Myrtle Rust reviewed

The impacts of the invasive plant pathogen *Austropuccinia psidii* on the Australian environment

R. O. Makinson 2018

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This Review provides background for the public consultation document

'Myrtle Rust in Australia – a draft Action Plan'

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Front cover: Top: Spotted Gum *(Corymbia maculata)* infected with Myrtle Rust in glasshouse screening program, Geoff Pegg. Bottom: *Melaleuca quinquenervia* infected with Myrtle Rust, north-east NSW, Peter Entwistle

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EXECUTIVE SUMMARY

This review of the environmental impacts of Myrtle Rust in Australia is accompanied by an adjunct document, *Myrtle Rust in Australia – a draft Action Plan*. The Action Plan was developed in 2018 in consultation with experts, stakeholders and the public.

The intent of the *draft Action Plan* is to provide a guiding framework for a specifically environmental dimension to Australia's response to Myrtle Rust – that is, the conservation of native biodiversity at risk. An environmental response plan has been largely lacking up to now. The proposed actions aim to:

- anticipate and minimise decline of native species and ecosystems at risk from this pathogen;
- prevent the total extinction of high-risk species;
- maximise the options for future recovery for at least some affected species and ecosystems.

The intent of this *review of impacts* is to provide the evidentiary basis for the proposed actions, by:

- synthesising information on Myrtle Rust and its effects, much of it previously unpublished or only available in specialist journals, in a form relevant and accessible to all key stakeholders;
- describing the risks to Australia's natural, social and economic assets posed by Myrtle Rust;
- describing meaningful conservation actions that can be taken now and in the future;
- outlining the technical basis for potential recovery actions for some species and ecosystems;
- showing that a coordinated environmental response to Myrtle Rust will serve Australia's future environmental biosecurity interests.

Myrtle Rust is an introduced and highly invasive fungal disease of plants. It is of South American origin. First detected in Australia in 2010, it has established along the entire mainland eastern seaboard, in parts of the Northern Territory, and marginally in parts of Tasmania and Victoria. It is not yet present in South Australia or Western Australia.

Myrtle Rust has already proved capable of infecting 358 native species or subspecies, in screening tests and/or in the field. This 'host range' will increase as new hosts are detected and as the pathogen spreads to new areas. Only about 3% of species tested have failed to become infected.

Myrtle Rust affects only the plant family Myrtaceae, which makes up 10% of Australia's native flora and includes eucalypts, tea-trees, paperbarks, and lillypillies. Myrtle Rust can be managed in horticultural production systems, but is not amenable to direct management at this time in the wild.

The Myrtle Rust pathogen favours moist habitats and is unlikely to be a threat in drier areas. It is not a direct threat to human or animal health. However, loss of species, and resulting ecological change and loss of habitat, are likely to threaten some associated animal and plant species, and human social, cultural and economic values and assets.

Myrtle Rust has also arrived in recent years in New Zealand, New Caledonia, and South-east Asia. This pathogen is internationally recognised as a global biosecurity problem for natural environments containing the Myrtaceae family, and for industries dependent on it. Australia and its region so far have only one strain of this pathogen. Other strains are known, which would add to the threat. Their continued exclusion from Australia and its surrounds is a national and regional biosecurity priority.

The most serious species declines so far, are in north-eastern New South Wales, south-east Queensland, and the Queensland Wet Tropics. Several World Heritage Areas are affected. Myrtle Rust has an uncertain potential to cause damage to native flora in the monsoon tropics.

Myrtle Rust has potential to cause serious damage in the south-west of Western Australia if it arrives there and finds the climate suitable for establishment (as predicted by several research studies). The far south-west of WA contains some 40% of Australia's myrtaceous species. Continued exclusion of the pathogen from South Australia and Western Australia should be a domestic biosecurity priority.

83 of the 358 known host species were listed as 'threatened' or 'near threatened' in one or more Australian jurisdictions even before the arrival of Myrtle Rust, but most hosts were not previously listed, and some of those now in steepest decline were formerly widespread.

An estimated 45 species are known or suspected to be already in decline. These species are recommended in this review and the draft Action Plan for urgent conservation action – four on an emergency basis, 12 as high priority, and 29 as medium priority (end-2020). Some are likely to become extinct in the wild in the near future. The recommended priority actions are for:

- field survey to determine decline, and enable further prioritisation and damage assessment;
- identification of potentially resistant populations and genotypes in the field;
- capture of the widest possible range of plant 'germplasm' (seed banking or tissue banking) to conserve genetic diversity and to allow research directed at the eventual use of resistant genotypes to reinforce declining natural populations.

A further six species not yet in decline, from two World Heritage Areas, are recommended for precautionary seed or tissue banking.

Native species vary in their vulnerability to Myrtle Rust, although the research base is narrow and there are many unknowns. Rust-resistant eucalypts have been successfully bred in South America. Genotypes resistant to Myrtle Rust are known or suspected in some Australian host species, perhaps many. This provides a basis for research directed at the eventual recovery of many species of environmental and economic importance.

Also recommended in this review and the adjunct draft Action Plan are research programs into:

- the impact of Myrtle Rust on key ecosystems (rainforests, coastal heathlands, and paperbark wetlands);
- seed storage techniques for rainforest species not amenable to normal seed banking;
- the genetics and physiology of Myrtle Rust infection, and the potential for resistance trait transfer and selective plant breeding.

These research programs will both guide future prioritisation of investment, and allow anticipation of ecological and social, cultural and economic effects of the disease.

Further recommended actions relate to coordination of a national response, information assembly, social consultation, Indigenous cultural impacts, and information management.

These recommendations are contingent on the first overarching recommendation of the draft Action Plan: **to establish momentum, funding and leadership for a coordinated national environmental response to Myrtle Rust**. No national plan currently exists. No equivalent to the industry levies that help to fund responses to agricultural pathogens, exist for the environmental management sector.

The national response to Myrtle Rust to date has been largely led by primary industry agencies and research bodies. As the pathogen takes hold, a specifically environmental response is now an urgent necessity, for biodiversity conservation and the safeguarding of Australia's natural heritage assets. A strong environmental response to Myrtle Rust will also leave us better prepared for other broad-spectrum environmental pathogens likely to arrive in Australia in the future.

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INTRODUCTION

Australia's unique biological heritage is in part a product of our continent's long geographic isolation. This has allowed the evolution of a flora and fauna with only limited influence from elsewhere, highly adapted to Australia's climates and soils. This unique biota is also a defining feature of our cultural heritage, both Indigenous and non-Indigenous, and a priceless national asset in terms of heritage values, tourism, the maintenance of ecological function across the continent, and in relation to the vastly under-explored areas of genetic and biological resources.

Yet that same isolation has left our native biota and ecosystems with certain vulnerabilities. The ability of a wide range of exotic weeds and feral pest animals to establish and outcompete native species is well-known, especially in fragmented or disturbed environments. Invasive organisms (animal pests, weeds, and plant and animal pathogens) are recognised as leading causes of decline and extinction of native species, and a progressive decline in the quality and resilience of native ecological processes and habitats.

The role of invasive organisms in biodiversity decline is recognised in Australia through Australia's Biodiversity Conservation Strategy 2010-2030 (Natural Resource Management Ministerial Council 2010) and corresponding State and Territory strategies and policies.

The goal of controlling invasive alien species and their effects is also recognised globally through the *Convention on Biological Diversity* (CBD) and its Article 8 (United Nations, 1992). Other instruments within the CBD framework, to which Australia is a signatory, also address this goal. Two are particularly relevant.

The *Global Strategy for Plant Conservation 2011—2020* (GSPC), has as its Objective 2 that ''Plant diversity is urgently and effectively conserved''. GSPC Target 10 id for ''Effective management plans in place to prevent new biological invasions and to manage important areas for plant diversity that are invaded'' (Convention on Biological Diversity, 2010a).

The CBD *Strategic Plan for Biodiversity 2011-2020*, including the *Aichi Biodiversity Targets*, is another CBD instrument. Aichi Target 9 sets a global goal that "By 2020, invasive alien species and pathways are identified and prioritized, priority species are controlled or eradicated, and measures are in place to manage pathways to prevent their introduction and establishment" (Convention on Biological Diversity, 2010b).

In Australia, weeds and pest animals have been the main focus of investment in the areas of preventive environmental biosecurity, and (where this fails) in 'management' actions, or more rarely attempted eradication. Many millions of dollars are spent on these two groups of invasive species.

A third class of invasive organism has also long been recognised, although our national experience of it has been mainly in relation to primary industry species (livestock and crops) rather than as an 'environmental' or conservation problem for native species. This is the class of **exotic pathogens**, disease-causing microbes introduced to Australia. Micro-fungi, including those termed 'rusts', are conspicuously prominent among those exotic pathogens which cause diseases of plants.

The potential for direct economic impact of pathogens on agricultural products (mostly for pathogens which each affect only one or a few susceptible crop or livestock species) has led to a concentration of effort and expertise for biosecurity and incursion response in the primary industry agencies. By contrast, there is a relative paucity of planning, experience, expertise and investment on the pathogen front in the environmental agencies concerned with the protection of native biota.

A recent review of Australia's *Intergovernmental Agreement on Biosecurity* (IGAB) found that the mechanisms and resourcing of environmental biosecurity and response are sub-optimal and that "preparedness, surveillance and response arrangements are not yet mature" (Craik et al. 2017: Chapter 4).

An additional shortcoming in preparedness arrangements highlighted by the Myrtle Rust case, was the absence of any mechanism or planning by the environmental agencies themselves for the critical post-naturalisation management phase of a fast-moving and highly invasive broad-spectrum environmental pathogen. Since the first detection of Myrtle Rust in Australia, this absence has not been addressed. It remains a critical need for a more effective environmental response to other pathogens yet to arrive, including other strains of the Myrtle Rust pathogen, particularly those with a strong affinity for eucalypts.

In recent decades, the increased global movement of invasive pathogens – those able to naturalise and spread in a new environment – has increased greatly. This is particularly true for certain plant diseases that could potentially cause immense damage to native species and ecosystems lacking defences against them (Walker 1983; Wingfield et al. 2001; Fisher et al. 2012; Helfer 2014; Burgess & Wingfield 2017; Summerell 2017). *Broad-spectrum* invasive pathogens – those which, like *Austropuccinia psidii*, are capable of infecting more than one or a few new species – are an especially high-level threat.

A number of exotic plant pathogens are of particular concern for Australia, because they affect plant groups that are important constituents of Australia's native flora. Many of these pathogens are fungal, and inherently difficult to control, contain, or eradicate once established. Among them are pathogens of the three genera of eucalypts and their parent family (the Myrtaceae); *Acacia* (the wattle genus); the Proteaceae family (grevilleas, waratahs, and related genera); and some with even broader multi-family impact potential (see Part 7 'Plant pathogens – an emerging threat to wild biodiversity in a globalised world').

This increase in risk to global and Australian biodiversity from newly mobile pathogens has been well documented in the biosecurity and plant pathology disciplines. It has had some attention in terms of biosecurity settings, but has otherwise had very limited influence on policy, investment, research or preparedness in the environmental sector itself.

Until now, Australia has only experienced a few incursions of exotic and invasive 'environmental' pathogens, that is, those constituting a direct threat to Australian native biota.

'Phytophthora dieback' disease, caused by a non-fungal soil microbe (*Phytophthora cinnamomi* or 'Pc') has been a major cause of decline in the globally rich flora of south-west Western Australia over the last 30 or 40 years, and to a lesser but still concerning extent in some other States. In areas of heavy infection, it can have a devastating impact on native plant communities. This in turn can cause a 'cascade' of adverse ecological effects, causing declines in invertebrate, bird and mammal species due to the loss of shelter, nesting sites and food sources. Phytophthora dieback can cause permanent damage to ecosystems (Commonwealth of Australia 2014), and "is likely to infect over 2500 Australian native species … The pathogen is a threat, or possible threat to 144 native plant species listed as threatened under the EPBC Act … In the South-West Botanical Province … approximately 41 per cent of 5710 vascular plant species are susceptible to the pathogen. It may threaten several of these plant species with extinction."

'Chytrid disease' (pronounced 'kit-rid'), or chytridiomycosis, a fungal disease of amphibians caused by the microfungus *Batrachochytrium dendrobatidis*, arrived in Australia in the 1970s. Since the early

1990s it has been “directly implicated in the extinction of at least four species of native frogs and the dramatic decline of at least ten others” (Australian Government [2013b]).

Both the above diseases and their causative pathogens have been legislatively listed at Commonwealth level as Key Threatening Processes (KTPs) under the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act). Key Threatening Processes are a legislatively prescribed category that must be taken into account in certain areas of environmental management (not all threats to biodiversity are listed as KTPs). Commonwealth Threat Abatement Plans are current in place (for Chytrid) or under revision (for Phytophthora).

Much knowledge about Myrtle Rust has been difficult to access for many stakeholders who lack access to specialist journals. This Review is directed at making available to a broad range of stakeholders, as much knowledge as possible of the situation and the response options available. Stakeholders fluent in conservation science, plant pathology, or plant health will all find some material to be overly basic, although each may not know much about the others’ fields. A wider range of stakeholders will know little about any of these disciplines, so the Review outlines some basic factors from each.

Myrtle Rust – the ‘third bell’ for broad-spectrum pathogens of native biodiversity

A recently arrived broad-spectrum fungal pathogen of plants, scientifically named *Austropuccinia psidii* and in this country known as Myrtle Rust, has placed Australia on notice. It has already proved capable of affecting some 358 Australian native plant species or subspecies. These taxa are spread across 49 genera of the family Myrtaceae (52 in some literature, due only to different generic assignment of some species – generic names in this review follow the *Australian Plant Census*, see notes at Section 3.3 ‘*Host name standardisation’)*.

The number of hosts (host range) in Australia continues to expand. The figure of 358 used in this review, and detailed in Appendix 3, will be out of date almost as soon as this review is published. An accretion of c. 20 new hosts is expected shortly from susceptibility screening studies (L. Fernandez Winzer pers. comm.) and a likely further 10 or so from field reports (G. Pegg, J. Wills, and others, pers. comms). This underlies the need for resources to sustain the national host listing process, at present carried by an informal link group of scientists.

The Myrtle Rust pathogen, *Austropuccinia psidii*, has no known direct effects on human or animal health. It is pathogenic only on plants of the family Myrtaceae (including the small African family Heteropyxidaceae, regarded by some authorities as separate from Myrtaceae). The effects of Myrtle Rust infection on other biota (including humans) are indirect, but cumulative damage to host species may make the broader effects adverse and significant – examples are examined in this review.

The main *biological and ecological* risks associated with Myrtle Rust infection are:

- serious declines, in a short time-frame, in the extent and abundance of highly susceptible Australian native plant species – the eventual number undetermined, but an interim estimate of 45 species;
- a risk of regional or total extinctions of numerous species in the short- to medium-term;
- a risk of similar declines if the disease establishes in other parts of Australia that may be climatically suitable, particularly the south-west of Western Australia;
- consequent loss of ecological attributes of Australian ecological systems and landforms, varying with the species affected but involving loss of ecological resilience, resistance to weed invasion, suitability as habitat for native fauna and flora, and in some cases decline of water quality and erosion resistance;

- secondary declines of flora and fauna that are closely associated with species or habitats severely affected by Myrtle Rust.

Additional *social and economic* risks associated with the spread and impact of Myrtle Rust disease include

- cultural impacts, affecting both Indigenous and non-Indigenous cultural values;
- loss of genetic and biological resources provided by severely affected species, some currently exploited and many yet to be developed;
- economic impacts associated with the horticultural, forestry, native plant products, and ecotourism industries;
- a retardation of existing investment in ecological restoration in some ecosystems;
- an indeterminate but large cost in remedial conservation measures;
- a loss of public confidence in environmental biosecurity and conservation management arrangements.

Strategically, in the absence of a comprehensive national approach to Myrtle Rust and mitigation of its effects, Australia risks missing the opportunity to develop the learnings, systemic settings, expertise, and technology that may improve our ability to respond to future incursions of environmental pathogens. Several such pathogens have been identified as of particular concern (see Section 5.1 and Part 7, below). Most of them, like the Myrtle Rust pathogen, pose a threat that overlaps the environmental and production-sector domains, and all require a specifically environmental component of contingency planning, prevention of arrival, first response to arrival, and the extended response if eradication efforts fail.

The risks specific to *Austropuccinia psidii*, the Myrtle Rust pathogen, were accurately forecast by the then Primary Industries Ministerial Council in 2006:
"[*Austropuccinia psidii* is] … *one of the most serious threats to Australian production forests and natural ecosystems" ... It has a potential to cause direct mortality in the estimated 10% of all Australian native forest plant species (and the great majority of dominant species) that belong to the family Myrtaceae, and with indirect effects that may include habitat loss for native fauna and flora, retarded regeneration and recruitment of younger trees and successional species, greater impact of fire, and abiotic effects as a result of canopy decline including erosion, reduced water quality, reduced water retention in soil and vegetation and potentially large losses through lost production to the forestry industry*." (Commonwealth of Australia 2006).

In 2011, New South Wales gazetted a State-level Key Threatening Process listing for 'Introduction and establishment of Exotic Rust Fungi of the order Pucciniales pathogenic on plants of the family Myrtaceae', specifically in response to the arrival of Myrtle Rust and the possibility of future incursions of other strains of the same pathogen. The NSW Office of Environment and Heritage (2011) developed a tenure-based management plan for NSW national parks during the early phase of naturalisation, but this was largely unresourced and was rapidly outdated by events. Only some elements of that plan remain valid, and it was not accompanied by any impact reporting system. A new 'KTP Strategy' for Myrtle Rust in NSW is likely to be developed in 2018.

The Commonwealth has listed 'Novel biota and their impact on biodiversity' as a catch-all Key Threatening Process (KTP) for all environmentally invasive organisms of overseas origin. This national KTP specifically included "mortality, habitat loss and degradation caused by pathogens" as one of the forms of novel biota of concern (Australian Government, 2013a). The 'Novel Biota' KTP does not however provide any specific advice or prioritisation of effort relating to Myrtle Rust, and subordinate instruments that might do so have not yet been developed.

On the plant family Myrtaceae – environmental and economic significance:

The Myrtaceae (pron. 'mer-tay-see-ee') is the plant family that includes the eucalypts – i.e. *Eucalyptus* in the strict sense, plus *Corymbia* (the Bloodwoods) and *Angophora* -- as well as other genera including *Callistemon* and *Melaleuca* (Bottlebrushes and Paperbarks), *Leptospermum* (Tea-trees), *Syncarpia* (Turpentine), *Syzygium* (Lillypillies), and many others. 'Myrtaceous plants' is another way of referring to members of this family.

Myrtaceae occur on all continents except Antarctica, and through the Indo-Pacific islands. The family Myrtaceae in Australia has 88 native genera containing about 2253 species and subspecies (estimate courtesy Australian National Herbarium, Canberra; 24 Aug. 2010). A figure of 1646 or 'about 1650' species of Myrtaceae for Australia is cited in older and even some recent literature, but this is based on a 1992 statistic and is long out of date.

Myrtaceae comprise about 10% of Australia's native flora. The family Myrtaceae is hugely important in Australian ecosystems, and is structurally and floristically dominant in many of them.

Screening (inoculation) tests for susceptibility to *A. psidii*, plus field observations, to date account for less than 20% of Australia's Myrtaceae, but indicate that most are susceptible to varying degrees. Very few (approximately 3%) of screened taxa have failed to demonstrate infection in screening conditions favourable to the fungus (Berthon et al. 2018). Many native Myrtaceae however grow in areas of Australia climatically unsuitable for *A. psidii*, and are there unlikely to be affected.

2010 – The arrival of Myrtle Rust

In 2010, a long-forecast risk was realised with the arrival and establishment in Australia of a new plant pathogen, the fungus *Austropuccinia pisidii* (then known as *Puccinia psidii*). Eradication and containment efforts in eastern Australia failed. In the few years since, the Myrtle Rust pathogen has fully and invasively naturalised in wetter vegetation communities along most of Australia's east coast (inland to the escarpment, and onto the tablelands in parts of Queensland), and in parts of the Northern Territory. Myrtle Rust is also persistently present in cultivated situations in parts of Victoria and Tasmania, but is not yet reported from natural vegetation communities in those States. It is still absent from South Australia and Western Australia.

The Myrtle Rust pathogen requires relatively moist conditions and certain temperature ranges which mean that it is unlikely to become a problem in dry inland or cold montane areas, although seasonal outbreaks are possible in climatically marginal areas (and are known for example in Canberra). The potential for wide establishment of *A. psidii* in the monsoon tropics and in the south-west of Western Australia remains uncertain. For a discussion of current distribution and areas of projected bioclimatic suitability for the establishment of the Myrtle Rust pathogen, see Part 2 'Myrtle Rust in Australia'.

Myrtle Rust disease attacks the new growth of susceptible host species, damaging or killing new shoots and leaves, which can lead to progressive defoliation and plant stress or death as older leaves die naturally. The damage to new seasonal shoots (seasonal 'flush') also reduces or prevents flowering for those host species that produce their flowers on new wood each year, which is the case for most species. The reduction in flowering capacity by definition means a loss of fruit and seed production. *A. psidii* can also directly infect the fruits of soft-fruited Myrtaceae, of which there are many in the moist forest biomes along the east coast. Seedlings may be particularly vulnerable, although data for this life stage is very sparse so far – there are indications that seedlings may be highly susceptible in some species in which normal adult seasonal new growth is more resistant. For details of the biology, ecology and epidemiology of the pathogen and its disease, see Part 1 'About Myrtle Rust'.

Despite the climatic limits to the spread of *A. psidii* within Australia, its potential to cause major damage to economic and biodiversity assets is very large. Approximately 40% of Australia's native Myrtaceae species and subspecies (850+) occur within the broad east coast zone in which *A. psidii* is already fully naturalised; another 46% (1043 taxa) occur in the five most south-westerly IBRA bioregions in Western Australia, which are considered those most likely to be suitable for establishment in that State.

Susceptibility information exists for 417 taxa (species or named subspecies) of native and introduced Myrtaceae occurring in Australia, variously from glasshouse and laboratory screening trials and from and wild and cultivated field observations. Only 3% of species so far screened for susceptibility have failed to develop infection and sustain the rust life cycle under test conditions (Berthon et al., 2018).

Susceptibility ratings (from fully resistant to extremely susceptible) have been generated for 180 taxa to date (Pegg et al., 2018), most of them from Queensland, New South Wales, and Tasmania, although such ratings may change with more information. The proportion of known-host species from Queensland which fall wholly or partly within the Highly or Extremely Susceptible categories assigned by Pegg et al. (2014a) is 29% (48 species of 163), the remainder being rated as Moderately Susceptible or Relatively Tolerant. For details of host species, including susceptibility ratings, see Appendix 3.

Many species show apparent infraspecific (internal) variation in their levels of susceptibility, and definite evidence for more resistant populations or individuals is known in some otherwise highly susceptible species – the genetic basis of this is beginning to be understood for a few species.

Species declines due to Myrtle Rust infection

The actual impacts of Myrtle Rust on native biodiversity since 2010 are hard to gauge with accuracy as there have been very few field studies conducted (and none current by environmental agencies in the affected jurisdictions). However, sufficient evidence exists for several species to demonstrate severe decline on either a total or a regional basis, and indicative evidence and reports exist for several more. The data and observations available for 45 species that warrant a high priority for conservation action are provided in Appendix 1.

From common to Critically Endangered – a two-species snapshot:

The strongest evidence of acute decline on a whole-of-species basis is for two east coast taxa, Native Guava (*Rhodomyrtus psidioides*), and Scrub Turpentine (*Rhodamnia rubescens*). Both were widespread in NSW and south-east Queensland and of no conservation concern in either State prior to 2010. A study by Carnegie et al. (2016) assessed both species across their geographical range.

Carnegie et al. (2016) found all sample sites to be infected by the Myrtle Rust pathogen. Up to late 2014, after barely four years' exposure to the pathogen, adult mortality (death) rates in these species averaged 57% and 12% respectively (Carnegie et al. 2016). No plausible alternative cause of mortality could be identified, and the disease and decline process was tracked where possible. Some sites have been rechecked since the study concluded, and further mortality has occurred (A. Carnegie, pers. comm. Oct. 2017). Pegg (in conference, May 2017) provided updated figures for *Rhodomyrtus psidioides* at two NSW sites, with percentage deaths at Bongil Bongil National Park

NSW increasing from 72% in 2014 to 100% in 2016, and at Port Macquarie NSW 'site 1' from 12% in 2014 to 69% in 2016.

Defoliation levels of surviving sapling and adult plants were at levels two to three times the estimated normal. This reflects the high level of destruction of new growth inflicted by the pathogen, and the inability of the infected plants to adequately replace naturally senescent old foliage with new. 'Mean crown transparency', an index of foliage density relating to how much blue sky is seen when looking up through the crown, was 95% in *Rhodomyrtus psidioides* (estimated normal 25—35%), and 76% in *Rhodamnia rubescens* (normally 30—35%). As old leaves continue to die naturally, if new foliage does not replace it the plant loses all photosynthetic capacity, is starved, and dies.

Fruiting, and seedling recruitment, had effectively ceased in both species in the 2016 study, although isolated instances of fruit-set have been reported since for *R. rubescens*, within a context of continued overall decline.

The strong likelihood is that both these formerly common species will be effectively extinct in the wild within a very few years. Preliminary determinations to list these two species as Critically Endangered, on the basis of decline caused by Myrtle Rust, have been made in New South Wales (http://www.environment.nsw.gov.au/committee/preliminarydeterminationsbydate.htm). As at June 2018, both remain un-listed in Queensland, and at Commonwealth level under the EPBC Act. This illustrates the difficulty faced by current assessment and listing arrangements in keeping pace with this new threat, rather than reflecting any different estimations of impact or extinction risk.

FIGURE 1: Scrub Turpentine *Rhodamnia rubescens*, sucker resprout, stems and leaves heavily infected by *A. psidii*, Wambina Nature Reserve NSW, May 2011 (A.J. Carnegie, NSW DPI).


FIGURE 2: Native Guava *Rhodomyrtus psidioides*, sucker growth showing the after-effects of heavy *A. psidii* infection on new leaves, still with actively sporulating infection on stems. Wamberal Nature Reserve NSW, December 2010 (R.O. Makinson).

Multi-species rainforest decline: a south-east Queensland snapshot:

Pegg *et al*. (2017) document declines of a number of species in a Myrtaceae-rich wet sclerophyll/rainforest transition system in south-east Queensland from 2014-16, with some comparator sites in north-eastern NSW. They confirm the severe decline already noted by Carnegie et al. (2016) for *Rhodomyrtus psidii* and *Rhodamnia rubescens*. In addition, Pegg et al. (2017) document that the shrub/small tree species *Archirhodomyrtus beckleri*, *Decaspermum humile*, *Gossia hillii* and *Rhodamnia maideniana* "are in serious decline, with significant increases in tree mortality over the period of our study".

Effects on all these, and other less dramatically affected species were found to vary according to species, site, and the structural position of the affected individuals. The disease also takes a different course in different species, which showed varying degrees of branchlet dieback, whole-branch death, adult mortality, and overall defoliation as measured by crown transparency. These factors complicate forming an overall summary, but whole-tree death, seedling recruitment level, and crown transparency of surviving plants provide an overall indication of impact at the sites studied. The disease and decline process was tracked, and again no other plausible cause of the decline could be identified.

At the primary study site (Ryans Road), Pegg et al. (2017) report that "Assessments of species decline from 2016 to 2017 show a dramatic increase in tree mortality levels. Tree deaths from 2016 to 2017 (12 months) increased three-fold for *Archirhodomyrtus beckleri* (13% to 44%) and more than doubled for *Decaspermum humile* (36% to 73%) and *Gossia hillii* (18% to 38%). No deaths were recorded for either *Acmena smithii* or *Rhodamnia maideniana* within the study transects, despite significant levels of dieback recorded on *R. maideniana*." At one secondary site, "of the 87 *A. beckleri* trees assessed … 79% of trees were dead. The remaining trees showed evidence of branch death and dieback on living branches. No *A. beckleri* seedlings were located at the time of assessment". At another secondary site, the decline in *A. beckleri* "was less severe … all had some branch dieback but no evidence of branch death."

The mortality of *Rhodomyrtus psidioides* trees at the Ryans Road site had increased from 96.7% in 2014 to 100% in 2016, and "no evidence of root sucker regeneration or seedling germination was found at spots where *R. psidioides* trees had been killed by *A. psidii*". The mortality rate of *Rhodamnia rubescens* increased only marginally from 25% In 2014 to 30% in 2016, but a decline in tree health was observed with foliage loss occurring primarily from the lower branches". No seedling germination or regenerant juveniles were observed under or near any of the trees within the site, "nor was there evidence of flower or fruit production on the trees assessed."

For surviving established plants, Pegg et al. (2017) report that at the primary site, crown transparency for *A. beckleri* ranged 89.4% (mid-story) to 93.5% (regenerant under-storey); for *D. humile* 98.2% and 95.6% respectively; for *G. hillii* 94.7% and 91.1%; and for *R. maideniana* 85.3% (under-storey only).

FIGURE 3: *Decaspermum humile*, adult tree, almost dead, on disturbed rainforest margin; Tallebudgera Valley, south-east Queensland, May 2017. (R.O. Makinson).

Observations on other species, located outside the plots used for quantitative data collection, also showed significant impact for some. Saplings of *Syzygium hodgkinsoniae* "had very high incidence (90-100%) of rust infection on new shoots and expanding foliage. Dieback on all branches is likely to have been caused by past infection episodes … with symptoms typical of *A. psidii* infection evident. The impact of *A. psidii* on mature *S. hodgkinsoniae* trees was less obvious as foliage/crown density levels were high … However, the presence of branch dieback, dead growing tips on most branches and epicormic shoots was evidence of stress. These epicormic shoots were infected by *A. psidii*." For *Syzygium corynanthum*, of three large (25+ m height) trees closely examined, one showed "75% defoliation [and] 20% branch death, with the remaining branches showing evidence of dieback"; on the other two individuals "foliage loss was restricted to dieback at the very tip of branches … However, high levels of *A. psidii* infection were observed on new growth on both trees despite the overall low levels of decline in tree health."

Of all Myrtaceae at the site, only the over-canopy species (Flooded Gum *Eucalyptus grandis* and Brush Box *Lophostemon confertus*) appeared completely unaffected by Myrtle Rust infection (at least at adult stage). In the regenerating rainforest-type lower structural layers, only *Acmena (= Syzygium) smithii* appeared relatively tolerant of the disease, albeit with some branch dieback on 35% of trees. Of the nine Myrtaceae in those strata, *Syzygium smithii* is expected to become the dominant survivor.

The degree of floristic change in the vegetation of these Myrtaceae-rich sample sites is massive. Data presented by Pegg in conference (May 2018, Plant Biosecurity CRC Science Exchange) shows the prior 94% dominance of Myrtaceae in the forest mid-storey (i.e. trees below the emergent top canopy) will not be replaced, with only 63% of the understorey (sapling) layer now belonging to that family, and only 37% of the 'regeneration' (young juvenile) layer. Those Myrtaceae that do survive and mature will be of the few local species or individuals relatively tolerant of the Myrtle Rust pathogen (e.g. *Syzygium smithii*) only.

The results of Pegg *et al*. (2017) for a number of species in their study sites (*Archirhodomyrtus beckleri*, *Gossia hillii*, *Rhodamnia maideniana*, and the relatively resistant *Acmena smithii*) are consistent with other reports from elsewhere in southern Queensland and northern NSW (Appendix 1). The case of *Archirhodomyrtus beckleri* however highlights the existence of differential levels of resistance in what is currently regarded as a single species. *A. beckleri* has no formal subspecies, but is known (Brophy et al. 1996) to have two geographically separate 'chemotypes' (variants characterised by the secondary metabolites produced, such as leaf oils), with populations in northern NSW and south-east Queensland belonging to Chemotype 1, and those in Central and North Queensland belonging to Chemotype 2. Observations from the northern Chemotype 2 areas are scant, but seem to indicate lower or zero levels of occurrence of Myrtle Rust disease on this species, even at sites where *A. psidii* is prevalent on other species (J. Wills pers. comm. May 2018). Whether the chemical difference is causative or simply correlated with this apparently differential rust resistance is entirely unclear, but as with numerous other species it does point to the possibility of local persistence of resistant populations. Identification of such resistant genotypes is critical for future recovery efforts.

Decaspermum humile is also known to occur in two morphologically differentiated forms in southern and northern Queensland, with Pegg *et al*.'s (2017) study above indicating high susceptibility and severe impact in the southern metapopulation. Very few observations exist for the North Queensland metapopulation, although J. Wills (pers. comm. May 2018) reports saplings at Mt Lewis with apparently minimal damage, but a large adult at Downfall Creek close to dead.

The conservation implications of Myrtle Rust

Austropuccinia psidii is covered specifically by the listing in New South Wales (NSW Scientific Committee, 2011) of 'Introduction and establishment of Exotic Rust Fungi of the order Pucciniales pathogenic on plants of the family Myrtaceae' as a 'Key Threatening Process' under the then NSW Threatened Species Conservation Act 1995.
http://www.environment.nsw.gov.au/determinations/exoticrustfungiFD.htm

A. psidii falls within the ambit of the Commonwealth EPBC Act listing (Australian Government 2013a) of a Key Threatening Process, of 'Novel biota and their impact on biodiversity', which applies to introduced and invasive species that have a significant detrimental impact on the environment. The associated, but not statutory, *Threat Abatement Guidelines for the Key Threatening Process 'Novel biota and their impact on biodiversity* (Australian Government, 2013c) provide general recommendations for established and pending exotic invasive biota, and many of these are relevant for a coordinated environmental response to Myrtle Rust. Particular features of this pathogen, however, demonstrate a need for some management approaches clearly not envisaged in the formulation of those guidelines.

The potential conservation impacts of Myrtle Rust include *direct effects* on susceptible host species (e.g. rapid or gradual declines, probable extinctions in some cases), but also potential 'ecological' effects, which can be parsed into several categories:

- Floristic change in host communities as a result of declines of one or more constituent species and their replacement by other native or weed species;
- Potential declines of other native *flora* that are dependent on, or strongly associated with, declining myrtaceous species for habitat (epiphytic plants being a particular concern);
- Potential declines of native *fauna* that are dependent on, or strongly associated with, declining myrtaceous species for habitat, food, shelter, or other interactions;
- Potential biophysical environmental decline in some circumstances, potential cases including increased erosion and water quality issues for Myrtaceae-dominated creeklines and some wetland systems.

The most fundamental problem with the impact of Myrtle rust on wild species in Australia is *the difficulty of containment, and the intractability of the disease to management in the wild.*

The strain of *Austropuccinia psidii* present in Australia reproduces predominantly by an asexual (uredinial) life cycle (Morin et al. 2014). The resulting spores are both wind-dispersed and easily transported by human and animal vectors. *Containment and eradication* is in practice likely to be feasible only under specific conditions. In areas not subject to immediate recolonisation (spore load) from adjacent regions, eradication may be feasible after very early detection of a new outbreak, and where the point of initial establishment of the pathogen is accessible and amenable to vigorous management measures (as with Lord Howe Island in 2017). A degree of management may be feasible to contain the pathogen where climate and a limited set of susceptible host species combine to limit the rust's spread (as in Victoria and Tasmania to date), although eventual establishment in natural vegetation is likely to follow. Prevention of arrival on a large geographical scale is feasible where weather systems and surrounding climatic and vegetational regimes provide a buffer hostile to the pathogen, and where patterns of animal movement do not favour dispersal and human vectoring is amenable to control. This is the case with the 'upwind' states of Western Australia and South Australia, and is the rationale for the maintenance of Myrtle Rust-specific domestic quarantine measures by those jurisdictions. The great expanse of dry country (unsuitable for *A. psidii*) between these States and the east coast of Australia is obviously an important factor; narrower rain-shadow areas along the east coast have proved no barrier to spread of the pathogen.

Management in the wild of the Myrtle Rust pathogen is not feasible by any means currently available. Biological control organisms have been suggested, and should be scoped for feasibility, but at this point, their utility is speculative. Available fungicides are not specific to the Myrtle Rust pathogen, and hence are unsuitable for broadacre application in the wild as they may have negative effects on beneficial native fungi and toxic effects on other biota. Nevertheless, both biocontrol and fungicidal approaches have their place in the array of ex situ conservation-related techniques.

The number of species at risk on a continental scale cannot be accurately estimated at this early stage. Only 358 native taxa (species or subspecies) have had infectibility confirmed to date, either in the field or in lab/glasshouse studies (Appendix 3) – this represents 16% of Australia's estimated 2253 native Myrtaceae taxa. Some of these known hosts are from cultivation and occur naturally in areas climatically unsuitable for *A. psidii*, and so are likely only to be vulnerable in horticultural situations outside their native range. Many more however occur in areas of uncertain climatic suitability, particularly in the monsoon tropics and the south-west of Western Australia. The latter region has 1043 native Myrtaceae taxa in the five most south-westerly IBRA bioregions, an area which is partly or mostly congruent with some of the climate suitability models.

For the east coast, where *A. psidii* has been highly invasive and is now well established from southern NSW to Cape York, a picture is slowly emerging of serious decline in multiple species. Our ability to gauge the geographical and taxonomic range of this decline is badly hampered by the scarcity of field impact surveys to date. Most of the quantitative data that do exist, for only a few of the species of concern, have come from a small number of field studies by researchers based in the NSW and Queensland agriculture departments, and from a small number of university projects. Systematic field studies of Myrtle Rust impact from the environment agencies in those States are yet to be established, although numerous staff in both have accumulated considerable observations, yet to be pooled. The many field reports by reliable and botanically skilled observers only partly counterbalance the scarcity of formal studies. These observers comprise a mix of government agency staff, ecological consultants, native plant growers and enthusiasts, bush regeneration workers (community and professional), staff of regional botanic gardens, and others. As many such observers as possible were contacted in the course of this review, and some have been able to provide valuable indicative data for various species and regions. In the absence of any coordinated monitoring effort and widely available monitoring protocols, their observations are mostly non-quantitative.

Taking all available information sources into account, 45 taxa (species of subspecies) are known or strongly suspected to be undergoing serious decline along the east coast. For many of these, further field survey is urgently needed to quantify decline, predict its course, and identify any populational or regional trends towards disease tolerance or resistance. These *priority species for conservation action* are tabulated at Section 4.4 below and in Part 8 'Recommendations', and are discussed in detail in Appendix 1.

Lassaiz-faire, or management intervention?

Genetically based resistance to at least some strains of *Austropuccinia psidii* is known in a number of species. In South America resistant selections of several plantation eucalypts (of Australian origin) have been developed and deployed. A wider range of Australian species are known or suspected to have genetically determined resistance traits. Resistant genotypes are currently under study and selection for one of the native Australia crop species severely affected by Myrtle Rust (Lemon Myrtle, *Backhousia citriodora* – E, Lancaster, University of Queensland, work in progress; see also Lee et al. 2016). Susceptibility screening studies have also provided a partial basis of understanding in some other genera (see, e.g., Pegg et al. 2014b). Within affected species, natural selection in favour of resistant genotypes, and their gradual replacement of more susceptible genotypes, may occur over long time periods (many generations) in species subject to slow overall impact by Myrtle Rust. For many species the declines caused by the disease will be far too rapid for this to occur, and the habitats too fragmented for resistant genotypes to spread easily.

Selection and breeding of disease-resistance traits in crop and forestry plants is a well-established and well-resourced branch of science. In Australia this area of research and development is usually funded by government and commercial growers. Much of the expertise and many of the techniques developed in those production industries are relevant to a Myrtle Rust response for biodiversity conservation, but the aims are different. Where agriculture seeks a genetically uniform crop with defined features (including disease resistance), biodiversity conservation requires that we maximise the retention of genetic diversity alongside any disease resistance. The social investment and institutional settings are very different – the industry levies that sustain much agricultural R&D for disease response and breeding, do not exist for non-commercial species and ecosystems.

What are our options?

Genetically based resistance traits may be complex, and we cannot assume that their strength and heritability will be able to compensate for disease-caused declines. Nevertheless, the existence of resistance genes (R genes) offers some hope for the natural selection and eventual spread of resistant genotypes, in cases where the rust-mediated decline is extremely slow and where gene flow within and between host populations is possible.

In situations where Myrtle Rust is causing rapid decline, or where species distributions are fragmented, or where R genes are ineffective or lacking, the disease is likely to far outstrip any natural resistance process. This is certainly the case for some of the few species for which we have good data, and is likely to be the case for many more. In these cases, there are much more limited options if we are to avoid massive declines, and local or regional extinctions.

