

Myrtle Rust and the New Zealand Forest Industry



REPORT INFORMATION SHEET

REPORT TITLE Myrtle Rust and the New Zealand Forest Industry

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CLIENT NEW ZEALAND FOREST OWNERS' ASSOCIATION

CLIENT CONTRACT NO:

FRST CONTRACT NO:

SIDNEY OUTPUT NUMBER 57365

SIGNED OFF BY LINDSAY BULMAN, SCIENCE LEADER, FOREST PROTECTION

DATE MAY, 2016

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Cover

Myrtle rust on myrtaceous host species. Top left: *Lophomyrtus xralphii* 'Black Stallion'. Top right: *Lophomyrtus* sp. Bottom left: *Metrosideros collina* 'Spring Fire' (*M. collina* 'Thomasii'). Bottom right: *Syzygium jambos*.

Sources: Clockwise from top left: Agriculture Victoria. Biosecurity Tasmania, Dept. Primary Industries, Parks, Water and Environment. Queensland Department of Agriculture and Fisheries. NSW Department of Primary Industries.

SUMMARY

Introduction: This report examines the biosecurity implications of myrtle rust in relation to the New Zealand forest industry, and reviews possible options.

Biology: The disease myrtle rust is caused by *Puccinia psidii* which, unusually among rust fungi, is found on a large number of host species (in excess of 445), all in the family Myrtaceae. In its natural habitat in South America, it does little harm but, particularly in the last decade, different strains have spread widely to new host species and regions, and the disease can now be found in the Caribbean, Mexico, the United States (including Hawaii), Asia, Australia, New Caledonia and South Africa, but not New Zealand. *Puccinia psidii* disperses rapidly and widely by airborne urediniospores, and to a lesser extent, teliospores, which infect new leaves and shoots, and in some hosts also flowers and fruits, of younger aged plants. Fruiting pustules are produced in cycles of about 10-14 days during spring and summer (4-5 weeks in winter). Hosts vary in their susceptibility to different strains of *P. psidii*, and repeated infection may lead to shoot dieback and eventually death.

Risk for New Zealand: Myrtle rust has spread through the full length of eastern Australia in the six years since it was found north of Sydney in April 2010. However, it has not yet been detected in New Zealand, even though it is common for other rusts to establish here within one or two years of their discovery in Australia. It is likely that the greatest risk of entry is through the importation of live plants from Australia, and the Ministry for Primary Industries (MPI) has taken steps to reduce this possibility. Among other changes, the post-entry quarantine period for some myrtaceous species has been increased to 6 months, while imports of cut flowers are currently prohibited. Nevertheless, the risk is not totally negated since light dustings of spores on clothing, camping equipment, containers and other imports are easily missed, as may be inconspicuous symptoms on infected plants. Climate modelling has determined that environmental conditions are probably suitable for the disease in lower elevation areas throughout the North Island and possibly parts of the South Island.

Potential impact: A variety of indigenous and introduced myrtaceous plants are present in New Zealand. Some are known to be susceptible, but the precise vulnerability of most species is unknown. If myrtle rust does establish, the greatest commercial impact is likely to be to retail nurseries and cut flower exporters. There could also be serious consequences for the manuka honey industry. The impact on forestry is likely to be small. Eucalypt plantations make up about 1.5% of the plantation forest area and in Australia only young plantings are affected. It may be economic to apply fungicides. Some myrtaceous plants will probably become diseased to a greater or lesser degree in gardens, parks, other urban amenity areas and in rural settings. Potentially the greatest impact could be in native forest or scrubland, but this is impossible to predict. *Lophomyrtus* (e.g. ramarama) shrub cultivars are known to be very vulnerable in Australian gardens, but the susceptibilities of species of *Metrosideros* (e.g. pohutukawa and rata), already besieged by introduced possums, and of *Leptospermum* and *Kunzea* (e.g. manuka and kanuka) are unknown. Experience in Australia indicates that predicting which indigenous species will be most affected is problematic.

Deterrence and early detection: New Zealand has several measures in place to minimise the chances of a *P. psidii* incursion and for a quick response. Apart from the regulatory procedures referred to above, MPI has conducted a thorough pest risk analysis directed especially towards the live plant imports risk. MPI also runs a High Risk Site Surveillance (HRSS) programme targeting higher probability areas such as port environs. Diagnostic laboratories in New Zealand maintain capability for rapid molecular and morphological identification of *P. psidii* and their myrtaceous hosts. MPI also maintains a “hot line” for

public reporting of suspected incursions, and visits by science staff have been made to discuss myrtle rust with specialists in Australia. Nevertheless, there are some gaps. For instance, it is questionable if routine surveillance is frequent enough to detect a rust incursion before spores are released to infect new plants. Resources and personnel may not be ready to hand in the event of an incursion. Experience in Australia indicates that an immediate response is necessary for any hope of eradication.

The contingency plan: It is possible to learn from the Australian experience. A comprehensive pest risk analysis and a contingency plan were both in place prior to the discovery of myrtle rust in Australia. However, one week after its detection in April the National Management Group (NMG) determined that eradication was not possible, in the belief that the disease was already widespread, based on the perceived rapidity with which rusts in general are known to disperse. Two months later, surveys indicated that the rust was not spreading as quickly as anticipated during the cooler months and the eradication attempt was reinstated. However, this was finally terminated 6 months later when, with the warmer spring and summer conditions, airborne spores had become plentiful and the spread was more rapid. In New Zealand a set of comprehensive pre-incursion criteria is required to guide decision-making. The option to attempt eradication should be based on reliable knowledge on the extent of the incursion. However, obtaining this information should not delay an immediate interim start pending the eventual informed decision. The criteria guidelines should be part of an incursion management plan, which will include clear details of agreed actions, resources available, pre-determined funding commitments and a chain of responsibility during the different phases of an incursion. The plan should be tested in one or more simulation exercises.

Response options: Should *P. psidii* be found eradication will be possible, and should be attempted immediately, if:

- the pathogen is limited in distribution,
- the affected area is readily accessible,
- initial detection is during autumn or early winter,
- urediniospores are absent or present only in small numbers, and
- an active incursion response plan that can be readily implemented (which includes the prompt quarantining of infected nursery stock and destruction of diseased material) is in place.

Eradication will not be possible, and should not be attempted, if: *P. psidii* is widely distributed in parks, gardens and wilderness areas; access is limited; urediniospores are present in abundance on diseased plants during spring or summer; and a contingency plan does not exist or is incomplete or inactive.

Recommendation: If myrtle rust invades New Zealand it is likely to involve a variety of commercial and non-commercial interests. Not all industries that might be affected by myrtle rust are part of the Government Industry Agreement Deed. Despite these circumstances a successful eradication attempt cannot be undertaken in isolation. Although myrtle rust will probably not impact heavily on plantation forestry it is in the interests of the industry to be involved with the decision making on preparation for a possible incursion and to a response. A practical mechanism is needed to take account of those parties not included in a current agreement, without introducing excessive administration that might hinder progress. MPI has already set in train several processes that indicate they view myrtle rust as a serious threat. If myrtle rust does reach this country, a comprehensive, verified contingency plan ready to be implemented is an essential step towards successful eradication.

Myrtle Rust and the New Zealand Forest Industry

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May, 2016

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1 Introduction

The purpose of this review, commissioned by the New Zealand Forest Owners' Association, is to examine the implications of an introduction of myrtle rust to the forest industry in this country. It considers the chances of an incursion, its possible spread, host preference and potential impact. In particular, the review examines the likelihood of eradicating it if and when it is detected and the present "best practice" option available to forest managers. In other words, what else should we be doing now? For greatest likelihood of success, dealing with this threat should be coordinated in collaboration with other affected stakeholders.

A great deal has already been written and discussed about the risk of myrtle rust invading new regions and it was requested that this review be kept brief and to the point. Accordingly, it is presented as a compact synopsis of present knowledge rather than a comprehensive incursion plan (a document still to be written). It is an appraisal of the risk, built up from earlier evaluations such as the analysis by Ramsfield et al. (2010), which appeared soon after myrtle rust was found in Australia, and on the report of Scott and Miller (2013) following their visit to examine infested sites in that country. It also relies on detailed myrtle rust risk assessments prepared by the Australian Office of the Chief Plant Protection officer (OCPPO 2007), the Centre for Agriculture and Bioscience International (CABI 2016) and the New Zealand Ministry of Agriculture and Forestry (MAF, now Ministry for Primary Industries, MPI¹). Besides these, additional information is included from more recent publications. Discussion with, and reports by various people with firsthand experience of this disease outside New Zealand were also helpful (refer Acknowledgements). The review is largely unreferenced, for the sake of brevity, but a bibliography is provided as an appendix (App. 1).

2 Background

2.1 The nature of the pathogen

Myrtle rust (also known as guava rust, eucalyptus rust, or ohia rust) is caused by the basidiomycete rust fungus *Puccinia psidii*. Included among the many synonyms of this pathogen are *Uredo rangelii*² and *Uredo psidii* (names for the asexual stage). *Puccinia psidii* was first described from *Psidium guajava* (guava) in Brazil in 1884. It is considered indigenous to central and South America where it is genetically diverse, forming a complex (*P. psidii* s.l.³) composed of a number of races or strains⁴. These races vary in their ability to infect and cause disease in particular hosts or host groups (e.g. plants may be attacked more severely when inoculated with spores taken from diseased plants of the same species than when infected by races attacking other hosts⁵). Outside South America, two strains of *P. psidii* are reported in Jamaica, three in Florida, and one in each of Hawaii and Australia⁶.

¹ Clark 2011; this report is directed primarily towards the threat posed by imports of myrtaceous plants and plant material to New Zealand.

² The name *U. rangelii* was applied to the pathogen when it was initially found in Australia, before being synonymised with *P. psidii*.

³ Sensu lato, i.e. in the broad, not restricted sense.

⁴ Biotypes or "multilocus haplotypes". High genetic variability has been demonstrated within the *P. psidii* population in Brazil (in contrast to those in Australia and Hawaii), apparently through mutation, with different genotypes adapting to separate hosts.

⁵ In inoculation studies in Brazil, isolates of *P. psidii* from *Psidium guajava* did not infect *Eucalyptus* species and the reverse was also true. Two strains in Jamaica that infected, respectively, species of *Pimento* and *Syzygium* did not infect *P. guajava*.

⁶ Recent work indicates that the strain in Australia is the same as that in Hawaii, China, Indonesia and New Caledonia, and there is also genotypic similarity between isolates from Hawaii and Florida. This widespread strain has not been identified in Brazil, either because it is not common there or else it may have originated outside that country. There is also a strain common to Jamaica and Florida.

Like other rust pathogens, *P. psidii* is an obligate parasite and is studied on the living host rather than by using artificial laboratory culture media.

Several additional rust fungi occur on myrtaceous hosts, including *Puccinia cygnorum*⁷ on *Kunzea ericifolia* in Western Australia and *Physopella xanthostemonis* (synonym, *Uredo xanthostemonis*) on species of *Xanthostemon* in the Northern Territory. *Phakopsora juellii* (synonyms, *Phakopsora rossmaniae*, *Physopella jueli*) infects myrtaceous plants in Brazil⁸, and recently *Phakopsora myrtacearum* was described on three eucalypt species in eastern and southern Africa⁹. These species can be readily distinguished both micro-morphologically¹⁰ and by DNA analysis from *P. psidii* s.l.

2.2 Hosts

Puccinia psidii is unusual among rust fungi in that it is capable of infecting many plant species, all in the family Myrtaceae¹¹. By contrast, most other rust species are restricted to just one or several closely related hosts. The number of known hosts has continued to increase rapidly, particularly as *P. psidii* s.l. has spread globally to new regions. More than half of the present known susceptible species occur in Australia, which has approximately half of the world's myrtaceous genera and species, none of which evolved in natural association with *P. psidii*. As determined by field surveys and inoculation studies, *P. psidii* s.l. currently infects in excess of 445 species in 73 genera worldwide. All myrtaceous genera must therefore be considered potentially vulnerable. Among the most susceptible hosts are *Agonis flexuosa*, *Chamelaucium uncinatum*, *Decaspermum humile*, *Eugenia reinwardtiana*, *Gossia inophloia*, *Melaleuca quinquenervia*, *Rhodamnia angustifolia*, *R. maideniana*, *R. rubescens*, *Rhodomyrtus psidioides* and *Syzygium jambos*. However, species vary in their susceptibility to different pathogen races, from highly susceptible to resistant or tolerant (i.e. vulnerable to infection but showing few symptoms). There is also evidence of genetic variation in susceptibility within a species. As a result of variability in susceptibility between host species, the nature of the fungal population may be influenced by the composition of the flora, at least in the natural distribution range of *P. psidii*.

2.3 Distribution

Puccinia psidii s.l. is present in Mexico, Guatemala, El Salvador, Costa Rica, Cuba, Jamaica, Dominican Republic, Puerto Rico, Dominica, Trinidad and Tobago, Venezuela, Colombia, Ecuador, Brazil, Paraguay, Uruguay and Argentina, as well as Florida, California, Hawaii, Japan, possibly Taiwan¹², China, Australia (including Tasmania), New Caledonia, Indonesia (Sumatra) and South Africa. *P. psidii* is not known to occur in New Zealand.

2.4 Symptoms and signs

Symptoms of myrtle rust are more common on young, actively growing foliage, shoots and in some hosts, flowers and fruit. Symptoms may also be present on older material but these are a result of earlier infection that took place when tissues were still young. Small, chlorotic

⁷ This species was unknown in Australia until intercepted by New Zealand quarantine on a shipment of cut flowers. It is possible that there may be other unknown myrtaceous rusts in Australia.

