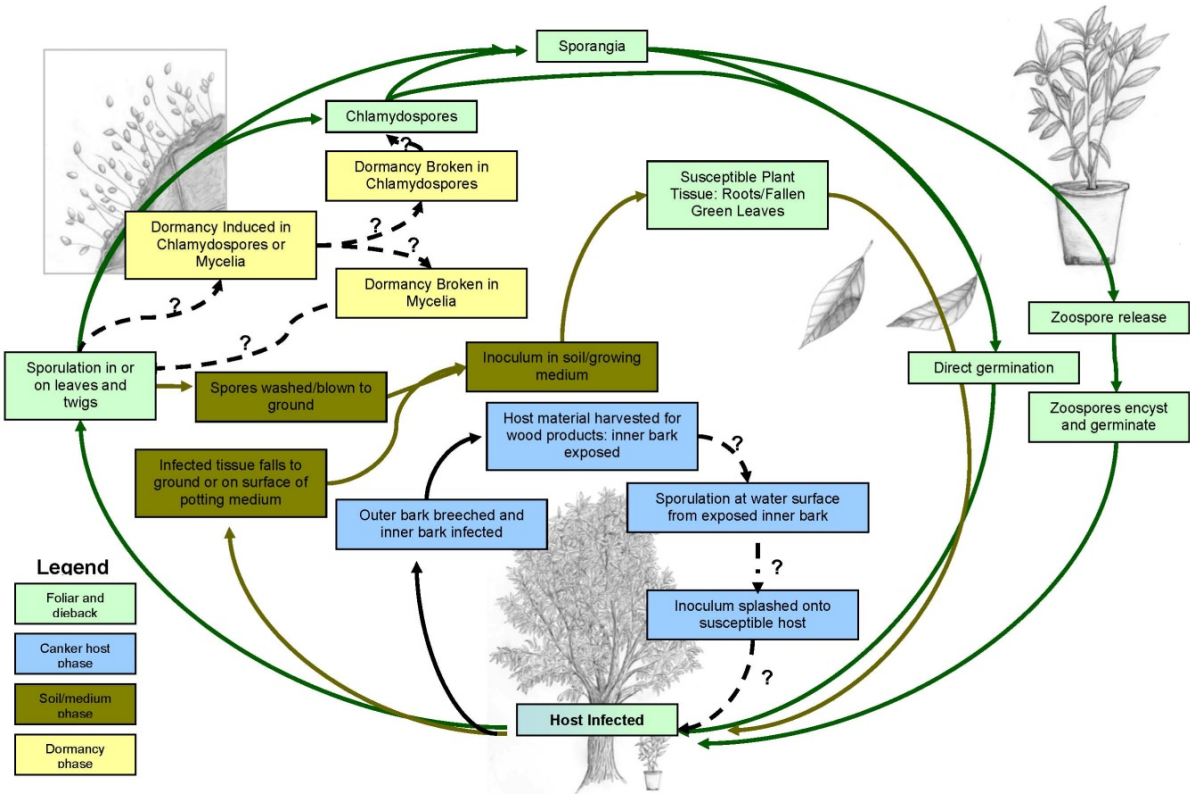

Figure 2. Proposed disease cycle for Phytophthora canker (Sudden oak death), leaf blight and dieback. Colour is used to designate different hosts and phases. Image taken from (**https://www.aphis.usda.gov/plant_health/plant_pest_info/pram/downloads/pdf_files/pra-cphst-08.pdf**)

Phytophthora ramorum produces several reproductive structures including sporangia, zoospores and chlamydospores (*Figure 3*). Sporangia give rise to the bi-flagellate zoospores, which have the ability to swim in water. Chlamydospores are resistant, resting spores that help the pathogen survive extreme temperatures, dryness and other harsh conditions. *P. ramorum* can survive within a temperature range of 2 to 27°C with optimal growth at 20°C. Spore structures commonly form on the surface of susceptible leaves and twigs following prolonged wetting. They are moved from plant to plant via windblown rain, in contaminated soil or through direct contact of infected leaves.

Under laboratory conditions, sporangia can be produced on moistened leaves of *Umbellularia californica* and *Rhododendron* spp. within 72 hours of infection (Davidson *et al.* 2002). Zoospores and chlamydospores can survive for over one month in moist conditions, but are susceptible to drying (Davidson *et al.* 2002). Infection of foliar tissue requires cool temperatures (ideal temperature of 18°C) and free water (minimum of 6-12 hours (Garblotto *et al.* 2002).

Phytophthora ramorum is heterothallic, meaning that sexual reproduction can only occur between two different mating types (Werres *et al.* 2001). The European population is predominantly A1 mating type and the North American population is A2 type (Brasier *et al.* 2002, de Gruyter *et al.* 2002).

Oospores (sexual spores) are formed from the union of A1 and A2 strains. As yet, this spore type has not been observed under natural conditions. Nevertheless, three Pacific Northwest nurseries and the Canadian nurseries have been infected with the European A1 strains, and in two of the Pacific Northwest nurseries, both the North American (A2) and European (A1) strains were found. The presence of both strains at the one location could potentially lead to sexual reproduction of the pathogen, potentially leading to more virulent hybrids, capable of exploiting new habitats and host species. However, laboratory crossing trials of the A1 and A2 mating types has not been successful,

suggesting the two pathogen populations may need to be considered as separated sub-species (Brasier *et al.* 2005).

Fruiting structures (sporangia and chlamydospores) are produced on host foliage, but have not been observed on infected oak or tanoak wood. This suggests multiple hosts are necessary to complete the disease cycle (Garbelotto *et al.* 2003, Rizzo & Garbelotto 2003). In oaks the pathogen is typically found in phloem tissue but often extends to the outer region of the xylem.

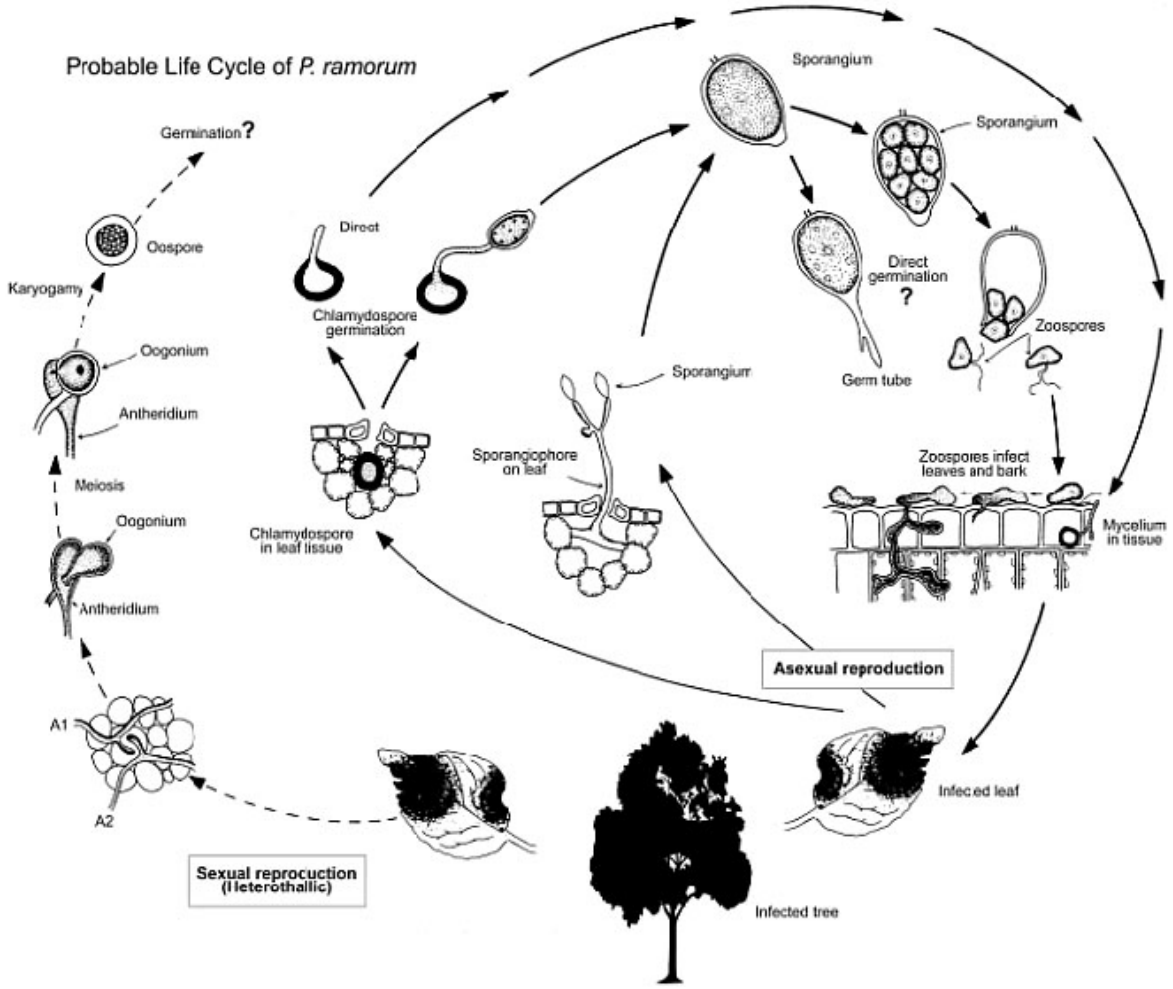

Figure 3. Life cycle of *Phytophthora ramorum* (O'Connor 2009) adapted from the life cycle of *P. infestans* (Agrios 2005)

4.1.4 Dispersal

Natural dispersal of *P. ramorum* occurs by various means, including drifting plant material, waterborne and soilborne chlamydospores and by waterborne, soilborne and possibly airborne sporangia. There are no reported vectors of the pest other than humans, although any animal that can move soil is potentially a vector (CABI 2018). *P. ramorum* has been proven to be moved effectively through the trade of ornamental plants and green waste.

Short distance pathogen spread between trees occurs mainly via spore (sporangia/zoospores) movement in rain splash and wind-driven rain. Spore spread through irrigation water is another pathway, with the pathogen able to be recovered from rivers downstream of infected irrigated plants. *P. ramorum* has been recovered from stream water approximately 1 km downstream of probable inoculum sources (Davidson *et* al. 2005; Sutton et al. 2009).

Inoculum of *P. ramorum* has been shown to be dispersed up to 15 m during wind driven events in California (Davidson *et al*. 2005). High winds associated with storms can spread rain droplets containing spores even further. Turner *et* al. (2008) reported that *P. ramorum* was detected in spore traps at least 50 m from the closest inoculum source. It has also been suggested that turbulent dry air dispersal may explain cases where dispersal has been observed over hundreds of metres in Oregon forests, and in some rare events, up to 4 km away (Hansen *et al*. 2008a,b).

Nursery stock (e.g. coast live oak, tanoak, huckleberry, and cultivars of *Rhododendron* spp. and *Camellia*) and infected plant material are the most likely means of long-distance transport. Spread also occurs in soil and water, and has been recovered from soil carried on hikers' shoes during spring rainy periods (Tjosvold *et al.* 2002; Kliejunas 2010). Oospores and chlamydospores of other *Phytophthora* species are long-lived and capable of survival in soil and dead host tissues under adverse conditions (Erwin & Ribeiro 1995). *P. ramorum* could be isolated from excised roots of various ornamental species inoculated with the pathogen and buried in potting mix for at least 8-11 months (Shishkoff 2007). It was shown to survive for up to 6 months in most potting media components and in soil infested with the pathogen, either as sporangia or chlamydospores produced in vermiculite culture or in infected rhododendron leaves (Linderman & Davis 2006).

4.1.5 Host range

P. ramorum has a very wide natural host range, including species in over 100 genera from 47 families of plants (Table 3). The pathogen's host range includes a diversity of tree, shrub and herbaceous species, and continues to expand as its geographic range extends. Both field observations of natural hosts and pathogenicity tests of *P. ramorum* on natural and experimental hosts (Tables 3 & 4) have demonstrated a number of Australian genera from a range of families to be highly susceptible to the disease. A wide range of exotic plant species have also been tested for pathogenicity including a detailed 4 year study of forest and woodland tree species, heathland species and ornamental shrubs in the EU (Sandsford *et al*. 2009).

While every effort has been made to include as many known natural hosts of *P. ramorum* as possible at the time of preparing this document (July 2019), readers should consult host lists maintained by key organisations such as APHIS (USDA) and Fera (DEFRA UK), which are referenced in Section 8.

Table 3. List of known hosts and plants associated with *P. ramorum* – information sourced from APHIS (2013), CABI (2018), COMTF report (May 2006; July 2018), Fera (November 2015), Sandsford *et al.* (2009) and from personal communication with Dr. Anna Brown, DEFRA, UK*

Scientific name[2]	Common name	Plant family
Abies alba	European silver fir	Pinaceae
Abies concolor	White fir	Pinaceae
Abies grandis	Grand fir	Pinaceae
Abies magnifica	Red fir	Pinaceae
Abies nobilis (syn. *Abies procera*)	Noble fir	Pinaceae
Acer circinatum	Vine maple	Aceraceae
Acer davidii	Striped bark maple	Aceraceae
Acer laevigatum	Evergreen maple	Aceraceae

[2] Confirmed hosts (marked in red) are naturally infected plants upon which Koch's postulates have been confirmed. Other hosts (in black) are plants that have been found naturally infected and from which *P. ramorum* has been cultured and/or detected using PCR (Polymerase Chain Reaction). For each of these, traditional Koch's postulates have not yet been completed or documented and reviewed.