Field surveys are essential to ground-truth the level of impact, to assess the available genetic stock, and to assign long-term priorities and investment. Among the priority species identified at Section 4.4 below, and detailed in Appendix 1, are many in which Myrtle Rust impact is already known or suspected to be at very serious levels, and the resulting decline very rapid. Less than half of these are under any form of study, and field surveys to confirm impact and to search for resistant genotypes are lacking for most. Surveys for impact and possible resistant genotypes are urgent for these priority species, and are likely to be a precautionary imperative for others in the near future. To help guide future actions for gauging decline, and for eventual recovery of such species, further field research into their ecological function and interdependencies with other biota are also necessary. For example, is there a threshold density of occurrence for a given species to maintain normal levels of pollinator attraction and outbreeding?

Precautionary germplasm banking (as seed or tissues) is not only a prudent option for these severe-decline species, but is the *only* guarantee that any options will remain open for the avoidance of extinction in the relatively near future. Germplasm capture will not happen at the necessary scale under current resource allocations. Moreover, many of the high-risk species are 'soft-fruited' Myrtaceae from moist forest environments, the seeds of which are not tolerant of normal seed bank storage. Technical solutions to this exist in some cases, but each species needs specific *storage and revival enablement* research in one of Australia's conservation seed banks. Other options (including tissue culture, cryopreservation, and extended 'inter-situ' cultivation) exist for those species that prove altogether recalcitrant for seed storage. For some species acutely affected by Myrtle Rust, the survivors are no longer able to produce seed at all in the wild, and protected *ex situ* seed orcharding is likely to be needed simply to generate enough seed to enable the storage enablement research. Australia's network of botanic gardens may play a critical role in such cases. For some species in severe decline, botanic garden holdings of live specimens already constitute a resource of great conservation value, and should be protected from Myrtle Rust outbreaks and integrated into a common program.

Reinforcement (or replacement) of high-risk natural populations with more rust-resistant natural genotypes from the same species is a future option in some cases. T*ranslocation* of this sort for conservation purposes is a well-established conservation practice in Australia. It does however carry its own risks, and needs careful prior evaluation. For the number and spatial scope of the species seriously affected by Myrtle Rust, it would need to be occur at an unprecedented scale.

Selective breeding for resistance and rewilding is a more interventionist approach, with no clear precedents in Australia although it is being evaluated for Tasmanian Devil (facial tumour disease) and some frogs (chytrid disease). There are some international precedents, particularly in North America, for the selection, breeding and rewilding of disease-resistant native plant genotypes. A step further, and potentially much faster than traditional breeding techniques for woody plants, would be the transfer of resistance genes within or between native species by techniques falling under the general heading of 'genetic engineering'. These techniques are at an unprecedented level of capability, and are discussed briefly in Section 6.6 below. Such highly interventionist approaches to biodiversity conservation carry biological social, and ethical complications and must be evaluated very critically. However if the alternative is multiple extinctions, then they must be examined and at least the groundwork laid for their possible use, before the opportunity is lost.

Resourcing of a conservation response over large geographical scales and for many species, whichever approach is chosen, is at least as big a challenge as the biological and technical problems. *Australia's Biodiversity Conservation Strategy 2010-2030* (Natural Resource Management Ministerial Council, 2010) states (*Principles*) that:
"*It is everyone's responsibility to conserve biodiversity. Governments will play a critical role, but unless the whole community works together to take up the challenge, then we are unlikely to stop the decline in biodiversity. This strategy is a call to action as well as a strategic document*."

To achieve an adequate response to the threat posed by Myrtle Rust, and by other pathogens yet to arrive, requires that we put this principle into operation in new and creative ways.

FIGURE 4: *Lenwebbia* sp. 'Main Range (P.R.Sharpe+ 4877)', defoliation and habit deformation after repeated *A. psidii* infection. Mt Merino NSW, 2016. (L. Weber).

PART 1: ABOUT MYRTLE RUST

1.1 Global context

Myrtle Rust is a plant disease caused by the fungal pathogen *Austropuccinia psidii* (formerly known as *Puccinia psidii*). It is native to South America and possibly Central America.

Several strains of this pathogen are known, of which only one strain is currently present in Australia and the surrounding region (Graça et al. 2011; Graça et al. 2013; Ross-Davis et al. 2013; Pegg et al. 2014a, 2014b; McTaggart, Shivas et al. 2016; Stewart et al. 2017).

A. psidii infects only species within the plant family Myrtaceae (including the formerly separate and very small African family Heteropyxidaceae – Alfenas et al. 2005). The Myrtaceae is a large family of shrubs and trees, which in Australia is dominant in many ecosystems. It includes the eucalypts, tea-trees, bottlebrushes, paperbarks, lillipillies, and many other species.

On host species native to South America, effects of infection by *Austropuccinia psidii* are usually mild (Tommerup et al. 2003). Highly susceptible species native to that continent were probably either eliminated long ago, or co-evolved with variants of the pathogen to make the plants more tolerant of infections and/or the rust less virulent. Partly for this reason, the disease only came to notice when it began to attack cultivated species of Myrtaceae that were not native to the South and Central American region. These crops included species of Guava (Winter 1884) and, from the early 20th century, *Eucalyptus* species of Australian origin being grown in plantation (S Gonçalves - Ministério da Agricultura, Rio de Janeiro, 1929 – not seen, cited in Graça et al. 2013; Joffily 1944). The high level of threat to eucalypts was not fully appreciated until large outbreaks in Brazilian nurseries and commercial plantations some decades later (Ferreira 1983; Dianese et al. 1984; Coutinho et al 1998). These commercially important hosts led to the common names *Guava Rust* and *Eucalyptus Rust* gaining wide use overseas for the disease caused by *A. psidii*.

Records of disease attributable to *Austropuccinia* (then still *Puccinia*) *psidii*, on commercial crops in the Caribbean area, date from the first half of the 20th century, when the Pimento (*Pimenta officinalis*) industry was severely affected (Smith 1935; Maclachlan 1938). It has been recorded in Mexico since at least the 1970s (Esperón-Rodríguez 2018). In 1977 a variant was detected in Florida USA (Marlatt and Kimbrough 1980) on allspice (*Pimenta dioica*), and in 1997 a second biotype reached Florida which vigorously attacked the naturalised Australian species *Melaleuca quinquenervia* – a pest weed of the Everglades wetlands (Rayachhetry et al. 1997).

The pathogen was repeatedly detected in the nursery industry in California USA from the early 2000s onward (Mellano 2006; Zambino & Nolan 2011), and apparently remains largely confined there to that industry and cultivated situations.

In 2005, a variant arrived in Hawaii (Killgore & Heu 2005), and within a year had spread to nearly all the Hawaiian islands, where it is known as ʻŌhiʻa Rust, after the Hawaiian language name for *Metrosideros* species, which are among the host plants. Its effects there have been most severe on some species of non-Hawaiian Myrtaceae that are widely naturalised, especially Rose Apple, *Syzygium jambos*. Effects on most native Hawaiian flora have so far been milder, although one already endangered native species, *Eugenia koolauensis*, has undergone serious further decline (of the order of 70% mortality) as a result of the disease, and is now close to extinction in the wild [Oahu Army NRP (2010, 2014)]. For Hawaiian case history, and important discussions of the potential added future risk from other strains – also a critical issue for Australia – see Loope (2010), Anderson (2012), and da Silva et al. (2013), and for the same issues in New Caledonia, Soewarto et al. (2017).

The pathogen then spread rapidly but unpredictably, and by mostly uncertain pathways, through the western Pacific area: Japan in 2007 (Kawanishi et al. 2009), Hainan in southern China in 2009 (Zhuang and Wei 2011), Australia in 2010 (Carnegie et al. 2010a), New Caledonia in 2013 (Giblin 2013; Soewarto et al. 2017), Sumatra in Indonesia in 2015 on the Australian species *Eucalyptus pellita* and *Melaleuca leucadendra* (McTaggart, Roux et al. 2016), Singapore in 2016 (du Plessis et al. 2017), and New Zealand in 2017 (https://www.mpi.govt.nz/protection-and-response/responding/alerts/myrtle-rust).

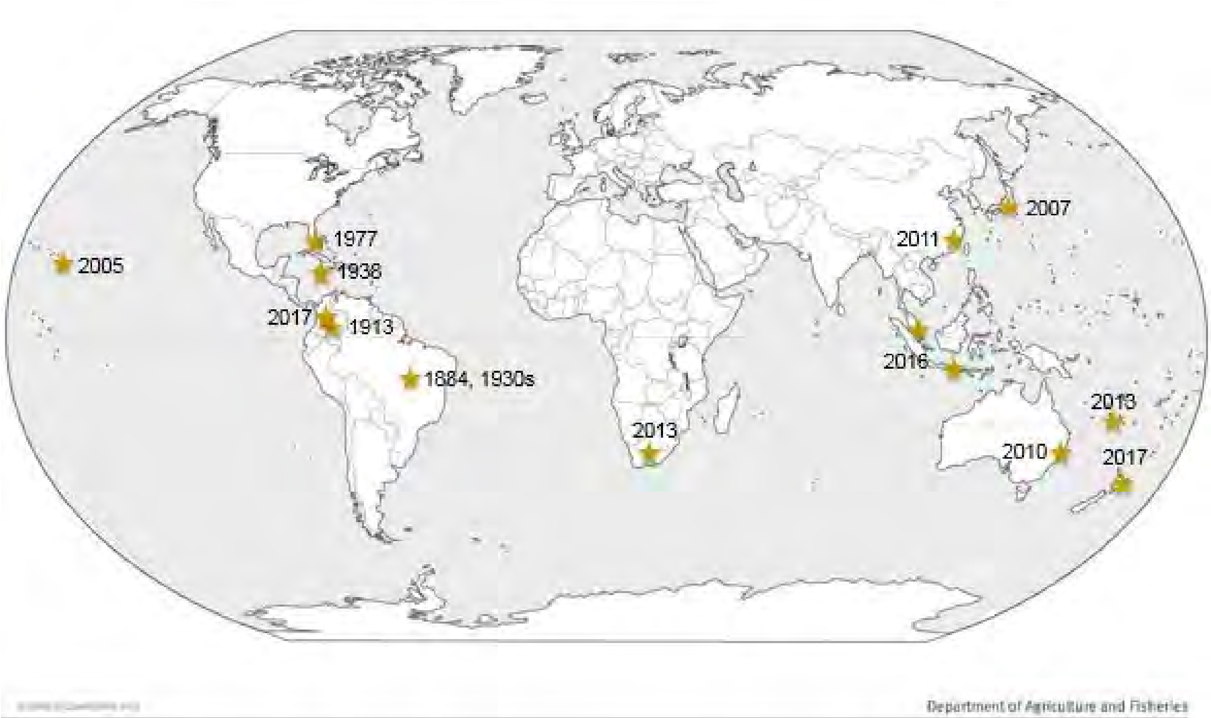

FIGURE 5: Global spread of *Austropuccinia psidii*. Image courtesy of G.S. Pegg and Queensland Department of Agriculture and Fisheries.

Further spread in the Indo-Pacific and south-east Asian areas is likely (Kriticos et al. 2013; Makinson & Conn 2014). *A. psidii* has not so far been reported from the island of New Guinea, but is present near the northern tip of Cape York, on the Tiwi Islands of the NT, and on at least three islands in Torres Strait (B. Waterhouse, DAWR, pers. comm. Nov. 2017).

A unique strain of the same pathogen was also detected in South Africa in 2013 (Roux et al. 2013, Roux et al. 2015, Roux et al. 2016).

A. psidii's international pathways and long-distance dispersal vectors have rarely been ascertained. Long-distance wind dispersal is possible, and seems the most likely mode of arrival of the pathogen (probably from Australia) on the Kermadec Islands north of New Zealand in 2017, in the wake of tropical cyclone Debbie. In most cases however, human or human-related vectors seem more likely to have been responsible for spread of *A. psidii* across sea gaps or other inhospitable terrain. Transmission of the pathogen from Florida USA to California is suspected to have been on cut flowers. The arrival in Hawaii in 2010 is very likely to have been on decorative myrtaceous foliage from California, based on earlier interceptions of contaminated shipments (Loope 2010). Viable spores were detected by Australian quarantine authorities in 2004 on a new-sawn eucalypt timber shipment from Brazil (Grgurinovic et al 2006). Movement on living plant materials or wood products are considered the most likely vectors in general (Grgurinovic et al 2006; Stewart et al. 2017), but the spores of *A. psidii* can be transported on various sorts of materials, including human clothing and accessories.

Austropuccinia psidii is considered a threat to wild native Myrtaceae species in all countries in which it has arrived, but the recent and rapid nature of its movement has meant that good data to demonstrate impacts (or lack thereof) so far only exists for a relatively few species in Hawaii, Australia, and New Caledonia. It represents a biodiversity threat in many other countries in which Myrtaceae form a significant component of the native flora, including much of the south-west Pacific islands, South-east Asia, parts of India, and parts of Africa.

The occurrences in California USA, Florida USA (in part – three strains may be present there according to Carnegie 2012), and Hawai'i and parts of Central America, have been demonstrated to represent a common genetic strain of the pathogen (the C1/C4 genotype – Stewart et al. 2017). The outbreaks in the western Pacific region (Australia, China-Hainan, New Caledonia, Indonesia, New Zealand), have been inferred from other strong evidence to also belong to this one strain (Stewart et al. 2017). Various authors refer to this widespread variant as the '*pandemic biotype*', '*pandemic strain*', or '*invasive genotype*' (although other strains may also have a 'pandemic' potential).

The pandemic strain of *A. psidii* has already proved capable of infecting 106 Australian native eucalypt species or subspecies. 84 of these taxa are as yet recorded as hosts in glasshouse inoculation screening only, with 22 from 'natural' infections (wild or cultivated). As yet however, field survey of eucalypt susceptibility in the wild is very inadequate, particularly for the seedling and re-sprout life stages. The ultimate impact of the pandemic strain of *A. psidii* on eucalypts in the wild is not yet predictable. Of added significance for Australia is that the economic losses and costs suffered by the plantation eucalypt industry in South America (Coutinho et al. 1998; Quecine et al. 2014) were caused by strains of the pathogen *other* than the pandemic strain now present in Australia. Two of the several strains characterised by Stewart et al. (2017), the C2 and C3 biotypes, are eucalypt associated in South America, where they appear to be currently confined. They do however have the potential to be highly aggressive also on non-eucalypt hosts (Silva et al., 2014). The screening tests run by Zauza et al. (2010) on a variety of Australian species utilised one race of this C2/C3 biotype (Stewart et al. 2017).

The arrival in Australia of any other strains of *A. psidii* could widen the host and geographic range of the pathogen in this country and have further and very great environmental and economic impacts. They would also increase the likelihood of sexual reproduction of the pathogen, with an increased chance of inter-strain outcrossing and further adaptation of the pathogen to Australian conditions.

1.2 Why are Australian Myrtaceae at such high risk?

While rust fungi occur world-wide, the distribution of individual rust species does not always correspond to the main centres of diversity of their host-plant families. Walker (1983), in a global synopsis, drew attention to the skewed global distribution of rusts on the family Myrtaceae. The centres of diversity of this plant family are in South America and in the Australian/Indo-Pacific region. However, the rusts that infect Myrtaceae are conspicuously concentrated in South America, and are almost entirely absent from the western Pacific and south-east Asian regions. This has meant that host species and their rust pathogens have had a long time to co-evolve in South America, and the assumption is that surviving host species have developed defences against, or tolerance for, the disease. Myrtaceae elsewhere however have never had that opportunity to co-evolve and adapt to this pathogen – they are epidemiologically naïve to it, and are more likely to be vulnerable to it as a result. In practice, some naïve species may nevertheless have defences, either as part of a general disease resistance syndrome or through possessing other traits that happen to help them tolerate or resist rust infection.

Walker (1983) specifically noted the near-total absence of rust fungi on the family Myrtaceae in the Australasian region, and that the presumed naivety of the vast majority Australian Myrtaceae has "most important consequences for plant quarantine".

Australia has numerous species of native rusts, on various plant families, but hardly any on native Myrtaceae. Native myrtaceous rusts are very rare – only two species are known, on three host plant species. Neither of these native rusts is closely related to *Austropuccinia psidii*. They are much more 'typical' rusts in having a very narrow host range, and neither appears to constitute any extinction threat to their host species. *Puccinia cygnorum* occurs naturally in the south-west of Western Australia, recorded in the wild only on *Kunzea glabrescens* (Makinson & Butcher 2014), and on the Western Australian species *Astartea fascicularis* in cultivation in New Zealand, from where it has since been eradicated (Shivas & Walker 1994; Makinson & Butcher 2014; Dick & Inglis 2011). *Physopella xanthostemonis* appears to have been recorded only twice, from the Northern Territory on two species of *Xanthostemon*, *X. eucalyptoides* and *X. paradoxus*, both of which also occur in the north of WA (Simpson *et al*. 2006). No available data suggest that either of these rusts is cause for conservation concern for their host species, although the discovery of *P. cygnorum* on host species in separate tribes of the family (*Kunzea* in Tribe Leptospermeae and *Astartea* in Tribe Chamelaucieae – Wilson *et al*. 2005; Wilson 2011) suggests some potential for a wider host range if more species were exposed.

With these rare exceptions, any rust detected on plants of the Myrtaceae in Australia is likely to be exotic in origin. While the discovery of further native Australian rusts on Myrtaceae is possible, there are not likely to be many, their host specificity is likely to be high (i.e. they will have a narrow host range), and their impact on native biodiversity in the wild is likely to remain low. However, Park *et al*. (2000) point out that naturally co-evolved pathogens may not show peak pathogenicity until their hosts are cultivated in monoculture.

The ubiquity of Myrtaceae in most Australian ecosystems exacerbates the vulnerability of susceptible Australian taxa and their ecological associations. In a system where there is only a single moderately susceptible species, with a more or less uniform seasonal period of new growth flush, transient weather conditions may enable the host to altogether escape infection in some years. Alternatively, it may be able to 'push through' a weather-dependent cycle of infection cycle, putting on enough new growth before or afterwards to ensure survival and reproduction for another year. In optimal conditions (for the plant), the local population of *A. psidii* of Myrtle Rust may die out altogether during an off-season, and new infections would be dependent on re-colonisation by incoming spores from elsewhere.

However, within the actual or projected naturalisation range of *A. psidii* in Australia, rarely or never does a terrestrial vegetation type contain only one species of Myrtaceae – the norm is several to many (often including dominant species), all with varying and overlapping durations of flush and new growth susceptibility. Some species (probably few) may not be susceptible to *A. psidii* infection at all. Some may be 'relatively tolerant', harbouring only a low frequency of infection that contributes only a low spore load to the environment. Other species again may be more highly susceptible. The presence of hosts in the latter two categories, coupled with microclimate 'refuges' that allow the pathogen to survive unfavourable conditions (e.g. dry seasons), will often ensure that there is no need for annual external recolonization by the rust. This means a relatively permanent presence of the pathogen that community, and a constant (even if seasonally low) level of spore load and infection. Given the rapid reproductive capability of the pathogen (10-12 days from a single-spore infection to a mature pustule with many thousands of new spores), there is potential for rapid build up of spore load and infection *whenever* suitable new plant tissues are present, assuming favourable weather conditions. The chances of any highly susceptible species escaping this constant threat of re-infection is accordingly reduced.

How many native Myrtaceae are there?

'Species' is a term requiring some interpretation in a conservation context and when estimating the impact of Myrtle Rust (and other pathogens). In taxonomic usage, 'species' is a rank distinct from the lower-order 'subspecies' and 'varieties' (all three are examples of *taxa*, singular *taxon*, which means an entity at any taxonomic rank). In conservation legislation in all Australian jurisdictions, 'species' is defined more broadly as meaning *any scientifically named or recognised entity, whether at the formal ranks of species, subspecies, or variety* – i.e. all recognised taxa at species rank or below. The distinction is important, since the legislative provisions for extinction-risk listings allow the listing of any of these subgeneric taxa. It is therefore important for the maintenance of accurate extinction-risk tracking to record the *infraspecific identity* (if relevant) of any host species of *A. psidii*, and to maintain host lists down to that level of resolution. Clarity as to host taxon identity, down to the lowest possible level of taxonomic resolution, also assists the identification of anomalies in infection records, informs priorities for comparative susceptibility screening to identify potential disease-resistance syndromes, and aids closer resolution of the proportional and spatial nature of impacts. The practice in some research projects of subsuming subspecies identities under bare parent species names (e.g. in host lists or spatial analyses) represents a loss of information with directly negative effects on the conservation effort and for resistance breeding efforts in commercial areas.

Differing estimates of the number of native Australian Myrtaceae taxa have been published in recent literature relating to Myrtle Rust. One estimate of 1,646 species (https://www.anbg.gov.au/aust-veg/australian-flora-statistics.html, originally published in 1992), was often cited in Myrtle Rust literature of the 2010-13 period (and even as late as 2017), but is dangerously obsolete, being based on source material dating from the 1980s and early 1990s before comprehensive information assembly and much recent taxonomic work.

An estimate of about 2253 native species in 88 genera, reflecting a much more complete data set, was published in NSW Scientific Committee (2011), those figures provided from the *Australian Plant Census* at the Australian National Herbarium, Canberra in August 2010. This improved estimate has been used in most of the more recent Myrtle Rust literature (2011—2018).

The *Australian Plant Census* (APC - https://www.anbg.gov.au/chah/apc/) tracks and documents the names (whether fully published or pre-publication 'phrase names') of scientifically recognised native and naturalised plant taxa occurring in Australia, based on published scientific literature and on the views of the State, Territory and Commonwealth herbaria. The recognition of new species and the generic re-assignment of some known species are ongoing processes as knowledge improves. Different scientific authors and institutions may have different views on generic assignment of species, or on whether some taxa should be ranked as species or subspecies. Only comparatively rarely is there disagreement on the biological reality of the named entities as such. The APC is a national 'consensus census' presenting a consolidated list of valid names, without implying a taxonomic judgement as to which of any competing synonyms may be more taxonomically correct for species where there is taxonomic disagreement – but it does provide a basis for a single national name set. For reasons discussed below (Section 3.3, under '*Host name standardisation*'), the 'lead names' used in the *Australian Plant Census* are preferred in this review, and for the revised

Australian host list at Appendix 3. For its Myrtaceae content, the APC is understood to be fully up to date with current State and Territory herbarium censuses and with published taxonomic and nomenclatural literature.

Very recent figures from the APC (A. Monro, Centre for Australian National Biodiversity Research, *in litt*. 17 Nov. 2017) indicate revised estimates for native Myrtaceae, excluding hybrids, of 87 accepted genera containing 2503 taxa ('simple' species, plus constituent subspecies and varieties of 'complex' species). These new figures are still subject to some further checking and are not used as the basis for statistics presented here, but would not greatly affect current statistics in relation to Myrtle Rust. For example, the proportion of Australian native Myrtaceae which are already known hosts of *A. psidii* would drop from 15% to 14%. Given the rate of increase in the host list, the discrepancy is not great, but a revised definitive number for natural Myrtaceae taxa in Australia will be useful.

Predictive maps of areas of climatic suitability for *A. psidii* in Australia vary considerably, but at least half of Australia's native Myrtaceae (i.e. roughly 1100--1200 taxa) occur in areas identified as climatically suitable for naturalisation of the pathogen (Berthon et al. 2018). From a conservation point of view, two regions bear a particular risk of large-scale biodiversity impact, through having proven or potentially suitable climate and the greatest diversity of myrtaceous species. These are the east coast, and the far south-west of Western Australia (this is not to discount the risk to species in less diverse areas also suitable for rust establishment and persistence). Exhaustive comparison of distributions, based on reliable estimates of host species range and habitat, are lacking, but it is likely that around 700 species are already exposed over part or all of their range on the Australian east coast (NSW and Queensland). Western Australia, which is not yet exposed to Myrtle Rust, has 1568 native Myrtaceae species, of which 1043 are concentrated in just five of the most south-westerly south-west IBRA Bioregions, the general area of WA considered most likely for *A. psidii* naturalisation under most predictive models (flora statistics courtesy K. Thiele, WA Herbarium, May 2013).

1.3 *Austropuccinia psidii* – Nomenclature and identity:

Key Points

- The changes in scientific name applied to the pathogen in Australia since 2010 (*Uredo rangelii* > *Puccinia psidii* > *Austropuccinia psidii*) do not invalidate management guidance literature (although this may also be outdated in some other respects).
- Taxonomic confusion as to the identity of the pathogen hindered some aspects of the initial 2010 response, and illustrates the need for pro-active pre-arrival international research on priority environmental pathogens, especially the development of DNA libraries.

Precision of scientific description, naming, and classification are essential throughout biology, and for correct diagnosis and effective management of pathogenic organisms. As these aspects of *Austropuccinia psidii* have undergone some evolution, and in Australia a brief period (2010-11) of uncertainty of identification, a summary is in order.

The order of Basidiomycete fungi referred to in this review as Pucciniales (Rusts), is also termed Uredinales in some older literature. For the purposes of this review they are treated as synonymous. The systematic placement of *Austropuccinia psidii* within this order is not in question.

Common names

The common name 'Myrtle Rust' was coined in Australia in 2010 to apply to disease caused by the newly arrived pathogen, now recognised by the scientific name *Austropuccinia psidii* (G. Winter) Beenken, and formerly (until 2017) *Puccinia psidii* G. Winter. The name 'Myrtle Rust' was applied by the Australian incursion response team, in part because of initial uncertainty in some quarters as to whether the newly arrived pathogen was or was not the same species as *Puccinia psidii*, various strains of which had long been known to cause diseases known overseas as 'Eucalyptus Rust' and 'Guava Rust' to reflect conspicuous host plant genera. The initial uncertainty in Australia was mainly taxonomic, but It seems likely that considerations of international trade and 'public relations' also lent some weight to a decision not to explicitly identify the incursion with the well-known threat represented by 'Eucalyptus Rust'. The choice of 'Myrtle' reflects the unusually broad host range of the pathogen, reaching right across the genera of the plant family Myrtaceae, various of which are sometimes known by the vernacular name 'myrtles'.

The taxonomic uncertainty as to the pathogen's identity as *Austropuccinia psidii* was resolved within two years, and that scientific name is now uniformly applied to it. The disease name 'Myrtle Rust' has become entrenched in Australian and in international usage -- it has for example been taken up in New Zealand. The same strain of this pathogen has been established in Hawaii since 2005, and is there known as 'Ōhi'a Rust, after one of the native plant species it infects there.

Myrtle Rust disease is not to be confused with Myrtle Wilt, a fungal but non-rust disease of the Australian native tree Myrtle Beech (*Nothofagus cunninghamii*, family Fagaceae) which is of some concern in Victoria and Tasmania. Myrtle Wilt is caused by the pathogenic fungus *Chalara australis*, which is considered indigenous to Australia (DSE Victoria, 2005).

Scientific name and classification

The Myrtle Rust pathogen, formerly known as *Puccinia psidii*, as of early 2017 has been assigned to a new genus as *Austropuccinia psidii* (G. Winter) Beenken, and placed in the family Sphaerophragmiaceae (Beenken 2017), which in turn belongs to the Order Pucciniales encompassing all fungi of the 'rust' type. Molecular characteristics and a morphological description of the species, new genus, and re-defined family are in Beenken (2017); a morphological description of the sole strain currently present in Australia, with illustrations of the two known spore types and the most conspicuous form of sporulating infection, is in Pegg et al. (2014a). Whole genome sequence data is at *DDBJ/EMBL/GenBank* under the accession LKHF000 00000 (Sandhu et al. 2016; see also Tan et al. 2014). On-line keys for the identification of Australian Rust and Smut fungi are available at http://collections.daff.qld.gov.au (see also Shivas et al. 2014)

The pathogen was first described, under the name *Puccinia psidii*, by G. Winter (1884) from Brazilian guava plants (*Psidium guajava*). It was first reported on a non-native eucalypt species of Australian origin (*Eucalyptus citriodora* – now *Corymbia citriodora*), in Brazil by Joffily (1944). It was long assigned, as the name indicates, to the genus *Puccinia* (pron. 'puckSINia'), one of the larger groups (genera) in the large rust family known as Pucciniaceae. The genus *Puccinia* contains many pathogenic as well as non-pathogenic rusts.

Until very recent decades, the taxonomic identity, classification and identification of pathogenic fungi has been through the combined use of morphology, symptomology, and pathotype. *Morphology* refers to the characteristic form, size, etc. of various life stages of the pathogen, especially spores. *Symptomology* refers to the visual manifestations of disease and its pattern of progress on the host plant. *Pathotype* is a loose term encompassing and defined by the range of plant hosts which the pathogen is capable of infecting and a known (or inferred) distinct genetic identity. Some of the limiting factors in this traditional taxonomic approach have been:

- incomplete genetic information;
- the great difference between life stages that may be exhibited by a single species of rust (much as a butterfly, its caterpillar, and its egg differ, despite being all the same organism);
- the difficulty in culturing (growing) some rusts in the laboratory to trace the changing life stages;
- the fact that some rusts spend different life stages on different hosts, sometimes without symptoms and not easily detected; and
- a simple lack of resourced field survey, except where economically important plant hosts are concerned.

The advent of increasingly rapid and inexpensive molecular techniques (e.g. DNA sampling and sequencing) since the mid-1990s has greatly enhanced and in some respects overtaken the traditional taxonomic approach. These techniques have radically improved the speed and accuracy of taxonomy, classification, and identification of samples, because DNA does not vary between life stages, and can be analysed readily from field samples if a broad reference set exists.

In the first decade of the 2000s, phylogenetic analyses based on DNA analysis (e.g. van der Merwe et al., 2007) had begun to show that the traditional classification of *Puccinia* was inadequate. Subsequently, studies by van der Merwe et al. (2008), Carnegie et al. (2010b), Liew et al. (2012? Unpublished); Tan et al. (2014) and Pegg et al. (2014a) all added evidence that the correct placement of the Myrtle Rust pathogen, *Puccinia psidii*, was not in the genus *Puccinia* and indeed not even within the family Puccinaceae. These results contributed to the reclassification and re-naming of *P. psidii* in a new genus, as *Austropuccinia psidii*, within a redefined family Sphaerophragmiaceae, by Beenken (2017). Note that the *austro*- (‘*southern*’) element of the genus name does not refer to Australia – it denotes ‘southern’, for “the South American origin of the *Puccinia*-like genus” (Beenken 2017). The reclassification is in general robust, the new name is being taken up globally, and the assignment of *P. psidii* to the new genus is unlikely to be subject to further change. Two peripheral caveats apply: the circumscription of the family may be subject to further refinement, and the possibility of re-ranking of some strains (variants) within *Austropuccinia psidii* to species level in the future is not out of the question. The main point is that the reclassification reflects the unique nature of *A. psidii* as the only species in the Pucciniales rust order known to have such a broad host range and a somewhat distinctive biology in other respects.

Prior to the arrival of the pathogen now known as *Austropuccinia psidii* in Australia in 2010, risk appraisal studies had all used the then-accepted name of *Puccinia psidii* (e.g. OCPPO 2007, Plant Health Australia 2009, although both noted names in *Uredo* as anamorphs). When Myrtle Rust was first detected in Australia (April 2010), the biosecurity response apparatus made the decision to apply the scientific name *Uredo rangelii. U. rangelii* is a taxon that Simpson et al. (2006) described on traditional morphological grounds as an uredinial anamorph (asexual life stage) related to but not necessarily identical to *P. psidii.* A peculiarity of fungal nomenclature is that different life stages of the same organism can bear different species names.

The implication, certainly in public and bureaucratic understanding, was that this was somehow distinct from *Puccinia psidii* (which was known to encompass several poorly understood pathotypes), and that the incursion organism might have a distinct biology and host range. Much of the scientific and biosecurity literature, and extension materials, dating from the period 2010-12 and relating to the Australian incursion, use the name *Uredo rangelii*. Later research (see below) has shown that the main morphological grounds for the distinction of *U. rangelli* from *Puccinia* (now *Austropuccinia*) *psidii* do not hold, and there is a strong scientific consensus, reflected in nearly all literature since 2012, to apply the latter names and discontinue the use of *Uredo rangelii* for the pathogen. The uncertainty was unfortunate from a communications point of view and certainly contributed to confusion among stakeholders. Along with other problems in the response, this probably contributed to lost opportunities in terms of public awareness and response resourcing (Cannon 2011; Invasive Species Council 2017). Subsequent clarifying research in Australia and overseas has resulted in a substantial step forward in understanding the pathogen. However this case indicates the need for a more pro-active resourcing of pre-arrival and internationally collaborative investigation into priority environmental pathogens, including the development of comprehensive DNA libraries.

From a practical point of view, scientific and extension literature from 2010-12, while now often dated in some respects (e.g. host range, distribution), is not invalidated simply because of the use of the name *Uredo rangelii* for the pathogen at that time – these materials remain broadly valid and relevant for understanding Myrtle Rust. Some management-related and educational materials with a continuing life (i.e. other than as references) retain the discarded name, and should be updated.

The recent and belated evolution of taxonomic understanding of the Myrtle Rust pathogen illustrates the potential for rapid advances in fungal taxonomy using molecular techniques. This highlights the need for intensive pre-arrival scientific investigation of potential high-priority environmental pathogens to reliably inform quarantine, response, management, and communications strategies.

1.4 The multiple strains of *Austropuccinia psidii*:

"Understanding the genetic diversity of Austropuccinia psidii is critical for understanding host associations, potential pathways of spread, and climatic requirements, all of which facilitate the development of management strategies." (Stewart et al., 2017).

Key points

- Introduction of any further strains of *A. psidii* to Australia or the western Pacific region, especially the eucalypt-associated strains, would represent a major escalation of environmental, economic, and cultural threat.
- Understanding and global sampling of genetic and reproductive variation in *A. psidii* has advanced but remains inadequate – active Australian promotion of international collaborative research is in Australia's interest.

Australia currently has one strain of *A. psidii*, known as the 'pandemic' strain or biotype because of its rapid and wide spread across the Pacific basin. Other strains, long known to exist from pathotype diagnosis, have recently been characterised at a genetic level, although global sampling remains incomplete. At least two of the genetically characterised strains are strongly associated with plantation eucalypts in South America, where they have caused significant economic losses (Coutinho et al. 1998; Furtado & Marino 2003; Tommerup 2003; Carnegie 2012; Cannon 2011 [citing Takahasi 2002]).

Introduction of any further strains of *Austropuccinia psidii* to the western Pacific and Australian region would represent an escalation of the threat to native biodiversity and associated economic and cultural values (Cannon 2011; Stewart et al. 2017; Berthon et al. 2018; Carnegie & Pegg in press, 2018). Current biosecurity regimes within the Pacific basin have shown a very limited ability to greatly retard the rapid spread of the 'pandemic' strain, despite some pre-incursion interdictions (Grgurinovic et al. 2006; Loope 2010), and the detection of other strains will be hindered by their being symptomatically identical to the established strain. In the absence of a standing program of genetic sampling, the first signal of a new-strain incursion may be only well after naturalisation and in the form of a change in symptomology on existing hosts, an expansion of host range, and/or an expansion of environmental range.

The existence of different strains or variants of *Puccinia psidii*, initially defined by pathotype/host range, had been inferred for some decades (MacLachlan 1938; Marlatt & Kimbrough 1979; Rayacchetry et al. 2001; Ferreira 1983; Coelho et al. 2001; Aparecido et al. 2003; Graça 2011; Graça et al. 2011; Quecine et al. 2014). The diagnosis and distribution of these variants was however uncertain, and in some literature this is reflected in the use of '*Puccinia psidii sens. lat*.' (abbreviated from *sensu lato*, 'in the broad sense'), to designate the whole assemblage of variants regarded as falling into this species.

A better resolution of the global genetic variation within *A. psidii* has been achieved only very recently. Stewart et al. (2017) used DNA microsatellite markers to delimit several unique multilocus genotypes (MLGs), which grouped their samples into nine distinct genetic clusters, each with variable degrees of internal genetic variation:

- C1: from diverse hosts from Costa Rica, Jamaica, Mexico, Puerto Rico, USA-Hawaii, and USA-California;
- C2: from eucalypts (*Eucalyptus* spp.) in Brazil/Uruguay and rose apple (*Syzygium jambos*) in Brazil;
- C3: from eucalypts in Brazil;
- C4: from diverse hosts in USA-Florida;
- C5: from Java plum (*Syzygium cumini*) in Brazil;
- C6: from guava (*Psidium guajava*) and Brazilian guava (*P. guineense*) in Brazil;
- C7: from pitanga (*Eugenia uniflora*) in Brazil;
- C8: from allspice (*Pimenta dioica*) in Jamaica and sweet flower (*Myrrhinium atropurpureum*) in Uruguay; and
- C9: from jabuticaba (*Myrciaria cauliflora*) in Brazil].

The strain present in South Africa does not correspond to any of these nine; its potential future spatial and host ranges are uncertain.

Australian-origin samples were not included in the Stewart et al. study, but separate work (Machado et al. 2015; Sandhu et al. 2016;) has indicated that the single C1 genotype present in Hawaii is identical to the single genotype present in Australia, notwithstanding minor mutations. The Indonesian and Australian genotypes are identical (McTaggart, Roux et al. 2016). The Japanese genotype (by ITS sequence) is highly concordant with that of Florida and Hawaii specimens. Stewart et al. (2017) accept the Hawaiian sampling (all clustered in C1) as a surrogate for the Australian strain, and conclude that the C1/C4 genotype is also present, as determined in other comparative studies, in China-Hainan since at least 2009 (Zhuang and Wei 2011), New Caledonia since 2013 (Giblin 2013; Soewarto et al. 2017), Indonesia (McTaggart, Roux, et al. 2016), and Colombia (Granados et al. 2017).

The C1 cluster, and the closely related (but slightly more genetically diverse) C4 cluster from USA-Florida, together constitute what has been tagged by several recent researchers as the *pandemic strain*, and by Stewart et al. (2017) as a *pandemic biotype* "associated with myrtle rust emergence in Central America, the Caribbean, USA-Florida, USA-Hawaii, Australia, China-Hainan, New Caledonia, Indonesia, and Colombia." The choice of the adjective 'pandemic' for this strain (definition: of a disease, occurring over a wide region or worldwide) reflects the *status quo*, but at least some of the other strains or biotypes may have similar potential to spread over wide regions. The C2 and C3 strains, discussed below, are key cases in point at least for the Australian region. In view of the paucity of myrtaceous rusts in the Indo-Pacific region (Walker 1983), and therefore a high degree of myrtaceous flora naivety to this class of pathogen, the advent of *any* further strains or species of exotic rusts pathogenic on Myrtaceae would be a significant potential threat to Australian species. The advent of any further strains of *A. psidii*, the rust with far the broadest host range known, would be acutely dangerous, regardless of the fact that one strain is already naturalised.

The threat from new incursions of *A. psidii* to Australia also relates to the potential for increased levels of sexual reproduction of the pathogen, giving it an even greater potential for adaptation to its new environment and hosts. The pandemic strain is thought to be largely and possibly totally clonal (asexually reproducing), a process which allows evolution by mutation, but not by the more powerful sexual system of chromosomal recombination. The presence of multiple genotypes in Australia, of whatever strains, could mean an increased risk of establishment of sexually reproducing genotypes.

The evolutionary origins, locales, and date of differentiation of strains, each with different host preferences and pathologies, remain uncertain and debated. In particular, the mode and location of origin of the 'pandemic' strain currently affecting Australia, and of those affecting eucalypts in South America, are moot. While it is possible that some strains have arisen recently and outside the region of common origin (i.e. after dispersal of basal lineages, and by genetic change and 'host-jump' on cultivated/introduced, or native and naïve plant species), others may have a more ancient origin within the South American biome (Graça 2013; Stewart et al. 2017; Tobias et al. 2016). Clarification depends in part on unresolved aspects of the mutational steps that resulted in strain differentiation.

The immediate source of the 'pandemic' C1/C4 biotype, prior to its dispersal around the western Pacific rim, remains undetermined, although dispersal from California to Hawaii by human agency (commercial cut foliage) immediately prior to 2005 seems probable (Loope 2010). The 'pandemic' strain has only very recently been detected in South America (Granados et al. 2017), in Colombia, but that may be a secondary introduction and may not represent its point of origin. Stewart et al. (2017) speculate that the pandemic strain may have arisen from the C5 genotype, detected in their sampling only on the non-native *Syzygium cumini* growing in Brazil but widely grown in the Americas and Indo-Pacific, and native to India, South-east Asia and Malesia.