⁸ *Uredo seclusa* has been described from only one collection from a myrtaceous host in Brazil.

⁹ The second known rust on *Eucalyptus*. It is not clear if it is introduced or derived from a local rust species.

¹⁰ For instance, in contrast to the other rusts, except *P. myrtacearum*, the spore producing units (sori) of *P. psidii* lack sterile hairs (paraphyses).

¹¹ As currently accepted, i.e. inclusive of the genus *Heteropyxis*, previously allotted its own family, the Heteropyxidaceae.

¹² One record in Taiwan has not been confirmed (Wang 1992).

or brown to grey, circular or angular lesions are the first indication of infection. Within 7-9 days these spots give rise to golden yellow pustules bearing copious quantities of bright orange-yellow, dry, powdery urediniospores¹³. Secondary infections may occur. On some hosts another spore type eventually appears in the form of similar looking, but brown coloured, teliospore masses (both spore types may also occur together). Spots and spore-bearing fructifications occur on both leaf surfaces, but are generally more developed and conspicuous beneath. Lesions eventually darken in colour, turning red-purple before fading and becoming drab as they age. The extent of symptom development depends on host susceptibility. Spores may not be formed from lesions on plants that are partly resistant, or their production may be sparse and delayed, whereas on more susceptible hosts, lesions expand and coalesce, and infected tissues become deformed and swollen. Diseased shoots may defoliate and die back, resulting in a stunted, bushy appearance, and in due course very susceptible plants may even die completely as a result of repeated infections. On eucalypts, profuse branching and galling can be an indicator of earlier rust infection. It is not known if the rust pathogen can survive asymptotically in older tissue.

The disease tends to lie dormant during the cooler months in winter, appearing as grey lesions on stems and leaves of infected plants, but becomes active with the onset of warm weather.

2.5 Biology and life cycle

2.5.1. Life cycle

Although, like all rust fungi, *P. psidii* s.l. reproduces by means of several different spore types, its life cycle is not fully understood. The pathogen may be autoecious, or in other words able to complete its sexual cycle on the same host species or on related members in the Myrtaceae, but this is not confirmed. Certainly, it multiplies asexually and spreads rapidly on myrtaceous hosts by means of urediniospores.

Successive generations of urediniospores infect only young tissues less than 30-40 days old in repeating cycles, especially during the warmer seasons from spring to autumn. Inoculation studies indicate that under favourable conditions during summer tissue spots appear within 3-5 days of infection and sporulation within 10-14 days¹⁴. However, this interval extends up to 4-5 weeks during winter when, however, urediniospores can still be produced. There is a possibility that urediniospore production may show an annual periodicity with greater abundance during epidemic or "wave" years. Nevertheless, urediniospores are generally produced prolifically and may travel airborne over long distances to new locations. They are dispersed to a lesser extent by means of insects (e.g. bees, which collect urediniospores as an alternative to pollen), birds and other animals, and possibly through rain splash. Infection is favoured by high spore densities and active growth of shoots and foliage on receptive hosts, and discouraged by periods of drought.

Teliospores of *P. psidii* germinate to produce basidia (metabasidia), each giving rise to four, delicate, spherical basidiospores. In heterocyclic rusts basidiospores infect an unrelated host species, but it has yet to be shown whether or not this occurs with *P. psidii* in its indigenous habitat or if, alternatively, basidiospores are able to infect the same or other myrtaceous hosts autoeciously. It is also possible that basidiospores are vestigial having become non-functioning. Evidence indicates that populations of the rust outside the natural distribution range are clonal, reproducing vegetatively by means of the urediniospores. The production

¹³ Refer Section 2.5.2.

¹⁴ The pre-reproduction or latent period.

of aecia¹⁵ and spermogonia (two other rust spore producing stages) has not been confirmed with *P. psidii*.

2.5.2. Environmental regulators

Urediniospore germination and infection occur under conditions of high humidity (a wet leaf surface for at least 6-8 hours), moderate temperatures (around 13-25°C; there is some variation in reports), and at low light or with a minimum of 8 hours of darkness. Continued moderate temperatures (15-23°C) and high humidity are then required for mycelial growth within the host. Production of urediniospores occurs at around 20°C, but is inhibited by temperatures below 15°C or around 30°C. Teliospores may possibly be produced over a broader temperature and humidity range, potentially allowing the rust to survive and reproduce when conditions are harsher. However, teliospores form basisiospores at approximately the same temperature as urediniospores.

Similar conditions favour myrtle rust in the field. On *Syzygium jambos* in Brazil, disease incidence and severity were correlated with periods of relative humidity greater than 90%, leaf wetness periods exceeding 6 hours and temperatures at night between 18 and 22°C. Comparable patterns were indicated by numbers of spores caught in trapping studies. The extent of disease may therefore vary in different years in regions where meteorological conditions show greater annual fluctuation.

The environmental conditions also affect spore survival. Teliospores can be looked on as resting or over-winter spores, and both they and urediniospores have thick walls and coloured pigments enabling them to resist desiccation and the harmful effects of ultraviolet radiation. This has undoubtedly assisted in their survival during movement between continents. Urediniospores may remain viable for between 22 and 90 days at 15°C and 35-55% relative humidity, and at least some (3%) for over 100 days at lower temperatures (4°C) and humidities (40% relative humidity). However, survival is less than 11 days when exposed to temperatures greater than 35°C. It is expected that teliospores can remain viable for longer periods and under hotter conditions. There is some variation in the values reported, which may be partly due to different experimental conditions, but also to disparities between races of *P. psidii* s.l. Spore survival is likely to be reduced in soil due to predation and decomposition, but infection may survive in living plants for several months during transport.

3 Risk of entry and establishment in New Zealand

With *P. psidii* s.l. already present in neighbouring Australia and New Caledonia, the potential for an incursion into New Zealand is considered to be moderate to high. The likelihood of possible modes of passage is here considered. On entry, if not immediately eradicated, the pathogen will undoubtedly come into contact with susceptible host plants which will enable it to establish and spread within the country. The consequences are uncertain, and will depend on the number and distribution of host species found to be susceptible and on how severely they become diseased. This aspect is considered in Section 4. In this section the possibilities of arrival and establishment are assessed.

¹⁵ It has been suggested that aeciospores of *P. psidii* may occur but be morphologically indistinguishable from urediniospores.

3.1. Pathways

3.1.1. Global movement

Puccinia psidii s.l. is native in Central and South America where it has been known since 1884¹⁶ (Fig. 1). From here it has spread on myrtaceous hosts around the world. A strain was found in Jamaica in the 1930s and *Puccinia psidii* s.l. has subsequently been reported in the following countries or regions (sequentially, by year of first record in brackets; Fig. 1): Dominica (1945), Florida (1977), Mexico (1981), California (2005), Hawaii (2005), Japan (2007), China (Hainan 2007, mainland 2009), Australia (New South Wales and Queensland 2010, Victoria 2011, Tasmania 2015), South Africa (2013), New Caledonia (2013), Indonesia (Sumatra 2016).

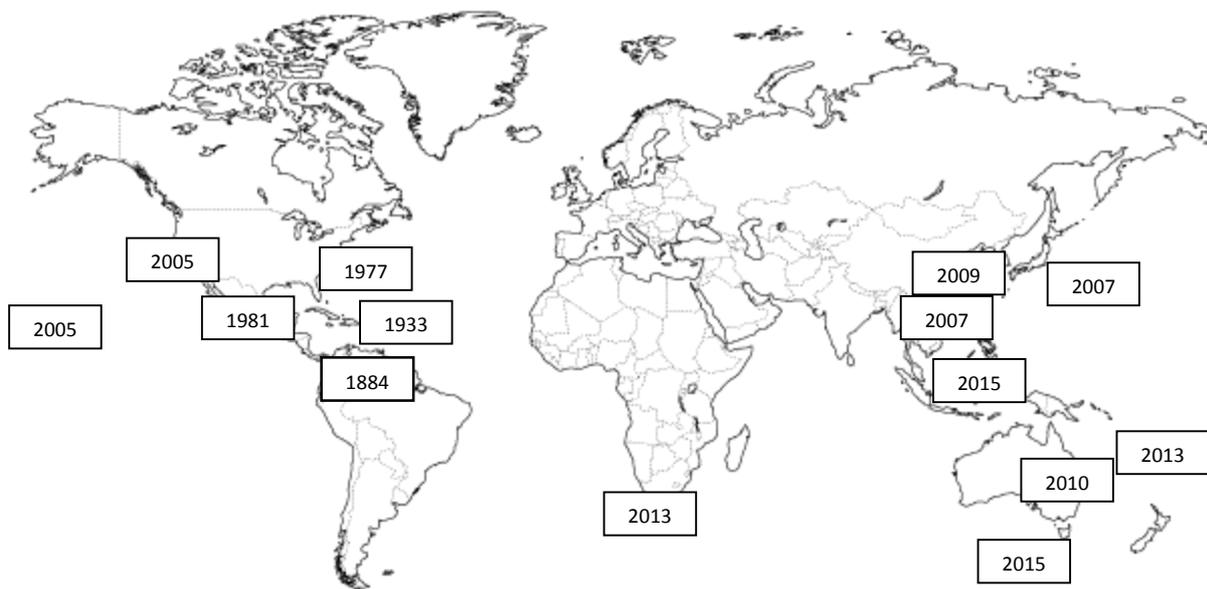


Figure 1. Global distribution of *Puccinia psidii* sensu lato with year of first record.

3.1.2 Transport on plant material

The accelerated global spread over the last decade (Fig. 1) is noteworthy and points more to transport on goods or trade products, particularly infected or contaminated plants, than to airborne movement of spores in air currents¹⁷. There are several known instances of unintended long distance transport of *P. psidii* on infected plants both within and between continents. Interceptions and nursery detections suggest that *P. psidii* reached California from Florida in the live plant trade. Movement of live plants from continental United States probably also accounts for the introduction into Hawaii. *Puccinia psidii* was intercepted on

¹⁶ Early records indicate that *P. psidii* s.l. is indigenous to the region encompassing Brazil and neighbouring countries, but the precise boundary of this region is not known. It has possibly spread from here into Caribbean countries and Mexico; it is known to be introduced in Jamaica and Dominica.

¹⁷ This is supported by genotype studies; see Footnote 6, Page 4.

myrtaceous foliage shipped from several counties in California in 2006-2007. The pathogen reached Japan on cuttings of *Metrosideros polymorpha* from Hawaii. It is not known how *P. psidii* arrived in Australia, although in 2004 viable spores were intercepted on timber, plastic wrapping and external surfaces of a shipping container of timber imports from Brazil¹⁸. Initial spread along the east coast of Australia was due to the unregulated movement of infected nursery plants (corrective measures were subsequently taken to quarantine and treat plants in nurseries). In South Africa *P. psidii* s.l. was found on a garden specimen of *Myrtus communis*, suggesting an introduction in the same way.

The movement of live myrtaceous plants and other plant material, whether regulated or not, is considered the greatest risk for the transport of *P. psidii* between regions. Susceptible plants are readily infected. Plant parts liable to carry the pathogen, externally or within their tissues, comprise flowers, fruits, shoots (stems) and leaves. Infection is not known within seeds, roots, or wood. Myrtaceous species are not deciduous, and are therefore always shipped with foliage present that is potentially liable to be infected. Although the typical signs of conspicuous bright yellow uredinial pustules are difficult to overlook in pre-shipment inspections, if conditions are not optimum, as in winter, these fructifications may not appear for up to 4-6 weeks, possibly after plants have moved on past the import border (bearing in mind that plants can be air shipped from Australia within a day). Small lesions may go unnoticed and plants infected with living mycelium may not show signs or symptoms at all. Light spore dustings on less susceptible plants may also pass inspection undetected. Spores persist and can remain viable for substantial periods.

Micro-propagated plants also pose some risk, though less so than for nursery grown stock. Tissue cultures are grown aseptically under sterile conditions, but a slight possibility of contamination does exist, even though not yet known for *P. psidii*. If such contamination were to occur, it would not be visibly detected for ca. 12 days if cultured at moderate temperatures (around 15 to 23°C).

The Ministry for Primary Industries is fully conscious of the real possibility of inadvertently importing *P. psidii* on whole plants, cuttings or as tissue cultures into New Zealand from infested regions and steps are in place to minimise the risk (Section 5.2).

3.1.3. Other human related transport

Because urediniospores are produced in such abundance through much of the year, there is a significant risk that items transported from rust infested areas may be contaminated with these infectious propagules. Such items may include shipping containers, timber, wood packaging, dunnage, plant waste, equipment and tools used on or around plants (e.g. chainsaws, secateurs), clothing, footwear, luggage, tents and camping gear, and other possessions or personal effects that may originate from localities where they have been exposed to diseased plants in the vicinity. Viable spores have been detected on clothing, cameras and spectacles belonging to people who have visited severely infested plantations. The chances of some of these items, such as clothing and camping equipment, coming into contact with susceptible hosts post-entry are also significant.

The risk of *P. psidii* s.l. entering and establishing in New Zealand in this way is not known, but would appear to be considerable. No matter how stringent the procedures, the chances of contaminating spores passing undetected through border security are high.

¹⁸ As a result, imports of *Eucalyptus* timber from countries with myrtle rust was suspended.

3.1.4. Aerial movement

The evidence suggests that the global spread of *P. psidii* s.l. has been primarily through trade (Fig. 1). Nevertheless, because of the proximity of Australia to New Zealand, and as the disease is well distributed along the eastern side of that country, the risk of urediniospores arriving in air currents cannot be ignored.