Scientific name[2]	Common name	Plant family
Acer macrophyllum	Bigleaf maple	Aceraceae
Acer pseudoplatanus	Planetree maple	Aceraceae
Adiantum aleuticum	Western maidenhair fern	Adiantaceae
Adiantum jordanii	California maidenhair fern	Adiantaceae
Aesculus californica	California buckeye	Hippocastanaceae
Aesculus hippocastanum	Horse chestnut	Hippocastanaceae
Arbutus menziesii	Madrone	Ericaceae
Arbutus unedo	Strawberry tree	Ericaceae
Arctostaphylos columbiana	Hairy manzanita	Ericaceae
Arctostaphylos glandulosa	Eastwood manzanita	Ericaceae
Arctostaphylos hooveri	Hoover's manzanita	Ericaceae
Arctostaphylos manzanita	Manzanita	Ericaceae
Arctostaphylos montaraensis	Montara manzanita	Ericaceae
Arctostaphylos montereyensis	Monterey manzanita	Ericaceae
Arctostaphylos morroensis	Morro manzanita	Ericaceae
Arctostaphylos pallida	Alameda manzanita	Ericaceae
Arctostaphylos pilosula	La Panza manzanita	Ericaceae
Arctostaphylos pumila	Dune manzanita	Ericaceae
Arctostaphylos rainbowensis	Rainbow manzanita	Ericaceae
Arctostaphylos silvicola	Silverleaf manzanita	Ericaceae
Arctostaphylos uva-ursi	Bearberry	Ericaceae
Arctostaphylos virgata	Marin manzanita	Ericaceae
Ardisia japonica	Ardisia	Myrsinaceae
Betula pendula	Silver birch	Betulaceae
Calluna vulgaris	Scotch heather	Ericaceae
Calycanthus occidentalis	Spicebush	Calycanthaceae
Camellia spp.	Camellia - all species, hybrids, cultivars	Theaceae
Castanea sativa	Sweet chestnut	Fagaceae
Castanopsis chryophylla	Giant chinquapin	Fagaceae
Castanopsis orthacantha		Fagaceae
Ceanothus impressus	Californian lilac	Rhamnaceae
Ceanothus thyrsiflorus	Blueblossum	Rhamnaceae
Ceratonia siliqua	Carob	Leguminosae
Cercis chinensis	Redbud	Fabaceae
Chaemaecyparis lawsoniana	Lawson's cypress	Cupressaceae

Scientific name[2]	Common name	Plant family
Choysia sp.		Rutaceae
Choysia ternata 'Aztec Pearl'	Mexican orange	Rutaceae
Chrysolepsis chrysophylla	Chinquapin	Fagaceae
Cinnamomum camphora	Camphor laurel	Lauraceae
Cinnamomum sp.		Lauraceae
Clintonia andrewsiana	Andrew's clintonia bead lily	Liliaceae
Cornus capitata	Bentham's dogwood	Cornaceae
Cornus kousa		Cornaceae
Cornus kousa x *Cornus capitata* 'Norman Haddon'		Cornaceae
Cornus nuttalii	Western dogwood	Cornaceae
Corylopsis spicata	Spike winter hazel	Hamamelidaceae
Corylopsis sp.		Hamamelidaceae
Corylus cornuta	California hazelnut	Betulaceae
Cotoneaster (large leaf variety)		Rosaceae
Daphniphyllum glaucescens		Daphniphyllaceae
Distylium myricoides	Mrytle-leafed distylium	Hamamelidaceae
Drimys winteri	Winter's bark	Winteraceae
Dryopteris arguta	California wood fern	Moraceae
Eucalyptus gunnii	Cider gum*	Myrtaceae
Eucalyptus haemastoma	Scribbly gum	Myrtaceae
Euonymus kiautschovicus	Spreading euonymus	Celastraceae
Fagus sylvatica	European beech	Fagaceae
Fothergilla major	Mountain witch hazel	Hamamelidaceae
Frangula californica	California coffeeberry	Rhamnaceae
Frangula purshiana	Cascara	Rhamnaceae
Fraxinus excelsior	European ash	Oleaceae
Fraxinus latifolia	Oregon ash	Oleaceae
Garrya elliptica	Silk tassel bush	Garryaceae
Gaultheria shallon	Salal, Oregon wintergreen	Ericaceae
Gaultheria procumbens	Many, including wintergreen	Ericaceae
Griselinia littoralis	Griselinia	Griseliniaceae
Hamamelis x intermedia	Hybrid witch-hazel	Hamamelidaceae
Hamamelis mollis	Chinese witch-hazel	Hamamelidaceae
Hamamelis virginiana	Witch hazel	Hamamelidaceae
Heteromeles arbutifolia	Toyon	Rosaceae

Scientific name[2]	Common name	Plant family
Hydrangea seemanni	Hydrangea	Hydrangeaceae
Ilex aquifoliium	European Holly	Aquifoliaceae
Ilex cornuta	Budford holly, Chinese holly	Aquifoliaceae
Ilex latifolia	Tarajo holly	Aquifoliaceae
Ilex purpurea	Oriental holly	Aquifoliaceae
Illicium parviflorum	Yellow anise	Schisandraceae
Kalmia angustifolia	Sheep laurel	Ericaceae
Kalmia latifolia	Mountain laurel	Ericaceae
Kalmia sp.		Ericaceae
Larix kaempferi/ Larix/ Larix decidua/ Larix x eurolepis	Japanese larch/ larch/ European larch/ hybrid larch	Pinaceae
Laurus nobilis	Bay laurel	Lauraceae
Leucothoe axillaris	Fetterbush, dog hobble	Ericaceae
Leucothoe fontanesiana	Drooping leucothoe	Ericaceae
Lithocarpus densiflorus	Tanoak	Fagaceae
Lithocarpus glaber	Japanese oak	Fagaceae
Lonicera hispidula	California honeysuckle	Caprifoliaceae
Lophostemon confertus	Brisbane box	Myrtaceae
Loropetalum chinense	Loropetalum	Hamamelidaceae
Magnolia sp.		Magnoliaceae
Magnolia acuminata		Magnoliaceae
Magnolia cavalieri	Michelia	Magnoliaceae
Magnolia delavayi		Magnoliaceae
Magnolia denudata	Lily tree	Magnoliaceae
Magnolia denudata x *salicifolia*	Magnolia hybrid	Magnoliaceae
Magnolia figo (*Michelia figo*)	Banana magnolia	Magnoliaceae
Magnolia grandiflora	Southern magnolia	Magnoliaceae
Magnolia kobus	Kobus magnolia	Magnoliaceae
Magnolia liliiflora (= *M. quinquepeta*)	Purple magnolia	Magnoliaceae
Magnolia salicifolia	Anise magnolia	Magnoliaceae
Magnolia stellata	Star magnolia	Magnoliaceae
Magnolia x loebneri	Loebner magnolia	Magnoliaceae
Magnolia x soulangeana	Saucer magnolia	Magnoliaceae
Magnolia x *thompsoniana*	Magnolia	Magnoliaceae
Mahonia aquifolium	Holly leaved barberry, Oregon grape	Berberidaceae

Scientific name[2]	Common name	Plant family
Mahonia nervosa	Creeping Oregon grape	Berberidaceae
Maianthemum racemosum	False Solomon's seal	Liliaceae
Manglietia insignis	Red lotus tree	Magnoliaceae
Michelia cavalieri	Michelia	Magnoliaceae
Michelia doltsopa	Michelia	Magnoliaceae
Michelia foveolata	Michelia	Magnoliaceae
Michelia maudiae	Michelia	Magnoliaceae
Michelia wilsonii	Michelia	Magnoliaceae
Molinadendron sinaloense		Hamamelidaceae
Myristica fragrans	Nutmeg	Myristicaceae
Nerium oleander	Oleander	Apocynaceae
Nothofagus obliqua	Roble beech	Nothofagaceae
Notholithocarpus densiflorus var. *echinoides*	Shrub tanoak	Fagaceae
Osmanthus decorus	Osmanthus	Oleaceae
Osmanthus delavayi	Delavay osmanthus	Oleaceae
Osmanthus fragrans	Sweet olive	Oleaceae
Osmanthus heterophyllus	Holly osmanthus	Oleaceae
Osmorhiza berteroi	Sweet cicely	Apiaceae
Osmorhiza decorus	Osmanthus	Apiaceae
Parakmeria lotungensis	Eastern joy lotus tree	Magnoliaceae
Parrotia persica	Persian ironwood	Hamamelidaceae
Photinia x *fraseri* (*P. glabra* x *P. serrulata*)	Fraser photinia	Rosaceae
Photinia fraseri	Red tip photinia	Rosaceae
Physocarpus opulifolius	Ninebark	Rosaceae
Picea sitchensis	Sitka spruce	Pinaceae
Pieris floribunda and *Pieris floribunda x japonica*	Mountain Andromeda and all cultivars of the hybrid with Japanese Pieris	Ericaceae
Pieris formosa and *P. formosa x japonica*	Himalaya Andromeda, and all cultivars of the hybrid with Japanese Pieris	Ericaceae
Pieris japonica	Japanese Pieris	Ericaceae
Pieris sp.		Ericaceae
Pickeringia montana	Chaparral pea	Fabaceae
Pittosporum undulatum	Sweet pittosporum, Victorian box	Pittosporaceae
Prunus laurocerasus 'Nana'	Dwarf English laurel	Rosaceae

Scientific name[2]	Common name	Plant family
Prunus lusitanica	Portuguese laurel cherry	Rosaceae
Pseudotsuga menziesii	Douglas-fir	Pinaceae
Pyracantha koidzumii	Formosa firethorn	Rosaceae
Pysocarpus opulifolius	Ninebark	Rosaceae
Quercus acuta	Japanese evergreen oak	Fagaceae
Quercus agrifolia	Coast live oak	Fagaceae
Quercus cerris	European turkey oak	Fagaceae
Quercus chrysolepis	Canyon live oak	Fagaceae
Quercus falcata	Southern red oak	Fagaceae
Quercus ilex	Holm oak	Fagaceae
Quercus kelloggii	California black oak	Fagaceae
Quercus parvula var. *shrevei*	Shreve's oak and all nursery grown *Q. parvula*	Fagaceae
Quercus petraea	Sessile oak	Fagaceae
Quercus phillyraeoides	Ubame oak	Fagaceae
Quercus robur	English oak/pedunculated oak	Fagaceae
Quercus rubra	Northern red oak	Fagaceae
Rhododendron spp.	Rhododendrons (including azalea)	Ericaceae
Rhus diversiloba	Poison oak	Anacardiaceae
Ribes laurifolium		Grossulariaceae
Rosa gymnocarpa	Wood rose	Rosaceae
Rosa "Meidiland"	Hybrid rose	Rosaceae
Rosa rugosa	Rugosa rose	Rosaceae
Rosa spp. (several different cultivars)	Rose	Rosaceae
Rubus spectabilis	Salmonberry	Rosaceae
Rubus ursinus	Blackberry	Rosaceae
Salix caprea	Goat willow	Salicaceae
Sarcococca hookeriana var. *dignya*	Himalayan sweet box	Buxaceae
Schima argentea		Theaceae
Schima (yunnanensis) spp.	Schima	Theaceae
Schima wallichii	Chinese guger tree	Theaceae
Sequoia sempervirens	Coast redwood	Taxodiaceae
Sorbus aucuperia	Rowan/mountain ash	Rosaceae
Syringa sp.		Oleaceae
Syringa vulgaris	Lilac	Oleaceae

Scientific name[2]	Common name	Plant family
Taxus baccata	European yew	Taxaceae
Taxus brevifolia	Pacific yew	Taxaceae
Taxus x media	Yew	Taxaceae
Taxus sp.		Taxaceae
Torreya californica	California nutmeg	Taxaceae
Toxicodendron diversilobum	Poison oak	Anacardiaceae
Trachelospermum jasminoides	Star jasmine, Confederate jasmine	Apocynaceae
Trientalis latifolia	Western starflower	Primulaceae
Trillium ovatum	Western wake robin	Melanthiaceae
Tsuga heterophylla	Western hemlock	Pinaceae
Umbellularia californica	California bay laurel, pepperwood, Oregon myrtle	Lauraceae
Vaccinium intermedium		Ericaceae
Vaccinium myrtillus	Bilberry	Ericaceae
Vaccinium ovatum	Evergreen huckleberry	Ericaceae
Vaccinium parvifolium	Red huckleberry	Ericaceae
Vaccinium spp.		Ericaceae
Vaccinium vitis-idaea	Cowberry	Ericaceae
Vancouveria planipetala	Redwood ivy	Berberidaceae
Veronica spicata (syn. *Pseudosimachion spicatum*)	Spiked speedwell	Scrophulariaceae
Viburnum bodnantense	Arrowwood	Caprifoliaceae
Viburnum davidii	David Viburnum	Caprifoliaceae
Viburnum farreri (=V. fragrans)	Fragrant Viburnum	Caprifoliaceae
Viburnum lantana	Wayfaringtree Viburnum	Caprifoliaceae
Viburnum opulus (=*V. trilobum*)	European & American cranberrybush	Caprifoliaceae
Viburnum plicatum	Doublefile Viburnum	Caprifoliaceae
Viburnum tinus	Laurustinus	Caprifoliaceae
Viburnum x bodnantense	Bodnant Viburnum	Caprifoliaceae
Viburnum x burkwoodii	Burkwood Viburnum	Caprifoliaceae
Viburnum x carlcephalum x V. utile	Viburnum	Caprifoliaceae
Viburnum x pragense	Prague Viburnum	Caprifoliaceae
Viburnum x rhytidophylloides	Viburnum	Caprifoliaceae
Virbunum spp.		Caprifoliaceae
Viburnum tinus	Alleghany or Willowood Viburnum	Caprifoliaceae
Vinca minor	Lesser periwinkle	Apocynaceae

Table 4. Potential susceptibility of 73 native Australian plant species and three positive control species (not native to Australia) to foliar, branch and bole canker diseases caused by *Phytophthora ramorum*, and sporulation potential on foliage[a]. Table modified from Ireland (2012).