The lack of decisive evidence for the origin of the eucalypt-associated C2 and C3 strains led Graça *et al*. (2013: 6044) to go so far as to hypothesise (but not favour) a "remaining possibility … [that] *P. psidii* infections of native eucalypts in remote areas of Australasia have gone undetected to date. If sites exist where eucalypts and *P. psidii* have co-evolved, cryptic rust disease could easily go undetected until suitable environmental conditions and susceptible germplasm were available that allowed significant epidemiological spread."

This hypothesis is constructed solely on the basis of the degree of genetic variability exhibited by the eucalypt-associated strains in South America and their unknown origin. It would have required serial importations of the eucalypt-associated strain to South America from Australia, a series of successful naturalisation events there, and assumes a past and continuing lack of detection of these strains within Australia that, in the light of the aggressive nature of these strains on plantation eucalypts in South America, and other species here only since 2010, seems highly implausible. It is also fundamentally inconsistent with the centre of genetic diversity of *A. psidii* lying clearly within the Americas, and the lack of diversity within the Australian population of the pathogen. Graça *et al*. (2013) may be right that the evidence to date does not allow this hypothesis to be logically ruled out, but it is strongly contraindicated by the available evidence. From the point of view of Australian biosecurity and biodiversity conservation the only prudent course is to assume and act on a diametrically opposite assumption – i.e. that the eucalypt-associated strain/s are exotic to Australia and are a dire threat.

1.5 The biology and ecology of the Myrtle Rust pathogen

Key points

- Improved knowledge is needed of the life cycle and infective process (host/pathogen interactions at the spore germination and penetration phase), and host resistance mechanisms.
- Close monitoring, through structured recurrent sampling, is needed to detect both new-genotype arrival(s) and adaptive change within the pandemic strain that is currently in Australia.
- Wind-dispersal capability and easily human-mediated transmission necessitate an internationally coordinated biosecurity approach, to exclude further variants of *A. psidii* from the entire western Pacific region.
- Strong domestic biosecurity provisions should be maintained indefinitely to prevent the spread of Myrtle Rust to South Australia and Western Australia.

'Rusts' are plant diseases caused by a certain class of fungal pathogens (basidiomycete fungi of the order Pucciniales, in older literature known as the order Uredinales). About 7800 species of rust-causing fungi are known. Some are pathogens on important crop species (e.g. cereals) and forestry trees. Rusts are sometimes confused with 'smuts' which are diseases caused by a separate class of fungi.

Austropuccinia psidii is a *biotrophic* pathogen, i.e. it parasites and draws resources from living (not dead) plant tissue. It is highly unusual among rusts in having a very broad host range (over 450 species globally), and in some other aspects of its life cycle.

Until recently, much what we know about the biology, ecology, and climatic correlates of *Austropuccinia psidii* came from overseas studies (Central/South America, USA including Hawaii, and Japan), much of it derived from strains of the pathogen of undetermined genotype. Since about 2014, the accrual of knowledge specific to Australia and the 'pandemic strain' has been significant.

1.5.1 Life cycle

Knowledge of the details of the life cycle is essential for management and the accurate prediction of disease behaviour. This includes the stages of the life cycle that are actually used, and their relative frequency. The sexual part of the rust life cycle involves DNA recombination that increases the adaptive potential of the pathogen. Knowledge of the absence, or presence and frequency, of sexual reproduction, is essential to estimating the likelihood of new variants arising and of possible co-evolution trajectories of host and pathogen. Knowledge of genotypic variants (strains) and their varying manifestation on particular suites of hosts is essential for biosecurity and for estimating future impact risk. Even asexually reproducing (clonal) rusts can evolve to some degree through mutation (confirmed by Machado *et al*. 2015, to be occurring, although not necessarily persisting, since 2010 in the Australian 'pandemic strain'). This can, especially when combined with host jumps (McTaggart, Shivas, et al. 2016), also lead to evolutionarily new strains and pathotypes.

Rust life cycles can be complex. Some have up to five spore types with intervening growth stages (such rusts are termed *macrocyclic*), variously involving reproductive modes that can be shorthanded as 'sexual' and 'asexual', and often requiring two different and unrelated plant hosts at certain of these stages (the rust is then *heteroecious*).

Other rusts, including *Austropuccinia psidii*, have a simpler life cycle with fewer stages, or some stages present but not or not necessarily functional (Yamaoka 2014, and see a much-cited diagram of the life cycle options in Glen et al. 2007). Some can reproduce indefinitely on a single plant host species (these are *autoecious*) – *A. psidii* is one such.

The 'pandemic strain' of *Austropuccinia psidii* present in Australia is now known to be capable of indefinite asexual reproduction by one spore type (*urediniospores*), on many species of Myrtaceae, although not requiring more than one. It can thus be regarded as *hemicyclic* (or *demicyclic*), and at least functionally autoecious. The possibility of *A. psidii* as a whole being partially or ancestrally heteroecious, i.e. having an alternate spermogonial/aecial host in its region of origin in South America (either in the past or as a non-essential stage in the present day), was raised by Simpson *et al*. (2006), and is not altogether discounted by subsequent workers.

The 'pandemic strain' present in Australia is also known to produce *teliospores* and *basidiospores* (two consecutive stages of the sexual, recombinant part of the life cycle). However, a life-cycle study of that strain by Morin *et al*. (2014), while able to induce *in vitro* (lab) germination of the basidiospores, did not find them able to infect a host. While a single study may not be conclusive, the non-functionality of the basidiospore life stage in that study, and the absence of any contrary evidence, suggests that the Australian strain is clonal, or at least predominantly so. This conclusion is supported by Machado et al. (2015) on the basis of a low level of genetic diversity in microsatellites of samples assignable to the pandemic strain from Australia, China and New Caledonia. Machado et al. (2015) did find a low frequency of mutation in their study, but essentially random and not indicating any host-driven selection pressure. A caveat is that the Australian samples for the study were taken fairly early in the Australian outbreak (2012), and ongoing sampling and assessment of variation is needed.

Sexually recombinant reproduction of the pandemic strain of *A. psidii*, at a low frequency, cannot however be excluded, and its potential to drive adaptive evolution of the strain in Australia, and for genetic exchange through outcrossing with other strains if they are introduced to the Asia-Pacific region, is a significant dimension of risk for the future.

Clonality however appears to be a predominant pattern across *A. psidii* strains. Graça et al. (2013) comment that "Populations of *P. psidii* sampled from all hosts exhibited highly clonal structures as evidenced by the overrepresentation of multilocus genotypes, highly negative fixation indices, and lack of reticulation throughout most of the minimum-spanning network. Such results are hallmarks of asexually reproducing populations … and suggest a lack of regular meioses in the life cycle of *P. psidii*." However, clonality in *A. psidii* is not universal. Very recent work by McTaggart *et al*. (2017) on the South African strain, thought to have recently arrived there (Roux et al. 2013) but not yet known elsewhere, has confirmed both recombination and subsequent infection of a host by the sexual basidiospores of that strain in a laboratory study. The potential global host range of the South African strain remains unevaluated. This reinforces the need for continued measures to prevent or minimise the spread of strains internationally by any means practicable.

Additionally, and of particular concern for Australian and regional biosecurity, Graça et al. (2013: 6043) also discuss the likelihood of recombination occurring in the eucalypt-associated population in South America:

"The minimum spanning network revealed six loops in the eucalypt associated population that could be explained by recombination or by parallel mutations. Under an infinite alleles model, parallel mutations are considered highly unlikely and recombination is the favoured hypothesis to explain the occurrence of 4 different haplotypes at 2 loci (Hudson & Kaplan 1985). As the probability of parallel and/or back mutations may be significantly greater for microsatellites

compared with other types of markers, it is possible that the loops we observed in the minimum-spanning network were caused by parallel mutations rather than by recombination.
Further study of the mating system of *P. psidii* that includes the application of alternative marker systems such as SNPs may allow this hypothesis to be tested."

The potential for adaptive evolution is exacerbated by the breadth of the host range. Host diversity has been shown to be a strong driving force for evolution of the pathogen in South America (Graça et al. 2013; Machado et al. 2015). There is no evidence to date that this is occurring in Australia, but the sheer breadth of the Australian host range, with many host species co-occurring and with varying biologies, physiologies, and phenologies, provides a potentially very strong selective environment. The production of basidiospores and teliospores by the pandemic strain, even though these are not yet known to complete a recombinant life cycle, increases the latent potential.

A standing program of re-sampling and testing for genetic variation in *A. psidii* in Australia, and in the wider south-west Pacific region, is an essential part of an ongoing monitoring regime. Such a program should be designed to detect within-strain genetic change, and to contribute to biosecurity measures to detect the arrival of strains new to the region, as these may not be easily detected on host-range or symptomatic grounds alone.

For biodiversity conservation, the essential points from the current knowledge of strains and life cycle in *A. psidii* are:

- The pandemic strain appears to be largely or wholly clonal, resulting in a more limited likelihood of adaptive evolution in the near future than would otherwise be the case;
- Low-level mutations, known to be occurring in the pandemic strain, nevertheless give it some adaptive potential;
- The known occurrence of sexual recombination (and hence greater adaptive potential) in the South African strain, and its suspected occurrence in the aggressively eucalypt-associated variants in South America, provide an extra level of imperative for the exclusion of those variants from the western Pacific region (not just Australia).

1.5.2 Recognition in the field

The most common and conspicuous spore type is the asexual *uredioniospores*, produced in infection bodies called *urediniosori* which manifest at maturity as erupting pinhead-sized pustules on the host-plant surface. If the infection is dense, the pustules and spore masses may aggregate into a much larger almost continuous powdery yellow mass. The uredinial spore masses are typically yellow in colour, or less commonly a pale orange. This is the clearest manifestation of the Myrtle Rust disease and the most easily identified life stage of *A. psidii* for the non-expert, given that no other diseases of Myrtaceae in Australia exhibit similar pustules. Field monitoring by non-specialists will usually depend on the presence of these yellow pustules for high-confidence recording of Myrtle Rust occurrence.

FIGURE 6: Active Myrtle Rust on *Syzygium bamagense*, Iron Range, North Queensland, October 2014. (Jonathan Roth, Queensland Department of Environment and Science).

FIGURE 7: Myrtle Rust infection on *Melaleuca nodosa*, near Casino NSW, February 2011. (P. Entwistle).

After an infection peak and when spore masses are dispersed or washed off, residual evidence of infection may be present in the form of abnormal defoliation, dead or distorted young branchlets, or brown lesions on surviving leaves (see, e.g. Carnegie & Cooper 2011, Fig. 4; Pegg *et al*. 2014a, Fig. 1). 'Witches Broom' clusters of dead shoots are not uncommon, and rarely (e.g. *Melaleuca nodosa*) small nodules on deformed stems (G. Pegg, pers. comm.). However, in the absence of residual sporulating pustules, post-infection effects can be hard to attribute unequivocally to Myrtle Rust.

FIGURE 8: Dead new-growth branchlets and foliage on *Melaleuca quinquenervia*, NSW North Coast, July 2011. (A.J. Carnegie, NSW DPI).

The sexual-stage *teliospores* are produced in brownish or greyish teliosori, which are much less conspicuous and much less frequent, and harder to recognise by the non-expert. Teliospores are probably less mobile than urediniospores. Teliospores do however represent a recombinant stage of the life cycle, and to the degree that this part of the life cycle does progress successfully (via the succeeding basidiospore stage), there is a greater possibility of adaptive evolutionary change by the rust.

1.5.3 Spore dispersal and spore longevity

Spore longevity has only been closely studied under artificial conditions and for urediniospores. It is generally cited (often following Glen *et al.* 2007) as 90 days at 15^{o}C and 35-55% rH for reduction to "low levels of viability", but varies with ambient conditions. Lower longevity occurs at temperatures over 30^{o}C. Salustiano *et al*. (2008) report the survival levels of spores under various storage conditions, noting that spores in deep-freeze and liquid nitrogen storage maintained significant levels of viability at 150 days. For risk management purposes of a high impact pathogen, "low viability" does not equate to zero viability, and a withholding period of at least 120 days would seem more prudent for material under ambient conditions (and assuming no possibility of additive spore load).

Lana *et al*. (2012: 1) estimated that timber and pulp production facilities were likely to receive spores in "very low numbers" and that "the adverse environmental conditions encountered in these areas and during overseas transport do not favour spore survival. Thus, the risk of spread of this pathogen into new areas in the absence of infected host plants is considered extremely low to inexistent." This finding is inconsistent with, and *prima facie* disproven by, the report of Grgurinovic *et al.* (2006) of viable spores being detected on containers and a wood shipment to Australia from South America. Lana et al.'s estimation of this risk is not a safe basis for biosecurity precautions.

A recent apparent easing of conditions for imports of unfinished timber to Australia may have been based in part on the Lana et al. (2012) estimation of risk (Commonwealth Department of Agriculture and Water Resources, Australian Biosecurity Import Conditions website, (https://bicon.agriculture.gov.au/BiconWeb4.0/ImportConditions/Search/, accessed 03 June 2018). The conditions of import require decontamination of untreated Myrtaceae timber by specified means, and "treatment must be performed within 90 days of the date of export". In certain pre-export environments, 90 days would be plenty of time for the reacquisition of a spore load, which in any case could travel on untreated timber of any species (not just Myrtaceae). The degree of risk to environmental biosecurity relates of course to unpredictable post-arrival movement of goods (the spores have to come into eventual contact with suitable host tissue). The logic from an environmental point of view is not immediately evident.

Further study of longevity is required to enable general and specific risk assessments, including for seed-banks handling potentially contaminated seed-lots. Long-distance transmission to new areas via spore loads on human clothing and equipment (e.g. hats, rucksacks, tents) is distinctly possible (Tommerup *et al.* 2003) and may well be one mode of international and intercontinental dispersal. Studies on spore longevity under wild field conditions (once spores have dispersed and settled on bark, soil or leaf-litter where predation and degradation processes may occur) are lacking, but there seems to be a general consensus that longevity in these situations will be less – perhaps much less – than 100 days. in In any case, viable spores in this situation would need to relocate to suitable plant tissue (via re-entry to the air column) in order to germinate and establish, and it is likely that this is a low frequency event relative to primary aerial or animal/human dispersal and settlement directly on a host. It does however present a potential transmission risk if infected plant material incorporating ground litter is transported and used as mulch within a short time period, especially if delivered to the recipient site is a manner (e.g. via a blower system) that reinjects still-viable spores into the air column.

Teliospore longevity and durability are undetermined. The extension literature issued within Australia does not differentiate between spore types, suggesting a default assumption by the lead response agencies for Myrtle Rust is that it is similar to that of urediniospores, i.e. about 90 days to reach very low levels of viability. However, the teliospores are thicker-walled than the urediniospores, which may mean capacity for longer survival (G. Pegg, pers. comm. May 2018).

Dispersal of spores occurs by natural vectors (wind and animal), and by human activities. The uredinial spores are produced in large numbers, are lightweight and very mobile, being dispersed by wind, animals, people, and on plant material. On susceptible species, level of spore production may be astronomical – reports from Hawaii in the years immediately after *A. psidii* introduction refer to 'carpets of yellow' under infected plants, and in Australia field reports quite often include descriptions of heavily infected plants 'glowing gold', and less frequently refer to 'yellow clouds' of dispersing spores. Reports from the general public in Australia have shown vehicles parked under infected *Syzygium jambos* street trees to be covered in a layer of yellow dust (G. Pegg, pers. comm., May 2018).

FIGURE 9: Yellow *A. psidii* spores following a casual brush with an infected street tree of *Syzygium jambos*, Redlands Qld, September 2012 (R.O. Makinson).

The Myrtle Rust pathogen produces many thousands of highly mobile spores capable of wind dispersal, but human-vectored movement of spores is thought to be a major factor in long-distance dispersal. Human transmission of spores is a high risk for parts of Australia not yet invaded by *A. psidii*, and for the introduction of further strains from overseas. Ordinary laundering with household detergent will kill spores on clothing, but don't forget hats, tents, and tarpaulins. See guidance sheets at http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/shrubs-and-trees/myrtle-rust and http://www.environment.gov.au/system/files/resources/773abcad-39a8-469f-8d97-23e359576db6/files/arrive-clean-leave-clean.pdf

Confirmation of animal dispersal of *A. psidii* spores is largely lacking, although it is likely to the point of certainty. In the case of flying foxes and some birds, the potential dispersal distances may be large. Foraging ranges in a single night of 50 km are known for one common species of flying fox (DECCW NSW 2009), and regional migrations and longer distance individual movements are known. Tidemann & Nelson (2004) tracked two individual Grey-headed Flying Fox (*Pteropus poliocephalus*): bat L268, tagged in far north-eastern NSW, travelled south to the Hunter Valley region, where it utilised no fewer than 13 day-camps during an extended stay; with nightly foraging distances factored in, it effectively quartered the lower Hunter region, as well as transiting the entire NSW North Coast. Bat M681, tagged in Melbourne, travelled the coastal route to Sydney and back. Roberts et al. (2012) tracked 14 adult males of the same species for a mean of 25 weeks: "Collectively, these individuals utilised 77 roost sites in an area spanning 1,075 km by 128 km … Five individuals travelled cumulative distances >1,000 km over the study period. Five individuals showed net displacements >300 km during one month, including one movement of 500 km within 48 hours." J. Martin (unpublished data, *in litt*. 29 Feb. 2018) reports, for the same species, a longest single-night movement of c. 300km, and a maximum movement of ~1500km within one month". Roberts et al. (2012) state that "Detailed information on the movements of other Australian flying-fox species is limited, although there are reports of net movements of 486 km in 90 weeks for *P. scapulatus* [46] and 249 km in 49 weeks for *P. alecto*." All flying foxes are avid groomers, but also messy feeders; they are also very attuned to detecting even small local patches of vegetation presenting a preferred food, and when resources are locally poor they will travel long distances and search thoroughly. The likelihood of their being a significant vector for *A. psidii* spores seems inescapable. Myrtaceae nectar and pollen, especially of eucalypts and *Melaleuca*, and the fruits of some other genera, are a major part of their diet (Markus & Hall 2004). They are perhaps the most likely natural dispersal vector over long distances across monsoonal northern Australia, if the Myrtle Rust pathogen proves capable of permanent establishment there.

At a local scale, movement of spores by birds, arboreal marsupials, and some invertebrates is likely to be a common cause of movement of spores between myrtaceous plants. Visitation and apparent collection of the yellow spores of *A. psidii*, is recorded for introduced honey bees (*Apis mellifera*) (G. Pegg, pers. comm.) and at least one species of native bee (J. Lidbetter pers. comm.).

Release of the yellow uredinial spores from the mature pustule's spore mass may be by wind or other mechanical disturbance, including by rain splash. Rain-splash alone would result in only very local dispersal of spores, but may nevertheless play a role in inoculum load and disease development in the immediate vicinity (G. Pegg, pers. comm. May 2018). For effective dispersal of uredinial spores over appreciable distances, dry and preferably windy conditions are optimal (contrasting with the humidity, at least at night-time, needed for spore germination). The potential distance of effective wind dispersal is undetermined, but is potentially large. Savage et al. (2012) demonstrate, by modelling, the influence and interactions of seasonal and diurnal timing of spore release on the probability of long-distance dispersal. Intercontinental wind dispersal of spores of fungal plant diseases is known, but not common (Brown & Hovmøller 2002). Downwind dispersal may account for the arrival of the Australian strain of Myrtle Rust on Lord Howe Island (2016) and mainland New Zealand (2017), although this cannot be determined with certainty given the high frequency of human and goods movement between the three locales. The 2017 incursion on the remote and mostly unvisited Raoul Island (Kermadec group, c. 1100 km north-east of NZ) is likely to have been a wind-dispersal event. Wind-dispersal of spores from Australia to these and some other south Pacific locales is likely over time, and is one biosecurity pathway consideration for countries of the region such as New Zealand and New Caledonia, especially if other strains of *A. psidii* were to arrive in Australia. This highlights the need for a continued strict internationally coordinated biosecurity approach, aimed at exclusion of any further *A. psidii* genotypes from the entire region.

The rapid spread of the Myrtle Rust pathogen in 2010-13 at an inter-regional and inter-State level in NSW and Queensland was clearly facilitated by human activities (Carnegie and Cooper 2011; Pegg et al. 2014a). This was mostly likely by movement of live plants for commercial sale and domestic use occurring at a rate faster than tracing efforts in the emergency response phase could match. The pattern of occurrence and recurrence in Victoria also strongly suggests largely human-mediated dissemination for that State, and there is reportedly evidence that arrival there was via diseased plant material from NSW (D. Smith, Vic. DEPI, pers. com. to A. Carnegie, 3 March 2014). Human-mediated movement of spores is the most likely vector for further spread at these larger scales, particularly to South Australia and the south-west of Western Australia, and this provides strong grounds for the maintenance of domestic quarantine restrictions on the movement of live or recently harvested Myrtaceae plant material.

Further exacerbating this high potential for human assisted spread via the plant trade is the fact that under cooler conditions the disease cycle (sporulation, infection, to re-sporulation) can extend to 5-6 weeks compared to the normal 2 weeks (Carnegie & Lidbetter 2012). This increases the latency period (plant infected but not exhibiting symptoms), and therefore the chance of infected but non-symptomatic plants being moved inter-State. There is evidence of the introduction of *A. psidii* into new countries and continents via movement of nominally regulated infected plant material, including into Hawaii (Loope et al. 2008; Loope and La Rosa 2008) and Japan (Kawanishi *et al*. 2009).

While natural distribution is difficult or impossible to control, human-mediated spread is at least in some respects capable of modification to reduce risk.

1.5.4 Weather and microclimatic preferences

Both the spore germination and pustule growth stages of the pathogen require susceptible host species, suitable tissues (typically new leaves and very young stems), and favourable ambient conditions. The spore germination stage requires a wet leaf surface, within a suitable temperature range, and most literature states that these germination conditions also have to occur at night. However L. Morin [CSIRO, pers. comm. March 2014] considers that darkness may not be an absolute requirement for spore germination if other factors are conducive – moist and low-light conditions under a forest canopy may well permit daytime germination of spores. The requirement for leaf surface moisture is regarded as mandatory for successful germination.

Both germination and pustule formation require moderate temperatures, usually cited (e.g. Glen *et al*. 2007) as 13–22 (–25)^{o}C based on overseas data for undetermined strains of the pathogen (Ferreira 1981; Ruiz et al. 1989; Carvalho et al. 1994; Tessman et al. 2001). This is however an optimal temperature range only. Ruiz et al. (1989) reported a wider temperature tolerance range of 5—25^{o}C, on a eucalypt host. The 'pandemic strain' that occurs in Australia seems to be capable of completing the uredinial life cycle at quite low temperatures, albeit perhaps at lower rate and frequency. Kriticos *et al*. (2013) report that spore germination of an Australian isolate on agar disks "occurred over the complete range of temperatures tested (8.8–29.7^{o}C), but was the highest (>35%) between temperatures of approximately 12 and 20^{o}C … The lower temperature threshold for germination observed here is considerably lower than that indicated by the experiments of Ruiz et al. [1989] and Ferreira [1981]". This *in vitro* result accords well with field observations of continued uredinial pustule emergence with early winter overnight minima as low as of 8^{o}C (Lamington Plateau – G. Guymer, Queensland Herbarium, unpublished data) or even 2–5^{o}C (D. Smith, Victorian Department of Primary Industries, pers. comm. June 2012). Carnegie & Lidbetter (2012) state that the uredinial cycle can slow to a duration of up to 5-6 weeks during winter on the Central Coast of NSW, but is still active during June-July. Carnegie et al. (2016) note, for untreated wild *Rhodamnia rubescens* in a disease exclusion experiment, that "Incidence and severity of *P. psidii* generally followed a trend of increasing during periods of high rainfall and reducing during dry periods over winter"; the emphasis may be on the 'dry', however, as the study showed peaks of disease incidence and severity in winter and spring (see charts in Pegg et al., 2018: 41).

For north-east NSW and south-east Queensland, G. Pegg (pers. comm. May 2018) reports that whilst peaks and troughs of infection through the year are relatively constant, "in general disease levels (incidence and severity) are higher in the cooler months with levels increasing from March through until August and then declining in September-November and beyond depending on rainfall. The autumn flush on *Melaleuca quinquenervia* appears more susceptible than the flush during the warmer months". Pegg et al. (2018) present data for *Melaleuca quinquenervia* at study sites on the NSW Far North Coast, showing peaks of Myrtle Rust incidence in the July-September period in two consecutive years.

Low temperature may become a more significant factor at higher latitudes (Victoria, Tasmania), although even there it is unlikely to be straightforward and the absence to date of bushland infections may be governed by both climatic factors and a lower incidence or absence of the highly susceptible host species than is the case further north.

The upper limit of temperature for germination and infection development in the wild is also not fully determined. Lab and glasshouse experiments cited above indicate a sharp falling away of infection levels above about 30°C. G. Paterson (pers. comm. 28 Sept. 2017) reports from field observations that in the Mackay Queensland area, “Myrtle Rust [incidence] drops right away as soon as the temperature gets above 25-28°C, regardless of moisture”, although whether this temperature correlation is with the germination phase or some other aspect of the life cycle or physiology of the host, is uncertain.

The interplay of ambient temperature range and moisture is not straightforward, and in any case may be modified by microclimatic conditions, the availability of suitable host tissue, and stochastic factors that reduce spore load (e.g. Pegg reports, pers. comm. May 2018, that “We have also found the disease levels decline following periods of very heavy rainfall – spores being washed off”). These considerations make medium- and fine-scale predictive modelling of suitable *A. psidii* habitat, or forecast of seasonal risk, difficult.

In any event, it seems from the above data, and from observed instances of infection outbreaks in spring, that in eastern Australia *A. psidii* is well able to survive winter temperatures at frequencies that allow relatively rapid spring or summer outbreaks without needing to recolonise an area from elsewhere, as long as there is some suitable host-plant tissue available through the winter. In the more severe climate of the New South Wales tablelands, local overwintering is less likely, and recolonisation is probably required and later seasonal outbreaks more likely (subject to suitable conditions), as with a 2016 autumn outbreak in Canberra on several cultivated species (Phil Hurle, Australian National Botanic Gardens, *in litt*. 21 Sept. 2016).

The more general climatic conditions determining suitability areas for establishment and persistence of the Myrtle Rust pathogen are not well resolved for all regions of Australia, particularly for the monsoon tropics and the mediterranean south-west of WA – see Kriticos et al. (2013), Berthon et al. (2018), and discussion below. Predictive modelling scales are necessarily constrained by the available data, whether biophysical or derived from previously known host and pathogen occurrence correlates. This often dictates a fairly coarse-scale approach which will tend to mask the occurrence of suitable small-scale patches of microclimatic suitability or host species likelihood of occurrence. It can also lead to an underestimation of regional risk, the probability of rust persistence, and the degree of overlap between the pathogen and any one host species (the hosts often occurring only in suitable microhabitat to start with).

Whether a local outbreak occurs, and if so at what scale and pace, and with what level of impact, is governed by:

- the existence of general weather and/or microclimatic conditions suitable for Myrtle Rust dispersal (dry/windy), and establishment and growth (wet, warm);
- the presence of an initial rust spore load from the immediate habitat or wider region;
- the presence and density of susceptible hosts;
- the level of their susceptibility to (or tolerance of) the pathogen;
- their exhibition of suitable tissues.

When these conditions are aligned, a local outbreak may build rapidly to a high level of infection. What level of infection severity and resulting damage to the hosts then transpires, depends on the duration of conditions for continued re-infection (via dispersal of new spores and establishment of new infections) and the continued availability of suitable plant tissue.

Under sustained conditions favourable for the rust, very highly susceptible hosts may have much or all of their new seasonal growth (flush) heavily infected and killed, resulting in shoot death and loss of new leaves, and failure to set flowers for those hosts that do so on new seasonal growth. Most plants however have a reasonably extended flush period of at least a few weeks to a few months, in southern Australia often in spring and sometimes continuing through summer or with a secondary flush in autumn. If the temperature or moisture conditions for either rust spore germination or dispersal disappear for some weeks during this period, then most plants (except new seedlings) may have sufficient reserves to allow a further attempt at growth of new shoots. If rust spore levels remain low, the later stages of the flush period may succeed to a level where adequate new foliage is able to mature and replace old leaves. Depending on the ‘tightness’ of the flowering season, flowers may also develop on these new shoots, if that is the pattern for that host species.

FIGURE 10: Scrub Turpentine *Rhodamnia rubescens*, serial new shoot dieback, March 2011 (A.J. Carnegie, NSW DPI). First seasonal growth shoots were infected in December 2010 and soon died; the plant compensated by putting out further new growth, but by March 2011 this too was infected and is shown dying. The adult leaves at left are not exhibiting Myrtle Rust, but will not be replaced with new foliage as they age and die, and this branch will not be capable of flowering.

Conversely, where weather conditions remain optimal for Myrtle Rust disease development throughout the entire flush and/or flowering seasons, and there is adequate spore load to initiate and sustain a major outbreak, most or all new seasonal growth and flowering capacity may be lost. This is more likely to be the case in some climatic regions and microhabitats than in others, and will also be governed by the number of co-occurring host species which may have in-phase, out-of-phase, or partially overlapping flush seasons, that contribute to a more extended presence of *A. psidii* sporulation in that vegetation community.

The interplay of the above factors accounts for the unpredictability of and inconsistencies in Myrtle rust presence and severity year by year that are common in field reports, and underline the need for longitudinal monitoring to establish baseline information, especially for year-by year host recruitment and age-cohort progression.

The very steep decline of Native Guava (*Rhodomyrtus psidioides*) along the east coast appears to be a case of a highly susceptible species with no known resistance and with a high year-by-year probability of a full overlap between the seasonal flush and optimal conditions for Myrtle Rust. This conjunction occurs in a generally Myrtaceae-rich vegetation type (although this is not necessarily the case for individual study sites) that can sustain a continual spore load within easy dispersal distances through the entire flush period. In this case, some late-season regeneration from basal suckers is still occurring, but these too often become very heavily infected and seldom escape for long.

1.5.5 The infection process

Under optimal conditions, the clonal (uredinial) reproductive cycle of *A. psidii* may take as little as 10-12 days from infection of a host plant to the development of a mature sporulating pustule with many thousands of daughter spores. This short cycle allows the very rapid local build-up of infection levels and spore load when three conditions are met:

(a) suitable host species are present;
(b) the hosts are exhibiting tissues, typically young shoots and leaves – e.g. a seasonal flush of young foliage, or post-fire coppice growth, or large numbers of seedlings – but also in some species flower buds and soft fruits;
(c) suitable weather and microclimatic conditions are present.

The presence of suitable host species, exhibiting suitable host tissue, is a requirement for establishment and persistence of the pathogen. In general, *A. psidii* does not infect older stems and leaves, preferring young tissue, although it may occasionally attack older, apparently mature leaves on some species (e.g. Scrub Turpentine *Rhodamnia rubescens*).

For most susceptible host species, the most vulnerable tissues are new growth: seedlings and actively growing juveniles, seasonal new foliage, and re-sprouts and epicormic or coppice growth following fire or other damage. On some species, parts of flower buds and open flowers may become infected, and soft fruits may be susceptible in those genera that have them (e.g. *Rhodamnia*, *Rhodomyrtus*).

In the right ambient conditions, up to 90% of spores landing on suitable tissue may germinate (Xavier *et al*. 2001). Unlike many other rusts, *A. psidii* does not usually penetrate the leaf through the stomates, but directly through the leaf cuticle. It first develops an appressorium (the initial colonisation organ) and a first hypha (penetration peg) that breaches the cuticle and projects into the leaf between the anticlinal walls of the epidermal cells (Hunt 1968; Coutinho *et al*. 1998; K. Old cited in Cannon 2011; Taylor 2013). A haustorium then develops and mycelia parasitise surrounding plant cells, and under favourable conditions soon produce eruptive sporulating pustules (sori) which in turn produce new spore masses. The infection process is described in detail in Glen *et al*. (2007) and in Taylor (2013). Xavier *et al*. (2001), who used a Brazilian rust isolate, did observe some penetration through stomates, but at low frequency (2-7% in different clones of *Eucalyptus grandis*), in most of those cases without the prior formation of an appressorium.

Apart from the requirement for suitable tissue and a moist plant surface in low-light conditions, the physical and chemical factors that govern the success or failure of *A. psidii* spore germination and penetration remain uncertain, although some indications are available – see, e.g., discussion in Potts *et al*. (2016), Xavier et al. (2015). There is likely to be a complex interplay between the surface topography and chemical signals of the plant tissue, and those of the rust. The germination and penetration phase of *A. psidii* infection, prior to the activation of plant disease responses as such, are potential points of 'weakness' that may possibly be susceptible to control measures aimed at enhancing their failure rate, whether through host species breeding or engineering to enhance blocking mechanisms, or (in cultivation) through topical applications.

Where spore germination and hyphal penetration *are* successful, the host plant's disease resistance mechanisms in the strict sense come into play. Initial external symptoms can appear within 5–7 days of infection, although new techniques in metabolomics can identify protein synthesis activity characteristic of infection from much earlier in the process, within about 48 hours of infection (e.g. Tobias et al., 2018), including in highly tolerant and asymptomatic individuals.

Depending on the plant's level of resistance or tolerance, different symptoms may appear. The precise symptoms displayed by infected plants vary, in form, extent and severity. This dictates some differences in how disease expression is monitored for different species and life-stages, and complicates the development of a single monitoring protocol suitable for all situations in the field – symptoms appropriate to record for some species or stages may not be appropriate for others.

Berthon et al. (2018) calculate the percentage of Australian species that have been screened for Myrtle Rust susceptibility but have failed to sustain the uredinial life cycle as 3%. That is to say, the proportion of Australian Myrtaceae that a genuinely fully resistant to the pathogen is likely to be very low. Experimental inoculation conditions do not however provide a reliable guide to susceptibility in the field, which depends on many factors. It is the case that many Myrtaceae growing wild or in cultivation within the geographical zone invaded by *A. psidii*, and certain to have been exposed to the pathogen, have not yet been recorded as hosts. In part this may indicate a relative tolerance of the pathogen among some or many species, at least on life-stages observed to date, making detection less likely. A few species may be effectively 'immune', for example Brush Box (*Lophostemon confertus*), which has its entire natural range within the east coast Myrtle Rust zone of naturalisation, but has not yet been observed to exhibit infection symptoms either in the field or in inoculation trials (Tommerup et al. 2003; Zauza et al. 2010; Morin et al. 2011, 2012). Certainty is not possible in the absence of a systematic field monitoring program that checks species over all life stages and over a meaningful sample of their geographic/genetic ranges.

A necessary caveat on most inoculation trial results is that the great majority have involved a very small sample of the subject species' genetic diversity (many species are known to have genetically correlated variation in susceptibility), and overseas tests may not have used the 'pandemic' strain of *A. psidii*.

For symptomatic host plants, the lowest level of visually detectable infection (seen in taxa that have the highest tolerance of the disease) is the exhibition of a hypersensitive reaction by the host. On leaves, this takes the form of very small dark lesions surrounded by a narrow pale (chlorotic) halo. The lesion represents the site of infection and cell death, the halo represents a zone within which the host plant is auto-quarantining the infected spot, effectively a form of localised cell-suicide to isolate the infecting mycelia and deny the parasite the resources to grow. This reaction is not easy to detect, and may in any case be caused by a variety of pathogens and some non-pathogenic invertebrate pests. Specialist assistance is needed to diagnose this reaction.

Higher levels of infection (progressively lower tolerance) initially display as brown, black or purplish lesions. Prior to the presence of pustules, the lesions can be very difficult to distinguish from other minor damage, e.g. from other infections or insects. Very soon however the lesion area develops few to many yellow uredinial pustules. By the time this stage is obvious, spores are ready to disperse – handling and disposal of plants at this stage can very easily spread the spores unless strict protocols are followed.

At high levels of infection, lesions may coalesce, resulting in merged eruptive uredinial spore masses forming a yellow coating over much of the infected organ surface.

The distribution and density of pustules on various parts of the plant can be parsed into visually meaningful classes for field monitoring purposes (e.g. proportion of leaves affected, percentage of leaf surface affected, stems and fruits infected yes/no). Symptoms at this stage may vary with different host species. For images of this stage on a wider variety of host species and cultivars, see galleries on the Myrtle Rust pages of most State and Territory primary industry agencies' websites.

Severe infection on foliage often results in loss of affected leaves. If this process is repeated in consecutive flush seasons, then as old leaves die (from age or other non-rust causes) the plant will become progressively defoliated. Heavy foliar infection is usually accompanied by associated infection of new stem shoots, although in some species there may be marked difference between levels of infection on leaves and stems.

Repeated shoot death (as well as new leaf death) and subsequent loss of apical dominance, can result in a 'witches broom' effect of dead stem shoot axes at the tip of older branches (see Pegg *et al*. 2012, Figure 1). This may distort the entire subsequent habit (architecture) of the plant, with normally erect shrubs or trees that survive becoming stunted or more bushy. Branch dieback (tip death) can be usefully distinguished as a distinct symptom in assessing the progress of decline in some species and age classes, along with measurement of the level of whole branch death. Canopy transparency (as an index of defoliation) can only be effectively recorded on large shrub- or tree-sized individuals, and can become complex in dense forest ecosystems. It can however, provide an effective method of showing rates of change in tree health over time.

Other plant parts affected in some species may include flower buds and flowers, usually the sepals and receptacle, and fruits in some of the fleshy-fruited genera. Rust lesions on these may open the way for secondary infection by other fungi and bacteria, leading to death of fruit before seeds become ripe or dispersed. Pegg et al. (2018) report that *A. psidii* infection has been identified on flowering and fruiting structures of 32 species of Myrtaceae in Australia.

The post-infection signs of Myrtle Rust disease, especially at the more severe end of the infection scale, can also be informative: these include: new shoot tip death, brown blistering of surviving leaves, aggregated dead shoots in a 'witches broom', overall distorted branch growth or distorted whole-plant habit, branch death, and whole-plant death. Agents other than *A. psidii* can of course cause some of these symptoms. Reliable attribution of these effects to Myrtle Rust may require an expert eye, or knowledge that a site or plant has recently undergone Myrtle Rust infection and no other pest or disease impact, or close inspection to detect late-remaining pustules on surviving young tissue. Some indices, such as crown transparency (an index of defoliation), ideally need a baseline average from healthy plants to assess significance, although at the extreme end of the scales (e.g. 80%+ crown transparency) an estimate of causality and impact can be made even in the absence of baseline transparency if other factors are present. In areas where Myrtle Rust has been established for some time and unexposed plants are no longer available, the best available baseline may be just the first set of measurements.

Symptom expression may vary between species, and within species between seasonal timing of infection. The descriptive terminology and definitions for levels of infection in the field vary somewhat between different recent researchers. A tested and standardised technique for scoring disease incidence, severity and symptomology is detailed in Pegg et al. (2018).

1.5.6 Infection outcomes

In summary, repeated heavy infection in more highly susceptible species may cause:
Leaves:

- Death of new leaves
- Inferred reduction of function of damaged surviving leaves (no studies to date);
- Non-replacement of senescent old foliage;
- Decreased foliage density over time, heavy or complete defoliation if severe.

Shoots and branchlets:

- Loss or growth-distortion of new shoots;
- Consequent loss of leading meristem dominance; distorted bushier habit in severe cases;
- Consequent loss of flowering capability (and hence fruit/seed) in terminally flowering species;

Flowers and fruits:

- Indirect reduction of flower (and hence fruit/seed) production through reduced vigour or death of apical shoots (for terminal-flowering taxa)
- Diseased flowers (some species only)
- Diseased fruits (soft-fruited species only)
- Increased likelihood of secondary infection by other fungi and bacteria (no studies to date).

Major branches and whole plants:

- major branch death (after repeated cycles of infection and tip dieback, over multiple seasons);
- Decreased photosynthetic capability, reduced plant energy resources;
- Increased likelihood of stress-related secondary disease;
- Adult plant death; seedling death;
- Sucker, coppice and epicormic growth infection and death.

Host species demography and interactions:

- Increased distances between surviving plants (including resistant individuals);
- Reduced pollination frequency; pollinator search-pattern shifts as scarcity increases;
- Reduced diaspore production and survival (pending selection and spread of any resistant genotypes);
- Consequent fragmentation and likely reduced gene flow;
- Reduced ability to compete within environments, compared to more tolerant hosts or non-Myrtaceae;
- Increased local or general extinction risk.