The weather patterns and motion of the atmosphere have been well studied in relation to the trans-Tasman transport of airborne biota. There are many examples of organisms (as well as dust and smoke) being carried in this way from Australia to New Zealand, and rust fungi provide notable examples. The poplar rust pathogens, *Melampsora larici-populina* and *M. medusa*, reached the western side of New Zealand in 1973, within a year of their detection in Australia, and spread quickly throughout both countries. Other examples are antirrhinum rust (*Puccinia antirrhini*) which was found in Auckland 14 months after its arrival in Australia in 1952, and was widespread within 2 years; and oxalis rust (*P. oxalidis*) which spread rapidly within New Zealand after being found here in 1977, 9 months after its detection in Australia and 3 months after being found on Norfolk Island. The willow rust, *Melampsora coleosporioides*, also spread quickly, being found throughout the country within two years of its introduction to New Zealand, which occurred 7 months after it was found in Australia. Other such examples include the rust *Melampsora euphorbiae* on *Euphorbia* species and a race of stripe rust (*Puccinia striiformis*) on cereals.

In contrast to these patterns, *P. psidii* has been present in Australia, where it is now well distributed, for 6 years, yet has still not been detected in New Zealand. However, it is premature to assume that it will not reach here in this way. A strain of the blackberry (*Rubus fruticosus*) rust, *Phragmidium violaceum*, was only found, on the east coast of New Zealand, 6 years after being illegally introduced into Victoria, Australia, after which it spread to the South Island west coast and to Northland within 2 years. On the other hand, there are rust fungi in Australia that have never been found in New Zealand. Neither *Aecidium balansae* nor *A. fragiforme*, for instance, which infect leaves of *Agathis* species in New Caledonia, and in parts of Australia, Asia and the Pacific, respectively, occur on *Agathis australis* (kauri) in New Zealand. There may be reasons: the climate may be too cold, they may require an alternate host that is not present here, or *A. australis* may be resistant to infection. But it is also possible that spores do not reach this country in sufficient numbers even from Australia.

What is the prognosis for *P. psidii*? Are too few viable urediniospores crossing the Tasman Sea in wind currents, or is it just a matter of time as the population of the rust, and hence spore quantities, continues to increase in Australia¹⁹? Or are spores arriving already, but failing to make contact with susceptible hosts of sufficient distribution density in a receptive condition (i.e. with young vigorous shoot and foliage growth) in locations and at a time of year when environmental conditions are optimal for infection to occur? Or is it even possible, unlikely as it may seem, that *P. psidii* is already present undetected somewhere in a part of the country so remote that dispersal to new target hosts is ineffective?²⁰

¹⁹ Carnegie and Cooper (2011) suggest that the more tropical myrtle rust differs from the temperate poplar and antirrhinum rusts, which in Australia were first detected in summer and spring, respectively. Now that myrtle rust is becoming more established, it would be interesting to see if periods of spore production differ between them and whether this could shed some light on trans-Tasman dispersal behaviour.

²⁰ The heteroecious juniper rust, *Gymnosporangium clavariiforme*, which alternates between *Juniperus communis* and *Crataegus monogyna* (hawthorn), was successfully eradicated in Otago in 1960 by removing the single infected telial host tree. However, unlike *P. psidii*, *G. clavariiforme* does not produce profuse asexual urediniospores that disperse long distances.

It remains to be seen whether an airborne incursion of *P. psidii* will eventually take place. However, if such an occurrence occurs, there is a good chance that it will be in an isolated location so inaccessible that any surveillance will not be sufficiently comprehensive to detect it early enough to effect a successful eradication. This is because *P. psidii* can complete its life cycle on a single host, conditions are likely to favour spore germination and infection, urediniospores can survive for weeks and are readily dispersed, and the infection cycle is short allowing a rapid increase in spore levels.

3.2. Potential hosts

A list of the indigenous and naturalised myrtaceous species in New Zealand is presented in Appendix 2, while Appendix 3 lists some of the more common myrtaceous amenity and garden plants. These lists also indicate the species known from overseas work to show some susceptibility to *P. psidii* s.l. However, these susceptibility records are far from complete, since not all species have been exposed to the pathogen, and the degree of susceptibility is not known for many that have. Species that are uncommon or less densely distributed overseas may eventually prove to be more susceptible than first thought, as they are subjected to increasing inoculum loads during the period that *P. psidii* is continuing to spread and establish, particularly in Australia. Many of the species listed are widely distributed across New Zealand in native forest, scrubland, and in rural and urban situations. Some occur as young saplings or shrubs in regrowth indigenous forest or scrubland. Many of these species are found in parts of New Zealand considered climatically suitable for the rust (refer Section 3.3.2), increasing the potential for rapid spread and thus posing a challenge for eradication attempts. However, rapid spread will also depend on whether one or more widely distributed host species prove to be highly susceptible, becoming severely affected and increasing the general quantity of urediniospores.

Appendix 2 includes some well-known indigenous plants such as pohutukawa (*Metrosideros excelsa*), northern rata (*M. robusta*), kanuka (*Kunzea* aff. *ericoides*) and manuka (*Leptospermum scoparium*), as well as several lesser known species such as swamp maire (*Syzygium maire*) and ramarama (*Lophomyrtus bullata*). Pohutukawa, Kermadec pohutukawa (*M. kermadecensis*), manuka and ramarama are known to have some susceptibility to *P. psidii* s.l., but it is unclear how they will respond in New Zealand. A large number of exotic myrtaceous species are also present in New Zealand, particularly some originating from Australia (Appendices 2 and 3). Many have commercial value including species of *Eucalyptus* and nursery plants, and some susceptible hosts have become naturalised in some parts of the country, such as *Syzygium smithii* and *S. australe*.

3.3 Establishment and spread

3.3.1. Experience overseas

Puccinia psidii s.l. spread rapidly within several countries, including Jamaica, Hawaii, Australia and New Caledonia. In Hawaii, for instance, it was found throughout all but one of the islands within a few months of its initial detection. It is now present in localities along the full length of the east coast of Australia. However, its distribution remains limited within Florida and California, in the United States, and also in South Africa, where, however, it has only been found comparatively recently.

The Australian strain of *P. psidii* was first detected on *Agonis flexuosa* by a cut flower grower in April, 2010, on the New South Wales coast north of Sydney. By December, 2010, it had been identified in ca. 140 nurseries and in private gardens and was also found in native vegetation. In some localities the disease spread from areas where infected plants were established, and it appears that spread in Australia has been fostered by the movement of nursery stock as well as by spore dispersal (see Section 6.2). The pathogen reached

southeast Queensland late in 2010, and continued to spread northwards. It was found in Cairns in June, 2012, and is now present as far north as Cape York, Melville Island (Tiwi Islands), and Darwin. In New South Wales and Queensland the disease is present mainly within a zone approximately 100 km in from the coast (Fig. 2). In Victoria *Puccinia psidii* was first found in a nursery, in December, 2011, and has spread within that state in nurseries, amenity plantings and other urban settings. It was also detected in a nursery in the Australian Capital Territory. *Puccinia psidii* is now present in native forests of various types along the coast from southern New South Wales to the Daintree rain forest in northern Queensland and is also established in coastal heath, paperbark (*Melaleuca quinquenerva*) wetlands and other natural ecosystems.

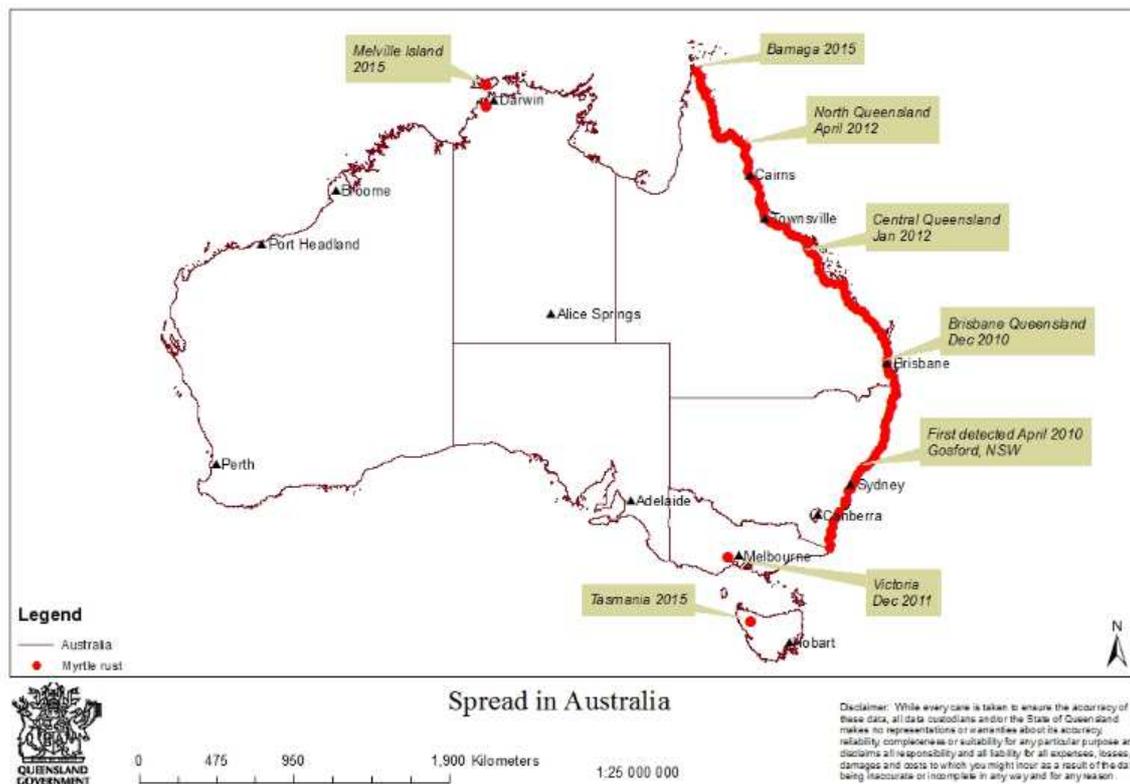


Figure 2. Spread and present distribution of *P. psidii* s.l. in Australia shown in red. From: <http://www.pbcrc.com.au/news/2016/pbcrc/myrtle-rust-threat-australian-landscape-and-plant-industries> (accessed 10 May, 2016).

In Tasmania, myrtle rust was first found in a private home property at Burnie on the northwest coast on 19 February, 2015. During the first season (to May, 2015) 71 properties were found with the disease, on *Lophomyrtus* cultivars, *Ugni molinae* and *Agonis flexuosa*, all exotic to Tasmania. In the second season, to March, 2016, over 1100 properties were inspected around Tasmania, with myrtle rust being found in 30 private gardens in north and northwest Tasmania, all on *Lophomyrtus* varieties. To date it has not been detected in natural vegetation and Biosecurity Tasmania has an eradication programme underway. This includes close interaction with nursery personnel and the public (Fig. 3). Diseased material is being destroyed and a prohibition on movement of material of *Lophomyrtus* cultivars and *Ugni molinae* between three zones across the whole state is in place.



Figure 3. Notice at entrance to the Royal Tasmanian Botanic Gardens, Hobart. Taken 19 April, 2015, 2 months after the discovery of *Puccinia psidii* in Tasmania (IAH).

3.3.2. Climate zones

A number of climate models have been generated to predict and map the regions where *P. psidii* is most likely to thrive. These models incorporate environmental variables selected over ranges judged to be suitable, or not, for infection, development and survival of the pathogen (refer Section 2.5.2). Variables include various indices derived from factors such as air temperature (including minimum and maximum limits for pathogen development, degree days etc.), soil moisture and drought tolerance thresholds. Model outcomes have also been usefully superimposed on distribution maps of important myrtaceous host species. Validation is achieved by comparing model outcomes with known distributions of *P. psidii* s.l. In this respect, it is instructive to compare model predictions for Australia, particularly Tasmania (Fig. 4), with the distribution pattern developing in that country (Fig. 2), and relate this to predictions for New Zealand. There is slight variation between predicted patterns for New Zealand from different models, but all indicate that *P. psidii* s.l. appears capable of establishing and surviving in the low- to mid-elevation areas around the North Island (Fig. 4)²¹. Earlier models suggest it may also persist along parts of the east coast of the South Island and in the Chatham Islands (contrast Fig. 4). These maps are “broad brush” and do not account for possible localised microclimates where *P. psidii* may be able to survive and develop²². The map in Fig. 4 relates to present climate. The area in which the pathogen is likely to thrive may expand somewhat under climate warming scenarios.

²¹ However, one early model confines the disease to Auckland and Northland.

²² Pimento trees (*Pimenta dioica*) in Jamaica were more severely affected where leaf wetness persisted in mist-prone valleys and on shaded northern and western slopes.