Species [b]	Susceptibility			Sporulation potential
	Foliar	Branch	Bole canker	
Positive control hosts				
Notholithocarpus densiflorus	High	High	High	High
Rhododendron cv. Colonel Coen	Moderate	High	…	High
Umbellularia californica	Moderate	High	…	High
Australian hosts				
Acacia dealbata	Low	Low	Low	Moderate
Acacia melanoxylon	Low	Low	…	Unlikely
Acmena smithii	Low	Low	…	Marginal
Adenanthos obovatus	Moderate	Tolerant	…	…
Agonis flexuosa	Low	Low	…	Marginal
Atherosperma moschatum	Low	Low	…	Unlikely
Banksia attenuata	Moderate	Tolerant	…	Marginal
Banksia marginata	Low	Tolerant	…	Marginal
Bauera rubioides	Moderate	Low	…	…
Billardiera heterophylla	Low	Tolerant	…	…
Brachychiton populneus	Moderate	Low	…	…
Bursaria spinosa	Low	Tolerant	…	…
Callitris rhomboidea	Low	Low	…	…
Ceratopetalum apetalum	Low	Low	…	…
Correa alba	Low	Low	…	…
Correa backhousiana	Low	Low	…	…
Correa decumbens	Low	Low	…	…
Correa cv. Ivory Bells	Low	Low	…	…
Correa reflexa	Moderate	Low	…	Marginal
Correa cv. Sister Dawn	High	Tolerant	…	…
Corymbia ficifolia	Moderate	Low	…	Moderate
Corymbia maculata	Low	Low	…	Marginal
Dicksonia antarctica	Low	Low	…	Unlikely
Dodonea viscosa	Low	Low	…	Marginal
Eucalyptus camaldulensis	Low	Low	…	…
Eucalyptus cneorifolia	Low	Moderate	…	…
Eucalyptus dalrympleana	…	…	High	…
Eucalyptus delegatensis	Moderate	Low	…	Moderate
Eucalyptus denticulata	Moderate	High	Moderate	Moderate

Eucalyptus diversicolor	Low	Low	Tolerant	
Eucalyptus globulus	Low	Low	Low	Marginal
Eucalyptus gunnii	High	…	…	…
Eucalyptus haemastoma	Moderate	Tolerant	…	High
Eucalyptus leucoxylon	Low	Low	…	…
Eucalyptus pauciflora	Moderate	Low	…	Marginal
Eucalyptus regnans	High	Tolerant	High	Unlikely
Eucalyptus saligna	Low	Low	…	…
Eucalyptus sideroxylon	Moderate	Moderate	…	…
Eucalyptus viminalis	Low	Moderate	Tolerant	High
Eucryphia lucida	Low	Low	…	…
Grevillea synapheae	Moderate	Low	…	…
Hakea rostrata	Low	Low	…	…
Hardenbergia violaceae	Low	Moderate	…	Unlikely
Hedycarya angustifolia	Resistant	Low	…	…
Isopogon cuneatus	High	Low	…	…
Isopogon formosus	High	High	…	High
Lagarostrobos franklinii	Low	Low	…	…
Leptospermum grandiflorum	Low	Low	…	…
Leptospermum lanigerum	High	Low	…	…
Leptospermum scoparium	High	Tolerant	…	Marginal
Lomandra longifolia	Low	…	…	…
Lomatia myricoides	Low	Tolerant	…	…
Macadamia tetraphylla	Low	Tolerant	…	…
Melaleuca squamea	High	Low	…	…
Nothofagus cunninghamii	Low	Moderate	…	High
Nothofagus moorei	Low	Low	…	Marginal
Olearia argophylla	Resistant	Low	…	…
Phyllocladus aspleniifolius	Resistant	Low	…	…
Pittosporum undulatum[c]	Resistant[c]	Tolerant	…	Unlikely
Podocarpus lawrencei	Resistant	Low	…	…
Polyscias sambucifolia	Moderate	Low	…	…
Pomaderris apetala	Resistant	Low	…	Marginal
Prostanthera lasianthos	Low	Low	…	Marginal
Senecio linearifolius	Low	Low	…	…
Stylidium graminifolium	Low	Tolerant	…	…
Tasmannia lanceolata	Low	Low	…	…
Taxandria marginata	High	Low	…	…
Tristaniopsis laurina	Low	Low	…	…

Viola hederaceae	Low	…	…	…
Xanthorrhoea australis	Low	…	…	…
Xanthorrhoea preisii	Low	…	…	…

[a] Calculations for susceptibility based upon measures of severity and infection potential as outlined in Ireland (2012).
[b] Positive control species are known to be naturally infected in California.
[c] *Pittosporum undulatum* has been reported as an associated host (Table 3) and identified as a potentially highly susceptible foliar host in another study (Hüberli *et al*. 2006).

4.1.6 Climatic predisposition

P. ramorum is considered to be a cool climate species. In northern America, the current geographic distribution of the pest includes a wide range of forest types within the Mediterranean climatic region of California. The pest is also active in colder climates of central Europe and the UK. Together with the cool climate, moisture levels are important for *P. ramorum* infection. This is demonstrated by natural infections of forests in coastal "fog belts" of California, and areas receiving mean annual rainfall ranging from 850 to 2000 mm.

4.1.7 Current geographic distribution

P. ramorum is found in North America and throughout Europe, although molecular and biological evidence suggests that it is not native to either continent. In 2017, *P. ramorum* was detected in a forest in north-west Vietnam, leading to speculation that it might originate from East Asia (UK Forestry Commission 2017). CABI (2018) also lists restricted distribution of *P. ramorum* in Kerala (India). There have been no records to date of *P. ramorum* being found in Central and South America, the Caribbean, Africa or Oceania countries.

4.1.7.1 North America

P. ramorum has been reported in natural ecosystems of California and Oregon. Infected material (under eradication) has been found in nurseries in more than 20 other states (Sandsford *et al*. 2009). It has been reported that two large wholesale nurseries in California and Oregon mistakenly sent *P. ramorum* infested plant material to numerous states across the US in 2004 (CABI 2018, citing personal correspondence with R. Bulluck, National Science Director, USDA-APHIS-PPQ, 2018). As a result, surveys were conducted in all affected states. The pathogen was subsequently detected in 41 states, although these detections were considered episodic and the infested plants were destroyed. CABI (2018) lists the current distribution details for *P. ramorum* in states of the US, based on information currently available.

The disease caused by *P. ramorum* was first observed in California in 1995 on tanoak (*Notholithocarpus densiflorus*), and had spread to Oregon by 2001. In nurseries, the pathogen was identified in 2001 and by 2003 it was widespread through California, Oregon, Washington and British Columbia (Canada) nurseries (COMTF, undated).

Presently, the pathogen is subject to eradication and containment measures when found in nurseries, although eradication is no longer considered feasible in the natural ecosystems in California. Attempts to eradicate the pathogen in forests of Oregon have been undertaken since its discovery there. Its distribution has remained limited to a small area near the town of Brookings, suggesting that the eradication effort there has at least slowed the movement of the pathogen (Kanaskie *et al*. 2007). Ongoing surveys of nurseries and regulation of nursery stock continue to limit the pathogen's spread.

In Canada, *P. ramorum* was first detected in 2003 on four rhododendron plants at one nursery in British Columbia and one rhododendron plant on a residential planting originating from the infested nursery. Subsequently, the pathogen has been detected on plants shipped from Californian nurseries,

and was found at up to 35 sites within British Columbia. The pathogen has not been detected in Canada outside of nurseries and residential plantings, and is still classed as being under official control.

There are four distinct clonal forms of *P. ramorum* which are referred to as North American lineages 1 and 2 (NA1, NA2), and European lineages 1 and 2 (EU1, EU2) (Ivors *et al.* 2006; Brasier 2012). The pathogen also has two different mating types (A1, A2) which are required to come together for sexual reproduction to occur. NA1 (of the A2 mating type) is the only lineage found in natural ecosystems of California and Oregon, while NA1, NA2 and EU1 are all found in North American nurseries (Ivors *et al*. 2006; Ireland *et al.* 2013).

4.1.7.2 Europe

P. ramorum is widespread in Europe, being reported in Belgium, Denmark, Estonia, Finland, France, Germany, Ireland, Italy, Luxembourg, the Netherlands, Norway, Poland, Slovenia, Spain (including Mallorca), Sweden, Switzerland and the UK including the Channel Islands (Jersey and Guernsey). The pathogen has been confirmed absent in Austria, Cyprus, the Czech Republic (1 import interception eradicated), Hungary, Latvia, Lithuania, Malta, Portugal and Slovakia. There are no reports on the status of *P. ramorum* in Greece, Bulgaria and Romania (the latter two only joined the EU in 2007).

Although the species was not formally described at the time, *P. ramorum* was first found on *Rhododendron* species in Germany and the Netherlands as far back as 1993 (Werres *et al*. 2001). In Europe, the pathogen is mainly present in non-tree hosts grown in containers located at nurseries and retail garden centres. However, in several countries (including Germany, Ireland, Luxembourg, the Netherlands, Norway, Spain, Switzerland and the UK) some infected plants have been found outside nursery situations in managed parks and gardens and/or in wild (woodland) situations. Infected trees have been found in the UK and the Netherlands. The pathogen is under official control wherever it is found in Europe.

Multiple outbreaks have occurred throughout the UK and Scotland and can all be tracebacked to nurseries and garden centres. Between April 2002 and June 2007 in the UK, there have been 558 nursery outbreaks at 475 sites across England and Wales, of which the pathogen was successfully eradicated from 459. In natural and semi-natural environments, there have been 185 outbreaks across 166 sites in England and Wales; eradication efforts have so far been successful for 60 of these outbreaks (D. Slawson, *personal communication*).

EU1 is the dominant lineage of the pathogen in European nurseries and forests, although a newly discovered lineage EU2 has been found in Northern Ireland and Southern Scotland, mostly from *Larix* but also from *Quercus*, *Rhododendron* and *Vaccinium* (Van Poucke *et al*., 2012).

4.1.8 Potential distribution in Australia

Much of Australia's highly productive forests, old growth forests and temperate rainforests fall within the climatic envelope suitable for *P. ramorum* establishment, including cool temperatures and high rainfall (850-2000 mm; *Figure 4*; Smith *et al*. unpublished data). It is likely to be a major ecological threat to southern Australian forest or woodland ecosystems, amenity trees, horticultural crops and to home gardens in areas where the climatic conditions are a similar climate to California. Furthermore, the common practise of planting exotic plants (e.g. rhododendrons) in private gardens adjacent to wet sclerophyll native forests in Australia provides a significant potential pathway for this pathogen to spread should it enter Australia on infected exotic ornamentals.

Ireland *et al*. (2013) developed a simulation model using CLIMEX to estimate the global climate suitability patterns for establishment of *P. ramorum.* The authors found that in Australia, climatically favourable areas for the pathogen were confined to the temperate moist periphery, predominantly in New South Wales, Victoria, Tasmania and south-west Western Australia, although coastal areas of south-east Queensland and South Australia were also shown to be favourable. *P. ramorum* was projected as being restricted by hot, arid conditions in Australia. All areas in New Zealand were predicted to be either moderately or highly favourable to *P. ramorum*.