Ecological:

- Floristic change, species replacement
- Greater light at sub-canopy and ground level with crown thinning of adults; hence increased ground layer vegetation including weed invasion, inhibiting native regeneration;
- Loss of habitat for resident epiphytes and resident fauna;
- Loss of resource for transient associated fauna, especially seasonal or migratory;
- In some habitats, reduction or loss of roles of dominant or keystone species in maintaining ecological or biophysical functions (e.g. *Melaleuca* wetlands).

These effects and their resulting changes may be rapid or gradual, depending on severity of infection and specific effects. Susceptible species that grow in the wild in effective 'monocultures' (i.e. are patch-dominant with little understorey) may be at significant risk, especially if rare cohort-recruitment events coincide with suitable conditions for rust. Examples might include some thicket-forming *Leptospermum* species, and some predominantly cohort-recruiting dominant forest tree species after major disturbance (potentially, for example, Blackbutt *Eucalyptus pilularis* after severe fire).

PART 2: MYRTLE RUST IN AUSTRALIA – PRELUDE, INCURSION, ESTABLISHMENT

2.1 Pre-arrival assessments of risk

Walker (1983) reviewed the biogeography of a range of plant parasitic fungi, and drew attention to the paucity of rusts on Myrtaceae in the Australasian region. He noted the ability of some of the South American rusts of Myrtaceae to infect species of some important Australian genera in cultivation there, concluding that this had "the most important practical consequences for plant quarantine. The need for rigid exclusion of these rusts [of Myrtaceae] from the Australian region is obvious."

In Australia, an initial precautionary response took place through the quarantine apparatus. Restrictions aimed at preventing the importation of the pathogen then known as *Puccinia psidii* were imposed from the mid-1980s, applying to plants and seeds of a number of susceptible genera (Navaratnam 1986). In the 1990s, a coalition of concern in South Africa and Brazil (Coutinho et al., 1998), reviewed the risk to eucalypts, albeit mainly from the point of view of the plantation industry worldwide, and identified key research questions for an improved understanding of the pathogen and for resistance breeding for the timber industry. An important (if in hindsight environmentally inadequate) program of international research was initiated in 2000 with Australian Government funding through the Australian Centre for International Agricultural Research (ACIAR). This program involved collaborations with South and North American researchers, and provided a general assessment of the problem (Old et al., 2004), predictive risk mapping (Booth et al. 2000; Booth & Jovanovic 2012), and the susceptibility screening of some Australian species (Tommerup et al. 2003; Zauza et al. 2010). The susceptibility screening results of Zauza et al. (2010) should be read with an eye to the limited host sample sizes used, and the choice of pathogen isolate (UFV-02, assignable to the C2/C3 genotype of Stewart et al. 2017 and hence differing from the pandemic C1/C4 genotype now present in Australia) – this resulted in 'highly resistant' scores for several species now known to be highly susceptible to the C1/C4 strain.

Tommerup et al. (2003) nevertheless summed up this research by stating that "the rust is a serious threat to tropical, subtropical and possibly temperate plantations [of eucalypts] in Australia and … world wide. In Australia there is an additional threat to native vegetation …".

During the same period, steps were taken to develop a molecular diagnostic tool for the identification of the pathogen (eventually published as Langrell et al., 2008). In 2004, this tool was used successfully to identify live spores of *Puccinia psidii* in Australia on an imported shipment of sawn timber from Brazil (Grurinovic *et al*., 2006), a rare case of confirmation of one of the many potential pathways for intercontinental transmission of the disease.

However, no specific scoping of the possible *environmental* impacts was conducted either at this stage or subsequently. In New Zealand, by contrast, the Department of Environment commissioned a scoping study of the potential impacts of this and other exotic pests and pathogens on native forest biota (Ridley et al 2000), setting a different tone and knowledge base for later environmental engagement.

In 2006, the threat appraisal for Australia was escalated through the biosecurity apparatus to Ministerial Council level, resulting in an assessment that:
"[*Austropuccinia psidii* is] … *one of the most serious threats to Australian production forests and natural ecosystems" ... It has a potential to cause direct mortality in the estimated 10% of all*

Australian native forest plant species (and the great majority of dominant species) that belong to the family Myrtaceae, and with indirect effects that may include habitat loss for native fauna and flora, retarded regeneration and recruitment of younger trees and successional species, greater impact of fire, and abiotic effects as a result of canopy decline including erosion, reduced water quality, reduced water retention in soil and vegetation and potentially large losses through lost production to the forestry industry." (Commonwealth of Australia 2006).

In subsequent National Contingency Plans (Plant Health Australia 2008, 2009), *Puccinia psidii* was assessed as having:

- a high potential for entry to Australia,
- a high establishment potential,
- a high-to-extreme spread potential,
- a high environmental impact, and
- a high-to-extreme economic impact.

The projection for environmental impact was not argued in other than general terms, partly reflecting the inadequate knowledge base at the time but probably also the inadequate engagement of environment agencies with biosecurity assessment processes (Craik et al. 2017)

In April 2010, Myrtle Rust disease was detected onshore for the first time, on the NSW Central Coast. By the end of 2012, it had naturalised along most of the eastern seaboard. Still no appraisals of the environmental threat posed by it, or coordinated impact monitoring programs, were commissioned – the 'as yet unknowns', coupled with its apparent intractability to management and containment, created a discouraging fatalism on the environmental front.

2.2 Incursion and establishment

Austropuccinia psidii was first detected in Australia on the New South Wales Central Coast in April 2010 (Carnegie et al. 2010a; Carnegie & Cooper 2011). Within three days of the first report and sample, an emergency response was initiated (24 April) under the nationally funded Emergency Plant Pest Response Deed (EPPRD). The response was suspended a week later on the (much disputed) grounds that eradication was not feasible. It was then resumed on 2 July, before terminating in December when the pathogen was finally, and with fuller consensus, declared no longer eradicable.

By 2010, State and Commonwealth biosecurity authorities had five years of experience of incursions assessed and managed (or not) under the Emergency Plant Pest Response Deed (EPPRD), a coordination and funding mechanism instituted in 2005. Few previous cases in which an emergency response was invoked had involved a pathogen with broad-scale environmental threat potential. The mechanism of assessment and response and the EPPRD, as it existed in 2010, is outlined in Carnegie & Cooper (2011), Cannon (2011), Howard et al. (2015), and Carnegie & Pegg (in press 2018). These writers provide elements of a critique of the 2010 emergency response process from various perspectives. McAllister et al. (2017) analyse the period from a more academic systems theory standpoint, but with the benefit of interviews with some of the key individuals. Other elements of a critique were advanced in submissions to a Senate Inquiry into Environmental Biosecurity in 2014-5, particularly those of the Plant Biosecurity CRC, the Invasive Species Council, and the Australian Network for Plant Conservation. The Inquiry report and submissions are at https://www.aph.gov.au/Parliamentary_Business/Committees/Senate/Environment_and_Communications/biosecurity/Public_Hearings .

These critiques, and the timeline of the 2010 response (traced in detail in Carnegie & Pegg, in press) are not restated here, but certain elements common to most of them stand out as relevant. In some cases the relevance lies in their legacy effect on the muted environmental response to Myrtle Rust, and in other cases as problems that still remain inadequately resolved for future incursions of broad-scale environmental pathogens:

- *The decision (30 April 2010) to suspend the nationally funded emergency response only a week after first detection, subsequently reversed on 2 July*. This is perhaps the most widely criticised element of the response, although parties differ, with the benefit of hindsight, as to whether an uninterrupted effort might have resulted in eradication. It is important to note that NSW agencies (Office of Environment & Heritage, Forestry Corporation, and the Department of Primary Industries) continued a joint State-funded containment/management response through the April to July period, but on reduced interim funding and without the benefit of EPPRD resourcing and a clear eradication goal. The resumption of a national eradication approach was only achieved through the efforts of Plant Health Australia, industry representatives, and some of the scientists involved. The interruption, coupled with other factors below, certainly resulted in confused messaging as to the seriousness of the threat, and lost opportunities for early engagement by the environmental sector. A clear lesson from this would seem to be the need for a more precautionary approach to cancelling eradication efforts for pests and pathogens of high potential for naturalisation and broad environmental impact.

- *Initial taxonomic uncertainty*. The NSW outbreak was initially identified under the uredinial morpho-species name *Uredo rangelii*, and given the common name Myrtle Rust. Its identity with the Eucalypt/Guava Rust pathogen, then still known as *Puccinia psidii*, was debated by some specialists, and their position was adopted by the response apparatus, until an accumulation of DNA evidence (2010-13) showed the pathogen to be fully assignable to *Puccinia psidii* (Carnegie et al. 2010b; Pegg et al. 2014a, Stewart et al. 2017). Some scientific participants and external close observers aver privately that the decision (to adopt both scientific and common names distinct from the globally known pathogen) was in part to down-play the significance of the incursion, whether for reasons of international trade or to 'not frighten the horses' domestically; these views rarely appear in print, but see McAllister et al. (2017). An arguable defence for the new common name is that it better reflects the broad host range of the pandemic strain of *A. psidii* than any of the previous common names. The generalisable lesson though would again seem to be the need for a precautionary approach (assume worst case until proved otherwise), and a need for more investment in offshore, pre-arrival investigation of genotypic variation in priority pathogens.

An additional element noted by some stakeholders in the scientific and community-environmental sectors was the *high level of secrecy* around the 2010 response decision-making, and a very restricted information flow. Invited collaborators in those parts of the response apparatus concerned with scientific evaluation and decision-making, were required to sign general confidentiality agreements (as distinct from specific-item confidentiality), and this continued for most of 2010. While confidentiality provisions in biosecurity responses are neither uncommon nor intrinsically unreasonable, their general nature and the lack of breadth in the environmental representation within the charmed circle, coupled with the apparent lack of any strategy for engagement of the wider environmental sector, resulted in poor messaging to that sector. This was exacerbated by slow or absent uptake of the issue within the NSW and Commonwealth environmental agencies. A series of seven public communiques from the Myrtle Rust National Management Group (NMG) over the course of 2010 had good penetration of the horticultural and forestry sectors but very poor penetration of the botanical, ecological and community-environmental sectors, probably reflecting a lack of adequate stakeholder analysis outside traditional agro/forestry thinking.

The restricted information approach adopted by the NMG through 2010 contrasts strongly with the approach taken in New Zealand since their outbreak in early 2017, which has involved frequent and comprehensive public updates issued jointly by the primary industries and conservation agencies – to the benefit of their response. Redacted versions of some 2010 papers of the NMG were released following a Freedom of Information request by the Invasive Species Council in 2014. They show that while there may have been a rationale for financial uncertainties and some private tenure data to be understandably withheld, much of the content was identical in type (new areas, new hosts, etc.) to that issued freely in New Zealand (some such information did make its way to the NSW DPI website, but slowly). A Plant Health Australia 'Myrtle Rust Incident Debrief' of April 2011, released under the same request, is about 70% redacted, so perceptions from that workshop of lessons for the future are not directly in the public domain.

At State (NSW) level, the lead agency (Department of Primary Industries) promulgated much high-quality material through its website, with multiple PDF brochures on recognition of the disease, reporting details, and advice on management in domestic and commercial situations, and calls for reporting of Myrtle Rust sightings through the exotic plant pest hotline and by email.
This elicited a strong response from both the general public and more aware stakeholder groups (as also occurred in Queensland in 2011-12). Moreover, the information drive was, for a time, resourced to enable screening of reports for reliability, and some follow-up field checks. This fell away in 2011-12 as the shape of the naturalisation zone became clearer and DPI effort had to move to other priorities. No attempt seems to have been made to transition the existence and servicing of this public response to a form (whether State or national), that could continue to contribute to monitoring the spread and impact of Myrtle Rust in the natural environment. No other integrated monitoring scheme has yet emerged, despite the existence of a sizeable network of motivated and skilled stakeholders with the potential to contribute.

The above criticisms, though significant at the time, are quibbles compared to the major failing of the period – the lack of transition of the issue to environmental agency management, even though the biodiversity threat was abundantly clear. A particular loss was the level of public awareness expressed in the initial DPI-led reporting program, which could have been transitioned into a most useful tool for two-way awareness and data gathering had it been taken up as part of an environmental response.

Howard et al. (2015) note that "At that time, there was no formal mechanism to provide a clear path for decision making and cost sharing when transitioning from eradication to longterm management of noneradicable plant pests. Draft arrangements had been developed to support short- to medium-term containment programs, but these arrangements were still to be finalized. It was widely acknowledged that further support was needed to attempt to reduce the impact of the pathogen on the natural environment, the community and affected industries in Australia. However, the lack of formal transition arrangements highlighted the gap in national arrangements for pests that are not eradicable, but where further coordinated action is in the national interest. Therefore, in 2011, the Federal Government through the Department of Agriculture, Fisheries and Forestry (now the Department of Agriculture), established a set of pilot transition to management programs, one of which was for the myrtle rust pathogen. The goal was to use the outcomes of the pilot programs to guide the ongoing development of formal transition arrangements. The pilot program for myrtle rust consisted of a Federal Government investment of AUD $1.5 million from July 2011 to June 2013 to facilitate coordination and governance, and to provide necessary research funding.
The research funds were allocated for a number of theme-based research and development projects."

The Myrtle Rust Transition to Management Program did indeed commission several important 'backdrop' research programs, all of them significant and worthwhile – and none of them focussed on environmental concerns. The main direct benefit for the latter were the approximately yearly workshops (excellent, but with a very small number of environmental sector representatives) that provided valuable points of information exchange.

2.3 The distribution of the Myrtle Rust pathogen in Australia, current and future

2.3.1 Current distribution of *Austropuccinia psidii* in Australia

The Myrtle Rust pathogen – the 'pandemic' strain of *Austropuccinia psidii* – is fully naturalised in New South Wales and Queensland, where it has proved highly invasive in moister ecosystems. It is naturalised in limited parts of the Northern Territory, with an uncertain potential for invasiveness. It is marginally naturalised in cultivation (but not known to have invaded native vegetation) in Victoria and Tasmania. It has not to date been recorded in South Australia or Western Australia.

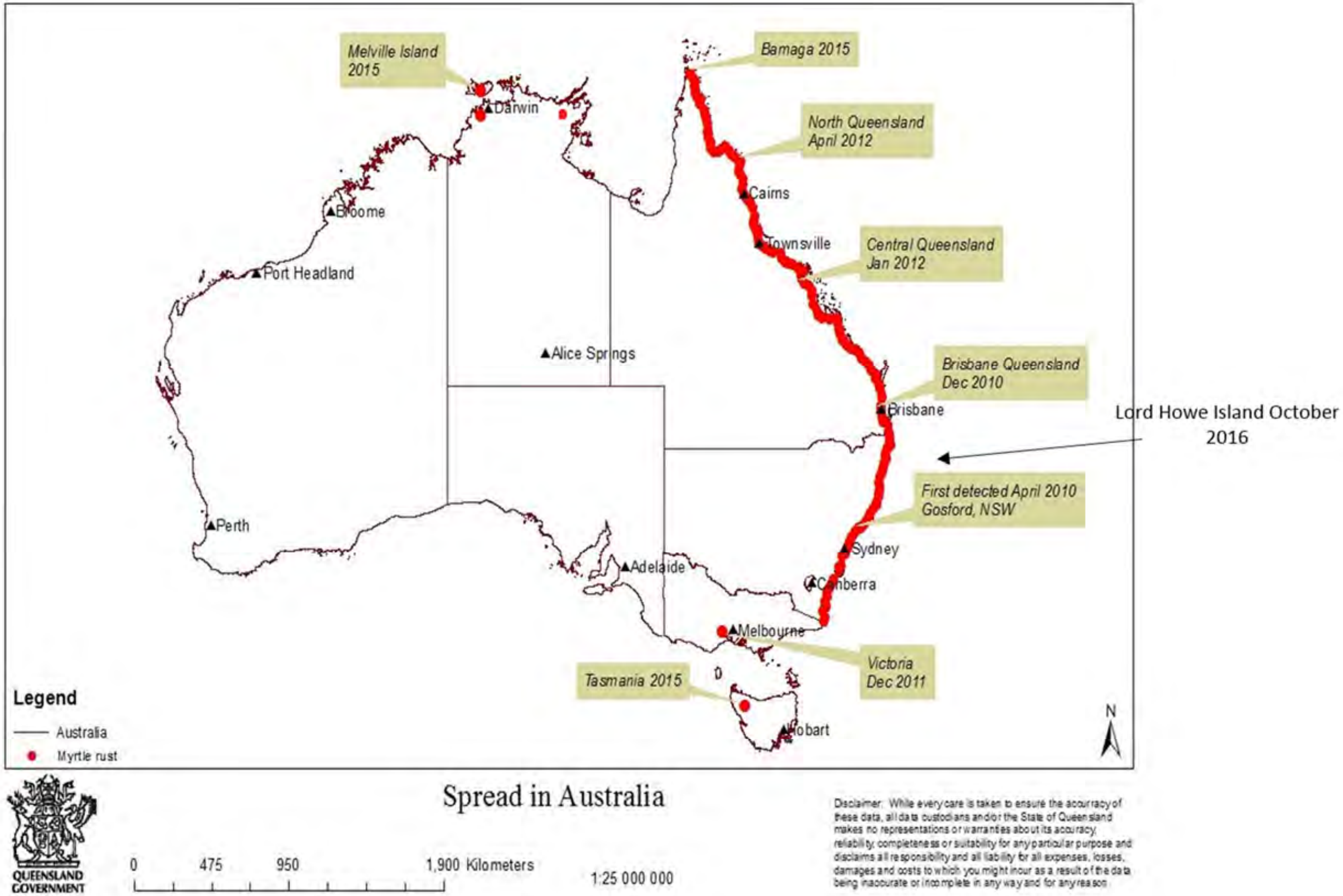

FIGURE 11: Australian distribution of *Austropuccinia psidii* (the Myrtle Rust pathogen) as at June 2018. Map modified from version provided courtesy of G. Pegg, Queensland Department of Agriculture and Fisheries.

Queensland: *A. psidii* is fully naturalised along most of the Queensland coast from the NSW border almost to the tip of Cape York Peninsula, but with some apparent breaks in distribution in drier areas, e.g. the Rockhampton rain-shadow (but very probably present there in suitable small habitats, or at low levels, or simply not reported). It is present through much or all of the Wet Tropics, with the northernmost record at Bamaga just south of Cape York, and on three of the Torres Strait Islands (on *Eugenia reinwardtiana* – B. Waterhouse, DAWR, *in litt*. 3 Nov. 2017). It has not been reported so far from the western side of the Cape York Peninsula or in the Gulf country, but no targeted monitoring is known to have occurred there. There is one reported location west of the Great Dividing Range, on the Walsh River north-west of Chillagoe, a tributary of the Mitchell River system, which flows to the Gulf of Carpentaria (on *Melaleuca leucadendra* – P. Entwistle pers. comms 2014, 2015).

Pegg et al. (2014a) documented the spread of the Myrtle Rust pathogen in Queensland. In south-east Queensland Myrtle Rust is reported from as far inland as the Toowoomba area, and in the north, on the Atherton Tableland, it extends at least as far west as Tolga, Yungaburra and Mareeba (Pegg et al. 2014a; G. Sankowsky, pers. comm., 30 Aug. 2017). Other relatively high-altitude areas of heavy occurrence include Eungella National Park on the Mackay Highlands, at approx. 680m a.s.l. (WJF McDonald, G. Paterson, pers. comms. Sept 2017); the Windsor Tableland (G. Sankowsky, pers. comm 30 Aug. 2017; A. Ford CSIRO pers. comms Sept. 2017); and most or all of the way up Mt Lewis (c. 1200 m a.s.l.) in the Wet Tropics (WJF McDonald pers. comm. 22 Sept 2017).

New South Wales and ACT: *A. psidii* is naturalised along most of the NSW coast, from the Queensland border south to the Moruya area. South of Moruya it is known only from infections of cultivated garden and street plantings south almost to the Victorian border (Akolele near Bermagui, CL Jordan pers. comm. April 2013; Tathra, Wallagoot and Bermagui, pers. comm. DL Jones, 21 Aug 2017). Myrtle Rust is largely confined to the coastal zone and altitudes in NSW, although in the Clarence River valley it extends inland to at least Mallanganee west of Casino. There have also been a number of records on cultivated plants in Canberra, ACT (e.g. in autumn 2016, P. Hurle, ANBG, *in litt*. Sept 2016), although its ability to overwinter in Canberra is doubtful.

On Lord Howe Island, Myrtle Rust was first reported on cultivated plants exotic to the island in October 2016, where it was detected early thanks to a strong vigilance regime, and has been the subject of an ongoing control program. Subject to further monitoring, the eradication is considered likely to have succeeded (Lord Howe Island Board, 2016, 2017; H. Bower pers. comm. Feb. 2018). The disease was not detected on any native Lord Howe Island Myrtaceae during the outbreak. The Lord Howe Island Group, a World Heritage Area, has five endemic species of Myrtaceae, all endemic; four are known hosts from inoculation testing (Morin 2011, 2012). Lord Howe Island remains at high risk of reinfection from mainland Australia and New Zealand.

Victoria: Myrtle Rust was first detected in Victoria in December 2011. As of September 2017, it has been detected at more than 80 sites. Most are in production nurseries and wholesale outlets, and on cultivated plants on public and private and private lands. It has not been detected in natural bushland. Most detections have been in the Melbourne region, with outliers in Ballarat, East Gippsland, Tynong North, and Shepparton. Since 30 June 2012, restrictions on importing Myrtle Rust host material from other states have no longer applied (http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/shrubs-and-trees/myrtle-rust, accessed 22 Sept. 2017). Myrtle Rust is best regarded as marginally naturalised in Victoria.

Tasmania: Myrtle Rust was first detected in Tasmania in February 2015. As of September 2017 is only been found in the greenlife industry and on cultivated plants, mostly in the north and north-west of the State. Infection has been found on only three species to date, none of them native to Tasmania and only one an Australian native. No infections in natural bushland have been detected. (http://dpipwe.tas.gov.au/biosecurity-tasmania/plant-biosecurity/pests-and-diseases/myrtle-rust#Whatdoweknowaboutmyrtlerust, accessed 22 Sept. 2017). Myrtle Rust is best regarded as marginally naturalised in Tasmania.

Northern Territory: Myrtle Rust was first detected in the NT in May 2015, on both cultivated and wild native species on Melville Island (Tiwi Islands group). Later in 2015 it was detected in the greater Darwin area, and subsequently on Bathurst Island, and in May 2017 in eastern Arnhem Land at Gapuwiyak (J. Westaway, DAWR, *in litt*. Sept. 2017). Spread has been slow, and host range remains restricted, so far as is known.

Commonwealth external territories: *Norfolk Island*: Myrtle Rust was detected on introduced plants on Norfolk Island in October 2016. (Hansard, Senate Rural and regional affairs and transport legislation committee, Wednesday, 24 May 2017). Norfolk Island has no native Myrtaceae species. *Christmas Island*: Myrtle Rust has not to date been reported from Christmas Island.

The remaining States (**Western Australia, South Australia**) have not reported any incidence of Myrtle Rust to date, and maintain active vigilance and exclusion programs. The Western Australia environment agency has an advanced Preparedness Response Plan.

Affected World Heritage areas:
The *Wet Tropics*, *Fraser Island*, and *Gondwana Rainforests World Heritage Areas* are all fully within the east coast zone of full naturalisation of Myrtle Rust.

The *Lord Howe Island Group WHA* experienced an incursion of Myrtle Rust from 2016 (see under New South Wales, above), and Lord Howe Island itself provides much apparently suitable habitat with four of the five endemic Myrtaceae species known hosts through inoculation.

The *Greater Blue Mountains WHA* is on the margin of the near-coastal zone of infection reports, but there are few reports of the pathogen from within its boundaries. Some lower elevation parts of it may be climatically and floristically suitable for permanent or transitory occurrence of the disease in native vegetation, and constant inward movement of a spore load by human vectors is almost certain.

The *Kakadu WHA* has not to date had any reported incidence of Myrtle Rust, but the incidence of Myrtle Rust on the Tiwi Islands and in eastern Arnhem Land makes exposure likely. Known host species (from inoculation trials and natural infections) occur in the WHA, but the behaviour and viability of the pathogen in the monsoon tropics remains poorly known.

2.3.2 Determining factors for invasion and establishment
The establishment of *Austropuccinia psidii* in any one place is governed by three factors:

- Pathogen presence: the arrival of viable spores.
- Floristic determinants: the presence of susceptible host species, and their exhibition of tissues suitable for infection.
- Climatic determinants: the presence of suitable climatic or microclimatic conditions for the rust life cycle, on either a permanent or intermittent basis.

Pathogen presence: *A. psidii* uredinial spores (the most common type) have demonstrated high mobility, both airborne and by human and animal vectors. This means that over the long term few regions that are broadly contiguous with the established naturalisation zones are likely to escape some incoming spore load. Some areas of potential naturalisation (such as the south-east of South Australia and the south-west of Western Australia) may be protected indefinitely through a combination of natural factors and management actions. Prevailing weather patterns and large intervening regions of unsuitable climate offer some protection. Strong biosecurity precautions (focussed on the human vector aspect) will also offer important protection. Some smaller 'islands' of potentially rust-suitable habitat in eastern Australia, while much closer to areas of permanent Myrtle Rust establishment, may have escaped infection to date (detections are lacking, but so are targeted searches), and may continue to do so. Possible examples (not confirmed by field checks) include the moister plant communities of the Nandewar Ranges of NSW, and of the gorge country of Central Queensland.

Floristic determinants: The ubiquity of Myrtaceae in terrestrial ecosystems across most of Australia's non-arid environments virtually guarantees the presence of at least some nominally susceptible species in all areas that are fully or even marginally suitable for the establishment of *A. psidii* and the manifestation of Myrtle Rust disease. Field and greenhouse records of susceptibility to *A. psidii* indicate that a very high proportion of myrtaceous species can be expected to be susceptible to infection, albeit not necessarily exhibiting disease in the field, and if doing so then to varying degrees of severity and depending on the floristic composition of any one region. Of the 597 species of Myrtaceae native in Queensland (Bostock & Holland 2017), a figure including species of semi-arid habitats unlikely to ever harbour *A. psidii*, 145 species (24.3%) were reported by Pegg et al. (2014a) as identified hosts from 'natural' infections (i.e. in the wild or in open cultivation, and with greatly varying degrees of observed severity). An exact proportion of the *moist-habitat* species would be more meaningful, but data available for this review are inadequate to calculate this – it is nevertheless likely to be approximately double the above proportion. More Queensland records have accumulated since the 2014 study, and it is highly probable that many species actually subject to some level of infection were (and remain) absent from records due to insufficient survey.

The proportion of Myrtaceae that are known hosts in Queensland does not provide any sure guide to the breadth of floristic vulnerability elsewhere. Queensland has a high proportion of Australia's species and genera of the Tribe Myrteae. The Myrteae is one of the 17 tribes within the Myrtaceae (Wilson 2011), and has a particularly high proportion of susceptible species and genera (e.g. *Gossia*, *Rhodamnia*, *Rhodomyrtus*, among many others), although it is important to note that all 17 tribes have at least some (often many) Australian taxa known to be susceptible to *A. psidii* infection.

The south-west of Western Australia has an extremely high diversity of Myrtaceae at both generic and species levels, and while the myrtaceous tribes Myrteae and Kaneae (both of which contain a high number of susceptible genera and species) are absent from the region, all tribes present do contain known hosts. Several of these, particularly Melaleuceae, Leptospermeae, and Chamelaucieae, are highly speciose and contain a number of known host species of high susceptibility. A continued program of susceptibility screening of taxa within the areas deemed most likely to be suitable for Myrtle Rust seems desirable in principle, but may not provide much information about actual patterns of wild plant susceptibility unless conducted on a multi-provenance basis (cf. Potts et al., 2016, for Tasmanian *Eucalyptus* species).

FIGURE 12: Myrtaceae in Western Australia. Top: IBRA v7 Bioregions (©Commonwealth of Australia 2012) (red=1043 species of Myrtaceae). Lower: SW WA detail from Kriticos et al (2013): Ecoclimatic area suitable for Myrtle Rust.
Of the 2253 native Myrtaceae species in Australia, 1568 are in WA. 1043 of the WA species are in just 5 south-west IBRA bioregions: 502 in Geraldton Sandplain (GES), 378 in Swan Coastal Plain (SWA), 449 in Jarrah Forest (JAF), 154 in Warren (WAR) and 548 in Esperance Plain (ESP). Flora statistics courtesy K. Thiele, WA Herbarium, May 2013

Climatic and microclimatic determinants: Modelling studies aimed at predicting the eventual distribution of *Austropuccinia psidii* in Australia were initiated in the early 2000s, but were then by definition constrained to using overseas (mostly South American) data on rust occurrence and their climatic correlates.

One of the most widely promulgated of these pre-arrival predictive maps was that Booth & Jovanovic using the BIOCLIM program (in Glen *et al*. 2007; see also Booth et al. 2000), which showed risk areas for *Puccinia psidii* based on climatic conditions alone, and informed by South American field data and controlled-environment trials. In broad, this map and related smaller-scale projections for NSW, Queensland, and the NT, indicated:

- a high risk of pathogen establishment along the east coast from about Jervis Bay NSW to Cape York Qld (risk index 0.7—1.0, i.e. 70—100%), flanked to the inland by progressively lower-risk bands along the Great Dividing Range (0.5), and the western fall of the GDR (0.3—0.4);
- the far south coast of NSW, the east Gippsland and the Melbourne regions in Victoria, the north-west and north-east of Tasmania (including the Furneaux Islands group), and the southern tips of the Eyre and Yorke Peninsulas in South Australia, were all assigned a 0.3—0.4 (30-40%) rust risk rating;
- parts of the Western Australian coast in the Esperance region were assigned a 0.3—0.4 (30-40%) rust risk rating, as was a more or less continuous band along the coast from Bremer Bay to about Cervantes north of Perth;
- the Shark Bay and Carnarvon regions, Barrow Island, and the Kimberley coast from Broome to about Cape Bougainville, were all assigned a 0.3—0.4 (30-40%) rust risk rating;
- In the Northern Territory, parts of eastern and western Arnhem Land, and the Tiwi islands, were assigned a risk rating of 0.5—0.6; the remainder of the Top End of the NT (extending inland as far as Katherine) was assigned a 0.3—0.4 (30-40%) rust risk rating, as were disjunct areas along the Gulf of Carpentaria coast from about Borroloola to the Mornington Island region of Queensland, and much of the interior and western flank of Cape York Peninsula;

The east coast, Victorian and Tasmanian, and to some extent the NT projections have been largely validated by reality; the lower risk areas along the Tablelands and their western fall have as yet been subject only to very limited and possibly transient incursions.

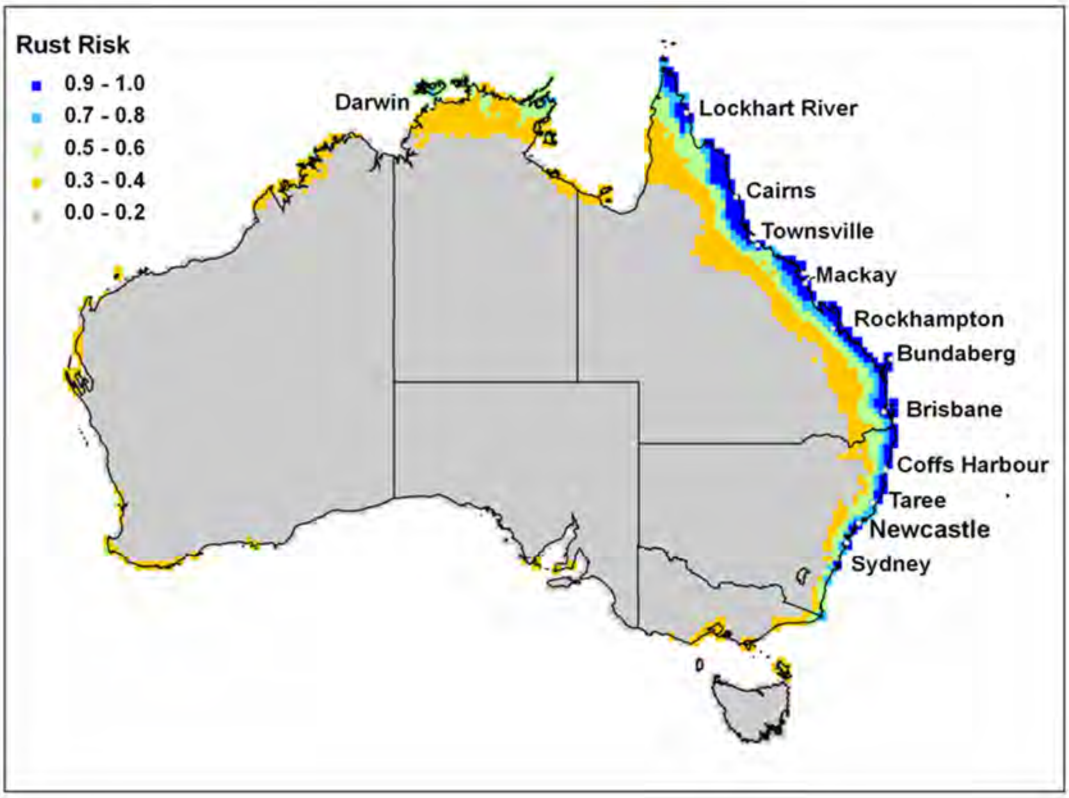

FIGURE 13: Revised rust risk areas for *Puccinia psidii* in Australia, generated by T. H. Booth and T. Jovanovic, first published in Glen et al. 2007 – see also Booth et al. (2000) and Booth & Jovanovic (2012) for context. Dark blue areas represent highest risk, light blue, light green and orange areas show decreasing levels of risk. Grey areas signify lowest risk.

An alternative risk map for Australia (using NAPPFAST software, based on overseas bioclimatic data for aggregated rust variants, and showing likelihood of Rust occurrence as climatically favourable years out of ten) was generated by Roger Magarey (USDA), published initially in Plant Health Australia (2009), and documented in Magarey et al. (2007). This map was noteworthy for showing a high likelihood of occurrence in a broader strip of the east coast and ranges, and a risk in a few years per decade extending from the coast well into inland Central Queensland (not to date realised in any actual infection reports), and in the semi-arid zone in parts of southern and central Australia. Victoria, Tasmania and New Zealand appear in this output of the model as almost risk-free. This map also indicated a high likelihood of permanent establishment through all but the highest elevation areas of Indonesia and Papua-New Guinea.

Elith et al. (2013; see also Elith & Burgman 2014), using MAXENT software, produced an instructive set of maps. These were a cautionary set of examples showing how different assumptions and constraints on the rather small available data sets, including taxonomic uncertainty of the sort prevailing in 2010-12, could produce drastically different map outcomes. The maps in the paper should thus not be taken as necessarily predictive. Their point remains valid, as the available data sets for *A. psidii* in Australia are still relatively small.

Kriticos et al. (2013) used CLIMEX software to generate a global climatic niche model. This was based on genotypically undifferentiated sources of occurrence data from the Americas and Hawaii, and available biological information on the pathogen's response to climate-associated variables. It involved the generation of an Ecoclimatic Index (EI) "which reflects the combined potential for population growth during favourable periods and survival during stressful periods"; the model was then validated using data from newly invaded areas of Australia, China and Japan (the pandemic strain). The global map of modelled EI largely confirmed the suitability of American and Hawaiian actual occurrence regions, but "in Eastern and Southern Asia, it is only limited by cold stress in northern China, and hot and dry stress in India, respectively … Highly favourable climates exist in coastal parts of the Mediterranean (restricted by hot and dry stress), high elevation areas throughout Central Africa, and eastern coastal regions of South Africa and Madagascar ... In Australasia, the island chains of the Solomon Islands, New Caledonia and Vanuatu are also highly suitable climatically (Fig. 4c). In New Zealand, much of the North Island and a very small area in the north of the South Island are climatically suitable." New Caledonia and NZ North Island have since been invaded.

For eastern Australia, the Kriticos et al. (2013) EI map largely corresponds with that of Booth & Jovanovic (in Glen et al. 2007, see above) for the zone of highest suitability along the east coast, but with a narrower zone of lower suitability west of the Great Divide in Queensland and a much broader lower-suitability zone west of the Divide in NSW and Victoria, and a larger area of vulnerability in south-eastern South Australia. For the south-west of WA, it indicates similarly narrow zone of high suitability from about Esperance to Bremer Bay, but then much larger zone of high suitability west of a line from about Bremer Bay to Cervantes, encompassing nearly all the most forest and seasonally moist shrublands of the region. Inland areas of the southern and northern wheatbelts are of lower suitability, with zero suitability north of Kalbarri.

The Kimberley and Gulf of Carpentaria coasts are shown as unsuitable, and only marginal areas of lower suitability are modelled for the Northern Territory (Tiwi Islands, Coburg Peninsula, and the far north-east of Arnhem Land). The generally low or zero suitability of the monsoon tropics seems to result from indices showing a low likelihood of pathogen survival during the Dry season, at least at the spatial scales for which climate data was applied. This may however underestimate the ability of the pathogen to survive in moist microclimates within areas of zero EI under the model. The authors note "significant uncertainty surrounding the wet and hot-wet tolerance limits for *P. psidii* when considering the modelled risks in the tropics."

Kriticos et al. (2013) then apply a spatial layer showing the species richness of Myrtaceae, confirming the highest density of potential hosts falling within the high-EI area of WA, and the next three highest EI areas all within the now-actual zone of *A. psidii* invasion in eastern Australia. A separate layer shows most hardwood forestry operations falling within the potential suitability zones defined by the model.

Berthon et al. (2018) used a constrained set of Australian Myrtle Rust occurrence data (276 'natural environment' records) to generate climate suitability within Australia under current and projected future (year 2050) climates. The use of Australia-only data to calibrate the model was intended to produce a tighter estimate of climatic niche, and to avoid the problem identified by Elith et al. (2013) of predictive errors resulting from multi-strain data (i.e. strains of the pathogen having different environmental tolerances). This study is also the first to factor in climate change.

Broadly, the Berthon et al. (2018) published maps for current climate show the existing naturalisation zone along the east coast, but with three regions of unsuitable climate on the northern Queensland coast. The southernmost of these, the rainshadow area from Rockhampton to just south of Mackay, certainly is climatically and floristically distinct, being drier overall. It nevertheless holds pockets of mesic (moist) vegetation types, with their own floristic composition, likely if Myrtaceae are present to harbour *A. psidii* on a permanent basis.

The other two suitability gaps are puzzling, but probably derive in part because of the exclusion from the model of all records from cultivated situations, because “nurseries and residential gardens … may have different microclimates due to active management such as provision of water and shade … The use of these occurrence data may overestimate the climate niche of this species.” This is true up to a point, especially for nursery records. However, it results in a number of host species for which the only available records are from open cultivation being excluded from the climate-suitability calculations.

A prime example is a set of species native to the Wet Tropics but known as infected only in arboreta and gardens in north-eastern NSW and south-east Queensland. Whilst these areas of cultivation do differ climatically from the Wet Tropics, the exclusion of these species appears to be the source of the oddly ‘unsuitable’ areas for *A. psidii* in the resulting maps, i.e. the areas on Cape York Peninsula from (approx.) Hopevale to Coen and from Lockhart River to Cape York. Again, these areas, while not rainforest dominated at the scale used for the model, harbour many vegetation types and species likely to be fully amenable for *A. psidii* establishment and persistence. The absence of records from them reflects the severe paucity of even the most basic presence/absence surveys in the region north of Mossman. It is highly unlikely that *A. psidii* is actually absent from these regions.

To the south, Berthon et al. (2018) show climatic suitability continuous along the NSW coast, into East Gippsland, and right across the southern third of Victoria, extending into the Mount Gambier area of South Australia and then patchy to about Strathalbyn. They show most of Tasmania, except a portion of the eastern interior, as suitable. The Western Australian suitability zone is much more limited in extent than that of the main map of Kriticos et al. (2013), being similar to that of Booth & Jovanovic (in Glen et al. 2007): i.e. near-coastal only, from about Israelite Bay to Yallingup. In the north of WA, only a very limited area of the north-west Kimberley is modelled as suitable, very small areas of the Northern Territory (too small to register on the published map), and none on the Gulf of Carpentaria coast.

For future (year 2050) projected climate, the model predicts for Queensland a narrow contraction of the suitable range for *A. psidii* along the western (inland) edge of its current distribution, and a narrow expansion of range along the western edge in NSW. It predicts a slight contraction southwards for Victoria and South Australia.