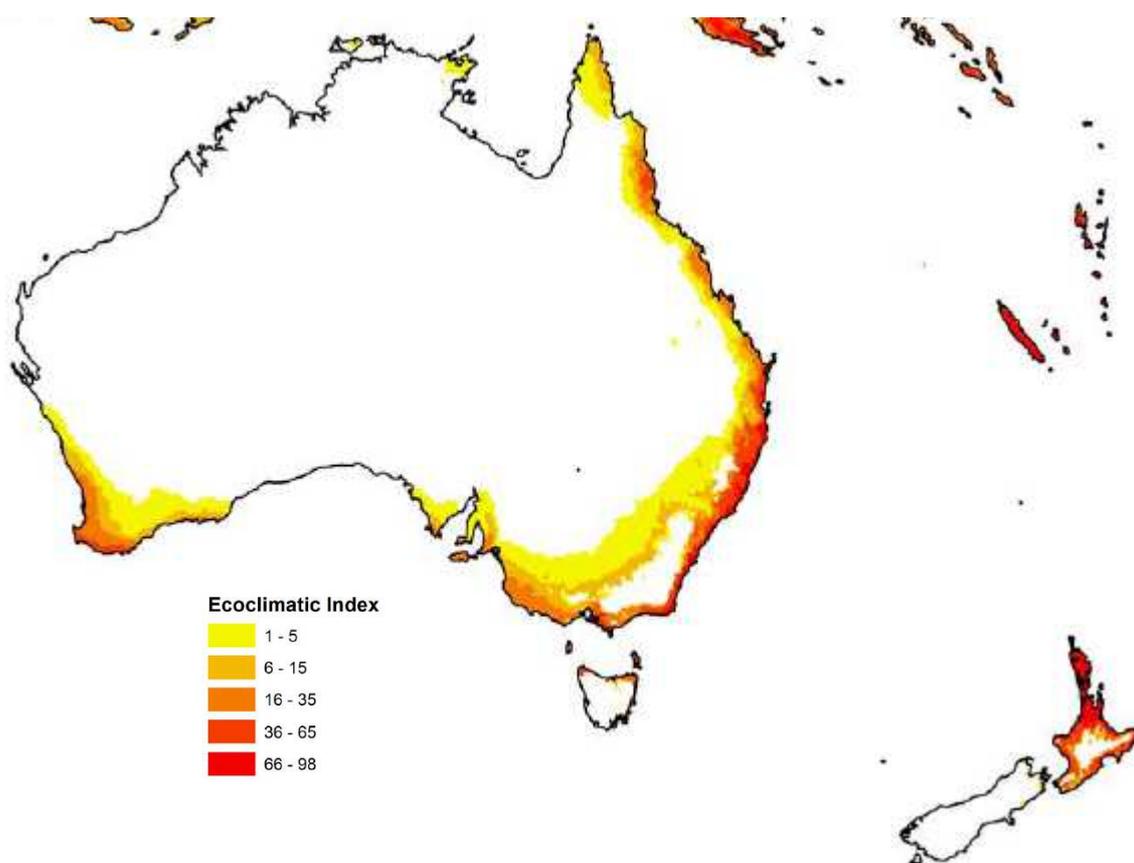


Figure 4. Relative climate suitability for *Puccinia psidii* s.l. in Australasia as indicated by the CLIMEX Ecoclimatic Index (EI). 0 = no potential for establishment; 100 = optimal conditions for infection, growth and survival of *Puccinia psidii* year round. A map ignoring inability to survive during stressful periods (and insufficient annual heat sum requirement) expands the potential distribution of the pathogen to all of the North Island and most of the South Island. After Kriticos et al. (2013).

3.3.3. Assessing the risk

Whether or not *P. psidii* arrives on airborne currents or with plant or other material, the risk of it spreading and establishing in New Zealand is high under a current scenario.

Symptomless plants may pass the border unnoticed (border procedures are in place to counter this possibility).

There is a broad range of indigenous and exotic myrtaceous plants in this country, some known to be susceptible (the pathogen readily infects new hosts).

Puccinia psidii is genetically variable and successful in a variety of habitats and settings.

The climate is suitable for the pathogen in at least part of the country throughout much of the year.

Asexual urediniospores are produced rapidly in quantity (especially on susceptible hosts) and are quickly dispersed over long distances (experience in other regions indicates that once established outside a limited zone it will be impossible to eradicate).

Susceptible plants are likely to be situated in proximity to diseased plants.

If not adequately regulated, infected retail nursery plants will be moved widely around the country.

4 Potential effects and impact in New Zealand

This section examines the possible effects an incursion of myrtle rust is likely to have on the New Zealand economy and environment. Emphasis is placed on commercial forestry, but this industry cannot be considered in isolation. *Puccinia psidii* s.l. does not recognise this distinction, of course, and moves freely between natural and artificial forests and urban areas.

4.1. Overview of overseas experience

Puccinia psidii s.l. is not known to cause significant damage to indigenous myrtaceous plants in its native environment. However, it has had a severe impact on some myrtaceous hosts in commercial plantations, amenity plantings and where it has been introduced to new native vegetation environments. It has also been recognised as an export trade risk sometimes leading to quarantine restrictions by importing countries.

Puccinia psidii was found infecting introduced eucalypts in Brazil in 1912²³. A major rust outbreak occurred in nursery stock in Brazil in 1973, destroying 400,000 seedlings of *Eucalyptus grandis* originating from South Africa. Losses frequently occur in susceptible clones in forest plantations (e.g. 50% of plants damaged in 1995-96; a mean annual increment loss of 20 m³/ha in young eucalypt plantations). The disease is managed by using resistant eucalypt clones and some application of fungicides. Losses have also occurred in eucalypt plantations in Uruguay. The disease significantly affects fruit in Brazilian guava (*Psidium guajava*) plantations sometimes causing heavy losses. It is managed using fungicides. The introduced *Syzygium jambos*²⁴, grown in gardens and elsewhere, is also frequently severely attacked.

A new strain²⁵ of *P. psidii* in Jamaica caused serious damage to *Pimenta dioica* in the early 1930s, leading eventually to the closure of the all-spice oil industry.

Puccinia psidii has been present in southern Florida since 1977, almost exclusively on *P. dioica*, but from 1997 damage occurred to the introduced weeds *Melaleuca quinquenervia* and *Rhodomyrtus tomentosa*, in effect a biocontrol caused by a new pathogen strain. Since 2001 the disease has become significant in nurseries, home gardens and on native myrtaceous hosts, possibly as a result of the introduction of a further strain.

Losses of up to 10% in ohia (*Metrosideros polymorpha*) plants in nurseries in Hawaii have been experienced, despite regular fungicide application. However, although ohia is widely distributed in native vegetation, it has not been seriously attacked, despite heavy spore pressure from infected *Syzygium jambos*. Within the elevation range of the pathogen, *P. psidii* is found on less than 5% of ohia trees in natural forest, and on less than 5% of the foliage on those affected. By contrast, indigenous *Eugenia reinwardtiana* and endemic *Eugenia koolauensis* are highly susceptible²⁶. Stands of the exotic *S. jambos* have been heavily diseased by repeated attacks, with dieback and death of large trees.

The long term effects in Australia are still unknown and spread of the pathogen is not yet complete. However, there are already a number of effects. Although present in young eucalypt plantations, *P. psidii* is not making a significant impact on the forest industry. The

²³ The notion that this was a host shift by the strain on *Psidium guajava* has been discounted and the origin of the strain on eucalypts remains unexplained.

²⁴ Native to Southeast Asia.

²⁵ *Pimenta dioica* was unaffected by an existing strain already present on exotic *Syzygium jambos*.

²⁶ *Eugenia reinwardtiana* is also indigenous in Queensland, Indonesia and elsewhere in the Pacific.

main hardwood plantation species, of moderate susceptibility, is *Eucalyptus globulus* ssp. *globulus*, grown mainly in Victoria, South Australia, Tasmania and Western Australia. Only young or coppiced plants (e.g. following fires) and nursery stock are likely to show any infection. However, there is a potential for quarantine restrictions on the export trade in forest products (and in shipment of flowers). In Australia, the most seriously affected industry is the production of essential (“native”) oil from *Backhousia citriodora* (lemon myrtle), which now requires regular fungicide use. The disease is also affecting trading in nursery and garden plants, and cut flower, foliage and honey production. More chemicals are now being used in the propagation of myrtaceous plants in retail nurseries, which have also faced quarantine restrictions, inspection costs and some changes in the species stocked, with some susceptible hosts no longer grown. Amenity plantings of some exotic species such as *Syzygium jambos* have also been significantly impacted. The disease is common in urban settings with frequent reports from parks and reserves as well as home gardens. However, one of the biggest concerns in Australia has been the potential impact on a small number of species in the indigenous vegetation. *Rhodamnia rubescens* (scrub turpentine) and *Rhodomyrtus psidioides* (native guava) have been severely affected throughout their range in eastern Australia. Several rare and endangered species are also very susceptible. *Melaleuca quinquenervia* (paper bark) woodland is affected in river and wetland ecosystems.

4.2 Commercial

An incursion of *P. psidii* s.l. to New Zealand may potentially impact on profitability in forestry, feijoa orchards, plant nurseries, cut flowers and honey production. The economic consequences are considered to be moderate.

4.2.1. Plantation forestry

Eucalypts are planted on a relatively small scale in New Zealand for timber or pulpwood. There were nearly 24,000 ha established as at 1 April, 2014, constituting 1.4% of the total forest plantation estate (NZFOA 2014). Most of these stands are in the central North Island, with small quantities in Northland and Auckland, all in areas likely to support *P. psidii* (10,000 ha of *Eucalyptus nitens* pulpwood stands in Southland are in a climate zone unlikely to be affected by the pathogen, Fig. 4). Saw log species include *E. saligna*, *E. botryoides*, *E. delegatensis*, *E. regnans*, *E. pilularis*, *E. fastigata* and *E. obliqua*, though the first three species listed are no longer planted. Future plantings may include *E. fastigata*, *E. nitens*, *E. mulleriana*, *E. globoidea* and *E. pilularis*. A number of the species listed are susceptible to *P. psidii* s.l. (Appendices 2 and 3). However, overseas experience suggests that while seedlings may be affected, later juvenile and adult stages will not, although early infection could lead to around 10-20% of the trees in young stands becoming malformed. Juvenile foliage persists on trees in pulpwood stands of *E. nitens* on some sites in the central North Island and Bay of Plenty regions, associated with the leaf spot fungus *Teratosphaeria eucalypti* (synonyms, *Kirramyces eucalypti*, *Septoria pulcherrima*), which could potentially favour attack by *P. psidii*.

4.2.2. Retail nurseries

Myrtaceous seedlings and young trees are produced in many commercial nurseries throughout New Zealand, although the full size of the industry is difficult to gauge (cf. Appendix 3). If *P. psidii* s.l. arrives in this country it is likely to be through a plant import. Nurseries are among the first places where the disease may be detected and provide one of the greatest risks of spreading it around the country on infected stock. Nurseries will experience economic loss in quarantine restrictions or closures, and in the destruction or treatment of diseased plants. It will be possible to control myrtle rust with fungicides, but it is likely that some myrtaceous species will no longer be grown. There may be additional costs in treating plants for export.

4.2.3. Orchards; cut flowers and other products

Feijoa (*Acca sellowiana*), a known host of *P. psidii* s.l., is grown commercially in New Zealand by 200 growers. Fruit is exported to the United States, United Kingdom, Germany, Netherlands, France and Japan. In 2014, 500 tonnes were produced, of which \$1.7 m were sold on the domestic market and \$0.2 m internationally. A myrtle rust incursion could affect the industry by damaging fruit and introducing costs for disease control.

Exports of cut flowers, plants, seeds and other products (bulbs, corms and foliage) amounted to \$142.5 m in 2014, cut flowers and foliage making up \$26.5 m. However, myrtaceous species were not specifically differentiated, and it is not clear to what degree *P. psidii* might impact on the export trade in cut flowers (depending on the degree that myrtaceous species feature among cut flower exports) and other products, such as “tea tree oil”. Manuka or tea tree oil (from *Leptospermum scoparium* and *Kunzea* aff. *ericoides* in New Zealand) is used substantially in medicines, soaps and cosmetics.

4.2.4 Apiaries

There is currently a high demand internationally for manuka (*L. scoparium*) honey, which is perceived as having special antibacterial properties. Commercially, honey production may be the industry most affected by myrtle rust. Prices to beekeepers in the 2013-14 year for manuka honey were \$8.00-85.00/kg (compared to \$4.50-10.00/kg for other types of honey). Honey exports in 2014 were 8,706 tonnes (\$187 million) out of a total of 17,600 tonnes produced, but the proportion from manuka was not specified. Myrtle rust could impact on manuka flowers and pollen, leading to significantly reduced honey production.

4.3 Non-commercial

4.3.1 Amenity plantings

Myrtaceous species feature prominently among the trees and shrubs planted in parks, gardens, reserves and on rural properties (including shelter belts and shade trees). Myrtle rust may have a significant impact on some species, especially in gardens where there is more host variety (Appendix 3).

4.3.2 Indigenous vegetation

There is also potential for myrtle rust to affect the nature and biodiversity of indigenous forests, scrublands and other native vegetation, either by direct mortality or through reduction in seed numbers as a result of infection of flowers and fruits. A decrease in flowering in trees such as pohutukawa and ratas (*Metrosideros* spp.) may possibly adversely affect populations of nectar feeding fauna (birds, insects). Although the myrtaceous flora in New Zealand is more limited than that of Australia, species in several genera (*Metrosideros*, *Leptospermum*, *Kunzea*) occupy extensive areas and feature prominently in the vegetation composition. Less noticeable species in genera such as *Lophomyrtus*, *Neomyrtus* and *Syzygium* are still of significance and their decline could influence other biota. At least some native myrtaceous species are known to be susceptible (Appendix 2), and others are untested²⁷. Even lightly infected plants may act as “carriers”, providing inoculum to foster

²⁷ Genetic resistance to the pathogen may tend to be less likely among myrtaceous species outside the native range of *P. psidii* than those that have evolved in its presence.

disease spread in other hosts²⁸. Several native myrtaceous species are considered to be endangered (Appendix 2). More common species (*Metrosideros excelsa*, *M. robusta*) are already afflicted by the introduced brush tailed possum²⁹. The original extent of coastal pohutukawa forest is now reduced, even if the species itself is unlikely to become extinct. Forest of susceptible *Metrosideros kermadecensis*, another host of *P. psidii*, would also be endangered on Raoul Island. Manuka (*Leptospermum scoparium*) and kanuka (*Kunzea* aff. *ericoides*) form important tracts of native scrubland that help prevent erosion in hill country, serve as pioneer “nurse” vegetation for the regeneration of native forest, and provide a habitat for distinctive groups of insects and basidiomycete fungi (eg, *Russula* species). Areas of marginal land are now being planted in manuka, primarily for honey production.