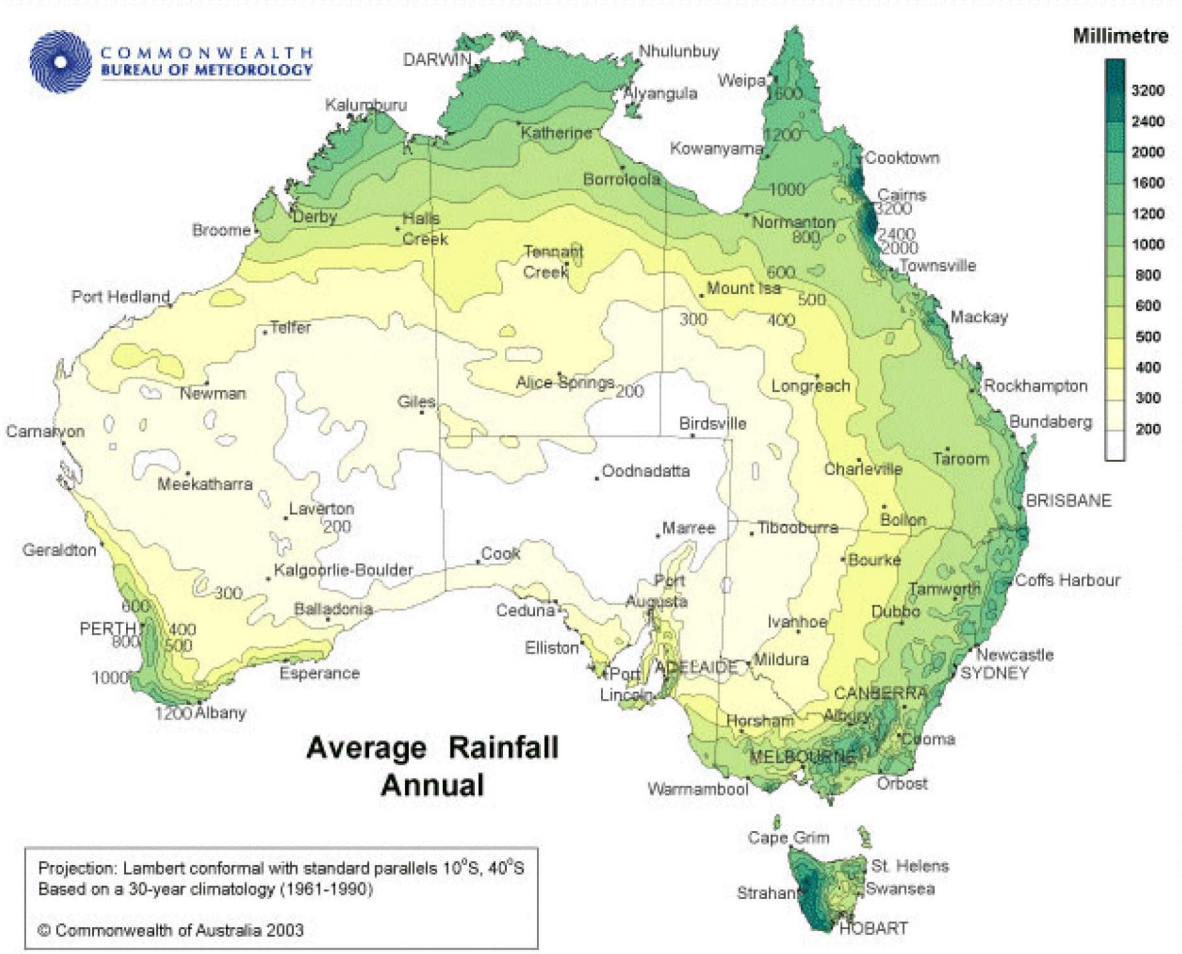

Figure 4. Rainfall map of Australia. In California, USA, susceptible species growing in areas above 850 mm are considered highly vulnerable to *P. ramorum*.

Once established in one area of Australia, *P. ramorum* is expected to spread very quickly over the climatically suitable regions, as the reproductive stages have short generation times and could potentially be wind-dispersed over large distances.

4.1.9 Symptoms

Symptoms caused by *P. ramorum* can be diverse, typically dependent on the host species, with three distinct disease syndromes observed (Hansen *et al.* 2002):

- sudden oak death – characterised by lethal cankers
- ramorum shoot dieback – which results from foliar infection and/or direct infection of stems
- ramorum leaf blight – which results from foliar infection

These symptoms are summarised in the life cycle diagram (*Figure 3*).

4.1.9.1 Sudden oak death

In oaks, the first symptom is the appearance of a bleeding canker with burgundy-red to tar-black thick sap oozing on the bark surface. The pathogen is typically found from the root crown (the area where the trunk fans out to the roots) to a height of 6 feet. Bleeding has occasionally been observed at greater heights.

Diagnostic symptoms on large trees include cankers on the lower trunk that have brown or black discoloured outer bark and bleeding sap (*Figure 5a*). Sunken or flattened cankers may occur beneath bleeding areas which appear as mottled areas of necrotic, dead discoloured inner-bark tissues when the outer back is removed (*Figure 5b*). Black 'zone lines' are often present within and around edges of the necrotic areas. On young or thinner trees, a distinct edge between necrotic and healthy tissues may also be visible. These cankers develop before foliar symptoms become evident. However, due to these girdling necroses, the whole crown of affected trees often appears to die rapidly (and hence the name 'sudden oak death'). *Eucalyptus gunnii* and *Nothofagus obliqua* have been shown to exhibit similar symptoms in the United Kingdom (Brown unpublished data).

Some plant species can be infected with *P. ramorum* but do not produce spores (terminal hosts). Such hosts may be asymptomatic or have symptoms develop over a number of years. Infested plant material (Wylder *et al*. 2016), growing media and soil could potentially still spread the pathogen via production of mycelium. Furthermore, even highly susceptible host plant species can support sporulation of *P. ramorum* without any symptoms of disease for 8 days and perhaps as long as 22 days (Denman *et al*. 2007, 2009).

Similar symptoms produced by other pests

Bleeding cankers resulting in dark stained wood is a symptom caused by other pathogens, such as *Botryosphaeria* and other *Phytophthora* species. In particular the soil-borne root and stem infecting *P. cinnamomi* can cause bleeding cankers on chestnuts, avocados, plane trees, several species of eucalypts and many other genera.

P. ramorum differs from other pathogens in attacking only aerial plant parts. Cankers caused by *P. cinnamomi*, *P. citricola* and *P. cactorum* usually start with root rot then develop into cankers on the main stem and move upwards (*Figure 6*). *Armillaria* species can also cause bleeding cankers but these can be easily distinguished by the white mycelial fans under the bark (*Figure 7*). Other exotic pathogens that can cause bleeding cankers in eucalypts include *Cryphonectria cubensis* (*Figure 8a*), *C. parasitica* and *Coniothyrium zuluense* (*Figure 8b*).

Figure 5. a) Bleeding canker on oak infected with *P. ramorum*. b) Bark removed, showing mottled areas of necrotic, dead and discoloured inner-bark. Photos by Bruce Moltzan, USDA Forest Service, Bugwood.org.

Figure 6. a) Bleeding canker on *Nothofagus obliqua* infected with *P. ramorum* in the United Kingdom. b) Bark removed showing mottled areas of necrotic, dead discoloured inner-bark (image courtesy A Brown, DEFRA UK).

Figure 7. Canker on chestnut (*Castanea sativa*) caused by *P. cinnamomi* in Victoria, Australia

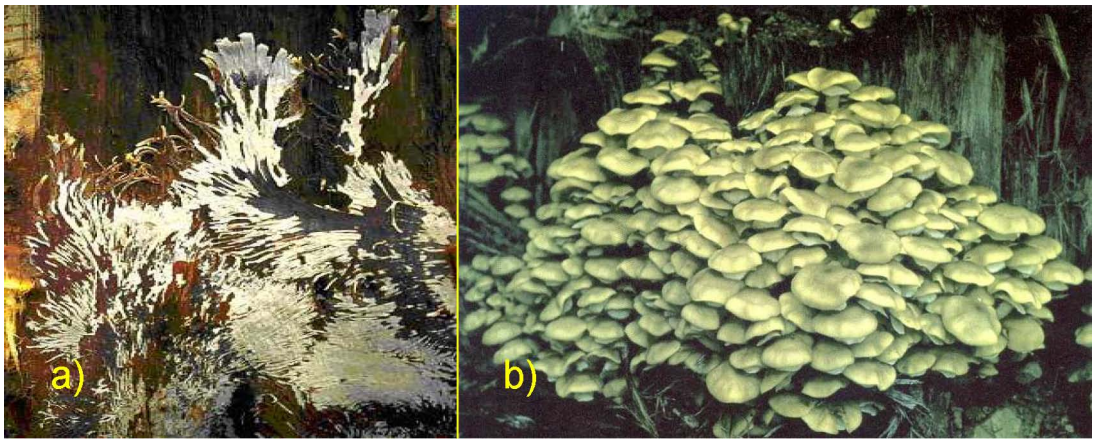

Figure 8. a) Mycelial fans under bark and b) fruiting bodies of *Armillaria* sp. causing cankers on trees

Figure 9. a) Canker on *Eucalyptus grandis* caused by *Cryphonectria cubensis* (Image EL Barnard, Florida Dept of Agric & Consumer Services, (https://www.invasive.org/browse/detail.cfm?imgnum=4825008). b) Serious and fatal fungal canker caused by *Coniothyrium zuluense* on *Eucalyptus* sp. Kwazulu, South Africa. (http://www.fao.org/3/a-y5041e.pdf)

4.1.9.2 Ramorum shoot dieback and leaf blight

The most common symptoms on shrubs such as rhododendron are shoot dieback and leaf blight (*Figure 10*). Ramorum shoot dieback is characterised by blackened shoots with or without foliage attached (*Figure 10a* and *Figure 11a*). Symptoms of Ramorum leaf blight include diffuse dark-brown spots or blotches with fuzzy margins frequently at the leaf tip (where moisture can accumulate and remain for extended periods and encourage infection; *Figure 10b&c*, *Figure 11c* and *Figure 12*). However, spots can also form elsewhere (drops with zoospores falling down on the leaf surface cause round, dark-brown patches). Eventually, entire leaves can turn brown to black and may fall prematurely. *P. ramorum* does not usually kill shrub hosts with the exception of *Viburnum* spp. (*Figure 11b*).

On many secondary hosts, the infection is seen primarily on the leaves, though symptoms on these hosts can be variable (Davidson *et al.* 2003, McPherson *et al,* 2000). Symptoms include leaf spots, stem and twig cankers, and shoot tip and branch die-back. In some cases the pathogen can reproduce rapidly on the leaf surface, making secondary hosts important as they allow for the rapid build-up of *Phytophthora* spores and serve as a source of infection.

Similar symptoms produced by other pests or abiotic factors

P. nicotianae, *P. citrophthora, P. heveae* and *P. kernoviae* may cause foliar symptoms similar to those of Ramorum dieback. *Colletotrichum, Botryosphaeria* and *Botrytis* also cause similar symptoms so care should be taken with the diagnosis (*Figure 13*). Abiotic factors, such as sunburn, can also be confused with Ramorum dieback, although in these cases a defined margin is usually expressed (*Figure 14*). The best way to distinguish abiotic damage from that caused by *P. ramorum* is to check the underside and leaf margins. For abiotic injury, margins of the lesions will be abrupt and distinct, not diffuse. Abiotic injury is often found distributed over the entire plant, while *P. ramorum* leaf spots are often found on only a few leaves or one portion of the plant.

Although hosts of *P. ramorum* show a range of symptoms, in general infection is characterized by irregular, necrotic leaf lesions, instead of distinct leaf spots. A leaf infection can develop down the petiole into twigs. Sometimes infections can occur initially on or develop into stems and cause blights, where stem and associated leaves wilt, become necrotic, and die. A distinct dark zone line can mark the advance of the infection on some species, such as California bay laurel.