Berthon et al. (2018) calculate that under current climate, “1285 Myrtaceae species are at risk of exposure to myrtle rust. This number decreases to 1224 species under future climate.” This study also presents a revised Australian host list, estimates of host species overlap with current and projected distribution of *A. psidii*, and a prioritisation of species for conservation action based on the climatic suitability model – for discussion of each of these aspects of the study, see Section 6.1 below, and Appendix 4).

With all such predictive models:

- Output is affected by the quality and quantity of data available – the lack of systematic surveys for presence and severity of *A. psidii* establishment over most of susceptible Australia remains a major impediment to predictive studies, particularly for the north.
- Output is affected by the spatial resolution of input data – small areas habitat suitable for the rust within a less suitable matrix (and often also sheltering the only local occurrences of some of the more susceptible species) will tend to be swamped at the scales used; conversely, occurrence data is usually too scarce for fine-scale modelling.
- The few or single maps actually published represent a synthesised view of the range of possibilities generated under any one model.

No models should be regarded as absolute predictors. In the Australian context, the prospects for *A. psidii* naturalisation and invasive spread in the mediterranean climate of south-west WA, and in the monsoon tropics, both remain uncertain. In Victoria and Tasmania, and prospectively South Australia, it is often assumed that the failure to date of *A. psidii* to fully naturalise is largely a function of being near its southern climatic limit (notwithstanding some of the models), but an equally important factor may be a paucity of highly susceptible species (particularly of the tribes Myrteae and Kaniae) in those States, to generate critical infection and spore load levels.

2.3.3 What role for modelling Myrtle Rust parameters?

A question of some importance is the role of further modelling (climatic or other) in the evolving Myrtle Rust situation in Australia. Modelling is an increasingly popular method of attacking environmental problems, in a context of rapidly declining on-ground monitoring and research capabilities in many agencies. At its best, modelling may allow anticipation of spread, occurrence, and possible severity of effects at larger scales. At its worst, it can overdetermine conservation priority setting in a manner at variance with real (on ground) trends.

Subjects for modelling relevant to the coming phase of the Myrtle Rust problem include:

- Pathway modelling (for potential dispersal and arrival routes to as-yet unaffected areas such as Western Australia, or for the incursion of other strains of *A. psidii* to Australia or the Asia-Pacific region);
- Climatic and/or habitat suitability modelling for pathogen establishment (potentially incorporating host species distributions and densities, future climate regimes, and other determinants);
- Spread modelling, a combination of the above approaches and other relevant factors for the pathogen as a whole, or for subsets of the whole, e.g. the likely dispersal patterns of a new genotype by different vectors.

All can be informative for both economic and biodiversity conservation stakeholders.

At the present juncture, pathway modelling, both at the domestic (for WA and SA) and national/international levels, should be a high priority for both Australia, involving both the agricultural/forestry and biodiversity management sectors. This priority is included in the recommendations of this review, and the adjunct draft Action Plan.

Climatic/habitat suitability modelling may well be a priority for Western Australian and South Australian authorities. However, the current paucity of data points from both monsoonal and mediterranean climates and habitats, necessary for an informative model output, poses a challenge. Spread modelling faces an analogous challenge for those States, given the lack of hard information on transmission modes and vectors (although many working assumptions could be made). Both of these modelling themes could be taken further in eastern Australia, or retrospectively for the country as a whole as a learning exercise. Such studies would hopefully be fundable from ordinary competitive research grant schemes. If they were to draw of funds specifically earmarked for an environmental response, there would need to be a clear idea of what they might add in terms of management options or guidance. With the exception of WA and SA, which need to define their own priorities for this approach, the question has to be asked whether or not modelling of these subjects is likely to yield meaningful results at this point, or whether the higher priority (especially for the barely-existent conservation dollar) is ground-truthing of current effects and the accrual of data for modelling at a later stage.

PART 3: CURRENT HOST RANGE OF THE MYRTLE RUST PATHOGEN IN AUSTRALIA

3.1 Host range – global

The most recent consolidated and published global host list for *Austropuccinia psidii* dates from 2014 (Giblin & Carnegie 2014a, at http://www.anpc.asn.au/myrtle-rust). That list, of c. 446 taxa in 73 genera, is now well out of date, largely on the basis of new host records from Australia (now 394 hosts including taxa of exotic origin) and New Caledonia (67 globally new hosts reported in Soerwato et al. 2017). Based on these, a revised global list would now stand in excess of 500 taxa.

3.2 Host range – Australia

The Australian host list, from a single strain of the pathogen, far exceeds the number of taxa recorded from all strains outside Australia.

A revised Australian host list is provided at Appendix 3 of this review, building on two main prior works discussed below (Giblin & Carnegie 2014a; Berthon et al. 2018). Unlike those prior lists, the list presented here standardises names on the 'consensus' Australian botanical usage provided in the *Australian Plant Census* (APC) (https://www.anbg.gov.au/chah/apc/), which is endorsed by the Council of Heads of Australasian Herbaria (CHAH). The reasons for this and other points of variance from previous lists are discussed below and in Sections 3.3 and 3.4.

A further expansion of host range is to be expected, even without further geographic spread of the Myrtle Rust pathogen, as screening and observation data accumulate, and particularly as regenerative life stages (seedlings and coppice growth) are investigated in more species. The number of hosts reported from the Wet Tropics in particular is likely to increase. It should be noted that only about 3% of Australian species tested by controlled inoculation for susceptibility to the pandemic strain of *Austropuccinia psidii* have failed to sustain the uredinial life cycle (Berthon et al., 2018), and even in some of those cases the lack of uredinia may have been due to the experimental time period being too short for the appearance of overt symptoms (see, e.g., discussion of *Baeckea linifolia* in Winzer et al., 2018).

It is anticipated that the host list at Appendix 3 will be out of date almost as soon as published. In additional to the likely or confirmed new host reports noted above, a tranche of c. 17 new hosts from screening trials is expected to be published later in 2018 (Laura Fernandez Winzer, Macquarie university, pers. comm. June 2018), and some new hosts from North Queensland are in write-up by Jarrah Wills (Queensland Herbarium, pers. comm. June 2018).

TOTAL HOSTS RECORDED IN AUSTRALIA: 394

369 of the hosts recorded in Australia are native (i.e. 358 natural species or subspecies, plus 11 hybrids of Australian parentage). 25 of the hosts recorded in Australia are of exotic origin. See Appendix 3 for details.

Note: in six cases, infection has been recorded in separate studies from both a species-rank entity known to comprise two or more subspecies but without the subspecies being specified, *and* a definitely identified subspecies. In these cases, both the 'subspecies uncertain' record and the 'subspecies identified' records are counted as distinct, and both contribute to the host-taxon total. This follows the practice of Giblin & Carnegie (2014a). Subspecies distinctions are significant for conservation listing and action, and potentially for future research studies as they indicate untested potential for differences in susceptibility or resistance. Maintaining these cases as separate entities in the host list maintains an information level which would be lost if the records were merged, and flags these cases for future investigation. The cases involved are in: *Calothamnus quadrifidus*, *Corymbia citriodora*, *Eucalyptus camaldulensis*, *Eucalyptus globulus*, *Eucalyptus resinifera*, and *Leptospermum madidum*. It may be possible, through further investigation of records from the source studies, to clarify some cases and either assign the 'subspecies uncertain' records to subspecies already scored (which would reduce the host list slightly), or to subspecies not otherwise scored (which would increase it).

NATIVE AUSTRALIAN TAXA (non-hybrid): species, subspecies, named taxonomic (non-horticultural) varieties, and suspected distinct infraspecific taxa: **358**

Of these, 232 taxa are known from 'natural' infections (i.e. not from deliberate inoculation in screening trials, and variously in the wild or in cultivated situations). Of those 232, 183 taxa are known from natural infections *only*, and 49 from *both* natural infection and deliberate inoculation records. The balance of Australian non-hybrid infections, 126, are from deliberate inoculation trials only. See Appendix 3 for details.

Two native species included on the host list at Appendix 3, *Rhodamnia longisepala* and *Rhodamnia whiteana*, are included on the basis of detailed expert observer reports (in both cases here assessed as fully reliable for host identification, and recording heavy infection). Both these species still require some supporting photographic evidence (in the absence of direct inspection by a pathologist) for full acceptance by the Myrtle Rust Environmental Impacts Working Group. They are included among the 'medium priority' species for field impact survey and germplasm capture in Part 8 and in the draft Action Plan (Makinson 2018).

A further new host report, which came to my attention too late for inclusion in Appendix 3 and the statistics for this review, is for *Baeckea frutescens*. Pegg et al. (2018) apply to it a susceptibility rating of relatively tolerant to moderately susceptible. They report more than 50% of trees sampled on the NSW far North Coast, having dieback on 50% or more of their branches, and reduced flowering on affected axes. *B. frutescens* occurs in both NSW and Queensland.

A further species, *Eucalyptus andrewsii* (reported under the preferred Queensland synonym of *E. montivaga*), known from a single less detailed observer report of heavy post-fire infection but lacking other evidentiary support, is here excluded from the host list, but is regarded as a probable host, requiring urgent field investigation to confirm. This species is included in the priority list for field impact survey in Part 8 (Recommendations) and in the draft Action Plan (Makinson 2018).

Two further new native host species reports, here considered likely to be accurate but lacking optimal evidence for the gatekeeper Myrtle Rust Environmental Impacts Working Group to confirm the infection, are not included in the host list at Appendix 3, but are recommended as 'keep watch' species for field observers (with a request for photo evidence). Both reports are from the Eurobodalla Regional Botanic Garden (M. Anlezark, Manager, *in litt*. 4 Oct. 2016) on the NSW South Coast, the initial reports courtesy of L. Fernandez at Macquarie University. The individual plants involved are linked to vouchers in the ERBG herbarium. *Kunzea parvifolia* (voucher ERBG8456) is reported as becoming infected in nursery propagation in both 2015 and 2016. *Leptospermum myrtifolium* (voucher ERBG 7130) is reported as becoming infected both in nursery propagation and in open cultivation in the Botanic Garden, also in both 2015 and 2016.

HYBRIDS of Australian parentage: 11

Hybrids may or may not be indicative of susceptibility or resistance in parent taxa. These hybrids are in the genera *Corymbia* (2), *Eucalyptus* (5), *Leptospermum* (2), *Syzygium* (1), and *Verticordia* x *Chamaelaucium* (1). See Appendix 3 for details.

EUCALYPT host numbers:

The pandemic strain of *Austropuccinia psidii* is known to be capable of infecting 107 species or subspecies in the three eucalypt genera, one of them exotic, and seven hybrids. The low proportion of natural infections recorded to date (compared to some other genera) is encouraging, but monitoring has been patchy, especially for seedling and coppice growth. See Appendix 3 for details.

- *Angophora* (3 species or subspecies, all with known 'natural' infection)
- *Corymbia* (9 species or subspecies, four from deliberate inoculation testing only, and five from *both* natural infection and inoculation testing), plus 2 hybrids (one from natural infection, one from inoculation only);
- *Eucalyptus* (95 species or subspecies, one exotic and 94 native; four from natural infection only, eleven from both natural and inoculative infection, and 80 from inoculation testing only), plus 5 hybrids (all from inoculation testing only).

EXOTIC TAXA (including hybrids) recorded as infected in Australia: 25

These are in the genera *Eucalyptus* (1), *Eugenia* (3), *Lophomyrtus* (3, one a hybrid), *Metrosideros* (7, one a hybrid), *Myrciaria* (1), *Myrtus* (1), *Pimenta* (1), *Psidium* (1), *Rhodomyrtus* (1), *Syzygium* (4), *Ugni* (1), *Xanthostemon* (1). See Appendix 3 for details.

AUSTRALIAN HOST GENERA : 49

These are genera represented by one or more species native to Australia. Some of these genera also occur outside Australia. Generic names used here follow the generic names recognised in the Australian Plant Census (https://www.anbg.gov.au/chah/apc/) and for that reason among others this set differs from that in previous lists (e.g. Giblin & Carnegie 2014a; Berthon et al. 2018) – see Section 3.3 under 'Host name standardisation for rationale). Host lists using other base nomenclature would have a genus number ranging up to 57 (e.g. Pegg et al., 2018).

The number of native host taxa in each genus is indicated in brackets, (hybrids excluded): *Agonis* (1), *Allosyncarpia* (1), *Angophora* (3), *Archirhodomyrtus* (1), *Asteromyrtus* (2), *Austromyrtus* (2), *Backhousia* (12), *Baeckea* (3), *Barongia* (1), *Beaufortia* (2), *Callistemon* (13), *Calothamnus* (4), *Calytrix* (1), *Chamelaucium* (1), *Corymbia* (9), *Darwinia* (3), *Decaspermum* (2), *Eucalyptus* (94), *Eugenia* (1), *Gossia* (13), *Homoranthus* (7), *Hypocalymma* (1), *Kunzea* (4), *Lenwebbia* (4), *Leptospermum* (27), *Lindsayomyrtus* (1), *Lithomyrtus* (2), *Lophostemon* (1), *Melaleuca* (26), *Metrosideros* (2), *Mitrantia* (1), *Neofabricia* (1), *Osbornia* (1), *Pilidiostigma* (4), *Regelia* (1), *Rhodamnia* (16), *Rhodomyrtus* (7), *Ristantia* (2), *Sphaerantia* (1), *Stockwellia* (1), *Syncarpia* (1), *Syzygium* (60), *Thaleropia* (1), *Thryptomene* (2), *Tristania* (1), *Tristaniopsis* (3), *Uromyrtus* (4), *Verticordia* (2), *Xanthostemon* (5).

3.3 Australian host lists – background issues

3.3.1 Issue -- host list scope:

A bare host list of species known to be subject to infection is useful. A static list, with no or rare frequency of updating, is much less so. A dynamic host list, going beyond bare host identity, is the optimum. To be fully useful for both agricultural and biodiversity management stakeholders, a host list should:

- be dynamic (frequently updated);
- have evidentiary standards applied by an informed expert gatekeeper panel (botanical and plant health/pathology);
- be resourced to allow data validation, with established lines of collaboration for further field checking where necessary;
- incorporate data beyond host identity and relevant to major stakeholder sectors (optimally informative about the geographic scope of occurrences; the context – wild, agricultural, lab, affected life stages of host species, etc; disease severity and symptomology; observations or data on variation in susceptibility; key conservation related information (listing status, natural distribution of the host, etc); and reference (source) information.

An optimal host list should also be easily publicly accessible, and on a stable web platform not subject to churn, preferably alongside other Myrtle Rust information relevant to various stakeholder groups.

The accrual of this range of data obviously implies that an optimal host list would be one output of an integrated monitoring program, able to accept data from and to service a dispersed monitoring effort (agencies, non-government specialists, and skilled citizen science observers).

This is not utopian. The Australian host list at Appendix 3 of this review, and the previous lists on which it builds, have been generated precisely from an effort of this sort, hitherto very much thanks to key primary industry players but with significant contributions from a wider network. The possibilities for extension of the information base by bringing more conservation sector players on board, is evident.

3.3.2 Issue – host list maintenance and evidentiary standards:

Myrtle Rust host lists on a State basis were initially compiled by departments of primary industry, as the lead response agency in each affected jurisdiction, as remains the case in the NT, Victoria, and Tasmania. As the pathogen became fully naturalised in NSW and Queensland, and agriculture agency priorities moved on, the maintenance there of up to date State host lists was no longer an assigned priority. Lists developed by State governments in affected jurisdictions, in all cases by the primary industry agency, have variable levels of currency – those of Victoria, Tasmania, and Northern Territory are up to date as at February 2018; those of NSW and Queensland are well out of date. Existing official State lists therefore cannot be simply merged to give an accurate national host list.

An assessment of the reliability of new host reports, before the inclusion of new hosts on national and global lists, is vital. Many Myrtaceae species look very similar to close relatives, and the identity of the host needs expert confirmation in all cases, either by specimen or by diagnostic photographs and ancillary data. Similarly, confirmation of the apparent infection as *A. psidii* needs at least photographic evidence of uredinial pustules. State agencies that have accumulated reports, usually the primary industry agencies, have consistently referred host evidence to Myrtaceae experts for confirmation, and have the internal capacity to confirm disease identity. New host reports from these agencies are regarded as reliable (except for occasional host nomenclatural details).

Nationally, no agency, agricultural or environmental, has seen fit to allocate the resources to establish either a national reporting point for new hosts and extensions of range, or for the minimal (c. 15 days/year) required to assess reports and maintain an up to date and scientifically rigorous national host list (erroneous and inadequately substantiated reports being common). The assessment and national list maintenance role has devolved to a largely own-time effort by a few concerned scientists in two agricultural agencies, two herbaria, and one non-governmental organisation, and published on an NGO website. The same group have maintained and published the nearest-to-current global host list. The practitioners involved are part of an informal, un-auspiced and unfunded national working group of concerned scientists (the Myrtle Rust Environmental Impacts Working Group, MREIWG). A sound although somewhat slow practice has evolved of collective scrutiny of new host reports and supporting evidence by a core membership of this group, including leading Australian experts on Myrtle Rust and the Myrtaceae, before taxa are approved for addition to the national host list. The absence of a national reporting point supported by agencies, and of an agreed national evidentiary standard, is a major hindrance to this work, as is the own-time labour input by those involved. Funding does not exist to enable follow-up of some high-probability reports of new hosts in the field, and there is heavy dependence on self-motivated and self-funded collaborators.

While the small group of practitioners concerned with the maintenance of the national host list have established preferred levels of evidence for the assessment of now host reports, these have not been widely promulgated. Similarly, field pro-formas for recording the incidence, severity and effects of Myrtle Rust disease on any species are available in slightly discrepant versions, but have not been packaged for general availability. Nor have they yet been complemented by a set of botanical/ecological field data prompts, to capture demographic and ecological aspects of target species and populations.

Both field pro-formas, and new-host reporting protocols (to encourage the frequency, accuracy and consistency of reports), should be developed to accompany on-line host lists. This is regarded as a priority by the MREIWG. The lack of such protocols, widely promulgated, and the lack of a resourced national clearing house for this and other functions related to Myrtle Rust, are a hindrance to the prompt flow of information that would assist detection of and response to the pathogen in both the production and conservation sectors (and save researchers much time).

A project currently in its early stages, funded by the National Environmental Science Program and based in Queensland (R. Fensham, Queensland Herbarium and UQ), is developing a citizen science reporting tool and web interface for Myrtle Rust. This project, while valuable and long overdue, is likely to generate new host reports and data – the issues of a permanent repository, and its relationship to the MREIWG for new host reports, are not yet resolved.

The host range of the Myrtle Rust pathogen in Australia and globally continues to expand, with rapid surges of new host reports as the disease reaches each new biome or region. Maintenance of an accurate and up to date host list and associated data is a fundamental part of tracking the pathogen and its effects. It is essential for alerting conservation agencies and other (including commercial) stakeholders, prioritising conservation actions, detection of new strains of the pathogen, and contributing to knowledge of phylogenetic patterns of susceptibility and resistance.

To be of maximum utility for conservation users, and without disregarding the needs of international plant name comparison in other disciplines (plant pathology, biosecurity, forestry), an Australian host list (or a version thereof) should also:
(b) include States of natural occurrence,
(c) include current extinction-risk categories for all jurisdictions,
(d) clearly indicate exotic (introduced) hosts recorded as infected in Australia.

Other key biological information, or references thereto (e.g. known seed orthodoxy/not), could also be added to the public side of a repository for monitoring data, perhaps on a moderated 'small-crowd-sourced' basis, greatly simplifying aspects of conservation action planning and research preparation and communication, given the otherwise dispersed nature of current information.

A further issue requires early resolution: the nomenclatural standard to be used for host species.

3.3.3 Issue – host name standardisation:

Plant taxonomy is a dynamic science with continual research resulting in a better understanding of the phylogeny and diagnostics of Australian (and global) plant species and their relationships. Plant scientific nomenclature follows the taxonomy, but is in some sense a separate step. Differences of scientific opinion between researchers, and different 'house views' between State, Territory, and national herbaria, mean that for some taxa the names applied vary across Australia, and overseas. The scientific validity of the taxon as such is rarely an issue among the known Myrtle Rust hosts to date. For the most part (at least in Australian Myrtaceae), the disputed elements are relatively few, and relate to either the *rank* of the taxon (whether it is a species or subspecies), or to its *generic assignment* (the genus into which it should be classified) – this results in *competing synonyms* (names) for the same taxon. Coupled with this is a tendency for some less taxonomically inclined researchers to use genuinely obsolete names supplied with their research material.

An example is the Anise Myrtle, a highly susceptible Myrtle Rust host, which was originally described as *Backhousia anisata* Vickery. That name is now regarded by all relevant experts as an obsolete synonym, but opinions differ as to whether the taxon is best classified in its own genus as *Anetholea anisata* (Vickery) Peter G. Wilson (the NSW Herbarium house view), or should be placed into the large genus Syzygium as *Syzygium anisatum* (Vickery) Craven & Biffin. These are current competing synonyms, either of which is scientifically valid. There is no dispute in this case as to the validity or circumscription of the taxon, or its rank as a species. The *Australian Plant Census* treats it as *S. anisatum*. In other cases, scientific opinion differs over rank, e.g. *Eucalyptus bicostata* versus *Eucalyptus globulus* subsp. *bicostata*.

National and international plant lists from conscientious researchers will generally lead with a preferred name but include competing and recently obsolete synonyms, for clarity of communication. Databases however do not cope with this discord as well as the human mind. For data-exchange purposes alone, some level of national standardisation is needed, without overriding the scientific independence of views of researchers and institutions. The *Australian Plant Census* provides a consensus view of nationally preferred nomenclature, without implying a taxonomic judgement as to which of the currently competing generic assignments is correct. APC is highly current for Myrtaceae occurring in Australia (native and introduced), and is likely to remain so. APC also requires a formulation for phrase-names of undescribed taxa that incorporates a unique identifier, avoiding the problem of confusion between 'sp. novs' within any one genus.

An additional problem relates to international plant nomenclature. Myrtle Rust host lists in each affected State or Territory have tended to follow the preferred local herbarium usage. At this local scale, nomenclatural disharmony is avoided or at least externalised. Australian consolidated national host lists to date (Giblin & Carnegie 2014a; Berthon et al. 2018) have had to deal with the disharmony and have followed an eclectic mix of State-preferred nomenclature, some APC-based usage, and some adherence to an international list of species names known as *The Plant List* (http://www.theplantlist.org/). *The Plant List* is a collaborative data set coordinated and maintained by US and UK institutions. *The Plant List* for Myrtaceae is however out of date for, and out of kilter with, Australian Myrtaceae for some taxa, especially newly described and 'undescribed' phrase-name species, many of which are of conservation significance. It does not for example recognise *Lenwebbia sp. 'Blackall Range* PR Sharpe+ 5387*'*, or *Lenwebbia sp. 'Main Range'*, both acutely threatened by Myrtle Rust (and both recognised in APC). *The Plant List* does not draw directly from the APC, so a time lag up to some years may occur before it recognises names in use in Australia, and the generic assignments it makes are based mainly on northern hemisphere views rather than current Australian views. These are sometimes in discord.

Plant pathologists and plant health scientists operate within a highly globalised discipline and communications network, with a strong bias towards agricultural and forestry species of international distribution. This validates a preference for global consensus plant name lists, such as *The Plant List*. Botanical taxonomists and conservation practitioners also operate within a strong global context, but in countries like Australia, New Zealand and New Caledonia, where there is a very high degree of plant endemism, more weight is given to the insights provided by local research. The two sectors unfortunately have historically had limited cross-over in research priorities and cross-awareness. The parochial and disciplinary disharmonies of plant nomenclature and preferred data sources are historically entrenched, and are reinforced by the still-limited interoperability of data systems based in different agencies and jurisdictions, and with different core data prescriptions.

There is no solution to the competing synonym problem that will satisfy all parties, and a switch at any stage between preferred nomenclatural standards for Myrtle Rust host lists can be seen as causing disharmony in the literature. That disharmony however already exists wherever names vary – the problem is simply externalised by the choice of any one standard (or by an eclectic mix). With Myrtle Rust in Australia increasingly becoming a major problem of biodiversity conservation, the maximum possible concordance of host nomenclature with the usages in the botanical, ecological, and legislative extinction-risk areas is desirable.

APC-compliant nomenclature for the Australian host list best serves that need. APC compliance would also provide an acceptable standard for the development of, or use of existing, data repositories currently not deployed on the Myrtle Rust problem. The AusPestCheck information system (maintained by Plant Health Australia, and increasingly used by State agriculture and forestry agencies) would for example be a strong candidate for national storage or duplication of the *spatial* data associated with *A. psidii* records, and those of future environmental pathogens. To play such a role however it needs to adhere to a defined national standard list of host names. Interoperability of this or other possible repositories with conservation and botanical databases would also require a standard.

3.4 Australian host lists – past and current

The host list provided at Appendix 3 uses *Australian Plant Census*-preferred host plant names as the 'lead names' for each taxon, but every effort has been made to include beneath these the recently obsolete synonyms and current competing synonyms. The list presented here builds on the two prior published Australian host lists discussed below.

As *Austropuccinia psidii* spreads, it becomes progressively more difficult for the new host reports to be generated by, or at least checked in person by, the very small teams of Myrtaceae and disease experts responsible for the rigorous standards of the 2014 list (Giblin & Carnegie 2014a). The informal Myrtle Rust Environmental Impacts Working Group (MREIWG), which includes a number of such experts, has assumed a gatekeeper role for the assessment of new host reports. The verification process however is unresourced in NSW and Queensland, and with increasing frequency reliance has to be placed on photographic evidence supplied by other parties. Images need to be adequate for both host identification and confirmation of unambiguous *A. psidii* presence (usually the yellow uredinia).

A number of new host reports yet to be assessed by the MREIWG have surfaced during a recent study by Berthon et al. (2018), and a few more during the consultative processes for this Review, including two apparently severely affected species and one in catastrophic decline. Some of those new host reports are here accepted in the host list at Appendix 3, but still require some elements of evidence to allow evaluation by the MREIWG. Other reports, probably fully reliable, lack to a slightly greater extent the evidentiary level preferred by the gatekeeper expert group – these are not included in the host list at Appendix 3, but are noted in Section 3.3 above. Others still are anticipated as a result of susceptibility tests now being written up (L. Fernandez Winzer, Macquarie University) and field surveys in the Wet Tropics (J. Wills, Queensland Herbarium).

Baeckea frutescens, a species of coastal heaths in NSW and Queensland, is now fully confirmed as a host by Pegg et al. (2018), but this information was seen too late for its inclusion in the host list and statistics for this review.

3.4.1. The Giblin & Carnegie (2014a) list:

The most authoritative consolidated Australian host list for *Austropuccinia psidii* published to date (Giblin & Carnegie 2014a, at http://www.anpc.asn.au/myrtle-rust) listed 346 taxa in 56 genera, comprising 325 native and 21 exotic taxa recorded as infected in Australia. 11 of the native taxa were hybrids of Australian species parentage (where known, hybrid parentage can be useful as an indicator for further screening for susceptibility or resistance). Hybrids subtracted, there were 314 species, subspecies, or named varieties of Australian native plants as known hosts.

This 2014 host list remains largely valid, but is now outdated by an accretion of new host records. In the absence of systematic surveys, a central reporting point, survey guidelines, and broadly promulgated guidelines for the type of evidence needed for new-host assessment, the reporting and evaluation of new hosts is often haphazard, resulting in delays which retard a conservation response. Some but not all new-host records have been received (or traced) and evaluated by the MREIWG, including reports located by Laura Fernandez Winzer (Macquarie University), and other sources (e.g. 30 Tasmanian *Eucalyptus* species from screening studies by Potts et al. 2016). Some other recent records, especially from Queensland and the Northern Territory, have been validated for both pathogen and host identity by primary industry department and local Herbarium expertise.

Two apparently erroneous host records in the Giblin & Carnegie (2014a) list have come to light, and are not included on the host list advanced in this review:

- *Eucalyptus drepanophylla*, shown as an inoculation record sourced to CSIRO, is traceable to Morin et al. (2011), but corrected in Morin et al. 2012 (Supplementary Table S1, footnote 'w') where it is noted as a misidentification of *E. siderophloia*. No other host reports for *E. drepanophylla* are known. *E. siderophloia* is also known from 'natural' infection in NSW and is retained as a known host.
- *Corymbia calophylla* x *C. ficifolia* hybrid, shown as an inoculation record, University of Sydney, and traceable to Sandhu & Park (2013), where it is scored as a '?' response ('not clear'), i.e. no uredinia observed.

Two species records for which primary documentation of infection has not been located by this reviewer, but which were published by Giblin & Carnegie (2014a), are retained on the list:

- *Eucalyptus cephalocarpa* and *Eucalyptus goniocalyx* [subsp. uncertain], both shown in Giblin & Carnegie (2014a) as inoculation records from work at the University of Sydney; both are mentioned in Sandhu & Park (2013 – Table 6) as species with testing "in progress" but not mentioned in the published results in that paper; it is assumed that unpublished confirmation of infection led to their inclusion by Giblin & Carnegie (2014a).

3.4.2. The Berthon et al. (2018) list:

An 'Updated Australian host list' is presented by Berthon et al. (2018 – Supplementary Table S1), comprising 417 named taxa and formula hybrids. They calculate the number of Australian native host species as 380, across 52 genera, and state that of these, 38% are known hosts from inoculation trials only, 48% from field observations (wild or cultivated), and 13% from both. They report that only 3% of species screened for susceptibility to the pandemic strain in Australia seem 'immune'.

The study calculates that 69% of native Australian genera have had fewer than 50% of their native constituent species screened for susceptibility; these genera range from very small (less than five species) to very large (*Eucalyptus*, *Syzygium*, *Melaleuca/Callistemon*). An important conclusion is that all taxa within the following 17 genera are known to be susceptible: *Allosyncarpia*, *Archirhodomyrtus*, *Barongia*, *Cryptocarya* [*sic* – in error see below], *Eugenia*, *Lenwebbia*, *Lindsayomyrtus*, *Metrosideros*, *Mitrantia*, *Myrtus*, *Osbornia*, *Rhodomyrtus*, *Stockwellia*, *Thaleropia*, *Tristania*, *Tristaniopsis*, and *Uromyrtus*. They also note that "Only a few genera, including *Eucalyptus*, *Lophostemon*, *Pilidiostigma*, *Syzygium*, and *Sannantha*, have at least one species recorded as completely resistant to myrtle rust on the basis of inoculation trials." (op. cit.)

Berthon et al. (2018) estimate that "there are 1285 species of Myrtaceae that occur in climatically suitable areas for myrtle rust in Australia under current climatic conditions. This includes 92 species listed as endangered at State level, and two at a national level" – it appears however that 'endangered' here should be read as 'threatened in one of three IUCN categories', 'endangered' being only one of these. Note also that these figures include some climatic areas not currently occupied by *A. psidii*, and are contingent on Berthon *et al*.'s modelling assumptions and parameters – see Section 6.1 and Appendix 4, for a discussion of issues.

The Berthon et al. (2018) host list and its derived statistics contain much new information, but also some errors, and certain caveats apply. It includes a number of taxa as hosts which were obtained for, or included in, screening studies, but for which definitive evidence of infection or completion of the uredinial life cycle is lacking; this is implicit in the legend to the supplementary table S1, but is nowhere explicit. The view taken here is that, while null or inconclusive scores from susceptibility trials are undoubtedly informative, taxa that have not shown a capacity to sustain the uredinial cycle of the pathogen should not be included on a 'host' list. These taxa are excluded from the host list presented in this review at Appendix 3, except where other and positive records exist to indicate completion of the rust life cycle. The problematic taxa on the Berthon et al. (2018) host list, excluded as hosts for this review, are:

- *Acca sellowiana* (exotic), *Corymbia calophylla* (R-L rating, resistant to low susceptibility), *Eucalyptus grandis* x *camaldulensis* (R), and *Psidium cattleyanum* (R-L), which are all sourced to Morin et al. (2012), but that paper and Morin et al. (2011) both assign them only disease scores of 1 ("no visible symptoms or some discolouration or chlorosis present that cannot categorically be attributed to the rust") or 2 ("chlorotic, purplish or necrotic spots or blotches only); i.e. no uredinia were observed. They are excluded here.

- *Eucalyptus andrewsii*, citing Morin et al. (2012) in error; *E. andrewsii* was scored positive for infection in a precursor report by Morin et al. (2011), but the identification was corrected in Morin et al. (2012, Supplementary Table S1, footnote 't') to *E. campanulata*. *E. campanulata*, is omitted as a host by Berthon et al. 2018, but reinstated here. *E. andrewsii* was not included on the list of Giblin & Carnegie (2014a), and is provisionally excluded from the host list in this review. However, a single field report exists of heavy infection on *E. montivaga* (the Queensland-preferred name for *E. andrewsii*) from G. Paterson, ecological consultant of Mackay Qld; unfortunately this report is not yet confirmed to optimal evidentiary level (no photo of host and infection), but should be field-investigated.

- *Eucalyptus bicolor*, as a preferred synonym for *E. largiflorens*, citing Sandhu & Park (2013) who have it under the latter name. In that study however, *E. largiflorens* is given (Table 3) an infection response of '?' (uncertain, no uredinia), and the species is here excluded. The *Australian Plant Census*, followed here, treats *E. bicolor* as a questionable synonym of *E. largiflorens*.

- *Eucalyptus bosistoana*, *E. caleyi*, and *E. melliodora*, similarly citing Sandhu & Park (2013), who assigned each of them a '?' ('uncertain') inoculation response, i.e. no uredinia observed. No other infection records for these species have come to light, and they are here excluded.

- *Gossia shepherdii*, citing "Pegg, unpublished data". Pegg (*in litt*. March 2018) suspects an erroneous label and that the correct identity is *G. myrsinocarpa*, a known host from other sources. *G. shepherdii* is here excluded.

- *Lophostemon confertus,* sourced to Morin et al. (2012) who report "no visible symptoms", and Sandhu & Park (2013) who assign it a score of 'HR' (highly resistant, "no visible sign of infection"). No infection records are known despite the wide occurrence of *L. confertus* in the wild and as a street tree through much of the east coast Myrtle Rust zone. It is here excluded.

- *Sannantha angusta*, sourced to Morin et al. (2012), but which is there explicitly stated in M2012 to have "no visible symptoms"; it is here excluded.

- *Sanantha tozerensis*, citing "Pegg, unpublished data". G. Pegg (*in litt*. March 2018) confirms species checked but found 'resistant' i.e. no infection confirmed; it is here excluded.

- *Syzygium johnsonii*, citing "Pegg, unpublished data". G. Pegg (*in litt*. March 2018) confirms species checked but was found 'resistant' i.e. no infection confirmed; it is here excluded.

- *Syzygium mackinnonianum*, citing "Pegg, unpublished data". Pegg (*in litt*. March 2018) confirms that name was in raw data provided, but was omitted from his final report as host identity could not be confirmed; it is here excluded.

- *Syzygium monimioides*, citing Sandhu & Park (2013) in error (the species is not mentioned there), and "Pegg, unpublished data". Pegg (*in litt*. March 2018) confirms species checked but was found 'resistant' i.e. no infection confirmed; it is here excluded.

- *Xanthostemon crenulatus*, citing "Pegg, unpublished data". G. Pegg (*in litt*. March 2018) confirms the species was checked but was found disease free; it is here excluded.

Additional caveats on the use of the Berthon et al. (2018) revised host list include:

- *Cryptocarya laevigata* is included, citing 'NSW BioAtlas: Myrtle Rust records'. A search of the NSW BioNet Atlas (http://www.bionet.nsw.gov.au/) by this writer has not yet located this record, although it may have been since corrected there. More problematically, *C. laevigata* is in the family Lauraceae, which is nowhere known to be infected by *Austropuccinia psidii*. This host record should be discarded.

- Two separate entries from the Giblin & Carnegie (2014a) host list, for '*Decaspermum humile*' [known to be the southern metapopulation], and '*D. humile* North Queensland form', are conflated into a single entry. The Myrtle Rust Environmental Impacts Working Group (MREIWG) preference is to maintain them as separate as they may be distinct cryptic taxa (MREIWG, minutes of meeting 11 October 2016, unpublished), and were assigned markedly different susceptibility ratings by Pegg et al. (2014a); the MREIWG-preferred separate treatment is followed in this review.

- *Syzygium wesa* is reported as a new host based on 'NSW BioAtlas: Myrtle Rust records'. A search of the NSW BioNet Atlas (http://www.bionet.nsw.gov.au/) by this writer has not yet located this record, and at best (pending MREIWG assessment) it should be regarded as an unconfirmed host report, and is here excluded.

- *Psidium guajava*, citing Morin et al. (2012), which however reported it as showing "chlorotic or necrotic flecks without any uredinia"; and Sandhu et al. (2013) who rated it HR ("no visible sign of infection"). These elements of the Berthon et al. justification of the species as a host are here rejected, but the species is retained on the host list on the basis of the single natural infection record (in NSW) flagged by Giblin & Carnegie (2014a).

- Some other species included as hosts by Berthon et al. (2018) are similarly derived from 'no infection' or 'uncertain' responses in the source documents cited, but are recorded with positive infection in other sources as shown in the appended revised host list, and are here retained. These are *Eucalyptus brunnea* (= *E. deanei*), *E. dalrympleana*, *E. mollucana* ("no visible symptoms" in Morin et al. 2012), *Callistemon linearis* (natural infection record as the synonymous '*C. rigidus*' in Giblin & Carnegie 2014a), and *Lophostemon suaveolens* (no uredinia in Morin et al. 2012).

- Berthon et al. (2018) assigned new 'synthesised' susceptibility ratings to many taxa, in an attempt to represent the different infection scores and terminologies in original studies, including both field-based and glass-house/lab-based ratings. The latter types of inoculation study are indicative of susceptibility *per se* (and its variation), but are likely to be less useful as predictors of field severity (as per Pegg et al. 2014a). In some cases, particularly with low-susceptibility taxa, the synthesised ratings presented create some ambiguity unless the original studies are carefully checked.

3.5 Disease severity ratings

Laboratory and glasshouse susceptibility ratings from inoculation trials (optimal conditions for infection) are not reliably applicable in the field, where a variety of factors will determine how the disease manifests (if at all) – see *Biology and Ecology* section above. Ratings from wild and open-cultivated situations (termed 'natural' infections by plant health researchers, e.g. Giblin & Carnegie 2014a), are in general more likely to be more reflective of actual susceptibility in wild populations.

However, so far only Pegg et al. (2014a; 2018) have applied these ratings on a large scale. Pegg et al. (2014a) found that of 163 Queensland hosts, 48 (29%) fall wholly or partly within the Highly or Extremely susceptible categories. This proportion may not apply in other biomes.

Some glasshouse trials however produce severity data that may prove to be of very direct value for conservation purposes (apart from susceptibility per se) – the large-sample and multi-provenance screening of Tasmanian eucalypts by Potts et al. (2016) is the most informative study to date of susceptibility variation in seedling-stage eucalypts.

Attempts to synthesise disparate ratings from glasshouse or laboratory inoculation susceptibility testing, with those derived from open cultivation or wild situations, may produce uninformatively broad rating spreads. Ideally, an optimal host list would be accompanied by observational data on the susceptibility of adult-plant seasonal flush, post-fire re-sprouts, and seedlings for all taxa.

3.6 Known hosts on extinction-risk lists

83 Australian known-host taxa are listed on legislative or (for Victoria only) advisory extinction-risk ‘threatened species’ schedules in one or more jurisdictions; these are shown in Table 1 below. This includes two listings still in progress in NSW, one technically ‘unconfirmed’ host species in Queensland, and one parent of a known-host hybrid (the susceptibility of which may or may not be informative for the parent species). The table includes some hosts known only from inoculation tests or observations in cultivation, and not yet exposed to Myrtle Rust in the wild (e.g. SA and WA taxa) – see full host list at Appendix 3 for detail.

Nearly all the taxa shown have been listed on the basis of threats or declines *other than* Myrtle Rust. Very few (<4 ?) taxa have yet been listed in any jurisdiction with any consideration of the additional threat posed by this pathogen. Myrtle Rust can in many cases be expected to exacerbate the level of threat, assuming exposure of host populations in suitable climatic conditions.

However, it cannot be overemphasised that a known host being already listed as Threatened, even if it has a high susceptibility rating, *is not* a straightforward guide to the eventual level of threat, or to its priority for urgent conservation action and investment. Not all threat-listed known-hosts have their entire distribution within the Myrtle Rust environmental envelope (although many do), and current susceptibility ratings are based on limited observations (in the absence of a comprehensive integrated impact monitoring scheme).