The risk to the indigenous vegetation from *P. psidii* s.l. is therefore uncertain. There may be little effect, but there is also potential for serious impact.

4.3.3 Human health

Puccinia psidii s.l. is not known to cause harm to humans.

4.3.4. Social and cultural

Predicting the impact on people as a society of an incursion of *P. psidii* is subjective and hazardous, but the effect would be real. The public response would no doubt depend on the degree of species loss in gardens, parks, reserves, as well as in the native vegetation, flora and fauna. More prominent plants would generate greater concern. Pohutukawa (*Metrosideros excelsa*), in particular, is significant to both Pakeha and Maori. The English name, New Zealand Christmas tree, evokes in the minds of many a recollection of dark green trees with gnarled and twisted stems, flowering a brilliant red in early summer by cliff and sea. To Maori, pohutukawa trees with individual names are of special significance in places such as Kawhia, Te Araroa and Te Reinga. Manuka and kanuka were once thought of as weed species that colonised neglected land cleared of native forest for farmland, though useful for stock shelter and valued for firewood and tool handles, but many would now consider them of greater worth, forming part of wild natural New Zealand. To some, the sight of a magnificent eucalypt on farmland in the country, exotic species though it may be, is cause for admiration. The social and cultural impacts of myrtle rust are therefore also uncertain, but genuine, and will depend on the host species affected.

4.4 Conclusion

There is considerable uncertainty about the impact of the disease should myrtle rust eventually arrive and establish in New Zealand. This ambiguity renders any attempt at a cost benefit analysis a hypothetical and challenging undertaking. However, given the multiplicity of possible effects on both commercial industries affecting livelihoods (forestry, retail nursery, cut flower, feijoa, essential oil and honey production), and on non-commercial values (indigenous vegetation, amenity settings, social and cultural), an incursion of *P. psidii* s.l. must be considered a genuine hazard with potentially serious consequences.

²⁸ Depending on the genetics of the population, and assuming a single strain of the pathogen is present, selection pressure may eventually remove the more susceptible individuals, leading to a lessening of disease impact on the host population.

²⁹ And could be under even further stress in the event of an accidental introduction of the strain of *Ceratocystis fimbriata* that has been killing *M. polymorpha* in Hawaii since at least 2013. Prior to that date, plants of *M. excelsa* were observed diseased by *P. psidii* in the University of Hawaii Harold L. Lyon Arboretum, but possibly under unfavourable conditions for the host. Also not to be ruled out is a chance mutation of an existing strain of *P. psidii*, or a subsequent introduction of a further strain, with different host preferences, as possibly in Jamaica. There is evidence of some mutation already occurring in the Australian population of *P. psidii*.

5 Preparedness

5.1. Overseas experience

Procedures for a myrtle rust invasion were well in place several years before *P. psidii* was detected in Australia. These were itemised in two documents, a generic incursion plan, PLANTPLAN, formulated and periodically updated by Plant Health Australia (PHA 2009), and a pest risk assessment and incursion plan prepared by the office of the Chief Plant Protection Officer specifically addressing the myrtle rust threat, itself (OCPPO 2007). Myrtle rust was also identified as a disease of significance in a Nursery Industry Biosecurity Plan prepared by PHA and the Australian Nursery and Garden Industry. The myrtle rust-specific plan was comprehensive but did not include key administrative and management protocols, which were referred to the complementary PLANTPLAN. This document sets out the management arrangements for administration, control, information and communication, and describes the roles and responsibilities of decision-making agencies. Four stages of response are considered, these being investigation, alert, operational and stand down phases. It is during the alert phase that a decision on whether or not to attempt eradication is made by an established National Management Group (NMG) in discussion with a Consultative Committee on Emergency Plant Pests (CCEPP). Underpinning PLANTPLAN is a cost sharing agreement called the Emergency Plant Response Deed (EPPRD) relevant to a number of declared pathogens that included *P. psidii* s.l. Before the myrtle rust incursion occurred this document had been signed by government bodies and some stakeholder industries, but not forestry.

In the United States, where myrtle rust remains limited in distribution, there has been pressure to make *P. psidii* an Actionable Pest in order to restrict movement and further entry of diseased myrtaceous plants and flowers, both internationally and between states. Following the detection of *P. psidii* in Hawaii regulations were introduced to prevent the entry of further strains of the pathogen, although these rulings subsequently lapsed.

5.2. Measures in place

In New Zealand several arrangements are already in place designed to prevent an introduction of myrtle rust and to enable early detection and an effective response should an incursion occur.

Routine inspections of a specified sample of imported materials and plants are undertaken at the border under regulation, and inspectors are informed and will be familiar with the signs and symptoms of myrtle rust on myrtaceous hosts. Plants of certain myrtaceous species are also subject to quarantine containment for a defined period. A comprehensive pest risk analysis for myrtle rust, particularly involving nursery stock, has been prepared by MPI (Clark 2011). This has led to an adjustment of the regulations under which nursery stock is allowed into New Zealand, in order to minimise the myrtle rust risk. Following the initial disease outbreak in Australia, permits were suspended for the import from that country of myrtaceous plants and cuttings, but not for tissue cultures. At present, imports of species of *Acca*, *Agonis*, *Eucalyptus*, *Eugenia*, *Metrosideros* and *Pimenta* are now subject to 6 months post-entry quarantine observation before release, and conditions are also imposed on imports of tissue cultures of the same species (e.g. adequate packaging is needed to avoid accidental release). These regulations are based on information that has become available on urediniospore survival and the lapse time before symptoms appear on either infected plants or in potentially contaminated tissue cultures (Section 2.5). Not all myrtaceous host

plant species are subject to more than basic entry conditions³⁰ and in addition, for some species the post-entry holding period is only at level 2 quarantine standards. This requirement is not considered totally adequate for preventing the escape of urediniospores either through ventilation or on contaminated clothing of personnel (Clark 2011). The risk analysis also expressed concerns about whether the facilities in which plants are inspected on first arrival at the border are sufficient to prevent spore escape to the outside environment. Additional biosecurity regulations now also apply to some myrtaceous species as a result of the *Ceratocystis fimbriata* strain attacking ohia (*Metrosideros polymorpha*) in Hawaii. In July, 2015, MPI suspended all imports of myrtaceous cut flowers and foliage from Australia (not just New South Wales Queensland, Victoria and Tasmania), following the finding of myrtle rust in the Tiwi Islands, Northern Territory.

MPI (in collaboration with Scion) is also ensuring that up-to-date DNA sequencing capability is maintained in New Zealand for immediate diagnosis of suspected *P. psidii* samples³¹. DNA testing will be of particular value for suspect, symptomless samples. Likewise, there are complementary diagnostic facilities ready to undertake accurate and rapid morphological identification of *P. psidii* on field samples (Scion, Plant Health and Environment Laboratory, Landcare Research).

In the event of an incursion, it will also be important, to obtain quick identification of host sample material, which may be delayed if flowers or fruits are also not included. To address this, Scion has created a DNA sequence reference library of the major myrtaceous species present in New Zealand, to ensure a rapid determination when required.

There have been visits to Australia by MPI staff and pathology and botany experts from Scion in order to see and obtain first-hand experience with myrtle rust and the Australian myrtaceous flora, and to discuss pertinent issues with researchers in Queensland, New South Wales and Victoria. A report is held in Scion records (SIDNEY; Scott and Miller 2013).

There is no surveillance specifically for myrtle rust, but MPI runs an HRSS programme aimed at the detection of new plant pests that may impact on trees and shrubs in plantation and native forests, and in urban settings. About 7,000 annual inspections are carried out on trees in high-risk areas adjacent to airports, seaports, cargo facilities and in popular tourist spots. Forest and other inspections are also undertaken by SPS Biosecurity.

MPI maintains an emergency, free phone, 24 hour “hotline” number (0800 80 99 66) for immediate reporting of any incursions of suspected pests or diseases, including *P. psidii* s.l. There are myrtle rust information pages on the MPI and Auckland Council websites.

The New Zealand Forest Owners’ Association became a recent signatory (5 November, 2015) to the Government Industry Agreement for Biosecurity Readiness and Response (GIA). The GIA Deed sets up a mutual partnership arrangement, under the Biosecurity Act 1993, between MPI (representing the government) and industry in order to “improve biosecurity readiness and response outcomes”. It encompasses the rights, obligations, roles, responsibilities and commitments of each signatory, and sets out arrangements for decision-making, and equitable resourcing. There are eight other industry signatories besides FOA and MPI, representing the government. However, neither garden nursery interests, apiarists nor the Department of Conservation feature in this agreement, although there is a horticultural advisor from Horticulture New Zealand represented on the Deed Governance Group (DGG).

³⁰ Cleanliness and pre-export inspection providing a phytosanitary certificate.

³¹ Wellcome Ho, Angela Johnston, FBCC presentation, MPI/FOA workshop, Rotorua, 23 February, 2016.

5.3. What else is needed?

These precautions are beneficial and provide for a positive state of readiness. However, there are still some gaps which may allow entry by *P. psidii* unless corrective measures are taken (see previous section). In addition, there is the question of whether everything is in place to ensure that an incursion will be detected sufficiently early to effect an eradication (Section 3.1.4). And in the event that *P. psidii* is found, will there be an immediate availability of the facilities and materials necessary for an eradication attempt?

A basic need that remains is the preparation of an incursion plan specifically for myrtle rust (see Section 6). This will facilitate decision-making with respect to all aspects necessary to ensure *P. psidii* does not establish in New Zealand. It will also ensure that the operational side runs smoothly.

5.3.1. Before detection

For eradication to succeed, an incursion must be detected early, while *P. psidii* s.l. is still localised in distribution. Although MPI runs HRSS general pest surveillance (Section 5.2), the length of the intervals between surveys and the rapidity with which *P. psidii* can reproduce and disperse means that detection by this means may not always be in time. Australian information suggests that if surveys are conducted in winter, when symptoms are not so conspicuous, they are less likely to be effective. Experience in Australia also indicates that the best hope of detection is through nursery inspections, often by growers themselves, and by public interest and response. This is because an introduction may be more likely through entry of imported nursery plants. When found, after spreading into indigenous vegetation, it may already be too widely distributed. *Puccinia psidii* was initially detected in both New South Wales and Queensland in retail nurseries. Attention to ports and other populated localities is probably more important than conducting surveys in large wilderness areas where it may be more sparsely distributed. Other likely places may be amenity plantings, car park vicinities, botanical gardens, and so on. Where surveys are conducted in indigenous vegetation, priority might be given to tourist areas and other sites of human activity such as apiculture operations or ecotourism ventures and along tramping tracks and near huts. Native restoration plantings and road verges might also be considered, on the assumption that inadvertent spread by people and transported plant material will be detected and dealt with more readily than distribution through long distance wind dispersal. Possibly topographical features such as misty valleys could be selectively targeted, but until more information is available this remains uncertain. Focus should, of course, be on myrtaceous plants. Planting highly susceptible trap or sentinel plants, such as *Lophomyrtus xralphii* or *Syzygium jambos* near ports or nurseries may have value, pruning to encourage new receptive growth, and remembering that certain host species may not become infected by every pathogen strain. Such plants should be inspected weekly to remove any inoculum that might spread the disease to other plants.

It is clear that the public and people involved with the propagation of myrtaceous plants and trees should be kept fully engaged both before and after an incursion occurs. Plant nursery staff will already be informed of the risk through articles in garden and horticultural magazines etc., but publicity and regular release of reliable information needs to be fostered and maintained.

Professional diagnostic and survey field staff will already be well informed, but it should be kept in mind that sampling for *P. psidii* needs to be handled differently to that of some other fungi. Infected shoots and foliage should be enclosed within a bag before detaching, to avoid releasing and spreading spores, and samples should be carefully packaged during transit. The essential collection details need to be recorded. Laboratory examination should be undertaken in a place where spores will be contained. Material should be destroyed or rendered non-viable when examination is complete. Inoculation and incubation to produce

symptoms in order, for example, to quantify host species susceptibility, should be conducted under quarantine conditions. And diagnosticians should be familiar with identification procedures beforehand, whether from morphological descriptions or using molecular procedures.

It is also necessary to ensure that the necessary facilities, trained field personnel, resources and equipment are all available and readily accessible should an incursion occur and an eradication attempt eventuate. This is a large topic and will form part of an incursion management plan (see Section 6). To mention just a few items, places will be needed where infested plant stock can be placed in quarantine, and arrangements need to be in place for the destruction of diseased plant material. All this will depend on an adequate supply of funding.

An incursion will necessitate that an adequate supply of the right chemicals is ready to hand, especially of appropriate fungicides, whether for an eradication attempt or, if that should fail, for disease management. Much research has gone into the selection of fungicides effective against *P. psidii* s. l. A number of systemic and non-systemic fungicides are able to give good control of the disease, but none are able to completely eliminate infection. Therefore, fungicides are able to assist, e.g. by reducing spore loadings and reducing spread, but cannot accomplish eradication alone. The fungicides triadimenol, mancozeb, chlorothalonil and triforine give protection against infection for at least 10 days after application. Triadimenol, triforine, oxycarboxin also behave curatively, in that they are effective up to 6 days after infection. Azoxystrobin has also shown effectiveness in both prevention and curatively. Cuprous oxide, copper hydroxide and copper oxychloride were successful against coffee rust (*Hemileia vastatrix*) and were not readily removed by rain. It is necessary to spray the whole plant and although there are no reports of fungicide resistant strains of *P. psidii*, it would be sensible to vary the fungicides being used in spray programmes. Fungicides would be used mainly in nurseries and gardens, and would not be applied economically in plantations or tracts of native vegetation. Fungicides are used in guava crops and to some extent in young plantations of susceptible eucalypt clones in Brazil. It is also necessary to ensure beforehand that the fungicides to be applied are approved for use. For instance, chlorothalonil and triadimenol are highly toxic to aquatic organisms, which may affect their availability.