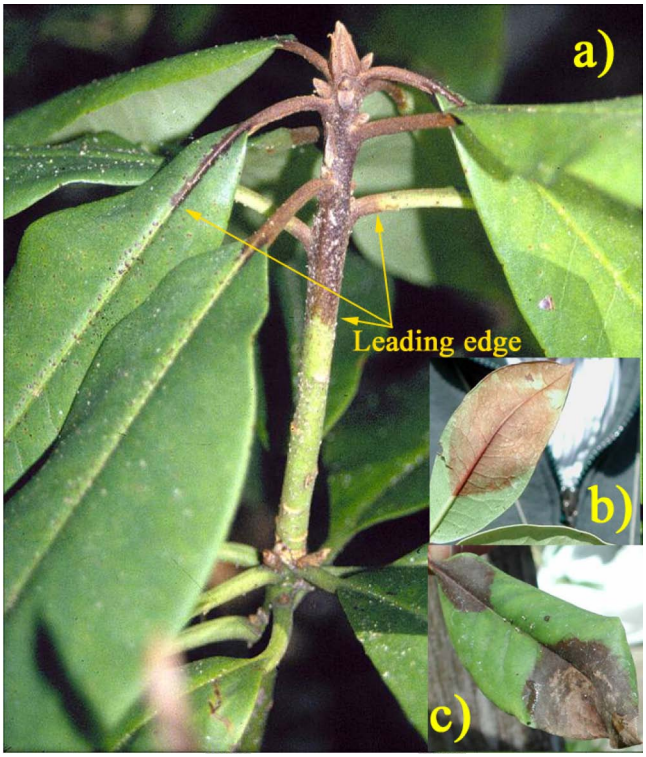

Figure 10. a) Shoot dieback of Rhododendron infected with *P. ramorum* (image courtesy E Hansen, Oregon State University). Underside (b) and top (c) of leaves infected with *P. ramorum* (images B Moltzen, Missouri Dept of Conservation)

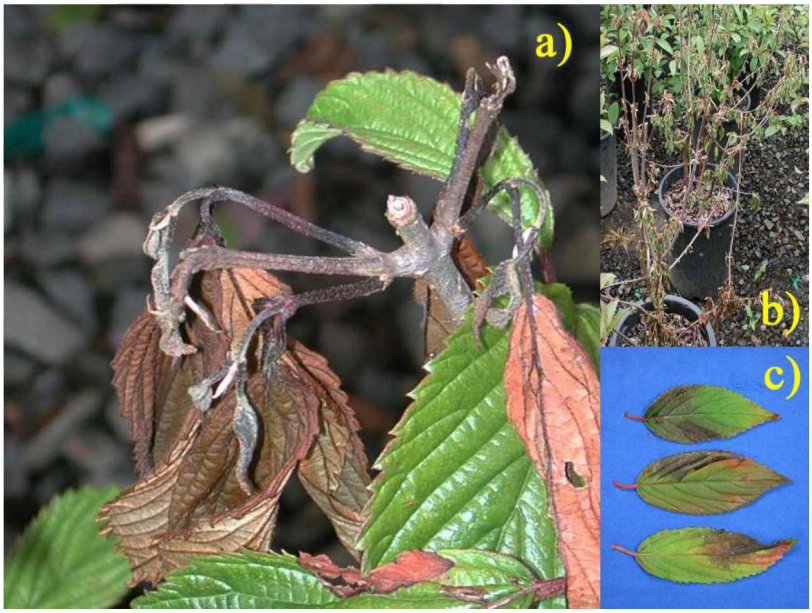

Figure 11. a) Shoot dieback of *Virburnum* sp. infected with *P. ramorum* (image Oregon Department of Agriculture), b) seedlings in pots killed by *P. ramorum* (image Oregon Dept of Agriculture), and c) leaf symptoms (image J Parke, Oregon State University)

Figure 12. *P. ramorum* infection on the leaves of California bay laurel (*Umbellularia californica*) (image J O'Brien, USDA-Forest Service)

Figure 13. Kino bleeding from the trunk of *Corymbia ficifolia* associated with *Botryosphaeria* infection in Victoria, Australia.

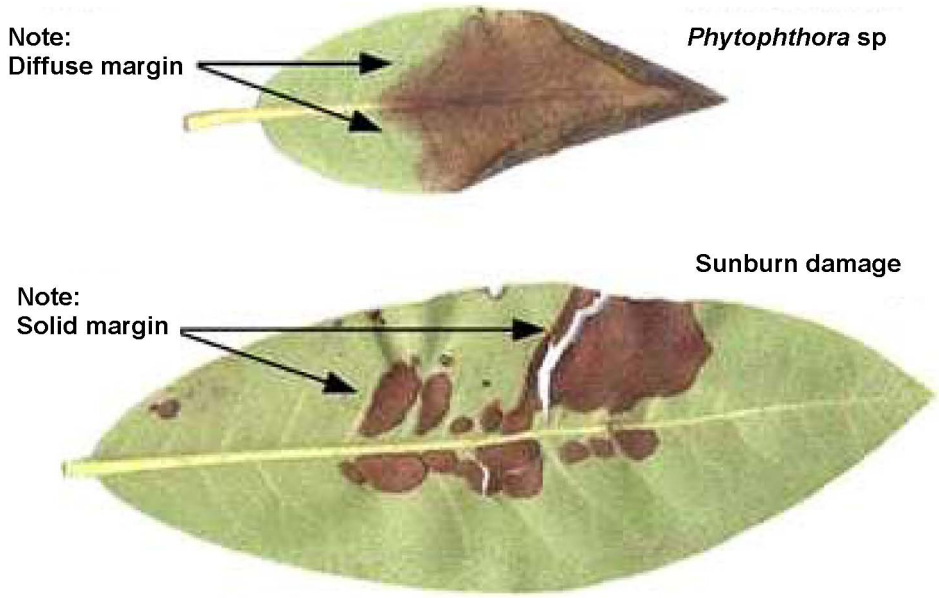

Figure 14. A comparison of leaf lesions caused by *Phytophthora* sp. compared to abiotic factors such as sun scorch. (T Tidwell, CA Dept of Food and Agriculture)

4.2 Diagnostic information

An expert with a good knowledge of *Phytophthora* spp. should investigate the plant material. Diagnosis of *P. ramorum* can be achieved at species level by either its growth characteristics in culture and morphology (if necessary followed by confirmatory biochemical or molecular methods), or by appropriate molecular methods. For detailed diagnostic information on isolation and identification of *P. ramorum* refer to the *Phytophthora ramorum* national diagnostic protocol[3] (Smith & Cunnington 2015).

Diagnostic approaches for *P. ramorum* are:

- **PCR** (Polymerase Chain Reaction) – used to determine the presence or absence of *P. ramorum*, and is capable of differentiating this pathogen from other *Phytophthora* species. Analysis can be completed using either conventional or real-time PCR.
- **Morphological methods** - used to isolate *P. ramorum* and other *Phytophthora* species from infected plant tissue. Plant tissue is selected from the leading edge of a canker or lesion and placed in selective media. Morphological characteristics of the mycelium, sporangia and chlamydospores can be used to aid identification.

Preliminary screening; serological methods

Preliminary serological screening methods can be used to pre-screen for the presence of *Phytophthora* spp., but such methods are not specific to *P. ramorum* and false negatives and positives are known to occur. They are useful for large scale surveys to reduce the number of samples being submitted for further testing.

[3] http://plantbiosecuritydiagnostics.net.au/app/uploads/2018/11/NDP-5-Sudden-Oak-Death-Phytophthora-ramorum-V2.pdf

4.3 Pathogen risk ratings and potential impacts

A pest risk analysis has been carried out for *P. ramorum*, taking into account the entry, establishment, and spread potentials, together with the economic and environmental impact of establishment. A summary of these ratings are shown in Table 5. Based on this information, *P. ramorum* is considered a high overall risk to Australia.

Table 5. Pest risk ratings for sudden oak death as determined in the Industry Biosecurity Plan for the Nursery and Garden Industry (2013)

Potential or impact	Rating
Entry potential	Medium
Establishment potential	High
Spread potential	High
Economic impact	High
Environmental impact	High
Overall risk	**High**

4.3.1 Entry potential

Rating: HIGH

The eight main pathways for the likely entry of *P. ramorum* into Australia are:

- Nursery stock for planting (excluding seeds and fruit) of known susceptible hosts
- Nursery stock for planting (excluding seeds and fruit) of non-host plant species accompanied by contaminated, attached growing media
- Soil/growing medium (with organic matter) as a commodity
- Soil as a contaminant (e.g. on footwear, machinery, etc.)
- Foliage or cut branches (for ornamental purposes) of susceptible foliar hosts
- Seeds and fruits of susceptible host plants
- Susceptible (isolated) bark
- Susceptible wood

P. ramorum can spread readily in soil and water and has a wide known host range (with potential to increase with further research). The overall potential of entry is considered to be **high**[4], mainly due to the wide host range and the ability of *P. ramorum* to persist in a variety of substrates (e.g. soil, growing media, bark, wood, foliage).

[4] Australian Department of Agriculture and Water Resources 2015, Final review of policy: importation of Phytophthora ramorum host propagative material into Australia. CC BY 3.0.

4.3.2 Establishment potential

Rating: HIGH
P. ramorum has a wide host range and suitable environmental conditions would allow establishment in many regions within Australia. The likelihood of *P. ramorum* establishment in Australia following entry is considered **high**.

Difficulties encountered by the European Union in management and eradication of this pest include the wide range of host plants cultivated in nurseries and the spread of the pest from nurseries to managed parks and gardens. In some of parts of the UK, eradication of the pest has been determined as unlikely and the control measures have moved towards containment with a view to suppressing inoculum levels in order to protect susceptible trees and reduce spread.

4.3.3 Spread potential

Rating: HIGH
P. ramorum has a wide host range, readily spreads in soil and water, and is likely to have relatively long lived spores which can be easily spread to other regions.

4.3.4 Economic impact

Rating: HIGH
Establishment of *P. ramorum* in Australia would require additional pest management practices to be put in place and result in movement restrictions for numerous ornamental and amenity species. Economic impact of a *P. ramorum* incursion would be highest to amenity plantings and in nursery settings.

Specifically, within production nurseries, there is a high likelihood of pest spread without strict movement restrictions, and additional chemical, mechanical and cultural controls required to manage/eradicate the pest, would result in a high economic impact. Experience from North America and Europe has shown nurseries to be ideal environments for *P. ramorum* establishment and spread. Establishment in the Australian nursery system could result in international trade restrictions.

If controls are lifted, environmental impacts may become an issue (see Section 4.3.5). Social impacts will be high as a result of infection and damage to plants in managed gardens, resulting in reduced visitor numbers and ultimately affecting the tourism industry when dependent on these gardens.

4.3.5 Environmental impact (including amenity)

Rating: HIGH
The known host range continues to increase for *P. ramorum* as the pathogen spreads into new areas. It is uncertain how many native species would be affected by *P. ramorum* should it be introduced into Australia, although a detached foliar inoculation study of 70 native species revealed that all species tested were able to be infected with the pathogen, with seven of these classified as potentially highly susceptible foliar hosts (Ireland *et al*. 2012a, Table 4). Also, in a parallel detached branch inoculation study of 66 native species, *P. ramorum* was able to infect all tested species, with two species identified as potentially highly susceptible branch dieback hosts (Ireland *et al*. 2012b, Table 4).

In addition to native species, many Australian cities and towns have exotic oak trees and other known host species that would be severely affected, including tree death, thus resulting in a significant amenity impact. The value of urban plantings to the community such as improving air quality, noise minimisation, city cooling, storm water velocity reduction and as wildlife corridors is hard to define in real terms. The loss of these significant urban assets will have an environmental and community

health impact that would add to any direct financial costs(s) attributed to crop losses due to *P. ramorum.*

4.3.6 Overall risk

Rating: HIGH
The overall risk to production nurseries is considered high, as susceptible host species are cultivated and a number of nursery practices aid in the establishment and spread of the pest. Although the pest favours mild and wet climates, its ability to form long-lived chlamydospores enables it to survive Mediterranean climates with hot and dry summers, as demonstrated in California. Survival in climates with cold winters, such as those of northern America and Europe has also been demonstrated. Additionally, in Australia the regions with the most suitable climate broadly coincide with areas of the most at-risk habitats.

5 Pest management

5.1 Surveys and epidemiology studies

5.1.1 Considerations

Information provided in Section 5.1.2 to 5.1.4 provides a framework for the development of early detection and delimiting surveys for *P. ramorum* in Australia. If evidence indicates that *P. ramorum* might only be present at a single or small number of production nurseries, rapid response action is recommended to eradicate the infestation before it spreads into natural areas.

Where *P. ramorum* is found in a production nursery that is in close proximity to potential host trees and shrubs additional factors and practices should be considered:

- Periodically inspect nearby potential hosts for symptoms of *P. ramorum* infection. Infected trees within the production nurseries may produce inoculum that can spread and cause infection of nearby plants.
- Rain runoff down slopes from areas with infected hosts may contain *P. ramorum* spores. Barriers including bunding should be used to prevent water and soil movement from infected areas.
- Irrigation should be selective, preventing irrigation on plants known to be infected with *P. ramorum* until they have been destroyed. Irrigation water pumped from surface supplies such as streams, creeks, ponds and dams in areas of infected native hosts may also be contaminated with *P. ramorum.* Such water should not be used for irrigation unless it is thoroughly disinfested. Consider having water periodically tested to detect *P. ramorum.*
- Avoid irrigation practices where the foliage is wetted for prolonged periods. If sprinklers are used, irrigate in the morning to allow thorough and quick drying of foliage. Overhead irrigation should be avoided on potential host plants of *P. ramorum* at a site where it has been detected
- Monitor and maintain irrigation systems to ensure the most uniform application of water to the crop. Correct low spots, areas of poor drainage, and clogged or leaking irrigation heads and under foliage irrigation systems such as drippers, spray stakes, flood floor, ebb/flow and capillary mats.
- Fungicides do not kill *P. ramorum* once an infection is established. However, fungicides may help prevent infection of healthy plants and slow spread. Rotation of fungicides will help prevent resistance from developing. Use only registered fungicides; also refer to minor use permits (e.g. PER81491).