Moreover, many of the species already suffering the most severe Myrtle Rust-related declines, including several at imminent risk of extinction, *are not currently listed in any jurisdiction*. The frequency of revision of the ‘threat lists’ varies with jurisdiction, but none operate rapidly, and no jurisdiction has yet taken proactive steps for precautionary listings. Many un-listed host taxa are much higher priorities for urgent conservation action than are many of the listed taxa.

Conservation action for those species already in steep decline but which are not currently listed as Threatened has been hampered over the last few years by the disinclination of some key granting bodies to fund actions for any taxa not on such lists. Given the lags and delays in listing in many jurisdictions (even prior to the advent of the Myrtle Rust pathogen), this problem has effectively precluded a proactive approach by agencies, institutions, and NGOs in a position to carry out data-gathering and precautionary actions. For example, the Commonwealth’s *Threatened Species Recovery Fund* Open Round in 2017 was restricted to species listed under the EPBC Act – only three of the 16 species regarded in this review as being the highest priority for conservation action are currently listed under that Act.

A more proactive approach to listing, based on projected declines, is essential if the risk-listing process is to catch up with the pace of Myrtle Rust impact and be a useful tool for guiding conservation action. Absent or pending that change, a widening of the eligibility terms for threatened entity funding, to admit as yet unlisted entities demonstrably threatened by Myrtle Rust, is essential if near-term extinctions from Myrtle Rust are to be minimised.

TABLE 1

Known hosts listed as Threatened or Near-threatened in Australian jurisdictions.

LEGEND AND NOTES:

- *Extinction risk codes*: **CR** = Critically Endangered, **r** or **R** = rare; **E** or **e** or **EN** = Endangered; **V** or VU = Vulnerable; **near-thr**. = Near Threatened; **T** = Threatened. Blank cells in the extinction-risk listings column indicate that the taxon is not listed in any Australian jurisdiction.
  Note: the codes and categories applied to indicate extinction risk in official lists vary with jurisdiction, in some cases even for equivalent categories (hence E, e, EN); they are rendered here as they appear the jurisdictional lists relevant to each taxon.
- Listings sourced from environment agencies and schedules, January 2018.
- Listings are legislatively gazetted in the jurisdictions shown, except for (a) entries derived from the Victorian non-legislative Advisory list, and (b) *Rhodamnia rubescens* and *Rhodomyrtus psidioides*, which have had Preliminary Determinations made for listing as Critically Endangered in NSW – final determinations not yet made.
- *Susceptibility rating codes*: RT = relatively tolerant, MS = Moderate susceptibility, HS = High susceptibility, ES = Extreme susceptibility.
- *Susceptibility rating source codes*: P2014 = Pegg et al. (2014a); P2017 = Pegg et al. (2017); P2018 = Pegg et al. (2018); Potts2016 = Potts et al. 2016.
- *Summary*: n = 83 taxa on legislative or advisory extinction-risk lists in one or more jurisdictions; this figure includes one parent species of one hybrid known-host, for which the actual susceptibility of each parent is not known.
  Commonwealth (EPBC Act) 18, Queensland 39, NSW 17, Victoria 9, Tasmania 8, SA 7, WA 8, NTerr nil.
- *Note*: *Rhodamnia longisepala* is technically an 'unconfirmed host', not having yet been approved by MREIWG for addition to the national host list, but the field report of A. Ford (CSIRO Atherton, pers. comms) of severe active (yellow pustule) infection on the Windsor Tableland, NQ, in September 2017 is here regarded as highly reliable for both host identity and disease occurrence.

Species (APC-preferred name)	**Synonyms**	**Susceptibility Rating**	**Extinction risk listings**	**Natural range**
Angophora floribunda			Vic (Advisory): r	Qld, NSW, Vic
Backhousia gundarara	Backhousia sp. sp. Prince Regent W. O'Sullivan & D. Dureau WODD 42); 'B. bundara' in error.	RT (Qld, in cult) (P2014)	WA: Priority 2	WA
Backhousia oligantha		HS (P2014)	Qld: E	Qld
Backhousia subargentea	Choricarpia subargentea		NSW: E	Qld, NSW
Baeckea linifolia		MS (P2014)	Vic (Advisory): r	Qld, NSW, Vic
Barongia lophandra			Qld: V	Qld

Species (APC-preferred name)	Synonyms	Susceptibility Rating	Extinction risk listings	Natural range
Callistemon formosus	Melaleuca formosa		Qld: near-thr	Qld
Callistemon linearifolius	Melaleuca linearifolia		NSW: V	NSW
Callistemon viminalis	Melaleuca viminalis	MS-HS (P2014)	WA: Priority 2	Qld, NSW, SA, WA
Calothamnus quadrifidus [subsp. *sensu* WA Florabase uncertain]			WA: subsp asper Priority 2; subsp. teretifolius Priority 4	WA
Calothamnus quadrifidus subsp. asper	Calothamnus asper		WA: Priority 2	WA
Darwinia glaucophylla			NSW: V	NSW
Eucalyptus agglomerata			Vic (Advisory list): r	NSW, Vic
Eucalyptus argophloia			Comm: V; Qld: V	Qld
Eucalyptus barberi		HR-VS (Potts2016)	Tas: r (rare)	Tas
Eucalyptus baueriana [subsp. uncertain]			Vic (Advisory): subsp. deddickensis e, subsp. thalassina e.	NSW, Vic
Eucalyptus camaldulensis (subsp. uncertain)			NSW: E population (Hunter Valley)	Qld, NSW, Vic, SA
Eucalyptus camfieldii			Comm: V; NSW: V	NSW
Eucalyptus camphora [subsp. uncertain]			NSW: E (subsp. relicta]	Qld, NSW, ACT, Vic
Eucalyptus curtisii		RT-HS (P2014)	Qld: Near-Thr	Qld
Eucalyptus dalrympleana		HR-VS (Potts2016)	SA: R	Qld, NSW, ACT, Vic, Tas, SA
Eucalyptus dunnii			Qld: V	Qld, NSW
Eucalyptus globulus subsp. globulus	Eucalyptus globulus [sens. strict.]	HR-VS (Potts2016)	Vic (Advisory): r	NSW, ACT* (naturalised), Vic, Tas, SA WA* (naturalised)
Eucalyptus globulus subsp. bicostata	Eucalyptus bicostata		SA: V; Tas: r [as globulus subsp. pseudoglobulus].	NSW, Vic, SA. (ACT* natiuralised)
Eucalyptus gunnii subsp. divaricata		HR-VS (Potts2016, (as 'E. gunnii')	Comm: E; Tas: e	Tas

Species (APC-preferred name)	Synonyms	Susceptibility Rating	Extinction risk listings	Natural range
Eucalyptus morrisbyi		HR-VS (Potts2016)	Comm: E; Tas: e	Tas
Eucalyptus pauciflora subsp. pauciflora		HR-VS (Potts2016)	SA: V	Qld, NSW, Vic, Tas, SA
Eucalyptus perriniana		HR-VS (Potts2016)	Tas: r; Vic Advisory List: r;	NSW, ACT, Vic, Tas
Eucalyptus radiata subsp.robertsonii		HR-VS (Potts2016)	Tas: r [subsp. robertsonii there treated as syn. of susp.radiata]	Qld, NSW. ACT, Vic, Tas
Eucalyptus risdonii		HR-VS (Potts2016)	Tas: r	Tas
Eucalyptus tereticornis [subsp. uncertain]		RT (P2014)	Subsp. rotunda: Qld: near-thr.	Qld, NSW, Vic, New Guinea
Eucalyptus viminalis [sens. str., = subsp. viminalis]		HR-VS (Potts2016)	SA: R	NSW, ACT, Vic, Tas, SA
Eucalyptus websteriana x E. crucis NB: hybrid; susceptibility of separate parents not known or confirmed			[WA: E. crucis subsp. crucis T-EN, subsp. praecipua T-EN; Comm: subsp. crucis E]	WA (both parents)
Gossia acmenoides		HS (P2014)	NSW: E (pop'n)	Qld, NSW
Gossia fragrantissima		MS (P2014)	Qld: E; NSW: E; Comm: E	Qld, NSW
Gossia gonoclada		HS (P2014)	Qld: E; Comm: E	Qld
Gossia inophloia	Austromyrtus inophloia	ES (P2014)	Qld: near-thr.	Qld
Homorathus croftianus			NSW: Endangered	NSW
Homoranthus montanus			Comm: V; Qld: V	Qld
Homoranthus papillatus		MS (P2014)	Qld: V	Qld
Homoranthus prolixus			NSW: V; Comm: V	NSW
Hypocalymma angustifolium [subsp. uncertain]		RT (P2014)	WA: T-VU [subsp. 'Hutt River (S. Patrick 2982)']	WA
Lenwebbia prominens		HS (P2014)	Qld: near-thr.	Qld, NSW
Lenwebbia sp. Blackall Range (PR Sharpe 5387)		RT (P2014) to ES (P2018)	Qld: E	Qld
Leptospermum barneyense			Qld: V	Qld
Leptospermum luehmannii		RT (P2014)	Qld: V	Qld, NSW

Species (APC-preferred name)	Synonyms	Susceptibility Rating	Extinction risk listings	Natural range
Leptospermum madidum subsp. sativum			WA: Priority 3	Qld, WA, NTerr
Leptospermum trinervium			Vic(Adv): r	Qld, NSW, ACT, Vic
Leptospermum wooroonooran			Qld: rare	Qld
Melaleuca armillaris [subsp. uncertain]			Vic (Advisory): r [subsp. armillaris]; SA: R [subsp. akineta]	Subsp. armillaris: NSW,Vic, Tas (naturalised ACT*, SA*, WA*). Subsp. akineta: SA
Melaleuca biconvexa			NSW: V; Comm: V	NSW
Melaleuca pustulata			Tas: r	Tas
Melaleuca squamea			SA: R	NSW, Vic, Tas, SA
Melaleuca squarrosa			SA: R	NSW, Vic, Tas, SA
Mitrantia bilocularis		MS (P2014)	Qld: V	Qld
Rhodamnia angustifolia		ES (P2014)	Qld: E	Qld
Rhodamnia glabrescens		MS (P2014)	Qld: near-thr.	Qld
Rhodamnia longisepala [see note above]			Qld: E	Qld
Rhodamnia pauciovulata		MS (P2014)	Qld: near-thr.	Qld
Rhodamnia rubescens		HS-ES (P2014)	NSW: Critically Endangered (prelim. Determination 2017)	Qld, NSW
Rhodomyrtus psidioides		ES (P2014)	NSW: Critically Endangered (prelim. Determination 2017)	Qld, NSW
Ristantia waterhousei		RT (P2014)	Qld: V	Qld
Sannantha tozerensis	Babbingtonia tozerensis, Baeckea 'Mt Tozer'		Comm: V; Qld: V	Qld
Sphaerantia discolor		MS (P2014)	Qld: V	Qld
Stockwellia quadrifida		HS (P2014)	Qld: V	Qld
Syzygium aqueum		RT (P2014)	Qld: V	Qld; Malesia, SE Asia, India

Species (APC-preferred name)	Synonyms	Susceptibility Rating	Extinction risk listings	Natural range
Syzygium buettnerianum			Qld: near-thr.	Qld; New Buinea, Solomon Is.
Syzygium glenum			Qld: E	Qld
Syzygium hodgkinsoniae			Qld: V; NSW: V; Comm: V	Qld, NSW
Syzygium macilwraithianum		RT (P2014)	Qld: V	Qld
Syzygium moorei		RT (P2014)	Qld: V; NSW: V; Comm: V	Qld, NSW
Syzygium mulgraveanum	Waterhousea mulgraveana	RT (P2014)	Qld: V	Qld
Syzygium paniculatum		RT (P2014)	NSW: E; Comm: V	NSW
Syzygium rubrimolle		RT (P2014)	Qld: V	Qld
Syzygium velarum			Qld: V; Comm: V	Qld
Thryptomene calycina			Vic(Advisory): r	Vic, SA
Uromyrtus australis			Comm: E; NSW: E	NSW
Uromyrtus lamingtonensis			Qld: V	Qld, NSW
Verticordia plumosa [var. uncertain]			Comm: vars ananeotes, vassensis - both. EN]; WA: var. ananeotes T-CR,; var. vassensis T-EN.	WA
Xanthostemon formosus			Comm. E; Qld:E	Qld
Xanthostemon graniticus			Qld: Vulnerable	Qld
Xanthostemon oppositifolius		HS (P2014)	Qld: V; Comm: V	Qld

Some of these listed, known-host species may not be exposed to serious risk from Myrtle Rust, at least in the jurisdictions where they are so listed, and under current climate. Most however are either already exposed or are at some level of risk of exposure if the geographic range of Myrtle Rust expands, and many are known to be in the higher susceptibility categories on at least a partial basis.

Not all the above species are on the list of priority taxa advanced in this Review (see Part 8), which is constructed on the basis of current known or suspected impact. Nevertheless, precautionary actions for *all* species on the list in Table 1 above, including the securing of large and representative germplasm collections, would be a prudent conservation step.

A range of *ecological communities* are at risk from the direct impact of Myrtle Rust on dominant or otherwise important species, and the cascade effects on other biota that may result. Many of these ecological communities are already listed as threatened in one or more jurisdictions for reasons other than, and pre-dating, the arrival of the Myrtle Rust pathogen. They are discussed in Section 4.6 below.

PART 4: IMPACTS

4.1 Impacts of *Austropuccinia psidii* on wild biodiversity outside Australia

Most of the land masses invaded by *Austropuccinia psidii* in the central and western Pacific region and south-east Asia have only been under its influence for a few years (see Section 1. 1, Global Context, above). Some (China, Japan, Hawaii) have a relatively low level of native myrtaceous diversity at both species and generic levels, at least in the areas known to be affected, although the family may still be an important component of the natural ecosystems and cultural heritage (e.g. Hawaii and New Zealand). Myrtaceae-rich countries (Malaysia, Singapore, Indonesia, New Caledonia, and potentially New Guinea and adjacent islands) are more comparable to Australia in terms of myrtaceous floristics, and have a higher proportion of the tribes (e.g. Myrteae, Syzygiaeae, Melaleuceae) with particularly high proportions of susceptible species. In most countries of the region, conservation infrastructure is less developed than in Australia and New Zealand. Only a few instances of impact on native biodiversity at species and ecosystem level have yet been reported.

In Hawaii, *Austropuccinia psidii* (ʻŌhiʻa Rust) arrived in 2005 and within a year had spread to most islands of the chain. As of March 2016, there were 38 native and exotic hosts recorded. ʻOhiʻa Rust's most dramatic effects there have been on some species of non-Hawaiian Myrtaceae that are widely naturalised, especially Rose Apple, *Syzygium jambos*. That species was once weedily dominant on many disturbed areas (somewhat like Lantana or Privet in eastern Australia), but nevertheless provided much habitat for native animal biota. Very large areas of *S. jambos* were very rapidly defoliated by *A. psidii* and died. The knock-on effects on associated fauna, and on soil retention, do not appear to have yet been documented. Effects on most native Hawaiian flora have so far been milder, although one already endangered native species, *Eugenia koolauensis*, has undergone serious further decline (of the order of 70% mortality) as a result of the disease, and while some survive it is now close to extinction in the wild [Oahu Army NRP 2010, 2014); Rob Hauff, Hawaiian Division of Forestry and Wildlife, *in litt*. June 2017].

In New Caledonia, Myrtaceae is the most species-rich flowering plant family (c. 257 species, of which 99% are endemic), and as in much of eastern Australia it is often dominant or co-dominant in ecological communities including rainforests, sclerophyll forests, savannas and maquis shrublands (Soewarto et al. 2017, and references therein). The two landmasses have many genera in common. Some New Caledonian native Myrtaceae species play a critical successional role in the restoration of native plant communities after disturbance, and are an important part of the territory's strategy for ecological rehabilitation of its extensive mining areas. New Caledonia acquired the pandemic strain of Myrtle Rust in early 2013, and observations of host range and effects in the wild are very limited so far. Soewarto et al. (2017) report infection of 70 species, 67 of them globally new hosts, and including nine rare and endangered native species, with five new host genera (*Cloezia*, *Stereocaryum*, *Arillastrum*, *Myrtastrum*, and *Sannantha* – the last genus also occurs in Australia). Most hosts were observed infected both in nurseries and in the wild. Soewarto et al. (2017) also report mortality of adult trees of the New Caledonia endemic species *Metrosideros brevistylis* in natural habitats. They speculate that "the large host range and severe damage associated with myrtle rust in New Caledonia indicate that ecological integrity could be compromised in the natural communities where Myrtaceae comprise the dominant or codominant species. Myrtle rust is also likely to affect commercial activities related to Myrtaceae cultivation". They also draw attention to the potential for adverse impacts on traditional cultural practices and values.

4.2 Australia – direct impacts on host species

Species studies

(i) Wet sclerophyll and rainforest margin species – whole of range

The most comprehensive impact data so far obtained for any species relate to two formerly common, soft-fruited Myrtaceae species of New South Wales and south-east Queensland. Native Guava (*Rhodomyrtus psidioides*) occurs from just north of Sydney NSW to north of Gympie Qld. Scrub Turpentine (*Rhodamnia rubescens*) occurs from the Moruya area on the NSW South Coast also to the Gympie Qld region. Both are small to medium tree species, although often encountered (in the past!) as shrub-sized saplings, in wet sclerophyll forest and rainforest margin situations. Both were the subject of whole of species surveys over their entire ranges by Carnegie et al. (2016). All sampled sites of both species were found to be infected. The study found that:

- Native Guava *Rhodomyrtus psidioides* (18 sites sampled) was found to have suffered "exceptional levels of tree mortality" at all but three sites, with a mean adult mortality of 57%. On surviving plants, mean crown transparency was 95%, with 82% having > 90% transparency (as against an estimated 'normal' of 25-35%).

- Scrub Turpentine *Rhodamnia rubescens* (43 sites) had a mean 12% adult mortality, was more variable between sites than the previous species, and had mean crown transparency of 76% (as against an estimated 'normal' of 30-35%).

At no sites of either species were surviving seedlings found, and flowering and fruiting levels were low due to new growth death prior to flowering. Fruits that did get through were often found to be infected by *A. psidii*. No plausible other causes contributing to the mortality and decline could be identified.

Data collection for the above study ceased in October 2014 – the two species had thus had between 3.5 and 4.5 years exposure to the pathogen, depending on area. The situation of these two species since then has continued to deteriorate, overall and at some of the sites sampled (A.J. Carnegie, NSW DPI, pers. comms 2017; Pegg et al. 2017, Pegg unpublished data 2018). There is no reason to think that decline of those species will slow or reverse. While the decline as expressed in adult mortality rates cited above seem superficially very different, this is in part an artefact of the very short time-frame over which the decline process has been operating. The apparently better survival rate (i.e. slower mortality rate) of *Rhodamnia rubescens* individuals does not equate to any better prospects for survival over a longer time frame. The observed decline trajectory for both species is unambiguously towards extinction within a very few years.

Following from external nominations made in April 2016, the NSW Scientific Committee in late 2017 made Preliminary Determinations to list both these species as Critically Endangered in New South Wales. They remain unlisted under Queensland and Commonwealth legislation.

FIGURE 14: Native Guava *Rhodomyrtus psidioides*, adult tree death after repeated *A. psidii* infection, Bongil Bongil National Park, NSW, August 2014. (Peter Entwistle).

(ii) Wet sclerophyll and rainforest margin species – regional study

Pegg et al. (2017) conducted a study over two years on a Myrtaceae-rich regenerating wet forest system in south-east Queensland (Tallebudgera Valley). The site was partially intact wet sclerophyll canopy forest (an emergent open over-storey of Brush Box *Lophostemon confertus* and Flooded Gum *Eucalyptus grandis)*, with a largely rainforest assemblage in the closed mid-storey and the under-storey, with Myrtaceae dominant (75%). This vegetation type is not unusual in areas of north-eastern NSW and south-eastern Queensland that are regenerating towards a marginally rainforest system.

Pegg et al. (2017) summarise their findings:
"In 2014 96.7% of *Rhodomyrtus psidioides* trees assessed at Ryans Road were dead, increasing to 100% in 2016. No evidence of root sucker regeneration or seedling germination was found at spots where *R. psidioides* trees had been killed by *A. psidii*. *Rhodomyrtus psidioides* at Ryans Road has been replaced by other species including the noxious weeds lantana (*Lantana camara*) and wild tobacco (*Solanum mauritianum*).

"In 2014 25% of *Rhodamnia rubescens* trees assessed at Ryans Road [the primary study site -- ROM] were found to be dead, with only a 5% increase when assessed again in 2016. However, decline in tree health was observed with foliage loss occurring primarily from the lower branches (Fig. 7). Seedling germination/regeneration was not observed under or near any of the trees within the site, nor was there evidence of flower or fruit production on the trees assessed.

"*Archirhodomyrtus beckleri*, *Decaspermum humile*, *Gossia hillii* and *Rhodamnia maideniana* were the most common mid- and under-story species of Myrtaceae. All these taxa were significantly impacted upon by *A. psidii* with branch death and dieback recorded on all trees, with significant increases in mortality for *A. beckleri*, *D. humile* and *G. hillii*. It is likely that in the very near future these species will become extinct from this location (extirpation) with no evidence of resistance identified in established populations during this study, nor evidence of resistant seedling recruitment. Tree deaths in the twelve months since the plots were first established have more than doubled for *A. beckleri*, *D. humile* and *G. hillii*, suggesting a dramatic decline. This will be a rapid change in the plant community structure, given that the disease was only detected in the region five years prior to our assessment [17,18]. The presence of plant species favoured by disturbance (e.g. *Neolitsea dealbata* http://keys.trin.org.au/key) is further evidence of the impact *A. psidii* has caused to this native ecosystem. To fully understand the changes in these ecosystems there is a need for continued monitoring at this site and establishment of long term monitoring plots in other regions. … Only *Acmena smithii* showed significant variability in susceptibility to *A. psidii* at our study site, with levels of impact significantly lower than recorded for other species. *A. smithii* is now the dominant regenerating species based on seedlings present."

At this primary study site, branch dieback and death rates, and crown transparency (an index of foliage density: 100 = no foliage present), were as follows (adapted from Pegg et al. 2017, Table 2 – see there for variance and notes):

Table 2 – Summarised impact data from Pegg et al. (2017)

Species	**Branch death %**	**Branch dieback %**	**Crown Transparency**
Archirhodomyrtus beckleri (understorey)	43.75	96.66	93.45
Archirhodomyrtus beckleri (mid-storey)	22.56	91.43	89.49
Decaspermum humile (understorey)	48.46	100	95.61
Decaspermum humile (mid-storey)	86.79	100	98.21
Gossia hillii (understorey)	33.89	96.87	91.11
Gossia hillii (mid-storey)	42.61	100	94.78
Rhodamnia maideniana (understorey)	4.74	93.42	85.28

Dieback, and particularly defoliation, at these rates for forest trees represent acute decline in the reproductive and survival prospects for the species involved, which collectively at this site make up most of the mid-storey canopy and under-storey biomass.

The mortality consequences were dramatically evident: "Assessments of species decline from 2016 to 2017 show a dramatic increase in tree mortality levels. Tree deaths from 2016 to 2017 (12 months) increased three-fold for *Archirhodomyrtus beckleri* (13% to 44%) and more than doubled for *Decaspermum humile* (36% to 73%) and *Gossia hillii* (18% to 38%). No deaths were recorded for either *Acmena smithii* or *Rhodamnia maideniana* within the study transects, despite significant levels of dieback recorded on *R. maideniana*."

Two auxiliary sites produced varying data for some species: *Archirhodomyrtus beckleri* at one had 79% tree mortality, but 0% at the other (albeit all with some branch dieback).

Pegg et al. (2017) also observed other species outside the study plots. “All juvenile (sapling) trees of *Syzygium hodgkinsoniae* had very high incidence (90-100%) of rust infection on new shoots and expanding foliage. Dieback on all branches is likely to have been caused by past infection episodes”. Adult trees of *S. hodgkinsoniae* were less defoliated but stressed enough to be putting out epicormic growth, which was in turn infected. *Syzygium corynanthum* at that time showed more variable effects on different plants, although all had high levels of infection on new growth; one adult tree had 75% defoliation and whole-branch death, which has since progressed. The site has recently been re-checked, and has since revisited the site and “there is now significant tip dieback on all trees within the site” (G. Pegg, pers. comm., May 2018).

The severe adverse impact of Myrtle Rust on the species named above is not restricted to the sites utilised by the above study. Observer reports from other Queensland and NSW areas are summarised in Appendix 1.

FIGURE 15: *Syzygium corynanthum*, near-dead, relict tree on regenerating rainforest margin, Tallebudgera valley Qld, May 2016. Most of the greenery in the upper crown is vines. (R.O. Makinson).

(iii) Species of Coastal Swamp Woodland.

Winzer et al. (2018) conducted an ex situ glasshouse study of the relative susceptibility and disease symptomology of three common species of this vegetation type, loosely defined as "dominated by a highly diverse combination of shrubs, trees, herbs, ferns and grasses, located from south-east Queensland to Sydney". The vegetation type, and the species studied, overlap several of the broad vegetation classes of Keith (2004), and parts or all of numerous recognised vegetation communities fully within the naturalised zone of Myrtle Rust, including parts or all of some (c. five) Endangered Ecological Communities listed under NSW legislation. The species studied are common on the north coast of NSW and extending into south-east Queensland. The study examined the effect of Myrtle Rust inoculation on seedlings, grown individually and together as two separate experiments. The species were *Melaleuca quinquenervia* (a known host in the wild, with susceptibility rated as varying from relatively tolerant to extremely susceptible in the wild [Pegg et al. 2014a]), *Leptospermum laevigatum* (a known host from previous inoculation studies), and *Baeckea linifolia* (a known host from natural infection and rated as medium-susceptible by F. Giblin [unpublished data 2016]).

B. linifolia showed no disease symptoms (even of resistant hypersensitivity), although the inoculated samples did exhibit reduced growth (a height reduction of 30% compared to the control when grown alone, and 22% in mixed planting), and leaf number (a reduction of 17% alone and 11% mixed). Biomass was reduced by a non-significant amount. This sounds a cautionary note for future studies; growth reductions of this degree, if exhibited in the wild, could affect competitive fitness of even apparently asymptomatic species or genotypes, and in commercial cultivation may have consequences for production rates.

Winzer et al. report that *L. laevigatum* and *M. quinquenervia* both exhibited explicit symptoms. *L. laevigatum* had a higher proportion of seedlings in the highest severity category (28%) with only 10% healthy (symptomless) plants, and by the end of the experiment showed a mean height reduction of 24% compared to the un-inoculated control. *M. quinquenervia* (known to be variably susceptible) had no plants in the highest severity category, 44% remained symptomless, and a mean height reduction of 38% compared to the un-inoculated control. Defoliation (leaf loss) nevertheless was similar for both. Leaf number was negatively affected by infection for both species. Biomass indices were markedly affected by *A. psidii* infection, being reduced in *M. quinquenervia* by 75% (total biomass), 79% (aerial shoots), and 77% (root system), and in *L. laevigatum* by 69% (total), 68% (shoot), and 75% (root).

In the mixed-planting experiment, broadly consistent results with the alone-plantings were found for infectibility and severity; effects on growth varied between species and over time. *M. quinquenervia*, showed a height shortfall of 45% compared to the un-inoculated control by the end of the four-month run, and a shoot biomass reduction of 85%. *L. laevigatum* showed a shortfall of 15% in height, and 54% in shoot biomass.

These results indicate, firstly, that relative severity (greater in *L. laevigatum*) does not necessarily correlate with relative impact on growth and fitness indices (greater in *M. quinquenervia*). Secondly, that even asymptomatic species (*B. linifolia*) and individuals, may be devoting significant metabolic resources to their (in this case presumably induced) resistance, to the detriment of some, though not all, growth indices. Winzer et al. (2018) do not rule out the possibility that their *B. linifolia* plants would have developed symptoms in time, and cite Pegg (unpublished data) to the effect that *B. linifolia* in the field is slower to develop infection symptoms than neighbouring infected species. The case nevertheless remains a warning against false negatives in survey conditions, and resulting assumptions about non-impact. The asymptomatic (or delayed) response to inoculation would be amenable to metabolomic studies and may be informative as to the mechanisms of induced resistance and the possibilities for intervention to reinforce it.

While glasshouse inoculation outcomes cannot be regarded as necessarily reflecting outcomes in the wild or in open cultivation, it seems likely from the symptomology results that the *M. quinquenervia* provenance used by Winzer et al. (2018) was on the less susceptible scale of variation (by provenance) identified by Pegg (unpublished data, see below); the effects of infection were nevertheless very marked.

(iv) Species of Wallum heathland of far north-eastern NSW

G. Pegg (Queensland DAF) and collaborators have work in progress on the effects of Myrtle Rust infection in the Myrtaceae-rich wallum heathland of the NSW far North Coast after fire, focussing on resprouting and seedling recruitment of ten species. Preliminary results presented by Pegg et al. (2018) indicate high Myrtle Rust impact on *Leptospermum trinervium*, and variable 'low to high' impact on *Leptospermum liversidgei*, *Melaleuca nodosa*, and *M. quinquenervia*. All four species are floristically important components of this vegetation type. Adult plant and seedling mortality was recorded for all four species. In *M. nodosa*, 32% of plants sampled had *A. psidii*-related dieback on all branches. In *M. nodosa* re-sprouts, *A. psidii* causes 'canker-like' nodules on the young stems, correlated with tip dieback and reduced flowering on infected stems. A new host, *Baeckea frutescens*, is also reported from this work.

(v) Broad-leaved Melaleuca woodlands

M. quinquenervia is a keystone species of many wetlands, floodplains, and watercourse margins along the east coast from Sydney to Cape York. *M. leucandendra* and *M. viridiflora* play a similar role for the tropical coast of Queensland and across the north of Australia to the Kimberley region. Any significant declines in these species caused by Myrtle Rust could be expected to have strong ecological effects on other biota and the biophysical environment (see Section 4.6 'ecological impacts', below). G. Pegg (Queensland DAF) and collaborators have work in progress on the effects of Myrtle Rust infection in these species. Preliminary results are presented in Pegg et al. (2018), with post-fire coppice growth of *M. quinquenervia* (a re-sprouter species after low to mid-intensity fire), showing a variable level of disease impact, 41% of coppicing trees having relatively low impact (infection symptoms limited to foliage only), 26% moderate (foliage and some new-stem dieback), and 33% severe (marked death of both foliage and new stems). Flowering of trees affected both moderately and severely in their initial coppice growth was markedly reduced (relative to 'low' impact individuals) in the second year after fire (near zero for 'severe' plants).

A second element of the project, again for *M. quinquenervia*, looked at the interaction of post-disturbance infection by *A. psidii* and (native) insect herbivory on the growth and survival rate of individuals. Chemical control of rust and insects separately resulted marked improvement in both indices compared to untreated controls, even more so when both treatments were used. The survival rate of untreated coppice was less than 30% (Pegg et al., 2018).

The final project element, involving all three species, is assessment of the resistance and susceptibility of seedlings; this varies markedly for each on a populational level (although not on any simple latitudinal or other geographical basis) from c. 20% to more than 80%.

FIGURE 16: Broadleaved Paperbark wetland*: Melaleuca quinquenervia* forest fringing open freshwater wetland, Urunga NSW, May 2017. (R.O. Makinson).

FIGURE 17: Myrtle Rust on young foliage of *Melaleuca quinquenervia*, north-east NSW, May 2011. (P. Entwistle).

FIGURE 18: Post fire epicormic regeneration in *Melaleuca quinquenervia*, near Lennox Head NSW, Sept. 2014: left, healthy regrowth on a Myrtle Rust-resistant plant; right, abortive regrowth on a Myrtle Rust-susceptible plant. Susceptibility in *M. quinquenervia* varies within and between populations.

(vi) Eucalypt species – field observations and indicative glasshouse studies

The host list at Appendix 3 includes 106 taxa in the three eucalypt genera (excluding hybrids) – *Angophora* 3, *Corymbia* 9, and *Eucalyptus* 94. To date, there are no published studies specifically of Myrtle Rust incidence, severity and impact on eucalypts in the wild.

Among the eucalypts listed as *A. psidii* hosts in Queensland by Pegg et al. (2014a), on the basis of observations in cultivation and in the wild, no *Angophora* species were assigned susceptibility ratings; three *Corymbia* taxa (*C. citriodora* subsp. *variegata*, *C. henryi*, and *C. torelliana*) were all rated as RT Relatively Tolerant (others unrated). Seven *Eucalyptus* were assigned ratings: *E. carnea* (RT-HS), *cloeziana* (RT), *curtisii* (RT-HS), *grandis* (RT-MS), *planchoniana* (RT-MS), *tereticornis* [subsp. uncertain] (RT), and *E. tindaliae* (MS).

Subsequent field observations in the wild have been made of significant infection levels on relatively few eucalypt species. Pegg et al. (2014b) mention unpublished data on impact on seedlings of *C. citriodora* subsp. *variegata*, *C. torelliana*, *E. cloeziana*, and *E. tereticornis*, and dieback of mature trees and coppice regrowth in *E. carnea* and *E. curtisii*. Some of this data was published in Lee et al. (2015) and Pegg et al. (2018). P. Entwistle (*in litt*.) reports serious damage to coppice regrowth of *E. tindaliae* in northern NSW. G. Paterson of Mackay, Qld (pers. comms 2017, 2018) reports “savage” infection on *E. resinifera* [here inferred to be subsp. *hemilampra*] seasonal new growth each year, and on seedlings and post-fire coppice growth; and on *E. montivaga* [= *E. andrewsii*] seasonal and sucker growth; both in the Eungella area.

FIGURE 19: Myrtle Rust attacking coppice regrowth of *Eucalyptus tindaliae*, near Bungawalbyn NSW, February 2012. (P. Entwistle).

FIGURE 20: Myrtle Rust on cotyledonary seedling of *Eucalyptus planchoniana* in a nursery, June 2011. One of a batch of 300 seedlings, all of which died. Early seedling stages remain unmonitored in the field for most Australian host species of the Myrtle Rust pathogen.

Apart from the above, most of the patchy records of Myrtle Rust infection on eucalypts in the wild derive from observations on seasonal new growth. The susceptibility of seedlings and post-fire epicormic or sucker regrowth remains unknown for most. These may be critically vulnerable life stages in some taxa, and a monitoring program focussed on these stages should be developed as a matter of some urgency.

In this regard, two glasshouse inoculation studies, both using well-documented multi-provenance wild seed inoculated with pandemic strain *A. psidii*, are informative.

Pegg et al. (2014b) screened nine *Corymbia* (spotted gum group) taxa for susceptibility and resistance, of which the non-hybrid members were *C. citriodora* subsp. *variegata* (CCV), *C. citriodora* subsp. *citriodora* (CCC), *C. henryi* (CH), and *C. torelliana* (CT). Resistant and susceptible seedlings were identified within all species, provenances, and test 'families' (in the silvicultural sense), albeit with significant differences in resistance at provenance and family level. The *Corymbia* hybrid clones tested showed marked resistance to infection, although the authors note that this may have had to do with different leaf surface characteristics resulting from their vegetative propagation (rather than from seed). For the species, estimates of the heritability of resistance, across all three assessment indices used, were moderate to high, indicating "a significant level of additive genetic variance for rust resistance within the populations", boding well for the potential for selective breeding via screening for production purposes (and, speculatively, for reinforcement of natural populations with resistant genotypes). The authors stress that for these taxa, selection needs to be made at the breeding family level rather than on provenance alone. However, pending such actions, "the results also suggest the potential for *P. psidii* to impact on young plantations using unimproved seed from all provenances studied, including some commonly used in plantation development in Queensland". There was "no apparent relationship between climatic conditions at the provenance origin and disease resistance". The authors do not directly address the implications for wild populations of these species. The above comment regarding plantation impact would suggest potential for significant wild impact as well, climatic conditions permitting. The potential for additive genetic resistance in such populations would not automatically be realised through natural selection alone over the short time frame during which impact and resulting ecological processes (floristic replacement, niche closure, etc) might be expected to occur.

Lee et al (2015) screened multi-provenance seedlings of *Eucalyptus cloeziana* (a significant Queensland timber species) and *E. argophloia* (listed as Vulnerable under both Commonwealth and Queensland legislation), finding variable resistance in both, and the latter possibly at risk in the wild if Myrtle Rust establishes in its habitat just west of the Great Dividing Range.

Potts et al. (2016) screened wild-sourced seedlings all 30 *Eucalyptus* taxa native to Tasmania, with the pandemic strain of Myrtle Rust. These taxa were: *E. amygdalina*, *archeri*, *brookeriana*, *coccifera*, *cordata* subsp. *cordata*, *cordata* subsp. *quadrangulata*, *dalrympleana*, *delegatensis*, *globulus* [*sens. strict*.], *gunnii* subsp. *gunnii*, *gunnii* subsp. *divaricata*, *johnstonii*, *morrisbyi*, *nebulosa*, *nitida* [syn. *ambigua*], *obliqua*, *ovata* [var. *ovata*], *pauciflora* subsp. *pauciflora*, *perriniana*, *pulchella*, *radiata* subsp. *robertsonii*, *regnans*, *risdonii*, *rodwayi*, *rubida* [subsp. *rubida*], *sieberi*, *subcrenulata*, *tenuiramis*, *urnigera*, *vernicosa*, and *viminalis* [*sens. strict*., i.e. subsp. *viminalis*]. The study found variation in susceptibility in all taxa, from highly resistant (HR) to very susceptible (VS), albeit in markedly varying proportions. A curious feature of the results is a markedly bimodal distribution of susceptibility in all taxa, with the major proportions being either HR or VS, and relatively few seedlings scored in intermediate categories. Insofar as this is not in part an artefact of the scoring classes used, it may repay further investigation as part of deeper research into resistance syndromes (genetic and physiological).

4.3 The impacts survey knowledge gap

Eight years after the first detection of *Austropuccinia psidii* in Australia, there is still no integrated program of environmental impact monitoring and research; no officially sanctioned national monitoring and assessment protocols; no sustained effort at a citizen science approach to enhance a monitoring effort; and no organised repository, centralised or dispersed, for observational data and information.

The studies cited above have originated from researchers in primary industry agencies in NSW and Queensland, and one university, with financial support from the Plant Biosecurity Cooperative Research Centre, and collaborations from a variety of government and non-government scientists and native plant experts (only some with institutional salary-time support) and private ecological and agronomic consultants.

Our knowledge base remains far from adequate for comprehensive assessment of either the impacts at species and ecological levels, or an estimation of the frequency and distribution of resistant genotypes, in those species that have any. The detection and confirmation of disease resistance is a precondition for research into the modes of that resistance, and for the possibility of future reinforcement of natural populations with resistant genotypes. Current knowledge is also inadequate for a final prioritisation of conservation actions, which in any case will be modified by the accretion of new host and impact reports, especially if the geographic range of *A. psidii* increases further. The emphasis in conservation actions at this point must be to (a) redress the information shortfall, and (b) to maximise the options for the future recovery of some of the affected species.

Even with optimal resourcing the scale of assessment that is needed of Myrtle Rust impact assessment in the field would far outstrip the capacity of overloaded agency staff alone, and a much wider network of informed observers, with the necessary observational and plant identification skills, would be essential.

A loose national ‘coalition of concern’ on Myrtle Rust, unresourced and un-auspiced, already exists. It encompasses government and non-government (commercial and community) practitioners and researchers, in plant health and pathology; plant ecology, conservation botany and plant systematics; native plant horticulture; and agronomy.

The observational reports on recommended priority species in this review (see Appendix 1 for detail) have been drawn from this network through interviews and email dialogues. Only reports assessed as reliable, on the basis of the known skills of the respondents are included here.

For many known host species (and for some not previously known as susceptible), these reports of infection levels and apparent damage (or not) are numerous enough and consistent enough to provide a fairly sure basis for assuming significant Myrtle Rust impact, and the need for urgent field assessment and for precautionary germplasm collection and enabling research for germplasm storage. In other cases they are too scattered to provide a firm basis for asserting severe impact and immediate assignment of priority, but are indicative of the need for further field assessment.