There is a need for a better understanding of the comparative susceptibilities of myrtaceous species in New Zealand to different strains of *P. psidii* s.l., especially the strain currently present in Australia. Observations on the behaviour of New Zealand native and exotic myrtaceous species in the presence of myrtle rust in Australia have been made, but these provide only limited information (Appendices 2 and 3). There is also the risk of a false perception of low susceptibility if, unknown to the assessor, fungicides may have been applied or symptomatic shoots removed before plants are evaluated. Planting and closely monitoring different species in appropriate locations would help, but climate controlled inoculation studies in Australia would provide definitive information. Opportunities for collaborative work with the University of New South Wales Plant Breeding Institute exist and should be investigated further.

5.3.2. Preparation for eradication

Preparing beforehand for an eradication operation also forms part of pre-incursion readiness prior to an incursion event. Despite the difficulty of achieving success, eradication should be attempted if it is determined quickly and reasonably reliably that the distribution of the incursion is limited in size. Just what that size is needs to be prescribed beforehand from reasoned thinking based on available knowledge. Although attempts to eliminate *P. psidii* have never yet succeeded in the countries it has invaded, it is possible that this may reflect an insufficient level of readiness rather than indicating that eradication cannot be accomplished.

6 Planning

An essential aspect of preparation for a myrtle rust invasion is to develop a comprehensive incursion or contingency plan. A necessary support document for this is a carefully prepared risk analysis for *P. psidii* s.l. The pathogen invaded Australia despite the fact that these preparations had already been carefully undertaken, so it is also salutary to examine the Australian experience to see what messages there are for New Zealand.

6.1. Pest risk assessment

A comprehensive risk analysis for myrtle rust was undertaken by MPI relating to imports of plants and tissue cultures, but not other facets to the same extent (Clark 2011). Such a document on the effects of a myrtle rust incursion on the forest industry, including a cost/benefit analysis, awaits consideration.

6.2. Lessons from the Australian incursion

Australian preparations for a myrtle rust incursion are briefly summarised in Section 5.1. Actual events that took place in Australia are described in detail in papers by Angus Carnegie (New South Wales) and Geoff Pegg (Queensland) and their co-authors, and provide valuable information for New Zealand.

Puccinia psidii was first identified on a number of plants of different myrtaceous species on 23-24 April, 2010, on the property of a native cut flower grower north of Sydney³². The area was quarantined, fungicide treatments were applied and delimiting surveys were conducted, revealing more infection at a site up to 9 km distant. The consultation committee (CCEPP) met for a second time on 30 April, 1 week after the detection, and recommended to the NMG that eradication was not possible because it reasoned that the pathogen had already spread extensively on plants shipped from the area and by means of spores into nearby native vegetation (though this had not yet been determined) where eradication would not be possible. Handling of the incursion moved into disease management mode during which time containment procedures and detection surveys to gain more information were conducted by state agencies on a limited budget. More infected premises were discovered, plant movements were traced and diseased material was destroyed. After 2 months, and following some pressure, the stand down decision was revoked because there were indications that the spread was not as rapid as expected during the cooler months that had passed, suggesting that eradication might still be possible. The NMG endorsed an upgrading of the state measures currently underway to a federal level, enabling full funding and resources, with the object of suppressing and eventually eliminating the pathogen from the country. However, after six more months, *P. psidii* was continuing to expand in both its range and number of diseased sites, which now included native vegetation. It was noticeable that with the approach of the warmer months in late spring and early summer the spread of the disease, which had thus far been solely through human and plant movement, was now being augmented by natural airborne dispersal³³. A final decision was made by the NMG on 22 December that *P. psidii* could not be eradicated and a new management phase was initiated aimed at minimising the impact. This phase has continued to the present time and involves management by states and industry, with research aimed at mitigating the effect of

³² Pustules with urediniospores were first seen by the grower in March and thought to be pollen.

³³ In other words, if myrtle rust is found in New Zealand in autumn or winter, there is a heightened chance of successful eradication, if acted on immediately, than if first detected in late spring or early summer.

the disease (e.g. learning more about the disease, seeking resistant host genetic material, and so on). There have been periods when plant movement has been restricted between infested and pathogen-free states, and international quarantine restrictions remain in place to reduce the chance of other strains entering Australia.

Experience during the handling of the Australian incursion indicates (Angus Carnegie, pers. comm.) that surveys and eradication procedures should commence immediately, even before the results of diagnosis and delimitation surveys are to hand; that there should be efficient, coordinated and resourced protocols in place which must be implemented with speedy, pertinent decision-making³⁴; that strong, pre-arranged links with industry and other stakeholders should be in place (with industry also well prepared); that the decision to cease eradication should not be taken hastily, but only after information is gathered and the situation is well appraised; that professional technical and advisory staff need to be clearly nominated pre-incursion and fully consulted during and after an incursion; that there should be training in response procedures beforehand; that all myrtaceous plants should be regarded as hosts, as it is difficult to predict in advance which will be affected; and that it should not be assumed that myrtle rust symptoms will always be easy to detect.

In Australia there was also a taxonomic issue whereby *Uredo rangellii* was initially thought to be distinct from *P. psidii*, which caused some confusion in the belief that there were two rusts with different climate requirements. However, this question has been resolved and should not apply in New Zealand. A more relevant issue is that, in a review of the handling of the incursion, it was considered that there should be a strategy in place for situations in which not all stakeholders are covered by the signed agreement (the forest industry was not a signatory prior to the myrtle rust incursion). On the other hand, the review endorsed the value of the thoroughly prepared pre-incursion agreement and plan, which provided directions for decision making and operational activity. This, again, is relevant to New Zealand which still requires an incursion plan for myrtle rust.

6.3. The incursion response plan

As noted, there is a need to develop a contingency or incursion plan for dealing with an introduction of myrtle rust into New Zealand. As far as the forest industry is concerned there are several comprehensive examples that form models for such a plan, dating back to 1982 when the first such document was formulated following mock disease and pest simulation exercises involving Conservancy and science staff in the then New Zealand Forest Service (NZFS 1982; MOF 1988, 1996; Gadgil 2000; Hosking 2001; Gadgil et al. 2003; PHA 2009, Ganley & Bulman 2016).

6.3.1. Components of the plan

The incursion plan provides a clear and concise description of procedures to follow in the event of an incursion. It incorporates all stakeholders, including government agencies, outlining their respective roles and responsibilities. This includes agreed financial commitments, the costs being shared in proportion to the respective potential stakeholder losses following an incursion (an equitable rationale is developed for distributing costs).

The different phases of the incursion event are dealt with separately in the plan, namely pre-detection, detection, post-detection and termination. The pre-detection phase is the time when all preparatory measures are established in readiness for an introduction of the pathogen, including the production of the contingency plan (Section 5). The detection phase is initiated with the discovery and correct identification of the pathogen, and includes a decision on whether or not an eradication attempt is feasible and should proceed. The post-

³⁴ It has been suggested that the *P. psidii* contingency plan was not followed to its full extent.

detection phase is determined by the eradication decision. If eradication is deemed possible, a full operation proceeds immediately as pre-planned. It has already been noted that eradication procedures should be set in motion even before this decision is made. If eradication is considered impracticable, the plan moves directly to the termination phase, when pre-planned disease management operations are initiated. This phase is the unfortunate fall back position that is entered at any time that it is decided that eradication cannot be accomplished.

The plan defines the bodies and administrative committees that will oversee proceedings and clarifies their roles and hierarchical responsibilities. Key members of these groups will be selected and agreed upon beforehand. There will be an over-arching body responsible for strategic decision-making. This group will depend upon an advisory group with links to other sub-groups dealing, respectively, with aspects such as science and technology, operations, legal aspects, communication and publicity, and accounting. The science group will advise on the identification, biology and behaviour of the pathogen, and will link to diagnostic laboratories. The operational unit will physically handle the eradication process. It will deal with aspects such as surveillance, sampling, containment, chemical treatment, removal and destruction of diseased material, sanitation procedures (decontamination), management of quarantine zones, induction training etc. It will require adequate resources such as personnel, vehicles, access to containment facilities, equipment and gear (e.g. GPS units, recording and sampling equipment, clothing). Responsibilities will be allocated so that there are clear roles for those doing the work. The accounting group will keep a record of expenses, to enable a costing of the eradication episode when it is eventually reviewed. Other sub-groups will deal with legal and regulatory aspects, policy, recording and reporting, and regular communication of information both internally among participants and externally to the public, stakeholder agencies and other interested parties. Efficient communication between the different groups and sub-groups on what is happening is essential. Other aspects to be considered include appropriate notification to international trading partners, any necessary additional border control actions, tracing sources and destinations of potentially infected stock and consideration of the environmental implications of any remedial actions.

The Australian experience demonstrates that the rationale defining the criteria on whether or not to attempt eradication should be carefully considered and defined in the plan beforehand. Generic factors favouring an attempt include the following: there will be a significant economic cost to industry if the pathogen establishes (including disease management costs; if feasible, there should be a prior cost/benefit analysis); the pathogen's reproduction cycle and dispersal are limited; there are topographical, climatic or host distribution barriers to spread; there are no known hyperparasites; vectors (including human agencies) can be controlled or managed; outbreaks are limited in number and size; weather conditions are likely to hinder pathogen development; there are few opportunities for secondary spread; there is ready access to the original detection site and to other potential host locations. Added to this are considerations about significant non-economic values that would be affected (referred to in Section 4.3). The eradication decision may have to be made assuming the identification and biological information are correct; control treatments are effective and available; the estimated economic losses are accurate; and the immediate survey data give a reliable representation of the distribution of the incursion.

The Australian plan (OCPPO 2007) listed a series of criteria for an eradication attempt specific to myrtle rust. These considered aspects such as the distribution and density of the outbreak (for eradication there should be fewer than 10 infected locations or less than 10km between infection centres and the overall infected area should occupy less than 100 square km); whether the infected area is in rural or urban surroundings or near native vegetation; whether the hosts are indigenous or exotic; whether or not infection is severe or mild (small sparse spots and no distortion or defoliation); how many host species are infected;

distribution and density of diseased plants in an infection centre (more or less than 500 m apart); whether or not it is feasible to implement quarantine control zones and/or permissible and practicable to apply fungicides; if there exist natural barriers (lack of hosts, unsuitable climate) to spore dispersal within 50 km of the infection centre; whether hot, cold or dry weather is expected (infection discouraged by temperatures <15 °C, >24 °C, or relative humidity > 80% for < 6h/day); and if in a national or world heritage area. The incursion plan will therefore carefully pre-define the criteria for attempting an incursion in order to assist the control group in its decision.

Overall, the plan is designed to enable the incursion response to proceed smoothly and rapidly, without delays in obtaining funding or awaiting committee decisions. For an efficient plan all conceivable scenarios should be considered beforehand in order to delegate decision-making to the correct key people in advance, leaving no gaps. This will be considerably assisted by one or more simulation exercises involving all stakeholders and other participants using an initial draft of the plan. With respect to myrtle rust, a variety of interests will be affected and there is a real risk of necessary actions being hampered by excessive bureaucracy.

6.3.2. Post plan procedures

Following the preparation of an incursion plan, it will be necessary to implement it. An incursion response committee (possibly the advisory group) will be required to undertake a significant amount of administrative work. All parties will need to be consulted in order to achieve agreement. They will need to consider and fully understand the plan prior to signing. It is at this stage that the running of a simulation exercise may be most valuable. The committee will need to meet at regular intervals to ensure that all is in place and update the plan where necessary.

6.4. Activities following an incursion

When a report of a suspected occurrence of myrtle rust is received, the following actions go into play with urgency. The suspect material is sampled in containment, identity is confirmed as *P. psidii* s.l., the material is destroyed, a quarantine area is established around the detection site and delimiting surveys are instigated for information on its distribution (Section 6.2). Attempts are made to trace the movement of any plant or other material that may originate from or be a source of the infected material. The movement of people is also checked.

The size and nature of the immediate survey area (as well as the separate quarantine zone) will depend on the time of year, the type of environment (urban, rural, or wilderness), the proximity and growth stage of potential host plants, on weather conditions (prevailing wind) and on the severity and extent of the infection. Surveys should especially target areas, plants and vegetation where the rust is more likely to be found. Emphasis will be on susceptible species with young growth. It may also be appropriate to survey more intensely where landscape features appear more suitable for infection (e.g. moist valleys). Surveillance in natural vegetation is likely to be more difficult.

Especially in a populated area, the distribution of information leaflets and appeals for public assistance will be of great value. However, members of the public should not sample but only report locations for subsequent careful sampling in containment by trained field teams. There should be prescribed sampling protocols that include accurate data collection and correct procedures for packaging and transporting to containment laboratories. Spraying with a fungicide a day before sampling may be beneficial.

It will also be necessary to conduct wider delimiting surveys outside the immediate search areas as soon as possible. This is obligatory in order to determine the full extent of the incursion and if possible to identify pest free areas. This aspect may be assisted by the deployment of moveable potted trap plants (Section 5.3.1) or placement of suitable spore traps of the correct type that will collect and hold urediniospores and teliospores for DNA detection. These will also need to be ready to hand.