- Wounded leaves (even tiny wounds or scratches) are much more susceptible to infection. Avoid handling host plants to reduce the chance of wounding when environmental conditions favour infection.
- Avoid plant contact with soil, use raised benches, gravel or other means to elevate susceptible plants and divert all drainage water and overland flow from growing beds.
- Plants that are suffering from poor vigour, disorders, or other serious problems should be removed from production areas and destroyed immediately (refer to destruction section). If only a small number of plants or plant parts can be disposed of at any one time, a cull pile may be used temporarily. The pile should be covered with a clear polyethylene sheet until the culls can be destroyed or composted.
- Unused growing media storage should be as far from infected plants as possible and covered with clear polyethylene sheeting to prevent pathogen spread. However, if crop debris is present in the growing media bays they may already be infested with *P. ramorum* and may need to be disinfested prior to use (disinfest growing media bays between batches).
- Loading and delivery areas should be as far from production areas as possible. Physical barriers may be required to prevent crop debris from blowing into loading and delivery areas assuming that businesses are able to continue to trade.

Agricultural inspectors and other production nursery visitors should avoid moving contaminated plant material and soil between production nurseries. Shoes, tools and vehicle tyres should be thoroughly washed of soil and then sanitised with a registered disinfectant. Extra precaution should be taken when working in areas known to be infested, including disposable overboots that may be used and disposed of onsite (see Sections 6.1 and 6.5.1).

5.1.2 Technical information for planning surveys

When developing surveys for *P. ramorum* presence and/or distribution, the following characteristics of the pathogen provide the basic biological knowledge that informs the survey strategy:

- Several clonal lineages of *P. ramorum* are known to exist and may need to be considered in diagnosing samples (e.g. Feau *et al.* 2019, Gagnon *et al.* 2014)
- No specific vectors are known in Australia, although bees, birds, mammals and equipment/machinery can transport plant parts carrying the pathogen
- Young or wounded leaves are highly susceptible to *P. ramorum* infection
- Endemic host species in Australia are likely to be numerous and widely dispersed
- Spores are readily wind and water dispersed over large distances
- Mechanical transmission risk is high on clothing, equipment and personal effects
- Significant proportions of Australia have favourable climatic conditions for *P. ramorum* spread and establishment

5.1.3 Surveys for early detection of an incursion in a production nursery

If an incursion of *P. ramorum* is to be eradicated, it must be detected very early, before the spores have had the opportunity to disperse very far or into soil or waterways. It is therefore necessary to consider pathways and plan surveys and/or sentinel plantings accordingly. Important points to consider when developing early detection surveys are:

- The greatest entry risk currently comes from travellers and illegal importations of host plants or other goods. Therefore, surveys at importing production nurseries, ports and populated areas are more critical than surveys of large areas of inaccessible native bushlands.
- Awareness information should be targeted at people who are in regular close contact with potential hosts in high risk areas or movement vectors (e.g. production nursery operators).
- Systematic and careful inspection of production nursery crops and propagative plant material is essential to prevent introduction of *P. ramorum* and limit its spread within and from contaminated production nurseries. Early detection of the pathogen, while at very low levels, will provide the best chance of eradication. BioSecure *HACCP* guidelines provide detailed procedures for crop monitoring, import inspection and site surveillance (NGIA 2016).
- An inspector must be trained to recognise *P. ramorum* symptoms and other similar disorders for comparison (see Section 4.1.9). A production nursery layout map that includes approximate locations of target species will be required to develop a strategy for surveys. A survey map should include species and cultivar names, locations, approximate quantity and sources of targeted plants within the area. However, consider all native plant species that have not previously been exposed to *P. ramorum* overseas as potential hosts. During the survey walkthrough, record the date, observations, and sampling information directly onto the survey map. The recorded information should be reviewed and used to develop an efficient survey strategy each time the nursery is inspected.
- Begin the inspection with an overview of the area from the crop perimeter or with a quick walk-through. If suspicious symptoms are apparent, immediately examine them more closely and take samples. If no symptoms are apparent, start by walking a systematic path through the crop. A common survey technique is to move relatively quickly down a walkway and scan both sides of adjacent production beds, back and forth. If suspicious symptoms are seen, inspect plants more closely. A good-quality 10x magnification hand lens can help identify many pest symptoms (although *P. ramorum* spores cannot be seen at this magnification). If plants are found with suspicious leaf spots or other symptoms, a sample should be taken and the plant marked with plastic tape or a flag with the location noted on the survey map. Also, a few plants can be selected at random to closely inspect for early stages of lesion development. In these containers, the investigator should look for leaf spots or fallen leaves with characteristic lesions. Surveys can be prioritised to highest risk stock. Summaries of BioSecure *HACCP* crop monitoring procedures for both protected and unprotected nursery production areas are shown in Tables 7 and 8.
- Stock or cuttings of hosts from outside sources should be monitored closely for development of infection, ideally in a separate area, for 3-6 months. Note outside-source plants on survey maps for weekly examination. Surveys should be intensified a few weeks after bud break and especially in rainy spring periods when environmental conditions are highly conducive to *P. ramorum* infection and development. For production nurseries surrounded by native hosts or adjacent to public parks and amenities, survey areas immediately adjacent to these hosts, especially wet areas, near puddles, or rain runoff zones.

5.1.4 Delimiting surveys in the event of an incursion

- In the event of an incursion, delimiting surveys will be required to inform the decision-making process
- The size of the survey area will depend on the size of the infected area and the severity of the infection, as well as prevailing winds during the period prior to detection

- All potential host species (refer to Section 4.1.5) should be surveyed, with particular attention (in the early phase) paid to the species in which the pathogen was initially detected
- In addition to inspection of possible host plants, material should be collected for diagnostic purposes (refer to Section 5.1.5)
- If the incursion is in a populated area, publication and distribution of information sheets and appeals for public assistance may assist

5.1.5 Collection and treatment of samples

Protocols for the collection, transport and diagnosis of suspect Emergency Plant Pests must follow PLANTPLAN (Plant Health Australia 2017). Any personnel collecting samples for assessment should notify the diagnostic laboratory prior to submitting samples to ensure expertise is available to undertake the diagnosis.

5.1.5.1 Collection of specimens

Sampling procedures

Different methods are used to sample for the pathogen depending on the type of material to be tested (Rizzo *et al*. 2002) and may include plant, water or soil samples.

Number of specimens to be collected

Where possible, collect triplicate samples from each host species, each sample covering the range of life cycle stages available (*Figure 2* and *Figure 3*). Also collect woody twigs and branches with swellings or cankers, which are indicative of an older infection. For nursery samples, entire plants can be bagged and sent to the laboratory.

Record the identity of the host plant. If the identity of the host plant is unknown, note as many details as possible and collect flowers, fruits and capsules, if available, to aid in identification. Where a seedling is infected and has no identifying structures (e.g. flowers, fruits, etc.), identify neighbouring trees and collect their flowers, fruits and capsules (if available). Record the location, preferably as GPS co-ordinates, or alternatively, a map reference or distance and direction from a suitable landmark. If the land is privately owned, record the owner's details with contact telephone numbers.

How to collect plant samples

The following plant sampling techniques have been taken from the National Diagnostic Protocol – *Phytophthora ramorum*, the cause of Sudden Oak Death (Smith & Cunnington 2015).

Bleeding cankers: Remove the outer bark in the area directly around the oozing sap until the margin of the lesion is evident. Remove pieces of cambium (approximately 7-10 cm length and width and 2-4 cm thick) which capture the margin between healthy tissue and diseased tissue; sample from multiple areas around the canker and place in a sealed container. Ideally, wrap samples in damp paper towel to avoid desiccation. Additionally, small pieces (approximately 1 to 2 cm^3) from the same areas as described above also may be removed aseptically and embedded directly in an agar medium (preferably a semi-selective medium) (Rizzo *et al*. 2002).

Shoots/twigs: Remove a piece of shoot or twig which captures the leading edge of the lesion (*Figure 8*) and place in a sealed container. Allow up to 5-7 cm on either side of the leading edge or, if possible, remove the entire shoot to allow for isolations in the laboratory. Multiple samples from one plant are preferable. Place a damp tissue with each sample to prevent desiccation.

Leaves: Remove 4-6 leaves, if possible, with symptoms as described above. Note that not all hosts display the same symptoms; therefore, if unsure, collect a sample which adequately represents the symptoms observed. Place samples in a sealed container with a damp tissue.

Packaging

Each sealed bag should be placed in a second bag along with additional paper to absorb excess moisture. Bagged samples should then be placed in a cardboard box or padded envelope with paper/ bubble/ foam to fill the remaining space and protect samples during transit.

All sample containers should be clearly labelled with the name, address and contact phone number of both the sending and receiving officers. Containers should also be clearly labelled in accordance with the requirements of PLANTPLAN (Plant Health Australia 2017). Containers should then be carefully sealed to prevent loss, contamination or tampering of samples. The Chief Plant Health Manager will select the preferred laboratory. Additional labelling includes the identification of plant species/parts affected, location of affected plant (where available include GPS reading) as well as symptoms and an image if available.

Refer to PLANTPLAN for packing instructions under IATA 650.

How to collect water samples

Water samples can be collected from any type of water body where *P. ramorum* is suspected including river or stream water, run-off water (e.g. from production nurseries), ditches, and puddles. Collect a minimum of 1 L of water from each sampling area; allow any sediment or debris to remain in the bottle. Samples should be kept in a cool ice chest (4-10°C) and should be processed within 48 hours (Smith & Cunnington 2015).

Alternatively, bodies of water can be baited *in situ* for an extended period of time (i.e. several days to two weeks depending on lesion development). This method is preferred as, in theory, the baits are exposed to more water. However, this method requires a longer sampling time and two visits to the baiting site (deployment and retrieval).

How to collect soil samples

Collect a composite sample (i.e. collect several scoops of soil from around a tree or block of plants into one bag) of approximately 1 L of growing media/soil (including debris) from affected areas; samples should be collected in a sealable plastic bag and placed inside a second bag to contain any leakage (Smith & Cunnington 2015).

Precaution

Overheating or desiccation of samples prior to despatch should be prevented. Samples may be stored at room temperature for several weeks if necessary. Avoid high temperatures and refrigeration.

Receipt

On receipt of samples the diagnostic laboratory should follow strict quarantine and processing guidelines. In keeping with ISO 17025 refer to PLANTPLAN (Plant Health Australia 2017).

5.1.6 Epidemiological study

The extent of infection on a nursery, property or within a region will depend on the amount of inoculum available and whether conditions have been favourable for the pathogen to spread from the initial focus. Sampling of plants will be based upon the origins of the initial suspect sample(s). Factors to consider will be:

- The proximity of other susceptible plants to the initial infection source, including both current and previous crops. This will include crops on the nursery or property with the initial infection source and those on neighbouring properties
- Machinery or vehicles that have been into the infected area or in close proximity to the infection source
- The extent of human movements into and around the infected area. A possible link to the recent importation of plant material, overseas travel or visitors from other regions should also be considered
- The source of any nursery stock propagation material
- If any other crops have been propagated from the same source and/or distributed from the affected nurseries

5.1.7 Models of spread potential

Kliejunas (2010) reviewed models used to predict the distribution and spread of *Phytophthora ramorum*, including regional and national models for the United States, as well as North American, European and international models. An international risk model developed for *P. ramorum*, using NAPPFAST[5] (Magarey *et al.* 2006, 2008) and the Intergovernmental Panel on Climate Change (IPCC) data set, was based on a favourable month having an average minimum monthly temperature of less than 28°C, an average minimum temperature of greater than 3°C, and at least 10 days with precipitation.

A CLIMEX simulation model was used to estimate the potential geographical range of *P. ramorum* globally, which suggested that the invasion of the pathogen in North America and Europe was still in its infancy (Ireland *et al*. 2013). It was also concluded that the pathogen appears to be climatically suited to large areas of Africa, Australasia and South America.

5.1.8 Pest Free Area guidelines

Determination of Pest Free Areas (PFAs) should be completed in accordance with the International Standards for Phytosanitary Measures (ISPMs) 8 and 10 (IPPC 1998a, 1999).
General points to consider are:

- Design of a statistical delimiting field survey for symptoms on host plants (see Section 5.1 for points to consider in the design)
- Plant sampling should be completed as described in the BioSecure *HACCP* manual (Nursery and Garden Industry Australia 2016), including plant monitoring (summarised in 7 and 8), indicator plants, and weed monitoring.
- Surveys should also consider alternative hosts (see Section 4.1.5) and not be limited to the primary infected host
- Survey around irrigation systems or waterways that may have transported spores
- Information (including absence of the pest) should be recorded

Additional information is provided by the IPPC (1995) in Requirements for the Establishment of Pest Free Areas. This standard describes the requirements for the establishment and use of pest free areas as a risk management option for phytosanitary certification of plants and plant products.

[5] NAPPFAST – The North Carolina State University/APHIS Plant Pest Forecast System

Establishment and maintenance of a PFA can vary according to the biology of the pest, pest survival potential, means of dispersal, availability of host plants, restrictions on movement of produce, as well as PFA characteristics (size, degree of isolation and ecological conditions).

5.2 Availability of control methods

Examples of control methods have been prepared by the Canadian Food Inspection Agency in the document 'PI-010 – Eradication Protocol for Propagation Nurseries Confirmed with *Phytophthora ramorum*' (inspection.gc.ca/english/plaveg/hort/pi-010e.shtml).

In a nursery, if the infested plants are high risk host plants from the Camellia, Rhododendron, Pieris, Kalmia or Viburnum genera, a destruction area will be established to cover all host plants within a block.