In considering the priorities for field assessment of Myrtle Rust impact, and subsequent assignment of conservation action priorities, it needs to be noted that the degree of infection and damage or mortality at critical life stages *other* than seasonal new flush (i.e. for seedlings and post-fire coppice growth) remains totally unsurveyed for very many known host species. This could prove to be of crucial importance for some species, especially those that tend to recruit in irregular cohorts following disturbance triggers like fire, where these coincide with seasonal peaks of *A. psidii* sporulation. It should be noted that in NSW and south-east Queensland, autumn, following the peak fire season, is also a peak period for Myrtle Rust disease outbreak.

Finally, even the host status of still other species that are not yet recorded or screened for susceptibility, remains an open question.

The following is a summary of the species of most concern. See Appendix 1 for further detail.

4.4 Species of highest current concern

The following is a summary list of Australian east coast and Northern Territory species that are of highest conservation concern due to known or suspected impacts of Myrtle Rust since 2010. Details of each species, and the information sources contributing to this listing, are presented in Appendix 1. The outcomes of impact surveys may modify germplasm capture recommendations.

TABLE 3 Priority East Coast and Northern Territory taxa (known hosts, n=45) for field impact survey, and germplasm capture:

- Impact survey needs to sample across the range of a species, include seasonal flush, seedling/juveniles, and at least a subsample of post-fire sites for non-rainforest taxa.
- Impact survey needs to incorporate search for rust-resistant individuals or populations, for further investigation.
- A number of species marked 'advisable' for germplasm capture are so categorised because low levels of impact data are available; some may prove to be in no immediate danger. However precautionary collection of sample germplasm *simultaneous with* the impact surveys is strongly recommended. Two reasons exist for urgency. For suspected non-orthodox species, storage testing takes time (months); bulk collection must wait on results, and if seed proves recalcitrant or short-lived in storage, alternative germplasm strategies may need to be devised. Rapid decline of species in the wild may also lead to seed production being reduced to negligible levels between one season and the next; postponed action may miss the window of opportunity.
- Target quantities of storable seed, or other forms of germplasm, should be calculated based on anticipated needs for storage research, viability and germination testing, provenance set resistance testing, and the establishment of translocation sites (e.g. for future seed production or resistance breeding programs).

Species	Natural distribution	Impact survey need and priority	Germplasm capture need and priority
Archirhodomyrtus beckleri (Southern Chemotype)	NSW, SEQ	Very High	Very High
Austromyrtus dulcis	NSW, Qld	Medium	Medium
Backhousia citriodora	Qld	Medium	Top-up only (a provenance set exists)
Backhousia leptopetala	NSW, Qld	Medium	Medium
Backhousia oligantha	Qld	Medium	Medium
Decaspermum humile (Southern Metapopulation)	Qld, NSW	Very High	Very High
Eucalyptus curtisii	Qld	Medium	Medium

Species	Natural distribution	Impact survey need and priority	Germplasm capture need and priority
Eucalyptus montivaga (= E. andrewsii, Mackay region population)	Qld	Medium, precautionary for post-fire response	Undetermined pending survey
Eucalyptus resinifera subsp. hemilampra (Mackay region population)	Qld	Medium, precautionary for post-fire response	Undetermined pending survey
Eugenia reinwardtiana	Qld (WA not current priority)	Very High	Very High
Gossia acmenoides	NSW, Qld	Medium	Medium
Gossia fragrantissima	NSW, Qld	Very High	Very High
Gossia gonoclada	Qld	In progress (T. Taylor)	Very High
Gossia hillii	NSW, Qld	Very High	Very High
Gossia inophloia	Qld	Medium	Medium
Gossia lewisensis	Qld	Medium	Medium
Gossia myrsinocarpa	Qld	Medium	Medium
Lenwebbia prominens	Qld	Medium	Medium
Lenwebbia sp. ‘Blackall Range’ (P.R.Sharpe 5387)	Qld	EMERGENCY	EMERGENCY
Lenwebbia sp. ‘Main Range’ (P.R.Sharpe+ 4877)	Qld	EMERGENCY	EMERGENCY
Leptospermum trinervium	NSW, Qld	Medium	Medium
Lithomyrtus retusa	Qld, NT,WA initially NT populations)	Medium	Medium
Melaleuca leucadendra	Qld NT WA	Medium (integrate with QDAF project)	Medium
Melaleuca lophocoracorum (newly reported host)	Qld	Medium	Medium
Melaleuca nodosa	NSW Qld	Very High	Very High
Melaleuca quinquenervia	NSW Qld	Medium (integrate with QDAF project)	Medium
Melaleuca viridiflora	Qld NT WA	Medium (integrate with QDAF project)	medium
Rhodamnia angustifolia	Qld	Very High	Very High
Rhodamnia argentea	NSW, Qld	Medium	Medium
Rhodamnia australis	Qld, NT	Medium	Medium
Rhodamnia costata	Qld	Medium	Medium
Rhodamnia dumicola	Qld	Very High	Very High
Rhodamnia longisepala (newly reported host)	Qld	Medium	Medium
Rhodamnia maideniana	NSW, Qld	Very High	Very High

Species	Natural distribution	Impact survey need and priority	Germplasm capture need and priority
Rhodamnia rubescens	NSW, Qld	Impact done (Carnegie et al. 2016). Survey priority is for resistant plants.	EMERGENCY
Rhodamnia sessiliflora	Qld	Medium	Medium
Rhodamnia spongiosa	Qld	Medium	Medium
Rhodamnia whiteana (newly reported host)	Qld	Medium	Medium
Rhodomyrtus canescens	Qld	Medium	Medium
Rhodomyrtus pervagata	Qld	Medium	Medium
Rhodomyrtus psidioides	NSW	impact done (Carnegie et al. 2016). Survey priority is now for resistant plants.	EMERGENCY
Stockwellia quadrifida	Qld	Medium	Medium
Syzygium anisatum	NSW	Very High	Very High
Syzygium hodgkinsoniae	NSW, Qld	Very High	Very High
Syzygium oleosum	NSW, Qld	Medium	Medium

Other known-host species for priority precautionary germplasm capture and storage testing:

- *Leptospermum polygalifolium* subsp. *howense*: NSW (Lord Howe Island endemic)
- *Melaleuca howeana* (Lord Howe Island endemic)
- *Metrosideros nervulosa* (Lord Howe Island endemic)
- *Metrosideros sclerocarpa* (Lord Howe Island endemic)
- *Syzygium fullargarii* (Lord Howe Island endemic)
- *Allosyncarpia ternata* (Northern Territory endemic).

All of these taxa are known hosts from inoculation except the *Leptospermum polygalifolium* subsp. *howense*. None are known to be currently undergoing infection or decline. The first five taxa are recommended here as priorities for germplasm capture because of their exclusive occurrence in a World Heritage Area (Lord Howe Island) known to be highly vulnerable to infection by *A. psidii*. *Allosyncarpia ternata* is a known host from inoculation and is a species of biological and cultural significance from the Kakadu WHA and adjacent areas.

Precautionary action on these taxa would be a positive flagship action within a wider conservation program as recommended in the draft Myrtle Rust Action Plan. A medium (end-2020) priority is recommended.

TABLE 4 Other taxa (not known hosts) for which precautionary field survey for infection and potential impact is strongly advisable.

These species are not known hosts, but have not been screened by inoculation or adequately surveyed in the wild. They are the remaining East Coast species in high-risk genera with natural distributions totally or near-totally within current zone of Myrtle Rust naturalisation (except for *Lithomyrtus* linariifolia, a Northern Territory species). Bracketed figures after genus name show number of known hosts *versus* number of Australian species in genus.

Genus	Species not yet known as hosts
Asteromyrtus (1/5)	*angustifolia* (Qld), *arnhemica* (NT), *lysicephala* (Qld), *symphyocarpa* (Qld, NT)
Austromyrtus (2/3)	*glabra* (Qld)
Backhousia (12/13)	*kingii* (Qld)
Gossia (12/20)	*byrnesii* (Qld), *dallachiana* (Qld), *grayi* (Qld), *lucida* (Qld), *retusa* (Qld), *sankowskiorum* (Qld), *shepherdii* (Qld).
Lenwebbia (3/4)	*lasioclada* (Qld)
Lithomyrtus (1/11)	*linariifolia* (NT)
Neofabricia (1/3)	*mjoebergii* (Qld), *sericisepala* (Qld)
Pilidiostigma (4/6)	*papuanum* (Qld), *sessile* (Qld)
Rhodamnia (14/19)	*fordii* (Qld), *hylandii* (Qld), *sharpeana* (Qld), *whiteana* (Qld, NSW)
Rhodomyrtus (7/7):	*trineura subsp. trineura (Qld)*
Ristantia (2/3)	*gouldii* (Qld)
Sphaerantia (1/2)	*chartacea* (Qld)
Syzygium sens. lat. (50 / c.75)	[all moist biome species not on host list]
Xanthostemon (5/16)	*arenarius* (Qld), *sp. Bolt Head (JR Clarkson 8805 Queensland Herbarium)* (Qld), *umbrosus* (Qld, NT, WA), *verticillatus* (Qld), *whitei* (Qld), *xerophilus* (Qld)

For many other known host species, reports of infection levels and apparent damage (or not) exist from various areas and situations along the east coast. In some cases, these are numerous and consistent enough to indicate a likelihood of Myrtle Rust impact and severity at a level which may have a cumulative impact over the medium or long-term. However, until this is field-assessed that timeframe could be anything from five years to many decades, and may apply only in parts of the range of some species. The non-inclusion of these many known-host species on priority lists here presented does not mean they should not be the subject of impact assessment and precautionary germplasm actions. Rather it signifies that we do not yet have the data to do so, relative to higher priority species. The resource options for achieving this level of survey for so many species, including informed 'citizen science' options, are discussed briefly in Part 6. Precisely because of their apparent tolerance of the disease, these species are a crucial reservoir for research into resistance syndromes, both constitutive and induced.

In considering the priorities for field assessment of Myrtle Rust impact, and subsequent assignment of conservation action priorities, it needs to be noted that the degree of infection and damage or mortality at critical life stages *other* than seasonal new flush (i.e. for seedlings and post-fire coppice growth) remains unsurveyed for very many known host species. This could prove to be of crucial importance for some species that tend to recruit in irregular cohorts following disturbance triggers like fire. Finally, even the host status of still other species that are not yet recorded or screened for susceptibility, remains an open question.

Genus-level considerations

Austropuccinia psidii has shown a capacity to infect at least some species in most of the Australian genera with which it has come in contact, across all tribes of the Myrtaceae. Some genera are small (*Neofabricia* – 1 species), some large (*Syzygium sens. lat*. – c. 75; *Corymbia* – c. 115; *Eucalyptus* – c. 750). Allowing for variation in species susceptibility, we have to consider the possibility of genus-level extinction over time in some cases.

TABLE 5 Some genera with worryingly high proportions of known-host members

Genus	Total Australian species	Known hosts
Austromyrtus	3	2
Backhousia	13	12
Gossia	20	13
Lenwebbia	4	4
Neofabricia	3	1
Pilidiostigma	6	4
Rhodamnia	19	16
Rhodomyrtus	7	7 (one subspecies not yet known as a host)
Ristantia	3	2
Sphaerantia	2	1 (+1 recent unconfirmed)
Syzygium sens. lat.	81	50
Xanthostemon	16	5 (+1 recent unconfirmed)

4.5 Species impacts – Regional summaries

The general current distribution of the Myrtle Rust pathogen is discussed under Section 2.3 'Distribution of the Myrtle Rust pathogen in Australia', above. These supplementary notes are an attempt to draw out some regional patterns from species data and observations. A major limitation is the lack of any coordinated monitoring program and central repository for records.

NSW South Coast, Victoria, and Tasmania

The NSW South Coast has only one naturally occurring species of extreme susceptibility, *Rhodamnia rubescens*. Reports of severe impact on *R. rubescens* (heavy infection, failure to fruit, defoliation, and whole-plant death) are consistent from Sydney to its southern limit in the Moruya area. *R. rubescens* near Moruya is also the southernmost reported occurrence of Myrtle Rust on a wild native plant in Australia to date. Two populations of *R. rubescens* are known in Booderee National Park (Jervis Bay), of which one is now apparently extinct and the other in severe decline (S. Pedersen, Booderee Botanic Gardens, pers. comms 2017, 2018).

The southern limit of *R. rubescens* is clearly not the climatic limit for Myrtle Rust. Reports of infection on open-cultivated plants, not subject to special horticultural treatment, occur at several locations as far south as Tathra in NSW (Akolele – C. L. Jordan pers. comm. April 2013; Wallagoot, Bermagui and Tathra – pers. comm. DL Jones, 21 Aug 2017), and in parts of Victoria and Tasmania.

The small population of the known host *Gossia acmenoides* that occurs in the southern Sydney Basin and on the Illawarra, and which was listed in NSW as an Endangered Population under legislation now superseded), has recorded infection and tip dieback (K. Mills *in litt*. 16 March 2017). There have been a number of records on cultivated plants in Canberra, ACT, most notably in autumn 2016 on multiple species at the Australian National Botanic Gardens (P. Hurle, ANBG, *in litt*. Sept 2016), although the ability of *A. psidii* to overwinter in Canberra is doubtful.

The apparent failure of the Myrtle Rust pathogen to 'jump the fence' into native vegetation in Victoria and Tasmania may be partly due to a marginal climatic suitability for full naturalisation of Myrtle Rust, but may also have to do with the paucity of high susceptibility species that would both be conspicuous for detection and contribute to the high spore loads that may be necessary for sustained outbreaks. It is however worth noting the varying (but consistently present) levels of susceptibility exhibited by seedlings of all native Tasmanian *Eucalyptus* species in inoculation tests (Potts et al. 2016). These results indicate quite high percentages of highly susceptible seedlings in some species. This in turn indicates at least a potential risk to regeneration in the wild if even a low level of infection and sporulation were to be present on neighbouring low-susceptibility species. It is hard to gauge the extent of bushland survey that may have occurred in either Victoria or Tasmania, other than by the lead agencies, and cultivated (and nursery) plants form the entire body of records to date for both both states. The survey effort in the Myrtaceae-rich heathlands of the Nadgee (NSW) and Mallacoota (Vic.) areas has apparently been low to date; this area is likely to be climatically suitable for the pathogen.

Sydney Basin and NSW Central Coast

The Central Coast was ground zero for Myrtle Rust in 2010. Early casualties were a large proportion of local *Rhodamnia rubescens* (surviving plants rare, and very rarely with any flowers, by 2016), and very rapid extirpation of all or nearly all local littoral rainforest populations of *Rhodomyrtus psidioides*. Two surviving plants of the latter, possibly suckers, were found in Wambina National Park under a thick cover of Bitou Bush as late as mid-2015 (D. Holloman, NPWS, *in litt*. July 2015), but the species appears to be effectively extinct in the region. The inland extent of *A. psidii* naturalisation is not precisely known, but reports of it extend inland to at least the Kulnura/Mangrove Mountain area, and it is likely that substantial areas of moister vegetation types in Yengo and Wollemi National Parks are now permanent habitat for *A. psidii*.

An odd feature of the original Central Coast outbreak was the recorded moderately heavy infection on new foliage of a planted stand of Turpentine (*Syncarpia glomulifera*, subspecies undetermined) at the first detection site (Carnegie & Lidbetter 2011; National Management Group 2010). Since that time, *S. glomulifera* has very rarely featured in records of infection. G. Paterson (Mackay, Qld, pers. comm. Sept 2017) reports that local stands near Gympie in south-east Queensland (here inferred to be of subsp. *glomulifera*) were "completely defoliated" in 2012-13, but with no further significant infection until January 2018 when infection on most new growth was noted after a period of cooler overcast and wet weather. The evidence overall is thin, but suggests the possibility of an induced resistance response in this species.

Infection has been widespread across Greater Sydney on a variety of both native and exotic species, including occasional transient outbreaks in heavily urbanised areas in the east (e.g. Surrey Hills; Makinson pers. obs.). Myrtle Rust has been much less frequently recorded in the much drier natural vegetation and climate of the Cumberland Plain and western sandstone areas, which have fewer high-susceptibility hosts, although recurrent outbreaks on more susceptible species in open cultivation occur in those areas (e.g. Mount Annan Botanic Garden near Campbelltown). Relatively few records exist from the lower Blue Mountains.

Hunter Region and NSW lower and mid-North Coast

After an initial scatter of records actively solicited by NSW DPI in 2010-12, reporting from the region from Newcastle to Nambucca has been very sparse, partly reflecting the thin scattering of native plant enthusiast groups. Decline of *Rhodomyrtus psidioides* and *Rhodamnia rubescens* in near-coastal associations has been consistent with adjacent regions. The wet forests and upland shrub associations of Mount Royal/Barrington, and of the Manning, Forbes, Macleay and Nambucca river catchments, have been very poorly surveyed. Preliminary unpublished data from a study by G. Pegg (DAF Queensland) indicates that *Melaleuca quinquenervia* seedlings on the mid-North Coast have relatively low percentages of seedings resistant to the disease (varying 20—35%). The coastal heath/woodland systems of the region have a number of other known host species in common with those further north, where at least four are known to be subject to high post-fire impact (Pegg, unpublished data – see next).

NSW Upper North Coast (north from Coffs Harbour) and south-east Queensland

This region is the worst-affected so far in terms of the number of highly susceptible species and observed severe infections and actual decline.

Floristically there is a steady northward increase in the incidence of highly susceptible species, and a more highly developed network of aware and skilled observers (agency and community) compared to further south. The area has a great deal of public and private investment in ecological restoration, especially of rainforest systems. The region is a prime area for the development of an extra-agency (skilled citizen science) monitoring network.

In the south of this region, valuable longitudinal observations of disease and high mortality in *Rhodomyrtus psidioides* and *Rhodamnia rubescens* in the Bongil Bongil National Park and surrounds were made 2011-2016 by M. Smith (NSW NPWS), and others in the Coffs Harbour area. The Bellinger River and Dorrigo hinterland forests have been little reported.

The region also contains extensive areas of *Melaleuca quinquenervia* and wallum heathlands, with some species currently under study by G. Pegg (QDAF) for post-fire response to Myrtle Rust – see under *Species studies (iv)* and *(v)* above for some preliminary results.

A rich suite of Myrtaceae occur in the Tweed caldera and on the Focal Peak Shield volcanics, extending along the Border Ranges. This Myrtaceae-rich belt extends west to Killarney and northwards across the Lamington Plateau and northwest to the Toowoomba region; a separate 'branch' extends north along the Gold Coast. The regional climate is fully sympatheic to *A. psidii* persistence, except perhaps on the highest areas of the Granite Belt..

One of the host-species closest to extinction as a result of Myrtle Rust infection is *Lenwebbia* sp. 'Main Range' (P.R. Sharpe+ 4877), a recently reported host undergoing very severe decline (L. Weber pers. comms 2017 and 2018, J. Mallee, NSW NPWS, pers. comm. March 2018; G. Pegg QDAF pers. comm. March 2018. Despite not having yet received a Latin name, this taxon is recognised as a 'good species' in both Queensland and NSW. Occurring at a few points around the southern periphery of the Lamington Plateau and on the Main Range in Queensland, it has only very recently been recognised as occurring on the NSW side of the border, although a majority of the plants probably occur on the NSW side (L. Weber pers. comms.), notably in Limpinwood Nature Reserve. It grows in a very limited ecological niche of cliff edges, cliff faces and steep ridgelines, in low cloud forest and shrubland, and is reported as almost entirely defoliated through the accessible parts of its range. *Lenwebbia* sp. 'Main Range' (P.R.Sharpe+ 4877) is still officially regarded in Queensland as of 'least concern' threat status (https://wetlandinfo.ehp.qld.gov.au/wetlands/ecology/components/species/?lenwebbia-sp-main-range-p-r-sharpe-4877), and is unlisted in NSW.

On both sides of the border, *Archirhodomyrtus beckleri* and *Gossia hillii*, significant rainforest margin species on metasediment soils, after a slow start are declining drastically in the manner described by Pegg et al. (2017) from the Tallebudgera Valley (Qld), and confirmed by J. Wills (pers. comm 25 May2018) as far north as Kin Kin albeit with less severe impact in the Eumundi area. On the Queensland side *Decaspermum humile* (South Queensland metapopulation) and *Rhodamnia maideniana*. *Rhodomyrtus psidioides* and *Rhodamnia rubescens* are in steep decline in littoral rainforest, subtropical rainforest, and wet sclerophyll to rainforest transition communities; the former is extinct at some sites, the latter nearly so (Pegg et al. 2017). From reliable reports (citations under 'Species Impacts 'above), severe decline is also occurring in Queensland in populations of *Rhodamnia dumicola*, *R. argentea*, and *R. whiteana* (the latter not yet officially evaluated for the national host list, but accepted for this review). The exact status of the already rare and Endangered *Gossia fragrantissima* has not been ascertained. By contrast, the near-border species *Uromyrtus australis* (NSW) and *U. lamingtonensis* (Qld), both known hosts and both thought likely to prove highly susceptible, have not as yet shown any signs of serious damage or decline (R. Kooyman pers. comm. May 2017; L. Weber pers. comm. Feb. 2018).

In the Brisbane to Sunshine Coast area, the already endangered *Gossia gonoclada*, and *Lenwebbia* sp. 'Blackall Range (PR Sharpe+ 5387)' are both severely affected (Pegg et al., 2018), as is *Rhodamnia rubescens* at most sites. The sandmass heathy woodlands of Cooloola, Fraser Island, and other islands have not yet been well surveyed for effects, but these have species commonalities with the wallum heaths further south (see above) and may be most at risk after fire.

Central Queensland

The Central Queensland region is very poorly surveyed for Myrtle Rust, and the scantiness of records and reports can give a probably erroneous impression that the region is largely unaffected. The wetter vegetation types favoured by the pathogen occur mostly in smaller patches except in the north and around Mackay. One of the few rapporteurs for the region (G. Paterson, pers. comm. 28 Sept. 2017) provides observations on several species. He states that the worst affected locally is Beach Cherry (*Eugenia reinwardtiana* – a known host rated as extremely susceptible by Pegg et al. 2014a), with c. 50% defoliation and 100% loss of new growth on local populations in the "devastating" first season (2012-13), and has continued to be severely affected each year. He notes that there are two forms of the species locally, large- and small-leaved, which can grow sympatrically, and that some of both are in remote locales and both are likely to be native; the former is noticeably more prone to severe Myrtle Rust attack. Mr Paterson reports that some volunteer seedlings of an 'elite clone' of the larger-leaved form in cultivation, destroyed in 2016 due to repeated rust attack, have survived and have shown no symptoms of Myrtle Rust for two years, despite heavy local spore load. *E. reinwardtiana* is known for morphological variation across its range, and this should inform any germplasm capture strategy for the species (here recommended as a priority). Mr Paterson's observations suggest a possible partial resistance syndrome that should be investigated.

Mr Paterson also reports *Melaleuca dealbata* as a host (not otherwise reported), and that it was "savagely hit" in the first few seasons but it is now rare to see more than a few spots on leaves". *Callistemon (Melaleuca) viminalis* and most other local *Melaleuca* species are "badly hammered" in some years, but with low levels of infection in 2017. *Backhousia citriodora* (Lemon Myrtle) is patchily widespread in the area and very prone to form apparently clonal patches, with correlating variability in apparent tolerance of *A. psidii*. Infection is common on most or all patches, and some show a noticeable reduction in flowering, but overall flowering and fruiting levels remain "ok". *Gossia bidwillii*, badly affected in the first few seasons, was less so in 2017. *Archirhodomyrtus beckleri* (the northern chemotype) has not been seen infected.

Mr Paterson reports significant infection levels on new growth and post-fire coppice and lignotuber resprouts in two *Eucalyptus* species near rainforest on the Eungella plateau, *E. resinifera* subsp. *hemilampra* (a known host from inoculation screening), and *E. andrewsii* subsp. *andrewsii* (reported under the Queensland-preferred name of *E. montivaga*). The former species is part of habitat for local populations of the Greater Glider and Yellow-bellied Glider, and is a preferred food source (nectar, foliage, sap) for the latter. These eucalypt observations should be investigated further.

Finally, Mr Paterson reports that the incidence of active Myrtle Rust in the Mackay area drops right away as soon as the daytime maximum temperature gets above 28^{o} C, regardless of moisture.

G. Pegg (pers. comm. May 2018) has unpublished observer reports of severe infection of *Lithomyrtus obtusa* west of Townsville. This species is widespread in eastern Queensland from Wide Bay to Cape York (and occurs in New Guinea).

North Queensland

Observations in this region are also very scanty outside some cities and on cultivated plants. A significant number of wet forest species native to this region are known as hosts from 'natural' (open air) infection on cultivated specimens with authenticated identification in botanic gardens and arboreta in north-eastern NSW and south-eastern Queensland, and have not yet been confirmed as infected within their natural range (let alone assessed for impact). For this reason they, along with other 'cultivation only' records, were excluded from the data set used by Berthon et al. (2018) to generate climatic suitability models and conservation priorities. However, *A. psidii* is well established on other locally confirmed species throughout the Wet Tropics and north to Bamaga near the tip of Cape York. It is reported from three of the Torres Strait Islands (B. Waterhouse, DAWR, pers. comm. Nov. 2017). *A psidii* is also established on the Atherton Tableland west at least to Tolga and Mareeba (Pegg et al. 2014a), and west of the Great Divide on the Walsh River on *Melaleuca ?leucadendra* (P. Entwistle pers. comm. 2015).

It seems highly unlikely that the rainforest species known as hosts in cultivation are not also subject to infection at some level in their wild habitat, and this review identifies some of these species as priorities for impact survey. CSIRO and other research agencies have an extensive network for permanent flora plots in Myrtaceae-rich vegetation types through the Wet Tropics (and indeed in other areas). These plots have detailed floristic records antedating the arrival of the Myrtle Rust pathogen and which constitute an ideal basis for impact assessment – requiring only institutional will and resourcing.

Highly reliable observations for the presence of active Myrtle Rust on a number of species in the Wet Tropics have been made by A. Ford (CSIRO, pers. comms 2017-18), who reports very heavy infection levels on *Rhodamnia spongiosa* (near Lake Tinaroo, 700 m a.s.l.), *Gossia hillii* and *G. myrsinocarpa*, and *Rhodamnia longisepala* (a very rare species endemic to the Windsor Tableland). Ford has noted (pers. comms Aug.—Oct. 2017) low to medium levels of infection on *Backhousia hughesii*, *Gossia bidwillii*, *G. grayii*, *G. lewisensis*, *G. shepherdii*, *Rhodamnia blairiana*, *R. costata*, *R. sessiliflora*, *Rhodomyrtus pervagata*, *Syzygium canicortex*, *S. corynanthum*, *S. cryptophlebium*, *S. dansiei*, *S. kuranda*, *S. luehmannii*, and *Uromyrtus metrosideros*. Ford also reports ex situ mortality in cultivated seedlings of *Callistemon polandii* (145 of 150 were killed by Myrtle Rust), and *Melaleuca lophocoracorum* ("many killed, others survived, and remain alive after in-ground planting"). The latter species has not hitherto been reported as a host, and is exceedingly rare in the wild near Ravenshoe. On the positive front, Ford reports that his active search for evidence of Myrtle Rust symptoms on the wild population of *Barongia lophandra* found none.

The fully riparian species *Tristaniopsis exiliflora* has been the subject of conflicting reports. This species is strictly rheophytic, growing in the flood-zone of creeks and rivers where it is often dominant. Any severe decline of this species could affect the hydrology of such watercourses. Heavy infection levels in recent years have been reported, and interpreted by some observers as decline. A. Ford (CSIRO, pers. comm. Sept. 2017) confirms repeated heavy infection (e.g. August 2017) but feels that evidence for high mortality up to that date is lacking; he acknowledges a lack of evidence either way in relation to effects on reproductive capacity or recruitment. G. Pegg (QDAF, pers. comm. May 2018) also has seen no adult mortality but confirms significant impact at Davies Creek on epicormic regrowth, seedlings, and flowers. In observations made since, J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018), "assessed 12 populations. Four populations showed no or very minor damage; these occurred in drier habitats (i.e. surrounded by woodland). The other populations located in moister habitats such as lowland or highland rainforest showed severe damage and active rust". Wills observed extensive defoliation of *T. exiliflora* along the Russell River, some more densely vegetated parts of upper Davies Creek, and elsewhere in lowland rainforest south of Cairns, with tip dieback and branch death, coppice growth badly infected, and no seedlings seen.

Some areas seem very prone to heavy Myrtle Rust infection on multiple species. For the Windsor Tableland, Ford reports (pers. comm.) nearly all of the many non-eucalypt Myrtaceae species present in the area infected or with post-infection symptoms, on both sides of the tableland but especially on the wetter side (but then also at drier sites).

J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018, work in progress) conducted a 17-day rapid survey of multiple species in North Queensland in May 2018. He reports:

- *Barongia lophandra* and *Mitrantia bilocularis*, both seen only in garden and arboretum situations where "badly hit"; *Eucalyptus resinifera* subsp. *resinifera* (a first field report if verified) significantly affected on coppice growth at Baldy Mountain, west of Atherton; *Gossia hillii* (multiple sites, seedlings to large trees), *Gossia punctata* (two populations) and *Gossia lewisensis* (Mt Lewis population) all with extensive damage; *Eugenia reinwardtiana* (small-leaved form, Musgrave River area) with active foliar rust and some tip dieback, immature green fruits not infected but old black fruit appeared dead; *Lithomyrtus obtusa* (two large populations near Cairns, c. 30 plants) with foliage almost untouched and fruiting heavily, but with very heavy infection on the fruits; *Ristantia pachysperma* (in lowland rainforest near Babinda and in lowland swamp rainforest in Russell River National Park) heavily infected at all stages from seedlings to large 20-30 m tall trees, some of the latter extensively defoliated, canopy trees, saplings and seedlings had died from the infection; *Rhodamnia spongiosa* "hammered everywhere seen", with heavy infection and significant defoliation and branchlet dieback; *Stockwellia quadrifida* (one observation only, active rust on seedling);

- *Rhodomyrtus pervagata*, *Rhodomyrtus macrocarpa*, *Rhodamnia sessiliflora*, *Gossia myrsinocarpa* and *Rhodomyrtus canescens* all showed active rust infection across multiple sites (from seedlings to small trees), with severe tip dieback and branch death, but also some variation in disease and impact levels – *Rhodomyrtus pervagata* and *Rhodamnia sessiliflora* were found at a few sites to be fruiting and flowering and seemingly healthy, and a few trees seemed to show some resistance.

- *Decaspermum humile* (Northern Metapopulation), 10 populations assessed at Black Mountain, Mt Lewis, Danbulla, and Downfall PSP – these showed minor to severe damage, with two large trees to 20m nearly dead and numerous seedlings badly damaged at Danbulla.

- *Gossia fragrantissima* was assessed at 8 populations from across its range, including the only population on the Sunshine Coast; no active rust was found, or damage that could be attributed to Myrtle Rust. The Sunshine Coast population had healthy fruit and flowers in January 2018.

- *Gossia bidwillii* seems "quite resistant" at multiple wild sites, as also *Gossia dallachiana* at more than ten wild sites; *Gossia fragrantissima* –Wills reports "I have assessed 8 populations from across its range including the only population at the Sunny Coast and have not found any active rust or damage that could be attributed to MR. The population at the Sunny Coast had healthy fruit and flowers in January 2018."

- *Melaleuca viridiflora* with occasional pustules only; *Pilidiostigma tetramerum* and *P. tropicum* both infected but with a low level of damage, still fruiting and with seedling recruits apparently establishing successfully; *Rhodamnia blairiana* (a montane species at 700+ m a.s.l.) relatively resistant; *Syzygium endophloium* with minor infection only; *Uromyrtus metrosideros* (Lamb Range), with extensive new growth but no infection evident;

- *Archirhodomyrtus beckleri* (Northern chemotype) seen at multiple sites and appearing untouched by Myrtle Rust; *Osbornia octandra* (Mangrove Myrtle) with no infection or any obvious signs of past damage on any of c. 10 plants at one site; *Sphaerantia discolor* (wild sites, only two individuals, in shade) with no obvious infection; *Thaleropia queenslandica* apparently uninfected at multiple sites;

- Four species and one subspecies not previously recorded as hosts of *A. psidii*, are reported by Wills on a preliminary basis as infected: *Gossia shepherdii* all mostly defoliated in four wild populations, and one remnant garden specimen near Topaz also severely defoliated and with epicormic growth covered in pustules); *Sphaerantia chartacea* (seen only in cultivation where new shoots covered in pustules but no branch death), and *Xanthostemon whitei* (only one pustule detected and minimal signs of damage). Infection on coppice growth of *Eucalyptus resinifera* subsp. *resinifera* at Baldy Mountain is also reported by Wills; previous host reports relate to subsp. *hemilampra* in the field and in inoculation trials, and *E. resinifera* (subsp. unspecified) in inoculation trials by Morin et al. (2011, 2012). These four taxa are noted here but are not included in the Australian host list at Appendix 3, pending write-up by Wills.

Syzygium bamagense in the Iron Range area is reportedly heavily infected (G. Pegg and J. Roth, pers. comms May 2018). Pegg (pers. comm.) also reports personal observations of pre-2017 adult mortality of *Gossia myrsinocarpa*, *Rhodomyrtus pervagata* and *Rhodamnia sessiliflora* at some sites, severe infection on *Ristantia waterhousei* from the Cairns and Daintree regions; and a further report (from R. Shivas) of *R. waterhousei* infection in the Babinda region.

An observation common to some of the few North Queensland rainforest observers (at least up to end 2017) is that adult mortality in the wild has ben rarely seen. Some report that some or most of these species (e.g. *Rhodamnia spongiosa*), while regularly heavily infected early in the seasonal flush, have seemed able to 'push through', with the flush outlasting the rust outbreak and more or less normal foliage restored by the end of season. However, there is little data as yet for any species on the impact on flower and fruit set. One interpretation of these reports is that the extended tropical wet season of the north may have engendered a longer period of capability for flush production in local species, and perhaps less favourable conditions for rust spore dispersal in the wettest months, compared to a more constrained flush period (more frequently coincident with optimal rust conditions?) in the subtropical south. G. Paterson's observation in the Mackay area of a daytime 28^{o}C maximum for Myrtle Rust 'activity', may or may not apply further north or in particular microclimates. However, given the paucity of monitoring and the propensity of Myrtle Rust timing and severity to vary with weather conditions, it seems more than probable that either some species were 'late starters' in exhibiting severe damage, and/or that a simple lack of observations had led to some underestimation of damage and mortality. The recent observations by Pegg (2015-6?) and Wills (2018) cited above, suggest that in any event damage in the Wet Tropics is now reaching conspicuous levels for some species. On the scanty evidence, a generalised tendency for highly susceptible taxa to be able to 'push through' does seem to contrast with the pattern in south-east Queensland and northern NSW. Analysis of data (herbarium records etc) on the timing and duration of seasonal flush for species common to the two regions, or for pairs of closely related taxa, would be desirable, as an adjunct to the indispensable expansion of field impact surveys.

Northern Territory

In contrast with the east coast, *A. psidii* has moved slowly in the Northern Territory since first detection in 2015, both geographically and in terms of host range. The initial detection, on Melville Island, was on the already known host *Eugenia reinwardtiana* (cultivated, not native to the NT) and the then-new host species *Leptopsermum madidum* (subspecies uncertain; cultivated) and *Lithomyrtus retusa* (wild, native). The Tiwi Islands, including Melville Island, feature as one of the higher susceptibility areas for *A. psidii* in the NT in several of the predictive climatic modelling maps. The mode of arrival on the island is unknown.

Myrtle Rust was subsequently detected in the Darwin area on *Syzygium armstrongii*, and at Berry Springs on *L. retusa*. More recently (2017) it has been detected on Bathurst Island on *L. retusa*, and in eastern Arnhem Land on *Eugenia reinwardtiana*. It has not to date been detected on *Melelaeuca leucadendra*, or on monitored plants of the extremely susceptible *Syzygium jambos*. The progress of the disease has been slow, but by late 2017 adult plant death in *L. retusa* was evident at some sites on Melville Island, and serious damage on the same species at Berry Springs (J. Westaway *in litt*. Dec. 2017; Westaway in press). Some *Lithomyrtus* species are known to have a low level of seed viability, and technically unresolved germination problems for cultivation; the former may present problems for *L. retusa* in the wild in the face of Myrtle Rust-mediated decline, and the latter for any ex situ conservation actions. Germplasm trials to determine seed biology for this species and *L. linariifolia* (see next) are recommended.

Other species of concern in the NT include *Allosyncarpia ternata*, which forms a single-species rainforest vegetation type in gorges and on drainage lines along the western Arnhem Land escarpment. *A. ternata* is a known host from inoculation trial (Morin et al. 2012). It has an establishment mode which may, depending on associated weather conditions, make it unusually vulnerable to infection by *A. psidii*. Juvenile plants for some years put out new aerial shoots in the Wet season, but these then die back during the Dry, with plant energy going into developing the root system rather than foliage; only later does a permanent aerial structure establish. This means the annual flush of new foliage accounts for 100% of leaf area during this phase; severe infection and damage to this flush may have proportionately greater impact than in species which retain a mix of old and new foliage.

Closely associated with *A. ternata* patches, occurring along their fringes, is the shrub *Lithomyrtus linariifolia*; the susceptibility of this species to *A. psidii* infection is not known. Another shrub species, *Dichapetalum timoriense* (family Dichapetalaceae), is largely or wholly restricted to the understorey of *Allosyncarpia ternata* forests; while not currently listed under either NT or Commonwealth legislation, Kerrigan (2004) regarded it as qualifying for Vulnerable status. Any decline of the *Allosyncarpia* overstorey would be likely to adversely affect *D. timoriense*.

Island Territories

On Lord Howe Island, a Myrtle Rust outbreak October 2016 was detected very early on monitored cultivated exotic plants. A prompt eradication response appears (subject to continued monitoring) to have succeeded (Lord Howe Island Board, 2016, 2017; H. Bower pers. comm. Feb. 2018) without any spread of the disease to the five endemic taxa of Myrtaceae (four of which are known hosts from inoculation testing – Morin 2011, 2012). Lord Howe Island remains at high risk of reinfection from mainland Australia and New Zealand. The five Myrtaceae species are important elements of much of the Island's vegetation, which floristically and climatically is likely to be highly suitable for *A. psidii* establishment and persistence. This review recommends precautionary large-scale germplasm banking as a flagship project for World Heritage protection. Only one of the taxa is likely to have non-orthodox seed requiring storage enablement testing and research.

Christmas Island has not yet been exposed to *A. psidii*, as far as is known, and the relatively few Myrtaceae species, couple with climate, make predictions uncertain. *Syzygium nervosum* (which also occurs in WA and the NT) was rated by Pegg et al. (2014a) as highly susceptible from cultivated specimens. Precautionary germplasm collection and storage enablement testing would be prudent.

Norfolk Island has no native taxa of Myrtaceae. It underwent an outbreak of Myrtle Rust on some exotic cultivated and naturalised species in October 2016, a few months prior to the first detection in New Zealand (Raoul Island). The handling of communications around the Norfolk Island outbreak was exceedingly poor. There was no public announcement of the outbreak as an extension of range, and it was communicated through Commonwealth biosecurity channels but apparently no further. No public communication on the Myrtle Rust outbreak on Norfolk Island has been available and no list of affected species has been available. The handling of the outbreak by Australian biosecurity authorities is hard to explain, unless an assumption was made that as no Island native species were involved, and that as Myrtle Rust was present on the Australian mainland (but not New Zealand at that stage), it didn't matter. The Commonwealth Department of Agriculture was certainly aware at the time of the risk posed by other strains of the disease (well ventilated at successive national workshops), yet seven months later, DAWR had still not confirmed whether or not the Norfolk Island strain was the 'pandemic' strain (Hansard 2017: 75—78). Word-of-mouth information from the island (Anon. pers. comm. May 2016) indicated that *Psidium cattleyanum* (Cherry Guava) may have been one of the affected species – this has still (June 2018) not been clarified. *P. cattleyanum* would, *if confirmed*, be a new host record for Australia. Its greater significance however is that the 'pandemic' strain of *A. psidii* has a very poor affinity for the genus *Psidium*, whereas some other strains have a greater affinity for it. Infection on a new *Psidium* host species might therefore be a signal of new strain arrival, and certainly requiring very prompt genetic diagnosis.

The need to maintain strain-level biosecurity measures is paramount. There are significant lessons to be drawn from the Norfolk Island outbreak, and swifter action and communication are needed in response to new reports of this pathogen. The fallacy of dealing with pathogen threats as unitary species-level entities, and the vital need to maintain strain-level biosecurity, is stressed by McTaggart, van der Nest, et al. (2016). This was recognised to some degree in the recent review of the Australia's biosecurity system (Craik et al. 2017) and its recommendations; it remains to be seen whether, and how rapidly, biosecurity procedures and practice will evolve accordingly.