Destruction of diseased plant material is important and can be undertaken by heating (e.g. solarisation in plastic bags), fire, burying or treatment with herbicides or fungicides (by hand or by air, depending on the scale). Fire carries the risk of dispersing spores in updrafts. Fungicides are discussed in Section 5.3.1. They can be used to kill spores before removing material, though this chemical treatment does not completely eliminate the pathogen. The precise procedure will be determined by the size of the material. It may be necessary to cut up larger items and bag or wrap in plastic sheeting. However, infested material should not be mashed and dispersed as mulch. Destruction of material in natural vegetation will be more difficult. There needs to be clarity in the incursion plan about legal rights and possible compensation.

With all field operations, clothing and footwear, equipment, vehicles and machinery should be cleaned between sites visited e.g. by having decontamination and wash areas. Sterilisation can be by heat, steam or sodium hypochlorite, as appropriate. Movement through infested areas should be as little as is necessary.

The quarantine areas should be set up immediately, even before the completion of identification and of the delimiting survey. The size of the area can be increased if necessary. Only essential movement should be permitted in this zone, and suitable covering garments should be worn that can be removed and cleaned. Vehicles should be steam cleaned. Movement may be more difficult to manage in urban areas where people's homes may lie within quarantine areas. In forests, the Australian plan distinguished a 1 km radius restricted zone and a 10 km radius control zone (OCCPO 2007). Roads should be closed and forestry operations cease.

Periodic reviews of progress should be conducted. If eradication appears to have been achieved before myrtle rust has spread far it will be necessary to undertake post-eradication monitoring for a set period³⁵ to confirm and declare that the pathogen has been eliminated. Alternatively, if the disease persists and may appear to be spreading, it will be necessary to decide whether to continue with eradication attempts, or to cease eradication and instead contain it within the area it already occupies; and/or to manage the disease; or to take no further action. When it is decided to cease attempting eradication, a report should be prepared that reviews the operation, the way it was carried out, include costs, and describe what was done well and what could be improved upon.

If eradication is deemed successful, it will still be necessary to maintain vigilance at the border, to prevent the introduction of the same or different strains of *P. psidii* s.l.

³⁵ "Eradication will be deemed successful only after two years with favourable climatic conditions and no detections of *Puccinia psidii*, despite comprehensive surveys of previously infested areas and host plants, including sentinel plants, in their vicinities" (OCPPO 2007).

6.5. Disease management

With disease management, proceedings enter a new phase. The purpose is now not to eradicate, but to slow the spread of the disease and minimise its impact. This is done by applying recognised treatments and procedures, and conducting research that will improve their effectiveness.

If the disease is not universally distributed, zones will be set up (as currently in Tasmania) to prohibit plant movement and prevent the disease moving to pathogen free areas. With *P. psidii*, containment may be difficult in the longer term because of the ready dispersal of urediniospores. The placement of zones may be influenced by the location of natural barriers (e.g. areas without susceptible plants or with an unsuitable climate). There may be stations set up at zone boundaries to wash vehicles and deposit and dispose of potentially infected material.

Within pathogen infested zones, fungicide application programmes will be necessary to reduce the impact of the disease in nurseries or in young eucalypt plantations, as is currently practiced in South America (Section 5.3.1). Control is not complete but reduces the disease to acceptable levels. However, fungicides are only cost effective in nurseries and high value crops.

It has been suggested that the planting of susceptible fruit or ornamental species, such as *Syzygium jambos* (rose apple), should be curtailed, since their absence may lead to reduced airborne spore loadings and diminished spread. In any case, retail nurseries will probably be reluctant to stock them. Special plants of value might be moved into pathogen free zones.

Research will be undertaken into a number of aspects to improve management efficiency and reduce costs. These will include epidemiology, fungicide application regimes, ecology, host testing, and pathogen taxonomy (including details about the particular strain). Although costly and long term, research into within-species genetic resistance will be undertaken to provide stock suitable for growing, in nurseries especially and desirably in forestry with respect to eucalypt plantations. In Brazil eucalypt clones used for commercial planting are routinely tested for susceptibility to four strains of *P. psidii* s.l.³⁶. A genetic marker linked to a major resistance gene in *Eucalyptus grandis* has been identified. Where eucalypts are grown from seed, identification of resistant lines may be more difficult. Resistance has also been recognised within *Melaleuca quinquenervia*.

It is likely that research will be undertaken to improve fungicide spray programmes by investigating new products and varying and testing different rates and application times of those currently employed.

Research may also be conducted in native vegetation (forest and scrub) to determine the ecological effects and the behaviour of the pathogen interactively on different hosts. Here, too, resistance will be sought among different species (e.g. *Metrosideros* species), especially those threatened or endangered. Other work will investigate disease epidemiology. More needs to be learned about the life cycle of *P. psidii* s.l. In the longer term, a biological control agent may be identified and deployed. Candidates include *Bacillus subtilis* (effective in liquid culture). Particular strains of rhizobacteria have been demonstrated to induce systemic resistance in *Eucalyptus grandis* × *urophylla*. *Fusarium decemcellulare* (*Albonectria rigidiuscula*) has been found to act as a hyper-parasite of *P. psidii*, and other fungi also co-occur in rust pustules. However, much work would be necessary before any fungus or bacterium could be recommended as a biological control agent.

³⁶ There is a risk that if resistance selection is against one strain of the pathogen, stock may still be susceptible to another strain, if subsequently also introduced. However, this is less likely when forestry is not clonal (Section 7.1).

7 Options for the forest industry

7.1. Do nothing

This will be the least costly choice. The main timber and pulp wood conifer species are not affected by myrtle rust. *Eucalyptus* plantations, although significant in area, make up a minor part of the forest industry (Section 4.2.1) and indications are that they will not be seriously impacted, and that any disease that appears may be manageable in the early stages of a rotation. The experience in Brazil suggests the threat should not be ignored, but in contrast to the clonal forestry practice in that country, eucalypts in New Zealand are planted as seedlings with a broad genetic base.

7.2. Act alone

Another option is to assist the protection of eucalypt plantations belonging to those owners who grow them within the forest industry, by supporting spray programmes and encouraging sanitation and the destruction of diseased plants. This might include funding research to improve fungicidal spray regimes, develop resistant planting stock (as is being done in Australia and South Africa), if needed, and the like. Any local pathogen elimination attempts would be undertaken independently, without interaction with non-forestry parties likely to be affected by myrtle rust, not as part of a national myrtle rust eradication programme. This option, then, would effectively be at the disease management phase, since it is not realistic to consider attempting country-wide eradication in isolation. Efforts to eradicate *P. psidii* in, say, a quarantined stand of manuka (*Leptospermum scoparium*) would not be helped if there were urediniospores drifting in from an adjacent diseased eucalypt stand, even if it was under a fungicidal spray regime, which would not totally eliminate the pathogen

If either of these two options is favoured (do nothing or act alone), national eradication would be seen as not a plantation forestry issue by forest growers. Although other groups have interests, eradication would be primarily between MPI and the nursery industry, this being the most likely source of an introduction. If discovered early while still confined to a nursery, ideally during autumn or winter, there *might* be some chance of a positive eradication under this scenario. However, the odds of success would be increased if all affected groups operate together.

7.3. Act in collaboration

This is the “good neighbour” approach. If myrtle rust is found in New Zealand, the chance of eradication is greatest if all stakeholders act together in a coordinated way.

The parties likely to be affected by myrtle rust are numerous and varied (Section 4), and this could lead to significant challenges in administration and in coming to an agreed response. One can visualise various agencies likely to be interested, whether or not they are in a position to sign an Operational Agreement. These might include the Forest Owners’ Association, Apiculture New Zealand, Nursery and Garden Industry New Zealand, New Zealand Farm Forestry, Horticulture New Zealand, Royal New Zealand Institute of Horticulture, New Zealand Flower Growers Association, New Zealand Flower Exporters Association, not to mention potential involvement by research bodies such as Scion, as well as the Department of Conservation, Regional Councils and Maori interests. It would be

necessary for MPI to take the lead and drive the process, especially with such a disparate assemblage. Not least among the issues is the small number of relevant industries signatory to the GIA Deed, many of which are likely to have limited funds available. If the myrtle rust threat is to be taken seriously, the government as lead agency will need to play a significant role as coordinator. It may be possible to limit the active participants to key stakeholders, but with opportunity for submissions and resource contributions from smaller industries and interest groups.

7.4. Conclusion

The Ministry for Primary Industries is concerned about the potential introduction and establishment of myrtle rust in New Zealand as evidenced by the actions they have put in place, including the preparation of a pest risk analysis, the adjustment of import regulations specifically to reduce the likelihood of an introduction and the development of DNA protocols for speedy and accurate identification of *Puccinia psidii* should an incursion be detected. MPI, as the principal government biosecurity agency, is the body best suited to organise a comprehensive incursion plan that will define responsibilities and describe protocols that will effect an eradication should the pathogen appear. It is suggested that MPI should consider preparing such a plan and that they and the Forest Owners' Association agree on their respective roles as part of a mechanism devised to enable all industry stakeholders (and the Department of Conservation) to participate in an advisory capacity according to the size of their industry or organisation³⁷.

8 Acknowledgements

Preparation of this report was assisted by conversation or correspondence with a number of people with experience of myrtle rust in Australia, including Angus Carnegie, Geoff Pegg, Peter Scott and Elizabeth Miller. Matt Buys provided information on DNA barcoding for identification of myrtaceous species in New Zealand. Lindsay Bulman made helpful and constructive comments on an earlier draft of this report.

³⁷ The National Pest Plant Accord between the Nursery and Garden Industry Association, regional councils and government departments with biosecurity responsibilities, may offer some possibilities to assist in setting up an agreement. <http://www.biosecurity.govt.nz/NPPA>.

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Appendix 2: New Zealand myrtaceous flora indicating species known to be susceptible to myrtle rust

Excludes additional species found only in garden, horticulture, amenity and cultivation settings.

*^C = casual exotic; *^N = naturalised exotic in at least part of the country; no superscript = indigenous.

S = known to have some susceptibility to *Puccinia psidii* sensu lato (recorded in Australia or elsewhere, field observation or by inoculation; degree of susceptibility generally not provided, but if available, indicated as **ES** extremely susceptible, **HS** highly susceptible, **MS** moderately susceptible, **LS** low susceptibility or relatively tolerant- data from Queensland); many species remain untested.

Information from: <http://floraseries.landcareresearch.co.nz/pages/index.aspx> (New Zealand flora), Ramsfield et al. 2010; Clark 2011; Carnegie and Lidbetter 2012; Giblin and Carnegie 2014a,b.

- *^C **S** *Acca sellowiana* (O.Berg.) Burret (= *Feijoa sellowiana* (O.Berg) O.Berg.)
- *^C**ES** *Agonis flexuosa* (Willd.) Sweet (cultivar 'Afterdark' very susceptible in cultivation in Australia; moderate to severe damage in field)
- *^C *Agonis juniperina* Schauer
- *^C **S** *Angophora costata* (Gaertn.) Britten
- *^C **S** *Astartea fascicularis* (Labill.) DC. (false Baeckea)
- *^C **S** *Callistemon citrinus* (Curtis) Skeels
- *^N *Callistemon linearis* (Schrad. & J.C.Wendl.) DC. (= *C. rigidus* R.Br., *C. pinifolius* (J.C. Wendl.) Sweet, *Melaleuca linearis* Schrad. & J.C.Wendl.)
- *^N**ES** *Chamelaucium uncinatum* Schauer (Geraldton wax)
- *^C *Corymbia ficifolia* (F.Muell.) K.D.Hill & L.A.S.Johnson (**LS** *C. ficifolia* × *C. ptychocarpa*)
- *^C **S** *Eucalyptus agglomerata* Maiden¹
- *^C *Eucalyptus bancroftii* (Maiden) Maiden (= *Eucalyptus tereticornis* var. *bancroftii* Maiden)
- *^N **S** *Eucalyptus botryoides* Sm.
- *^C *Eucalyptus calophylla* R.Br. ex Lindl.
- *^C **S** *Eucalyptus cinerea* Benth.

- *C *Eucalyptus cordata* Labill.
- *C *Eucalyptus cypellocarpa* L.A.S.Johnson
- *N *Eucalyptus delegatensis* R.T.Baker
- *C *Eucalyptus dendromorpha* (Blakely) L.A.S.Johnson & Blaxell
- *C **S** *Eucalyptus elata* Dehnh.
- *C *Eucalyptus eugenioides* Spreng.
- *C **S** *Eucalyptus fastigata* H.Deane & Maiden
- *N **S** *Eucalyptus globulus* Labill. subsp. *globulus*
- *C *Eucalyptus globulus* subsp. *maidenii* (F.Muell.) J.B.Kirkp.
- *C**MS** *Eucalyptus grandis* W.Hill
- *N *Eucalyptus gunnii* Hook.f.
- *C *Eucalyptus leucoxydon* subsp. *megalocarpa* Boland
- *C *Eucalyptus macarthurii* H.Deane & Maiden
- *C *Eucalyptus muelleriana* A.W.Howitt
- *C *Eucalyptus nicholii* Maiden & Blakely
- *C **S** *Eucalyptus nitens* (H.Deane & Maiden) Maiden
- *C **S** *Eucalyptus obliqua* L'Hér.
- *C **S** *Eucalyptus ovata* Labill.
- *C **S** *Eucalyptus pilularis* Sm.
- *C *Eucalyptus piperita* subsp. *urceolaris* (Maiden & Blakely) L.A.S.Johnson & Blaxell
- *C *Eucalyptus pulchella* Desf.
- *C **S** *Eucalyptus punctata* DC.
- *C **S** *Eucalyptus regnans* F.Muell.
- *C **S** *Eucalyptus resinifera* Sm.
- *C **S** *Eucalyptus robusta* Sm.
- *C **S** *Eucalyptus saligna* Sm.
- *C *Eucalyptus sideroxydon* Woolls.