In relation to silvicultural practices, management guidelines for *Phytophthora ramorum* in Californian forests can be found in the USDA Forest Service document 'A reference manual for managing sudden oak death in California' Swiecki *et al*. (2013). The manual covers exclusion from non-infested areas, reducing disease risk in susceptible stands, monitoring oaks with the disease, and restoring affected forests. It has been shown that fresh wounds are optimal infection sites. In restoration projects, avoid bay laurel (*Umbellularia californica*) if possible, especially in areas where oaks may be growing. Eradication has been attempted in southern Oregon, USA, via the burn-and-slash technique (Goheen *et al.* 2002) and has been shown to be effective (Hansen *et al.* 2019).

Knowledge to support a complete control program is still limited. However, the following control methods are available (CAB 2012):

- Kiln drying: 55°C for at least 1 hour to kill the pathogen.
- Composting following guidelines prescribing piles to be kept at 55°C for at least 2 weeks is successful providing oospores are not present.
- Soil heated above 40°C for 3 days removes all detectable *P. ramorum* (Yakabe & MacDonald 2010).
    - Prolonged heating of soil at 35-40°C for 42 days eliminates detectable propagules (Yakabe & MacDonald 2010).
- *P. ramorum* is susceptible to label-dosages of copper sulphates and copper hydroxides and in some formulations is moderately susceptible to mancozeb. The pathogen is sensitive to phosphites (also known as phosphonates). Phosphite injections are effective in oaks and tanoaks, but phosphite foliar sprays are not. The pathogen is extremely sensitive to metalaxyl, but drenches and foliar sprays are ineffective in oaks (Garbelotto *et al.* 2002b). In addition, chloropicrin, Vapam, iodomethane and Basamid have all been demonstrated to reduce *P. ramorum* propagules to below detection limits (Yakabe & MacDonald 2010). Many of these products are on PER81491 for use against all *Phytophthora* species.
- Water and moisture management are extremely important, especially when temperatures are between 15 and 20°C. Infection on bay (*Umbellularia californica*) leaves requires 9-12 hours of leaf wetness.
- Pathogen transfer from infected oaks is estimated to be low, however, transmission from a number of other host species, such as bays, madrones (*Arbutus menziesii*) and rhododendrons is high.
- Early infection can be detected on foliar hosts - new infection on bay leaves and Pacific madrones, or infection on new maple *(Acer macrophyllum*) and buckeye (*Aesculus californica*) leaves are good indicators of inoculum level.

- Whole sites as well as areas of soil and streams can be monitored by baiting with live rhododendron or madrone plants (air), or with rhododendron leaves and pears (**Davidson *et al.* 2002**).

Other control options may include:

- Host removal (Section 5.2.2)
- Chemical control (Sections 5.2.4)
- Physical control (Section 5.2.3)

5.2.1 General procedures for control

- Keep traffic out of affected areas and minimize movement in adjacent areas
- Stop irrigating affected areas; stop overhead irrigating known susceptible hosts; use bunding to divert water if necessary
- Adopt best-practice property hygiene procedures to retard the spread of the pest between fields and adjacent properties
- After surveys are completed, destruction of the infected crop is an effective control
- Intensively disinfest infected areas (e.g. growing beds, structures, etc) after crop removal and destruction using registered fungicides and/or disinfestation chemicals
- On-going surveillance of disinfested areas to ensure the pathogen is eradicated
- Do not use any material from infected crops for propagation of next crop

5.2.2 Host removal

Host removal may be feasible in a small area and is the first and most preferred method to eradicate *P. ramorum* at production nurseries. Care must be taken not to spread the spores, which are readily wind and water dispersed, so removal should be preceded by spore destruction using fungicides or disinfectants. If the plants are too large for physical removal, the application of herbicides or defoliants may just as effectively remove susceptible plant tissue.

5.2.3 Physical control

Attempted eradication of *P. ramorum* is currently being undertaken in affected Oregon forests, mainly via felling and total burning as 'clearcuts' (Goheen *et al.* 2002). All host vegetation within 15-30 m of infected plants was destroyed during the first two years of the eradication program, but in recent years the distance has been increased to at least 100 m to reflect new information on pathogen spread. All tanoaks on private land are injected with herbicide prior to felling in order to prevent sprouting from the stump following cutting and burning. Follow-up herbicide treatments are necessary to destroy residual material and stump sprouts. Most sites are planted with non-host or conifer seedlings after burning (Kanaskie *et al*. 2008).

5.2.4 Chemical control

A range of fungicides have been tested for activity against *P. ramorum* using both *in vitro* and *in vivo* tests.

Seven fungicides applied as foliar sprays at the manufacturers recommended rate on rhododendron and viburnum were tested for protectant and eradicant activity (Turner *et al*. 2006). On rhododendron, metalaxyl-M, azoxystrobin and fenamidone/mancozeb completely inhibited symptom development when applied as protectant treatments either 4 or 7 days prior to inoculation. However, on viburnum only metalaxyl-M was completely effective at all protectant timings. Fenamidone/mancozeb was effective when applied 4 days prior to inoculation but efficacy was greatly reduced when the treatment was applied 3 days earlier. Fungicides were generally less effective when applied as eradicants. The most effective was metalaxyl-M, completely inhibiting disease development when applied 4 days after inoculation.

None of the fungicides completely controlled disease development on viburnum when applied after the same time period. Despite the fact that metalaxyl-M was the most effective fungicide for control of *P. ramorum*, use of this fungicide has not been recommended due to the significant risk of the rapid development of fungicide resistance in the pathogen. Co-formulations and mixtures of metalaxyl-M with other active ingredients, including those shown to be effective in this study (e.g. azoxystrobin and fenamidone/mancozeb), need to be investigated to develop a protocol for durable fungicidal control of *P. ramorum* (Turner et al. 2006).

In Canada, Elliot *et al.* (2015) reported that the best control of *P. ramorum* mycelial growth, zoospore germination, and infection of rhododendron foliage was obtained with systemic fungicides (metalaxyl-M, dimethomorph, fenamidone, azoxystrobin, and pyraclostrobin) compared to contact and protectant fungicides (chlorothalonil, copper hydroxide and mancozeb). While these single-site mode of action systemic fungicides were found to be the most effective, their higher risk of resistance compared to contact and protectant fungicides, as well as to multi-site systemic fungicides and plant activators such as phosphite, was noted.

All fungicides listed above are registered for use in Australia against other fungal pathogens by the Australian Pesticides & Veterinary Medicines Authority (APVMA, PO Box 6182, Kingston, ACT 2604; ph. 02 6210 4701; https://apvma.gov.au/). If *P. ramorum* is detected in Australia, an additional permit would be required to enable the use of these chemicals for its management and/or destruction. Additional permits would be required from the Civil Aviation Safety Authority (CASA, phone 131 757, https://www.casa.gov.au/) for aerial application of the pesticide.

5.2.5 Biological control

Studies have demonstrated the potential of *Trichoderma asperellum* isolates 04-22 and 02-64 to remediate *P. ramorum* – infested soil under common production nursery practices in an open environment (Widmer *et al*. 2018; Widmer 2014). In a separate study (Widmer & Dodge 2013), three antagonistic fungi isolated from soil (*Penicillium daleae*, *P. herquei* and *Metarhizium anisopliae*) showed potential for controlling necrosis caused by *P. ramorum* when applied to leaves of rhododendron, although the authors did note some variability in responses.

Bailey *et al*. (2012) evaluated a range of commercial biofungicides on *in vivo* disease development and plant growth in four nursery species (*Gaultheria shallon*, *Rubus spectabilis*, *Rhododendron caucasicum* x *R. ponticum* var. *album*, and *Cornus sericea*) inoculated with three isolates each representing the NA1, NA2 and EU1 lineages of *P. ramorum*. The products tested were Actigard 50WG Plant Activator®, Actinovate® SP, Sonata®, Serenade®, Plant Helper®, SoilGard® 12G, Pro Mix BX Biofungicide™ and Aliette® (standard fungicide). Actinovate (*Streptomyces lydicus*) was the only product able to reduce disease severity by about 50% and improve growth of the susceptible hosts. None of the products tested prevented disease, and generally the level of control obtained was considered to be lower than would be acceptable for a commercial nursery.

6 Course of action

6.1 Destruction strategy

It is important to consider each situation on a case-by-case basis. Destruction of all hosts might be necessary; destruction of non-hosts might also be deemed appropriate. Nursery location, size and design of the nursery, wind and climate conditions, will need to be considered. Potential new hosts will need to be identified in the current literature and careful consideration will be required for Australian plants not previously exposed to the pathogen.

For attempted eradication of an initial incursion in a production nursery, the destruction of all plants of the infested consignment/area and within 100m (where appropriate) is the most feasible option. This should be completed following the application of a registered product (fungicide/disinfestant), preferably containing the active ingredient metalaxyl, to prevent the spread of spores. Plant debris should be destroyed and the growing area disinfested as indicated below. Depending on the situation, destruction of all known host plant species may be necessary (e.g. if water is recycled and a break down in water disinfestation has occurred within the known period of infestation or if infected plants are scattered around the nursery etc).

If removal/destruction of affected plants in an area is deemed impractical, repeated aerial fungicide spraying may be the only possible method of containment until such time that on ground destruction is possible or management is no longer deemed necessary.

In natural areas eradication may be impossible. However, if the area is small then it may be feasible to destroy all infected plants and all known host plants within a 100m radius of infected plants (as per eradication efforts in the USA).

Spores are aerially dispersed and may also ‘hitchhike’ on any person, animal, plant or object that is transported from within the infested area. Therefore, disinfestation methods for machinery, clothing, etc., are also necessary to establish successful eradication strategies. Heat treatment (including steam), sodium hypochlorite, calcium hypochlorite or quaternary ammonium compounds may all be useful in this context, although no detailed studies of spore destruction have been published. The minor use permit PER80699 has a range of products for use in production nurseries. Additional approved disinfectant products can be found by searching the APVMA PubCRIS Product search and Permit search databases (https://apvma.gov.au/).

6.1.1 Destruction protocols

Destruction protocols will be established as a priority at the commencement of an incursion.

- Refer to Section 5.3
- Infected plant material, infested growing media/soil, disposable equipment etc should be disposed of by autoclaving, high temperature incineration or deep burial
- Infected plants will be first treated by an appropriate fungicide to kill the pathogen and prevent dispersal of spores
- Any equipment removed from the site for disposal should be double-bagged

6.1.2 Decontamination protocols

Machinery, equipment, vehicles in contact with infected plant material or growing media/soil or present within the Quarantine Area, should be washed to remove plant material and growing

media/soil using high pressure water or scrubbing with products such as a degreaser or a bleach solution in a designated wash down area. When using high pressure water, care should be taken not to spread plant material or spores by aerosol water droplets. Combining degreaser or detergent or using steam with high pressure water would be preferred and high pressure water should be used in wash down areas which meet the following guidelines:

- Located away from crops or sensitive vegetation
- Readily accessible with clear signage
- Access to fresh water and power
- Mud free, including entry and exit points (e.g. gravel, concrete or rubber matting)
- Gently sloped to drain effluent away
- Effluent must not enter water courses or water bodies
- Allow adequate space to move larger vehicles
- Away from hazards such as power lines
- Waste water, growing media/soil or plant residues should be contained
- Disposable overalls and rubber boots should be worn when handling infected plant material or growing media/soil in the field. Boots, clothes and shoes in contact with infected plant material or growing media/soil should be disinfected at the site or double-bagged to remove for cleaning
- Skin and hair in contact with infested plant material or growing media/soil should be washed

Procedures for the sterilisation of plant containers and growing media are provided within the BioSecure *HACCP* Guidelines however, in the event of a *P. ramorum* incursion, procedures outlined in the BioSecure *HACCP* Guidelines may not be effective for the destruction of the pathogen. Any sterilisation procedure must be approved for use in the endorsed Response Plan.

6.1.3 Priorities

- Confirm the presence of the pest
- Prevent movement of vehicles and equipment through affected areas
- Stop the movement of any plant material that may be infected with the pathogen
- Determine the strategy for the eradication/decontamination of infected host material
- Determine the extent of infection through survey and plant material trace back

6.1.4 Plants, by-products and waste processing

- Any growing media/soil or infected plant material removed from the infested site should be destroyed by (enclosed) high temperature incineration, autoclaving or deep burial (refer to Sections 6.1.1 and 5.3)
- As the pathogen can be mechanically transmitted, plant debris from the destruction zone must be carefully handled and transported

- Infested areas or production nursery sites should remain free of known susceptible host plants until the area has been shown to be free from the pathogen

6.1.5 Disposal issues

- Particular care must be taken to minimize the transfer of infected plant material from the area
- Burning of plant material is not recommended as a destruction strategy as the air updrafts caused by the heat of the fire could disperse the pathogen spores
- Host material including leaf litter should be collected and incinerated or double bagged and deep buried in an approved site

6.2 Containment strategies

For some exotic pest incursions where eradication is considered impractical, containment of the pest may be attempted to prevent or slow its spread and to limit its impact on other parts of the state or country. Containment is currently being considered for inclusion within the EPPRD. For *P. ramorum*, containment is expected to be difficult once the pathogen has spread into the natural ecosystem. The practicality of local containment will depend upon the presence of natural barriers such as a large surrounding area without susceptible hosts or with an unsuitable climate. If *P. ramorum* becomes established in such a location, there may be an opportunity to delay its spread to other regions by local quarantine measures such as a ban on export of plants from the area, compulsory wash-down stations for vehicles leaving the infected area and encouragement of individual measures to reduce the likelihood of inadvertent dispersal by residents and visitors (refer to Section 5.2).