*C **S** *Eucalyptus sieberi* L.A.S.Johnson

*C *Eucalyptus tenuiramis* Miq.

*C **LS** *Eucalyptus tereticornis* Sm.

*C **S** *Eucalyptus viminalis* Labill.

Kunzea amathicola de Lange & Toelken in de Lange

S *Kunzea* aff. *ericoides* (A.Rich.) Joy Thomps. (Ramsfield et al, 2010, and Clark, 2011, list a number of unnamed indigenous *Kunzea* species with affinity to *K. ericoides*, some in decline, but the one most widespread is considered to be treated incorrectly as *K. ericoides*)

Kunzea linearis (Kirk) de Lange & Toelken in de Lange (= *Kunzea ericoides* var. *linearis* (Kirk) W.Harris; restricted distribution, population in decline)

Kunzea robusta de Lange & Toelken in de Lange

Kunzea salterae de Lange

Kunzea serotina de Lange & Toelken in de Lange

Kunzea sinclairii (Kirk) W.Harris in Connor & Edgar (= *Leptospermum sinclairii* Kirk; *Leptospermum ericoides* var. *pubescens* Kirk; restricted distribution, uncommon)

Kunzea tenuicaulis de Lange (= *Kunzea ericoides* var. *microflora* (G.Simpson) W.Harris; *Leptospermum ericoides* var. *microflorum* G.Simpson; restricted distribution, Taupo volcanic zone and a form on Whale Island; uncommon)

Kunzea toelkenii de Lange

Kunzea triregensis de Lange

*N **S** *Leptospermum laevigatum* (Gaertn.) F.Muell.

*C *Leptospermum minutifolium* C.T.White

*C **LS** *Leptospermum petersonii* F.M.Bailey

*C *Leptospermum polygalifolium* Salisb. subsp. *polygalifolium* (**S** an uncertain subsp. is susceptible)

S *Leptospermum scoparium* J.R.Forst. & G.Forst. (= *Leptospermum floribundum* Salisb. etc.; widespread, but three unnamed species with affinity to *L. scoparium* have restricted distribution, two being in decline)

Leptospermum scoparium var. *incanum* Cockayne (restricted distribution)

*C **S** *Leptospermum spectabile* Joy Thomps.

*C *Leptospermum variabile* Joy Thomps.

- S** *Lophomyrtus bullata* Burret (= *Lophomyrtus aotearoana* E.C.Nelson; widespread in North and northern South Island)
- Lophomyrtus obcordata* (Raoul) Burret (widespread in both islands)
- S** *Lophomyrtus ×ralphii* (= *Myrtus ralphii* Hook. f.; a natural hybrid between *L. bullata* and *L. obcordata*, yielding susceptible commercial cultivars)
- *C *Lophostemon confertus* (R.Br.) Peter G.Wilson & J.T.Waterh.
- *C *Luma apiculata* (DC.) Burret
- *C *Melaleuca armillaris* Sm. (**S** an uncertain subsp. is susceptible)
- *C **S** *Melaleuca ericifolia* Sm.
- *C **S** *Melaleuca hypericifolia* Sm.
- *C **LS** *Melaleuca leucadendra* (L.) L.
- *C **S** *Melaleuca styphelioides* Sm.
- Metrosideros albiflora* Sol. ex Gaertn. (= *Metrosideros diffusa* A.Cunn.; limited distribution north of Hamilton)
- Metrosideros bartlettii* J.W.Dawson (restricted distribution; population nationally critical)
- S** *Metrosideros carminea* W.R.B.Oliv. (= *Metrosideros diffusa* Hook.f.; northern half of North Island)
- Metrosideros colensoi* Hook.f. (= *Metrosideros pendens* Colenso; both islands)
- *C **LS** *Metrosideros collina* A.Gray (moderate to severe damage in field; LS "*M. thomasi*" is considered to be a cultivar of *M. collina*, Edwards 1990 in Dawson et al. 2010)
- Metrosideros diffusa* (G.Forst.) Sm. (both islands)
- S** *Metrosideros excelsa* Sol. ex Gaertn. (= *Metrosideros tomentosa* A.Rich.; northern North Island, coastal and Rotorua lakes, but planted beyond natural range)
- Metrosideros fulgens* Sol. ex Gaertn. (= *Metrosideros scandens* (J.R.Forst. & G.Forst.) Druce etc.; both islands)
- LS** *Metrosideros kermadecensis* W.R.B.Oliv. (= *Metrosideros villosa* Kirk; planted outside its naturally restricted distribution range and hybridises with *M. excelsa*)
- Metrosideros parkinsonii* Buchanan (restricted distribution)
- Metrosideros perforata* (J.R.Forst. & G.Forst.) A.Rich. (= *Metrosideros scandens* Sol. ex Gaertn. etc.; widespread)
- Metrosideros robusta* A.Cunn (= *Metrosideros florida* Hook.; North and northern half of South Island)

Metrosideros umbellata Cav. (= *Metrosideros lucida* (G.Forst.) A.Rich.; scarce in North Island)

*N *Myricaria germanica* (L.) Desv.

Neomyrtus pedunculata (Hook.f.) Allan (= *Myrtus vitis-idaea* (Raoul) Druce etc.; widespread)

*N **S** *Psidium cattleianum* Sabine

*N **S** *Psidium guajava* L.

*C **S** *Syncarpia glomulifera* Nied. (moderate to severe damage in field)

*N**LS** *Syzygium australe* (Link) B.Hyland

*C**LS** *Syzygium floribundum* F.Muell. (= *Waterhousea floribunda* (F.Muell.) B.Hyland)

Syzygium maire (A.Cunn.) Sykes & Garn.-Jones (= *Eugenia maire* A.Cunn; North and northern South Island in lowland forests where boggy)

*C**LS** *Syzygium paniculatum* Gaertn.

*N**MS** *Syzygium smithii* (Poir.) Nied. (= *Acmena smithii* (Poir.) Merr. & L.M.Perry)

*C**LS** *Tristaniopsis laurina* (Sm.) Peter G.Wilson & J.T.Waterh.

*N **S** *Ugni molinae* Turcz. (= *Myrtus ugni* Molina; Chilean guava)

¹Ramsfield et al. (2010) list the following exotic, non-naturalised species as being of commercial significance in New Zealand (in addition to others featured above): *Eucalyptus bosistoana* F.Muell., *Eucalyptus fraxinoides* (Dumort.) H.Deane & Maiden, **S** *Eucalyptus globoidea* (Hiern) Blakely, Maiden and **S** *Eucalyptus microcorys* (Delise) F.Muell.

Appendix 3. Some myrtaceous species (indigenous and exotic) planted in New Zealand gardens, parks and rural settings

S = known to have some susceptibility to *Puccinia psidii* sensu lato (recorded in Australia or elsewhere, field observation or by inoculation; degree of susceptibility generally not provided, but if available, indicated as **ES** extremely susceptible, **HS** highly susceptible, **MS** moderately susceptible, **LS** low susceptibility or relatively tolerant- data from Queensland); many species remain untested.

ES *Agonis flexuosa* (Willd.) Sweet (cultivar 'Afterdark' very susceptible in cultivation in Australia;
moderate to severe damage in field)

S *Acca sellowiana* (O.Berg.) Burret (= *Feijoa sellowiana* (O.Berg) O.Berg.)

S *Angophora costata* (Gaertn.) Britten

LS *Backhousia citriodora* F. Muell.

S *Callistemon citrinus* (Curtis) Skeels

Callistemon linearis (Schrad. & J.C.Wendl.) DC. (= *C. rigidus* R.Br., *C. pinifolius* (J.C. Wendl.) Sweet, *Melaleuca linearis* Schrad. & J.C.Wendl.)

S *Calothamnus quadrifidus* R. Br.

S *Calytrix tetragona* Labill.

LS *Corymbia ficifolia* (F.Muell.) K.D.Hill & L.A.S.Johnson (see App. 1)

S *Corymbia calophylla* (R. Br.) K.D.Hill & L.A.S.Johnson

S *Corymbia citriodora* (Hook.) K.D. Hill & L.A.S.Johnson

S *Corymbia maculata* (Hook.) K.D. Hill & L.A.S.Johnson

Corymbia papuana (F.Muell.) K.D.Hill & L.A.S.Johnson

Corymbia ptychocarpa (F.Muell.) K.D.Hill & L.A.S.Johnson

S *Corymbia tessellaris* K.D.Hill & L.A.S.Johnson

Darwinia oxylepis (Turcz.) N.G.Marchant & Keighery

Eucalyptus brevifoia F.Muell.

Eucalyptus caesia Benth. subsp. *magna*

Eucalyptus calycogona Turcz.

- S** *Eucalyptus camaldulensis* Dehnh.
- S** *Eucalyptus cinerea* Benth.
- S** *Eucalyptus cladocalyx* F. Muell.
- LS** *Eucalyptus curtisii* Blakely & C.T.White
- Eucalyptus desmondensis* Maiden & Blakely
- S** *Eucalyptus diversicolor* F. Muell.
- Eucalyptus dumosa* A.Cunn. ex J.Oxley
- S** *Eucalyptus elata* Dehnh.
- Eucalyptus eremophila* (Diels) Maiden
- Eucalyptus erythrocorys* F. Muell.
- S** *Eucalyptus forrestiana* Diels
- S** *Eucalyptus globulus* Labill.
- MS** *Eucalyptus grandis* W.Hill
- Eucalyptus gunnii* Hook.f.
- S** *Eucalyptus haemastoma* Sm.
- Eucalyptus leucoxyton* F. Muell.
- Eucalyptus macrocarpa* Hook.
- Eucalyptus mannifera* Mudie
- Eucalyptus microtheca* F. Muell.
- Eucalyptus nicholii* Maiden & Blakely
- Eucalyptus perriniana* F. Muell. ex Rodway
- Eucalyptus polyanthemus* Schauer
- S** *Eucalyptus regnans* F.Muell.
- Eucalyptus rubida* H. Deane & Maiden
- Eucalyptus salmonophloia* F. Muell.
- Eucalyptus sideroxyton* Woolls.
- LS** *Eucalyptus tereticornis* Sm.

- S** *Eucalyptus torquata* Leuhm.
- S** *Eucalyptus woodwardii* Maiden
- S** *Eugenia brasiliensis* Lam.
- S** *Eugenia uniflora* L.
- S** *Kunzea baxteri* (Klotzsch) Schauer
Kunzea parvifolia Schauer
- S** *Leptospermum laevigatum* (Gaertn.) F.Muell.
- LS** *Leptospermum petersonii* F.M.Bailey
- S** *Leptospermum scoparium* J.R.Forst. & G.Forst.
- S** *Lophomyrtus bullata* Burret
Lophomyrtus obcordata (Raoul) Burret
- S** *Lophomyrtus ×ralphii*
Lophostemon confertus (R.Br.) Peter G.Wilson & J.T.Waterh.
Luma apiculata (DC.) Burret
- S** *Melaleuca argentea* W. Fitzg.
- S** *Melaleuca armillaris* Sm. (see App. 1)
Melaleuca bracteata F. Muell.
Melaleuca fulgens R. Br.
Melaleuca incana R. Br.
- LS** *Melaleuca leucadendra* (L.) L.
- LS** *Melaleuca linarifolia* Sm.
Melaleuca phoenicea (Lindl.) Craven (= *Callistemon phoeniceus* Lindl.)
- HS** *Melaleuca quinquenervia* (Cav.) S.T.Blake
- S** *Melaleuca salicina* Craven (= *Callistemon salignus* (Sm.) Sweet
Melaleuca subulata (Cheel) Craven (= *Callistemon subulatus* Cheel)
Melaleuca tamariscina Hook.
Melaleuca thymifolia Sm.

Melaleuca viminalis (Sol. Ex Gaertn.) Byrnes (= *Callistemon viminalis* (Sol. Ex Gaertn.)
G. Don

S *Melaleuca viridiflora* Sol. ex Gaertn.

LS *Metrosideros collina* A.Gray (as "*M. thomasi*", now called *M. collina* 'Spring Fire';
another cultivar is *M. collina* 'Tahiti')

S *Metrosideros excelsa* Sol. ex Gaertn.

LS *Metrosideros kermadecensis* W.R.B.Oliv.

Metrosideros robusta A.Cunn

Metrosideros umbellata Cav.

S *Myrtus communis* L.

S *Pimenta dioica* (L.) Merr.

LS *Plinia cauliflora* (Mart.) Kausel (= *Myrciaria cauliflora* (Mart.) O.Berg)

S *Psidium cattleianum* Sabine

S *Psidium guajava* L.

Sannantha virgata (J.R.Forst. & G.Forst.) Peter G.Wilson (= *Baeckea virgata* (J.R.Forst.
& G.Forst.) Andrews)

S *Syncarpia glomulifera* Nied.

MS *Syzygium cumini* (L.) Skeels.

ES *Syzygium jambos* (L.) Alston

MS *Syzygium luehmannii* (F.Muell.) L.A.S.Johnson

LS *Syzygium paniculatum* Gaertn.

MS *Syzygium smithii* (Poir.) Nied. (= *Acmena smithii* (Poir.) Merr. & L.M.Perry)

LS *Syzygium wilsonii* (F. Muell.) B. Hyland

S *Thryptomene calycina* (Lindl.) Stapf

S *Thryptomene saxicola* (A. Cunn. ex Hook.) Schauer

LS *Tristaniopsis laurina* (Sm.) Peter G.Wilson & J.T.Waterh.

S *Ugni molinae* Turcz.

LS *Xanthostemon chrysanthus* (F. Muell.) Benth.