In addition, reduction of local inoculum levels in and around susceptible crops may be effective in controlling disease levels. This may be achieved by the removal of highly susceptible hosts in the vicinity of vulnerable crops.

6.3 Quarantine and movement controls

Consult PLANTPLAN (Plant Health Australia 2017) for administrative details and procedures.

6.3.1 Quarantine priorities

- Plant material and growing media/soil at the site of infection to be subject to movement restrictions
- Machinery, equipment, vehicles and disposable equipment in contact with infected plant material or soil to be subject to movement restrictions

6.3.2 Movement controls

Movement of people, vehicles, equipment and plant material, from and to affected properties or areas, must be controlled to ensure that the pathogen is not moved off-property. Movement controls can be achieved through the following, however specific measures must be endorsed in the Response Plan:

- Signage to indicate quarantine area and restricted movement into and within these zones, including at walking tracks through naturally infested areas
- Fenced, barricaded or locked entry to quarantine areas
- Off-site movement of equipment, machinery, plant material or growing media/soil by permit only.
- Where no dwellings are located within these areas, strong off-site movement controls should be enforced
- Where dwellings and places of business are included within the Restricted and Control Areas movement restrictions are more difficult to enforce, however avoidance of contact with diseased plants should be regulated
- If a production nursery is situated within the Restricted Area, all production nursery operations must be assessed and possibly cease (at least temporarily) if posing an unacceptable risk, with no material to be removed without permission, due to the high likelihood of pathogen spread. Movement restrictions and entry conditions would be imposed on both host and non-host material
- Residents should be advised on measures to minimise the inadvertent transport of spores from the infested area to disease-free zones
- Clothing and footwear worn at the infected site should either be double-bagged prior to removal for decontamination or should not leave the site until thoroughly disinfected, washed and cleaned
- Plant material or plant products must not be removed from the site without permission
- All machinery and equipment should be thoroughly cleaned down with a high pressure cleaner (see Section 6.1.2) or scrubbing with products such as a farm degreaser or a 1% bleach (available chlorine) solution, prior to leaving the affected area. The clean down procedure should be carried out on a hard surface, preferably a designated wash-down area, to avoid mud being re-collected from the affected site onto the machine. Care should be taken when using high pressure water to contain all plant material, mud and pathogen spores dislodged during the cleaning process

6.4 Zoning

The size of each quarantine area will be determined by a number of factors, including the location of the incursion, biology of the pest, climatic conditions and the proximity of the infected property to other infected properties. This will be determined by the National Management Group during the production of the Response Plan. Quarantine areas are outlined below.

6.4.1 Destruction Zone

All possible host plants should be destroyed after the level of infection has been established. The delimiting survey will determine whether or not neighbouring plants are infected and need to be destroyed. Non-host plant material within this zone may be decontaminated or destroyed, based on recommendations in the Response Plan. The Destruction Zone may be defined as contiguous areas associated with the same management practices as the infected area (i.e. the entire nursery, property or forest area if spread could have occurred prior to the infection being identified).

Particular care needs to be taken to ensure that plant material (including non-hosts) is not moved into surrounding areas. It is recommended to destroy all host plants within 100m of infected plant/s or blocks, within a production nursery, although this would depend on the size and configuration of the nursery and surrounding vegetation and waterways.

6.4.2 Quarantine Zone

The Quarantine Zone is defined as the area where voluntary or compulsory restraints are in place for the affected property or properties. These restraints may include restrictions or movement control for removal of plants, people, growing media/soil or contaminated equipment from an infected property.

6.4.3 Buffer Zone

A Buffer Zone may or may not be required depending on the incident. It is defined as the area in which the pest does not occur but where movement controls or restrictions for removal of plants, people, soil or equipment from this area are still deemed necessary. The Buffer Zone may enclose an infested area (and is therefore part of the Control Area) or may be adjacent to an infested area. Given that there is evidence that *P. ramorum* can spread naturally up to 4km, it is recommended that the Buffer Zone extend a minimum of 4km.

6.4.4 Restricted Area

The Restricted Area is defined as the zone immediately around the infected premises and suspected infected premises. The Restricted Area is established following initial surveys that confirm the presence of the pest. The Restricted Area will be subject to intense surveillance and movement control with movement out of the Restricted Area to be prohibited and movement into the Restricted Area to occur by permit only. Multiple Restricted Areas may be required within a Control Area.

6.4.5 Control Area

The Control Area is defined as all areas affected within the incursion. The Control Area comprises the Restricted Area, all infected premises and all suspected infected premises and will be defined as the minimum area necessary to prevent spread of the pest from the Quarantine Zone. The Control Area will also be used to regulate movement of all susceptible plant species to allow trace back, trace forward and epidemiological studies to be completed.

6.5 Decontamination and farm clean up

Decontaminant practices are aimed at eliminating the pathogen thus preventing its spread to other areas.

6.5.1 Decontamination procedures

General guidelines for decontamination and clean up:

- Refer to PLANTPLAN (Plant Health Australia 2017) for further information
- Keep traffic out of affected area and minimize it in adjacent areas
- Adopt best-practice property hygiene procedures to retard the spread of the pathogen between growing areas/fields and adjacent properties

- Machinery, equipment, vehicles in contact with infected plant material or growing media/soil present within the Quarantine Area, should be washed to remove growing media/soil and plant material using high pressure water or scrubbing with products such as a degreaser or a bleach solution in a designated wash down area as described in Section 6.1.2
- Only recommended materials are to be used when conducting decontamination procedures, and should be applied according to the product label

6.5.2 General safety precautions

For any chemicals used in the decontamination, follow all safety procedures listed within each MSDS.

6.6 Surveillance and tracing

6.6.1 Surveillance

Detection and delimiting surveys are required to delimit the extent of the outbreak, ensuring areas free of the pest retain market access and appropriate quarantine zones are established.
Initial surveillance priorities include the following:

- Survey all known host growing properties and businesses in the pest quarantine area
- Survey all properties and businesses identified in trace-forward or trace-back analysis as being at risk
- Survey all host growing properties and businesses that are reliant on trade with interstate or international markets that may be sensitive to pathogen presence
- Survey other production nurseries selling at risk host plants
- Survey other host growing properties and backyards

6.6.2 Survey plan

Steps outlined in Table 9 form a basis for a survey plan. Although categorised in stages, some stages may be undertaken concurrently based on available skill sets, resources and priorities.

Table 9. Phases to be covered in a survey plan

Phase 1	Identification of properties that fall within the buffer zone around the infested premise Complete preliminary surveillance to determine ownership, property details, production dynamics and tracings information (this may be an ongoing action)
Phase 2	Preliminary survey of host crops in properties in buffer zone establishing points of pest detection
Phase 3	Surveillance of an intensive nature, to support control and containment activities around points of pest detection
Phase 4	Surveillance of contact premises. A contact premise is a property containing susceptible host plants, which are known to have been in direct or indirect contact with an infested premises or infected plants. Contact premises may be determined through tracking movement of materials from the property that may provide a viable pathway for spread of the disease. Pathways to be considered are: • Items of equipment and machinery which have been shared between properties including bins, containers, irrigation lines, vehicles and equipment • The producer and retailer of infected material if this is suspected to be the source of the outbreak • Labour and other personnel that have moved from infected, contact and suspect premises to unaffected properties (other growers, tradesmen, visitors, salesmen, crop scouts, harvesters and possibly beekeepers) • Movement of plant material and growing media/soil from controlled and restricted areas • Storm and rain events and the direction of prevailing winds that result in air-borne dispersal of the pathogen during these weather events
Phase 5	Surveillance of production and retail nurseries, gardens and public land where plants known to be hosts of pathogen are being grown
Phase 6	Agreed area freedom maintenance, post control and containment

6.6.3 Post-eradication surveillance

The period of pest freedom sufficient to indicate that eradication of the pest has been achieved will be determined by a number of factors, including cropping conditions, the previous level of infection and the control measures applied.
Specific methods to confirm eradication of *P. ramorum* may include:

- Monitoring of sentinel plants
    - Sentinel plants are to be grown in pots or small plots at the affected site. Plants are to be grown *in situ* under quarantine conditions and monitored for symptoms of infection
    - If symptoms are detected, samples are to be collected and stored and plants destroyed
- Surveying host plants with sampling for *P. ramorum* to be undertaken for a minimum of three years after eradication has been achieved
- Growing alternative non-host crops on the site and spraying out any self-sown host plants with a selective herbicide

7 Technical debrief and analysis for stand down

Refer to PLANTPLAN (Plant Health Australia 2017) for further details.
The emergency response is considered to be ended when either:

- Eradication has been deemed successful by the lead agency, with agreement by the Consultative Committee on Emergency Plant Pests and the Domestic Quarantine and Market Access Working Group
- Eradication has been deemed impractical and procedures for long-term management of the disease risk have been implemented

A final report should be completed by the lead agency and the handling of the incident reviewed. Eradication will be deemed impractical if, at any stage, the results of the delimiting surveys lead to a decision to move to containment/control. In this instance, it will still be desirable to prevent incursions of additional biotypes of *P. ramorum*, therefore, a review of current quarantine procedures may still be necessary to decrease this risk.

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8.1 Related Websites

www.forestry.gov.uk/pdf/EPAversion3.pdf/$FILE/EPAversion3.pdf

https://www.forestresearch.gov.uk/tools-and-resources/pest-and-disease-resources/ramorum-disease-phytophthora-ramorum/

www.suddenoakdeath.org/

https://secure.fera.defra.gov.uk/phiw/riskRegister/viewPestRisks.cfm?cslref=23022&riskId=23022

http://oregonstate.edu/dept/nurspest/sudden_oak_death.htm

https://www.aphis.usda.gov/aphis/ourfocus/planthealth/plant-pest-and-disease-programs/pests-and-diseases/phytophthora-ramorum/CT_Phytophthora_ramorum_Sudden_Oak_Death

http://www.padil.gov.au/pests-and-diseases/pest/main/136615

https://www.canr.msu.edu/ipm/uploads/files/Forecasting_invasion_risks/ramorumBlight.pdf

https://nature.berkeley.edu/matteolab/?page_id=117

https://anrcatalog.ucanr.edu/pdf/8156.pdf

https://www.ct.gov/caes/lib/caes/documents/publications/fact_sheets/plant_pathology_and_ecology/ramorum_blight_(sudden_oak_death)_12-20-12.pdf

www.inspection.gc.ca/english/plaveg/hort/pi-010e.shtml

9 Appendices

9.1 Appendix 1: Standard diagnostic protocols

For a range of specifically designed procedures for the emergency response to a pest incursion refer to Plant Health Australia's PLANTPLAN (www.planthealthaustralia.com.au/plantplan).

9.2 Appendix 2: Resources and facilities

Table 10 provides a list of diagnostic facilities for use in professional diagnosis and advisory services in the case of an incursion.

Table 10. Diagnostic service facilities in Australia

Facility	State	Details
Crop Health Services	VIC	AgriBio Specimen Reception Main Loading Dock, 5 Ring Road La Trobe University, Bundoora VIC 3083 Ph: 03 9032 7515; Fax: 03 9032 7064
DPI New South Wales – Elizabeth Macarthur Agricultural Institute	NSW	Woodbridge Road Menangle NSW 2568 PMB 8 Camden NSW 2570 Ph: (02) 4640 6327; Fax: (02) 4640 6428
SARDI Plant Research Centre – Waite Main Building, Waite Research Precinct	SA	Hartley Grove Urrbrae SA 5064 Ph: (08) 8303 9400; Fax: (08) 8303 9403
Biosecurity Queensland – Department of Agriculture and Fisheries	QLD	DAF Ecosciences Precinct Dutton Park Q 4102 Ph: (07) 3404 6999; Fax (07) 3404 6900
Department of Agriculture and Food, Western Australia (AGWEST) Plant Laboratories	WA	3 Baron-Hay Court South Perth WA 6151 Ph: (08) 9368 3721; Fax: (08) 9474 2658

9.3 Appendix 3: Communications strategy

A general Communications Strategy is provided in PLANTPLAN (Plant Health Australia 2017).

9.4 Appendix 4: Market access impacts

DAWR maintain the MICoR (Manual of Importing Country Requirements) website (https://micor.agriculture.gov.au/Pages/default.aspx) which sets out the requirements that exporters and the Department of Agriculture must meet for products and commodities to be accepted for import into specific overseas countries. MICoR is updated when there is a change to an importing country's

requirements. This website can be easily searched to find specific requirements for importing countries in relation to different hosts of *Phytophthora ramorum.*