4.6 Ecological community impacts

4.6.1 Subtropical wet sclerophyll and rainforest transition communities.

As summarised under species impacts above, Pegg *et al*. (2017) document the declines of several species in Myrtaceae-rich, wet sclerophyll-dominated forest of south-east Queensland. This type of community is common through much of the zone invaded by *Austropuccinia psidii* from about Coffs Harbour north to the Gympie area, and often has a strong warm-temperate or subtropical rainforest species component in the mid- and under-storey structural layers, often signifying a successional trend towards rainforest from a post-fire or post-clearing sclerophyll-dominated community. The Myrtaceae demonstrated as being under steepest decline in the above study are part of this rainforest-transition dynamic. Rainforest regeneration is a process socially valued and heavily invested in (by both Government and landowners) in much of north-coastal NSW and parts of south-east Queensland. The impact of Myrtle Rust on the success of ecological restoration projects is one factor in its overall impact on biodiversity. This relates not only to the potential loss of ability to regenerate desired species. Pegg *et al*. (2017) comment on the potential for weed invasion in the light gaps opened by the defoliation and mortality caused by Myrtle Rust disease, observing that "*Rhodomyrtus psidioides* at Ryans Road has been replaced by other species including the noxious weeds lantana (*Lantana camara*) and wild tobacco (*Solanum mauritianum*)." Carnegie et al. (2016) make a similar observation for Lantana "colonising gaps provided by mortality of *R. psidioides* stands". Such shrubby weeds, once established, can greatly hinder both natural and assisted forms of ecological regeneration, and can change the fire dynamics of the community making them more vulnerable to wildfire.

4.6.2 Coastal heath and heathy woodland communities

Vegetation communities falling under this general type are often Myrtaceae-rich and are very common along the east coast from Sydney to Maryborough, with more isolated occurrences further north and south. Their core distribution is thus completely overlapped by that of fully naturalised Myrtle Rust. These communities often interdigitate closely with patches of littoral rainforest and wet sclerophyll forest (see previous), and Broad-leaved *Melaleuca* wetlands (see next), each of which in turn contain highly susceptible species and may provide microclimatic refugia for the rust, and a spore reservoir, in dry and cold seasons when the more open heathy communities may be less conducive. The heathy communities form a major vegetation type in many conservation reserves of the region, especially on the NSW north coast and north to Noosa.

A few of the constituent known-host species of these heathy communities are under study – see under *Species studies (iv)* and *(v)* above for some preliminary results. The post-fire re-sprout and seedling phases of regeneration are of particular concern for rust impact, although some species (e.g. *Melaleuca nodosa*) are seriously affected on normal adult flush.

Evaluation of actual effects has barely begun, so scenarios for the future can be no more than speculative. One hypothetical situation, among others, concerns thicket-forming Myrtaceae (e.g. some *Leptospermum* species) in heath systems, especially on steep coastal slopes or old dune systems where, with long inter-fire intervals, they may completely dominate vegetation structure at small scales, preventing erosion and providing much faunal shelter. In such situations there is usually minimal recruitment except after fire. The thicket-forming species are often long-lived, suppressing other non-myrtaceous species in the same environment, although these usually remain present nearby. The thickets themselves, although they may persist for many decades, are not necessarily static – the heath systems are floristically and structurally dynamic particularly in response to fire. 26 species of *Leptospermum* are known hosts for *A. psidii*, although many so far only from inoculation tests. Very few have been studied for post-fire Myrtle Rust impact and susceptibility of seedlings and re-sprouts. An exception is with some northern NSW species (G. Pegg, unpublished work in progress), among which *L. trinervium* and *L. liversidgei* are exhibiting high-level Myrtle Rust impact after fire at some sites including seedling failure and some mortality of resprouting adults. Fire will trigger extensive re-sprouting and/or seed germination in these and similar species – a mass recruitment event. Sites are often adjacent to other systems with likely permanent *A. psidii* spore load. Very dense and extensive thickets may have few surviving seed of other species in the immediately local soil seed-bank; colonisation of a vacant site by other species may be slow. Under certain conditions of weather, spore load, and susceptibility, the potential for a catastrophic failure of a post-fire regeneration event, as a result of Myrtle Rust infection, is clear in principle. In this event, a range of ecological effects are possible. This may include simple colonisation and substitution by neighbouring native species, but if not, weed invasion may be likely if propagules are present, and soil surface exposure may be unusually high for unusually long, leading on steep slope and dune systems to an unusually prolonged risk of erosion. Effects on dependent fauna will be highly site-dependent and hard to predict, although total loss of thicket-forming Myrtaceae over a large area could be expected to have adverse effects.

4.6.3 Broad-leaved paperbark communities.

A trio of species of major concern, both in their own right and as conspicuous or dominant elements of riparian (river-bank), floodplain and wetland communities in tropical and sub-tropical Australia, are the Broad-leaved Paperbarks. *Melaleuca quinquenervia* occurs along the east coast of Australia from Sydney to Cape York, and was rated by Pegg *et al*. (2014a) as variably susceptible to Myrtle Rust infection (ranging from relatively tolerant to extremely susceptible). *M. leucadendra* occurs along the Queensland coast north from Rockhampton, in the Top End and Gulf regions of the Northern Territory, and in northern areas of Western Australia; it is rated as varying from relatively tolerant to highly susceptible to Myrtle Rust infection (*loc. cit*.). *M. viridiflora* occurs from about Maryborough in Queensland around northern Australia to the Dampier Peninsula of WA (and in New Guinea); it is rated as highly susceptible (*loc. cit*.).

The ecological significance of these Paperbark species, where they occur *en masse* across seasonally inundated floodplains or on water margins, is enormous. They are often the main or only tree species present, being among the few able to tolerate prolonged waterlogging. They play a major role in shading and cooling wetlands and watercourses. They contribute to the maintenance of water quality and water-table levels, and stabilise banks and floodplain soils. They provide a massive food (especially nectar) source for a very wide range of birds, mammals and invertebrates, and habitat for similarly large range of vertebrate and invertebrate species and epiphytic plants including several species of orchids. Data from Florida USA indicates that *M. quinquenervia* in wetlands also represents a very large proportion of total system biomass above and below ground. Changes in the density of stands and their recruitment success rates may have serious effects on any of these attributes, and may induce feedback loops that further reduce pollinator visitation and reproductive success.

Melaleuca quinquenervia is known as susceptible to a strain of *Austropuccinia psidii* in Florida USA, where it is an environmental weed of wetland systems; the pathogen is a factor in control programs there, is known to reduce flowering and therefore levels of seed-set, and appears to operate synergistically with insect herbivores to the detriment of the host plants. In Australia, Pegg *et al*. (2012), early in the Australian Myrtle Rust outbreak, reported seasonally very high (up to 90+% of individuals) levels of infection at one site in north-eastern NSW of 80-96%, with correlated reduced growth rates and markedly low flowering rates.

Work currently in progress by Pegg and collaborators (unpublished data, October 2017) involves susceptibility testing of plants grown from wild-provenanced seed of these three paperbark species. Preliminary results (Pegg et al., 2018; G. Pegg pers. comm. Oct. 2017) indicate that *M.*

quinequenervia has an average of 44% of seedlings resistant, *M. leucadendra* 25%, and *M. viridiflora* 31%. The very large variability in susceptibility and resistance between provenances (and by inference, populations) within each species, indicates *prima facie* both a potential for artificial and (over the much longer term) natural breeding-in of resistance traits. It also flags the possibility of serious impacts on recruitment in some of those populations in the short to medium term, with associated ecological damage long before natural selection can operate. As with all species showing variance in susceptibility, there is a need to determine the genetic and physiological bases of the resistance traits and their heritability, before either any assumptions can be made about natural selection of them or the viability of restoration seedstock.

The 'ecological function' of broad-leaved *Melaleuca* species is evident in general terms as above, but has been rather poorly investigated at a quantitative level. Finlayson (2005) documents the high productivity, biodiversity levels and values, and ecological dynamism of these woody wetland systems. He notes that "Despite the biodiversity values of the freshwater floodplains of northern Australia being widely recognized, there has not been a concomitant investment in developing the extent of knowledge of the basic functions and ecological processes that underpin the ecological character of these habitats". Consequently, we are not well-equipped to determine potentially critical ecological tipping points in the event of declines of these species.

DSEWPAC (2012) provides estimates of the carbon sequestration role of *Melaleuca* swamps, and by inference some of the potential effects of the woody vegetation component:
" Wetlands in the coastal areas, particularly mangroves, have the greatest potential as [carbon] sinks. In these systems, biomass production is high but methane emissions are limited by salinity. Carbon storage has been estimated at ~240 tonnes C per ha to 1m depth in vegetated freshwater wetlands such as melaleuca forests, and ~550 tonnes C per ha to 1m depth in mangrove swamps. … the vegetated wetlands of Australia are expected to be net greenhouse gas sinks due to the high rates of primary production and low rates of decomposition. … Wetland disturbance and drainage has major impacts on carbon fluxes in Australia's wetland systems. Drainage and the associated increased oxygen diffusion into wetland sediments has led to an oxidation of organic material, releasing carbon into the atmosphere as carbon dioxide. Drainage of mangrove and melaleuca forests in Australia is likely to have contributed significantly to greenhouse emissions. Page and Dalal (2011) estimate that an average of 25% of the organic carbon in drained Australian wetland soils would be lost from the top 1m of the profile in the first 50 years following drainage."

There is substantial data on basic ecological parameters for a limited number of mixed-species *Melaleuca*-dominated wetlands in the Top End of the Northern Territory (Finlayson 2005 and references therein). There is much less for the similar communities in WA and around the Gulf of Carpentaria.

Finlayson et al. (1993) examined litterfall dynamics in a monsoon-tropics *Melaleuca* floodplain forest co-dominated by *M. cajaputi* and *M viridiflora*, confirming their high productivity in terms of density (294 trees/hectare) and aerial biomass (263 t/hectare), heavy litter fall, and their large contribution to the turnover of detritus (and hence nutrient fluxes). Equivalent data for *M. leucandendra* dominated communities has not been located, but seems likely to be similar when adjusted for possibly differential tree density compared to the above two species (noted by Finlayson et al. 2006 – the partitioning of habitat between the various overlapping and sympatric species of wetland broad-leaved melaleucas has not been fully investigated).

In the subtropical east, Greenway (1994) provides some data on litter and nutrient dynamics of a *M. quinquenervia*-dominated system in south-east Queensland, involving both riparian and floodplain sites. Litter fall varied with seasonal and yearly conditions; litter accumulation ranged 2.3—3.5

kg/m^2, high for any community, and with high retention of carbon, nitrogen and phosphorus; Greenway posits that these woody wetlands may act as nutrient sinks. A corollary, applicable to any paperbark communities of this type, is that decline of the dominant woody species, absent its effective immediate replacement by another, would be liable to mobilise much of this accumulated nutrient (and much other anoxic sediment) into downstream flows.

Data on the biophysical and some significant ecological aspects of *M. quinquenervia* and the systems where it is dominant have been generated in Florida USA, where the species has long been a major naturalised woody weed of wetlands. *M. quinquenervia* in Florida has since 1997 been subject to aggressive infection (Rayachhetry et al. 1997) by the C4 strain of *A. psidii*, which is closely allied to the C1 strain found in Australia (the two together constitute the 'pandemic strain' – Stewart et al. 2017). The original Australian provenance/s and genetic variability of *M. quinquenervia* in Florida do not appear to have been determined, although Carnegie (2012) cites M.B. Rayamajhi (USDA) as observing wide variation in susceptibility to the local strain/s of *A. psidii*.

A wide range of Australian insect predators and pests of *M. quinquenervia* has been trialled, and some deployed, as biological control for this tree in Florida (Balciunas et al. 1995; Turner et al. 1998). Carnegie (2012) records that release and successful naturalisation of some of these insects may have triggered the surge in rust disease from 1997: "Once insects were released as biological control agents (e.g., weevils in 1997) their feeding resulted in the production of multiple fresh shoots, ideal for rust infection. There is some evidence of antagonistic effects of the biological control agents and *P. psidii* (e.g. *Oxyops* weevils don't feed on rust infected shoots [Rayamajhi et al. 2006]), but also of additive or synergistic impact: "the overall additive effects of multiple feeding guilds (weevil, psyllid and rust fungus) of natural enemies enhances efficacy of melaleuca regrowth control" (Rayamajhi et al. 2010)." Carnegie (2012) continues: "This has consequences for Australian flora and insect fauna. Myrtle rust could reduce food supply for Australian native insects (antagonistic effect) that feed on Myrtaceae, but could also be resulting in an increased (additive) impact on host plants by damaging regenerating shoots following insect damage. There are early observations of this interaction in Australia. Currently only small trees, or lower shoots on mature trees, of *M. quinquenervia* are affected by *P. psidii* in Australia. There are observations of miroid bugs and the rust on *M. quinquenervia* in northern NSW, as well as monolepta beetles and rust attacking *Rhodamnia rubescens* (P. Entwistle, pers. comm.). Observations in Florida indicate that all the insect biological control agents are inadvertent carriers of *P. psidii* spores."

An indicative study in Florida by Rayamajhi et al. (2008) showed strong site-dependent effects, but at the site most affected by weevil, psyllid and rust (*A. psidii*), strong declines in foliage, fruit, and seed biomass were registered.

G. Pegg (Queensland DAF) has preliminary research results indicating just such interaction in wild populations in Australia (unpublished data, in workshop Dec. 2017, see also Pegg et al. 2018), showing strongly differential survival rates of coppice regrowth when fungicide and insecticide were used separately and in tandem – i.e. an additive negative effect on regrowth survival when under pressure from both disease and insects.

The dominance of Broad-leaved Paperbark species within certain vegetation communities, their spatial extent, and their ecological function for associated aquatic and terrestrial biota, imply a very high degree of adverse 'cascade' effects if they were to undergo significant declines as a result of Myrtle Rust disease on either a local or regional basis. Very minor additional comments are provided below under 'Associated Fauna – Invertebrates'. A major research and information-assembly program is needed.

Key points for these Broad-leaved Paperbark communities are:

- Broad-leaved *Melaleuca* species are dominant across many seasonally inundated near-coastal floodplains and wetlands along the eastern and northern coasts of Australia, where forming dense low forest to open woodland; they are also important fringing trees on slow river and lagoon systems prone to seasonal overflow.
- No structurally and functionally equivalent species capable of maintaining the structure and biophysical function of floodplain woodland/low forest are likely to replace these *Melaleuca* species in the event of their decline, especially if that decline is rapid.
- There is variation in susceptibility, tentatively correlated with regional metapopulations.
- More-susceptible populations may undergo moderate to potentially severe decline through retarded adult growth and loss of flowering, and through mortality especially of juveniles; a more or less severe thinning effect may apply, perhaps for many decades, pending gradual accession of rust-resistant genotypes (if locally present). Total loss of the vegetation type, and niche closure, is possible in some circumstances.
- In the event of serious decline on a regional or local basis, loss of the ecological function and resource of Paperbark may be significant to severe for associated plants and fauna. Mass flowering of these species is a major seasonal nectar source for many vertebrates and invertebrates.
- More sunlight and higher temperatures at ground (or, in-season, water) level is likely to entail unpredictable but probably adverse results for most ground-layer vegetation, epiphytes, aquatic and terrestrial fauna, water quality.
- In the event of marked decline and thinning, with a loss of above-ground and below-ground biomass, nutrient fluxes will change, soil stability is likely to be adversely affected, hydrological changes (including loss of flood flow impedance and bank stability) may occur; and water-quality may decline. Local roles of paperbark stands in maintaining a hydrological barrier between brackish and freshwater pondages and groundwater may be jeopardised.
- The genetic basis and heritability of resistance traits in these Broad-leaved Paperbark species has not yet been determined. In principle, natural selection for more resistant genotypes may operate, albeit over long time frames, if robust and heritable resistant genotypes are locally present in sufficient density. In highly susceptible populations, decline of the ecological basis of the community (e.g. niche closure) may prevent recovery through natural selection, and would not mitigate collateral ecological damage in the meantime. Subject to much further research, the possibility of artificial selection of resistant host genotypes, and their use by translocation for reinforcement or replacement of highly susceptible genotypes, appears technically feasible – although such an intervention would require very careful examination of ecological and genetic risks and an extended and difficult social dialogue on ethics and cultural aspects.
- An existing research project (Pegg, QDAF), is focussed on *M. quinquenervia* communities and examining some aspects of Myrtle Rust susceptibility and resistance, and rust/insect interactions; its funding into the future is currently non-existent. An expanded research program into the full breadth of potential Myrtle Rust effects on Broad-leaved Paperbark species and communities (as recommended below) should maintain and extend this existing project as a key element.

4.6.4 Ramsar wetlands of potential relevance to Myrtle Rust

Australia currently has 65 *Wetlands of International Importance* listed under the *Ramsar Convention* (http://www.environment.gov.au/water/wetlands/ramsar). These vary greatly in type and in the prominence and ecological role of woody terrestrial vegetation.

A preliminary analysis indicates that there are 32 Australian Ramsar wetlands either within the current naturalisation zone of *Austropuccinia psidii* (seven in east-coastal NSW and Queensland), or in climatic zones elsewhere in regions identified as suitable for *A. psidii* establishment in two or more predictive mapping studies.

Relevant vegetation types and myrtaceous flora elements shown here are abstracted from the general vegetation information in Ecological Character Descriptions and linked documents on the *Australian Wetlands Database – Ramsar wetlands* website (http://www.environment.gov.au/water/wetlands/australian-wetlands-database/australian-ramsar-wetlands). Floristic data from these sources are not exhaustive, and Myrtaceae species other than those named here (including threatened species and both known and as-yet unknown Myrtle Rust hosts) may occur within Ramsar site boundaries in many cases. Currently known Myrtle Rust hosts are in **bold**.

TABLE 6: Ramsar wetlands with potential to be affected by Myrtle Rust

RAMSAR no, RAMSAR name	Relevant vegetation types	Myrtaceae elements (not exhaustive). Known hosts in bold.
Northern Territory – Limited areas of Myrtle Rust naturalisation since 2015-16		
1. Coburg Peninsula	Intertidal forested wetlands (incl. tidal freshwater swamp forests); Lagoon margins (f/water and saline/brackish); tree-dominated wetlands; monsoon forest.	*Eucalyptus tetradonta, E. miniata*; *Corymbia neosphylla, C. porrecta*; ***Melaleuca leucadendra***, ***M. viridiflora***, ***Syzygium angophoroides*** (a minor floristic element). Myrtle Rust detected in region 2017.
2. Kakadu National Park	*Melaleuca* forests; monsoon rainforests; riparian communities.	*Melaleuca* forests (a 'critical component'), ***M. leucandendra***, ***M. virdiflora***; ***Allosyncarpia ternata*** monsoon rainforest. Many other Myrtaceae closely adjacent.
Queensland: Myrtle Rust naturalised since 2010-12		
42. Bowling Green Bay	Intertidal forested wetlands; lagoon and stream margins; Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils.	*Melaleuca* spp. (many), eucalypt spp. (many); many other.
44. Shoalwater and Corio Bays Area	Very diverse set of wetland types, many supporting woody vegetation	*Eucalyptus/Corymbia* spp. (many), ***Melaleuca viridiflora*** / ***M. nervosa*** woodland; Beach Monsoon Scrub (Littoral Rainforest) incl. ***Eugenia reinwardtiana***; wet heath; lagoon fringe forest.
41. Moreton Bay	Floodplain and non-floodplain tree and heath swamps	*Melaleuca* spp. (many), *Eucalyptus* spp. (many); many other Myrtaceae.
51. Great Sandy Strait	Freshwater swamp forests and tree-dominated wetlands, wooded swamps, (incl. seasonally inundated)	*Melaleuca* spp. (many incl. ***M. quinquenervia***); eucalypt spp. (many); many other Myrtaceae in fringing woodland and wallum.
New South Wales: Myrtle Rust naturalised since 2010		

RAMSAR no, RAMSAR name	Relevant vegetation types	Myrtaceae elements (not exhaustive). Known hosts in bold.
52. Myall Lakes	Coastal swamp forest, lagoon fringes and river overflows. Heath and heath/forest systems.	Swamp forest with ***Melaleuca quinquernervia*** dominant or co-dominant. Complex of dry/wet heaths and heath-forests with various *Angophora*, *Corymbia* and *Eucalyptus* spp., ***Melaleuca nodosa***, *Kunzea capitata*, *Leptospermum attenutatum*, ***L. liversidgei***, ***L. juniperinum***, ***Syzygium paniculatum***. Many other Myrtaceae present. One federally listed TEC, four NSW-listed TECs.
24. Hunter Estuary Wetlands	Freshwater tree-dominated wetlands	***Melaleuca quinquenervia***; ***M. nodosa***; ***M. ericifolia; M. styphelioides***; ***Callistemon citrinus***; ***Syzygium* (*Acmena*) *smithii***; various Eucalypts
23. Towra Point Nature Reserve	Swamp forest, littoral rainforest, dune sclerophyll forest, bangalay forest	*Eucalyptus* spp., ***Syzygium paniculatum***, others.
Victoria – Myrtle Rust present in State but not fully naturalised at Feb. 2018		
21. Gippsland Lakes	Fringing shrubland	***Melaleuca ericifolia***; the nationally Endangered orchid *Thelymitra epipactoides* is present and probably associated with the *Melaleuca* areas.
13. Corner Inlet	Intertidal forested wetlands, incl. freshwater swamp forests; shrub wetlands; lagoon and stream margins	***Melaleuca ericifolia*** (dominant in Freshwater Tree-dominated Wetlands)
19. Western Port	Nil or minor fringe vegetation?	Nil or negligible?
18. Port Phillip Bay (Western Shoreline) and Bellarine Peninsula	Nil or minor fringe vegetation?	Nil or negligible?
57. Edithvale-Seaford Wetlands	Freshwater marsh, meadow, and open-water wetland	Nil or negligible?
South Australia – Myrtle Rust not yet present (Feb. 2018)		
66. Piccaninnie Ponds Karst Wetlands	Tea-tree shrubland; eucalypt woodland	***Leptospermum lanigerum, Melaleuca squarrosa***, *M. lanceolata*, ***Eucalyptus ovata*** var. ***ovata***
26. Bool and Hacks Lagoons	Aquatic, semi-aquatic	Nil or negligible?
Tasmania – Myrtle Rust present in State but not fully naturalised at Feb. 2018		
4. Logan Lagoon	Fringing shrubland and forest	***Leptospermum laevigatum***, ***Eucalyptus nitida***, ***E. viminalis***, ***Melaleuca ericifolia***
8. East Coast Cape Barren Island Lagoons	Forest/woodland	**Melaleuca ericifolia**; *Eucalyptus* spp. on inland areas.

RAMSAR no, RAMSAR name	Relevant vegetation types	Myrtaceae elements (not exhaustive). Known hosts in bold.
9. Flood Plain Lower Ringarooma River	Complex set of terrestrial woody veg types, most with Myrtaceae significant or dominant	***Melaleuca ericifolia, M. squarrosa, Leptospermum lanigerum, Eucalyptus amygdalina, E. pauciflora***
10. Jocks Lagoon	Shrub swamps, swamp forest	***Melaleuca ericifolia***; ***M. squarrosa***; ***Eucalyptus amygdalina***; likely various other *Melaleuca*, *Callistemon*, *Leptospermum*
12. Little Waterhouse Lake	Fringing coastal forest, heath	***Eucalyptus amygdalina***; other heath species?
WA (south-west) – Myrtle Rust not yet present (Feb. 2018)		
39. Lake Warden	Mallee shrubland	Fringing *Eucalyptus angulosa*, *E. platypus*, *Melaleuca cuticularis*, *M.* spp., *Calothamnus quadrifidus*
55. Lake Gore	Fringing shrubland and woodland	Minor -- fringing mallee shrubland (*Eucalyptus* and *Melaleuca* spp.
56. Muir-Byenup System	Fringing woodland and shrubland	Complex and floristically rich mosaic of *Eucalyptus marginata/Corymbia calophylla* forest, paperbark low forest, with *E. decipiens;* dense stands of *Melaleuca cuticularis*; stands of *E. occidentalis* with *M. cuticularis* and *M. violacea; M. viminea*, *M. raphiophylla* (sometimes dominant), *M. lateritia*, *Astartea leptophylla*. Other Myrtaceae present.
38. Vasse-Wonnerup System	Fringing woodlands	*Melaleuca rhaphiophylla*, *M. hamulos*, *M. cuticularis*) woodlands; *Eucalyptus rudis* woodlands.
36. Peel-Yalgorup System	Upslope Saltwater Paperbark scrub;	*Melaleuca cuticularis*, *M. rhaphiophylla*, *M. preissiana*, *Eucalyptus rudis*.
35. Forrestdale and Thomsons Lakes	Fringing woodlands	*Eucalyptus rudis*, *Melaleuca preissiana*, ***Euc. marginata*** dominants; plus c. 38 other Myrtaceae (several known hosts).
54. Becher Point Wetlands	Sedge marsh; shrub swamp	Not checked
WA (north-west) – Myrtle Rust not yet present (Feb. 2018)		
33. Roebuck Bay	Pindan scrub	*Melaleuca acacioides* forest (limited areas)
34. Eighty-mile Beach	Tidal freshwater swamp forests; shrub swamps; freshwater tree-dominated wetlands; forested peatlands	*Melaleuca alsophila* thickets; ***Melaleuca leucadendra*** on peat mounds;

RAMSAR no, RAMSAR name	Relevant vegetation types	Myrtaceae elements (not exhaustive). Known hosts in bold.
31. Ord River Floodplain	Riparian woodland; Mangrove (*Osbornia*)	*Eucalyptus* (9 incl. known hosts); *Corymbia* (9); *Calytrix* (3); Lophostemon grandiflorus; *camaldulensis*, *E. bigalerita*, *E. tectifera*, *Melaleuca* (7, incl. **M. *leucadendra***, **M. *viridiflora***); ***Osbornia octodonta***.
32. Lakes Argyle and Kununurra	Fringing woodland	***Melaleuca leucadendra***

4.6.5 Threatened Ecological Communities listed under the Commonwealth EPBC Act, at risk from Myrtle Rust.

The demographic and other effects of Myrtle Rust disease on ecologically ‘important’ species will only play out over decades, and data on many species and most ecological community-level impacts are as yet scanty. For these reasons it is not possible to assert projected effects on ecological communities (listed and not) with any assurance, but there is cause for concern for many (particularly the first shown). The vegetation communities shown below, listed under the Commonwealth EPBC Act as Threatened Ecological Communities (TECs), occur either in existing areas of *A. psidii* naturalisation and invasion, or in bioclimatic areas of moderate to high consensus likelihood of *A. psidii* climatic suitability according to the various predictive models and maps (see Section 2.3 above). All are Myrtaceae-rich and/or have known hosts as dominant or significant floristic elements. The ‘justifications’ here are necessarily brief and speculative.

- <u>Broad leaf tea-tree (*Melaleuca viridiflora*) woodlands in high rainfall coastal north Queensland</u> (Endangered). The dominant *M. viridiflora* is rated Highly Susceptible to Myrtle Rust (Pegg et al. 2014a).

- <u>Blue Gum High Forest of the Sydney Basin Bioregion (Critically Endangered)</u>. The main myrtaceous species of concern is the dominant *Eucalyptus saligna* (a known *Myrtle Rust* host overseas and from lab inoculation in Australia); seedling recruitment is a potentially threatened life stage. Turpentine *Syncarpia glomulifera* is a lesser floristic element of the community and a known host. The largest surviving BGHF remnant (at Cumberland State Forest, NSW) has *Rhodamnia rubescens* with persistent Myrtle Rust infection.

- <u>Littoral Rainforest and Coastal Vine Thickets of Eastern Australia</u> (Critically Endangered). Includes a significant myrtaceous component varying from region to region, but often with multiple species of *Syzygium* among a few other genera. Occurrences south of Gympie, prior to 2010, often included *Rhodomyrtus psidioides* as a conspicuous element. Other known *P. psidii* host species in this community include the low-susceptibility *Syzygium* (*Acmena*) *smithii* and (northern occurrences) the very high susceptibility *Eugenia reinwardtiana*.

- <u>Lowland Rainforest of Subtropical Australia</u> (Critically Endangered). Many known-host species occur in this vegetation type or on its margins, including some of the more seriously affected (genera include *Archirhodomyrtus*, *Gossia*, *Lenwebbia*, *Rhodomyrtus*, *Syzygium*). *Syzygium floribundum* (= *Waterhousea floribunda*), a known Myrtle Rust host, is a dominant of riparian areas in some occurrences. Various eucalypt species occurring as occasional emergent may also be at risk at recruitment stage.

- Mabi Forest (Complex Notophyll Vine Forest 5b) (Critically Endangered). Species sometimes occurring in riparian habitats within this community include the known Myrtle Rust hosts *Syzygium* (*Acmena*) *smithii*, *Melaleuca* (*Callistemon*) *viminalis*, and *Syzygium australe*.

- Swamp Tea-tree (*Melaleuca irbyana*) Forest of South-east Queensland (Critically Endangered). *M. irbyana* is not to date recorded as a Myrtle Rust host species. *M. nodosa*, a secondary constituent species of this community, is a recorded host of high susceptibility (Pegg et al. 2014a) and is known to be seriously affected in other communities where it occurs (G. Pegg and P. Entwistle, pers. comms 2017, 2018). *M. sieberi* also occurs in the community and is a recorded host from a few instances only.

Outside the current distribution of the Myrtle Rust pathogen in Australia, the following EPBCA-listed TECs are of concern. This is on the basis of their myrtaceous component, combined with their occurrence in areas that appear bioclimatically to be of medium to high likelihood of *A. psidii* establishment (see predictive maps in Glen et al. 2007, Plant Health Australia 2009, Kriticos et al. 2013, Berthon et al. 2018). The first set of six TECs (five in south-west WA and one in SA) are all in more or less mediterranean climates but at the wetter end of that biome at least in good years.

- *Corymbia calophylla - Kingia australis* woodlands on heavy soils of the Swan Coastal Plain (Endangered). The dominant species *Corymbia calophylla* does not yet appear to have been tested for susceptibility. Other Myrtaceae occur at lower frequency.

- *Corymbia calophylla - Xanthorrhoea preissii* woodlands and shrublands of the Swan Coastal Plain (Endangered). The main dominant tree, *Corymbia calophylla*, does not yet appear to have been tested for susceptibility. *Eucalyptus wandoo* (occasionally dominant) is a known host from inoculation testing under laboratory conditions (see Attachment 1). Other Myrtaceae occur at lower frequency.

- Shrublands and Woodlands on Muchea Limestone of the Swan Coastal Plain (Endangered). The co-dominant trees Eucalyptus decipiens and E. foecunda, and the major myrtaceous shrubs Baeckea robusta, Melaleuca acerosa, and M. huegelii, have not yet been tested for susceptibility. Numerous other Myrtaceae occur at lower frequency.

- Shrublands and Woodlands on Perth to Gingin ironstone (Perth to Gingin ironstone association) of the Swan Coastal Plain (Endangered). Swamp Kunzea (shown in Listing Advice as "*Kunzea aff. recurva*" – perhaps now = *K. glabrescens*?) and *Melaleuca viminea* (neither tested) are major elements; other Myrtaceae occur at lower frequency.

- Shrublands on southern Swan Coastal Plain ironstones (Endangered). The *Kunzea* shown in the Listing Advice as *Kunzea aff. micrantha*, and *Pericalymma ellipticum*, are typical and common elements. Neither have been tested for susceptibility. As per the Listing Advice, a number of Myrtaceae species are totally or largely confined to the southern ironstone soils, including *Calothamnus* sp. 'Scott River (Royce 84)', *Calothamnus quadrifidus* sp. 'Whicher (BJK & NG 230)', *Chamelaucium roycei* ms, *Darwinia* sp. 'Williamson (GJK 12717)', and *Melaleuca aff. incana* subsp. 'Gingilup (NG & ML 593)'. (Some of these taxa may have acquired formal names since listing – yet to be checked for concordance).

- Swamps of the Fleurieu Peninsula (Critically Endangered). The predictive maps generated to date mostly indicate a relatively low likelihood of establishment and persistence of Myrtle Rust in South Australia, but insofar as bioclimatically suitable areas for the rust exist in that State the models do encompass the Fleurieu Peninsula (see, e.g. Berthon et al. 2018). In this

TEC, the two dominant shrubs are both known hosts from inoculation screening: *Leptospermum lanigerum* and *L. continentale*.

- Arnhem Plateau Sandstone Shrubland Complex (Endangered). This TEC contains numerous Myrtaceous species, and at least six that are endemic to this TEC (see flora list at Appendix A of the Listing Advice): *Calytrix decussata*, *Calytrix faucicola*, *Calytrix inopinata* (shown as 'Near Threatened'), *Calytrix micrairoides* ('Near Threatened'), *Calytrix rupestris* ('Near Threatened'), *Calytrix surdiviperana* ('Near Threatened'); none have been subject to susceptibility screening to date.

Five further communities listed under the EPBC Act, all in the Sydney Basin, are also potentially affected, although they are somewhat drier communities and Myrtle Rust occurrence records to date are either not or only uncertainly assignable to them. These communities do however all have Myrtaceae species (including some known hosts) as dominant or conspicuous floristic elements, and all are somewhat prone to either wildfire or require periodic managed fire for conservation purposes. They may be subject to periodic rather than constant incursions of infection. The critical life stage susceptibilities of the potentially affected species have not been evaluated.

- Turpentine-Ironbark Forest in the Sydney Basin Bioregion (Critically Endangered). Turpentine (*Syncarpia glomulifera*) is a known host.

- Western Sydney Dry Rainforest and Moist Woodland on Shale (Critically Endangered). No records as yet of Myrtle Rust in this community, but most are on private land and have probably not been checked. Despite the predominantly dry sclerophyll landscape matrix, this community might maintain microclimatic conditions more conducive for Myrtle Rust disease. The known Myrtle Rust host species *Melaleuca styphelioides* is an important, sometimes dominant element; another known host, *Eucalyptus tereticornis*, is an important emergent species.

- Cumberland Plain Shale Woodlands and Shale-Gravel Transition Forest (Critically Endangered).

- Eastern Suburbs Banksia Scrub of the Sydney Region (Endangered). A near-coastal TEC of very few and small occurrences, with numerous Myrtaceae species.

- Shale/Sandstone Transition Forest (Endangered). A drier community, with some known hosts.

4.6.6 Threatened Ecological Communities listed under the New South Wales Biodiversity Conservation Act, known or likely to be at risk from Myrtle Rust.

In New South Wales, the broad vegetation formations and (bracketed) classes most likely on floristic and climatic grounds to be impacted over time by the sustained presence of Myrtle Rust include, using the scheme of Keith (2012):

- *Rainforests*: Subtropical, Northern Warm Temperate, Southern Warm Temperate, Cool Temperate (northern occurrences, and perhaps marginal for impact), Littoral, and Oceanic and Oceanic Cloud (both Lord Howe Island).
- *Wet Sclerophyll Forests*: North Coast, Northern Escarpment (?marginal), Northern Hinterland,
- *Dry Sclerophyll Forests* (uncertain levels for all): Clarence, Hunter-Macleay, Northern Gorge, Central Gorge (?marginal), Coastal Dune, North Coast, Sydney Coastal, Sydney Hinterland (?marginal), Sydney Sand Flats.

- *Heathlands*: Coastal Headland Heaths, Wallum Sand Heaths, Sydney Coastal Heaths.
- *Freshwater Wetlands*: Coastal Heath Swamps.
- *Forested Wetlands*: Coastal Swamp Forests, Coastal Floodplain Wetlands.

These formations and classes include the following Threatened Ecological Communities as listed under New South Wales legislation (http://www.environment.nsw.gov.au/threatenedSpeciesApp/SpeciesByType.aspx, accessed 22 Oct. 2017). Note however that not all of these are floristically or micro-climatically fully suited to *A. psidii* residency, and (in the absence of systematic surveys) not all have actual records of Myrtle Rust presence or absence to date. Most or all however are geographically suited to natural distribution of *A. psidii* spore loads at significant levels from relatively nearby communities likely to harbour the pathogen on a continual basis, and all have significant content of myrtaceous species known or likely to be susceptible to some degree. Some may nevertheless be only marginally or infrequently affected.

Critically Endangered Ecological Communities:

- Gnarled Mossy Cloud Forest on Lord Howe Island
- Blue Gum High Forest in the Sydney Basin Bioregion
- Eastern Suburbs Banksia Scrub in the Sydney Basin Bioregion
- Kincumber Scribbly Gum Forest in the Sydney Basin Bioregion

Endangered Ecological Communities:

- Bangalay Sand Forest of the Sydney Basin and South East Corner Bioregions
- Duffys Forest Ecological Community in the Sydney Basin Bioregion
- Freshwater Wetlands on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Illawarra Subtropical Rainforest in the Sydney Basin Bioregion
- Kurnell Dune Forest in the Sutherland Shire and City of Rockdale
- Kurri Sand Swamp Woodland in the Sydney Basin Bioregion
- Littoral Rainforest in the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Low woodland with heathland on indurated sand at Norah Head
- Lowland Rainforest in the NSW North Coast and Sydney Basin Bioregions
- Lowland Rainforest on Floodplain in the New South Wales North Coast Bioregion
- Pittwater and Wagstaffe Spotted Gum Forest in the Sydney Basin Bioregion
- River-Flat Eucalypt Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Southern Sydney sheltered forest on transitional sandstone soils in the Sydney Basin Bioregion
- Subtropical Coastal Floodplain Forest of the New South Wales North Coast Bioregion
- Swamp Sclerophyll Forest on Coastal Floodplains of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions
- Sydney Freshwater Wetlands in the Sydney Basin Bioregion
- Sydney Turpentine-Ironbark Forest
- Umina Coastal Sandplain Woodland
- Warkworth Sands Woodland in the Sydney Basin Bioregion
- White Gum Moist Forest in the NSW North Coast Bioregion.

Further NSW TECs occur largely or fully within the zone of *A. psidii* naturalisation, but are perhaps (pending monitoring!) less likely to suffer serious impact for climatic or microclimatic reasons . They may nevertheless contain species which are seriously affected on an occasional or ongoing basis, and may have potential for multi-species damage following disturbance events (e.g. fire). They are:

- Castlereagh Swamp Woodland Community;
- Central Hunter Grey Box-Ironbark Woodland in the New South Wales North Coast and Sydney Basin Bioregions;
- Central Hunter Ironbark-Spotted Gum-Grey Box Forest in the New South Wales North Coast and Sydney Basin Bioregions;
- Coastal Upland Swamp in the Sydney Basin Bioregion; Cooks River/Castlereagh Ironbark Forest in the Sydney Basin Bioregion;
- Grey Box-Grey Gum Wet Sclerophyll Forest in the NSW North Coast Bioregion;
- Hunter Floodplain Red Gum Woodland in the NSW North Coast and Sydney Basin Bioregions;
- Hunter Lowland Redgum Forest in the Sydney Basin and New South Wales North Coast Bioregions;
- Hunter Valley Footslopes Slaty Gum Woodland in the Sydney Basin Bioregion;
- Hunter Valley Vine Thicket in the NSW North Coast and Sydney Basin Bioregions;
- Hunter Valley Weeping Myall Woodland in the Sydney Basin Bioregion;
- Illawarra Lowlands Grassy Woodland in the Sydney Basin Bioregion;
- Lower Hunter Spotted Gum-Ironbark Forest in the Sydney Basin Bioregion;
- Lower Hunter Valley Dry Rainforest in the Sydney Basin and NSW North Coast Bioregions;
- Maroota Sands Swamp Forest; Melaleuca armillaris Tall Shrubland in the Sydney Basin Bioregion;
- Milton Ulladulla Subtropical Rainforest in the Sydney Basin Bioregion;
- O'Hares Creek Shale Forest; Quorrobolong Scribbly Gum Woodland in the Sydney Basin Bioregion;
- Robertson Basalt Tall Open-forest in the Sydney Basin and South Eastern Highlands Bioregions;
- Shale Gravel Transition Forest in the Sydney Basin Bioregion;
  Shale Sandstone Transition Forest in the Sydney Basin Bioregion;
- Sun Valley Cabbage Gum Forest in the Sydney Basin Bioregion;
- Swamp Oak Floodplain Forest of the New South Wales North Coast, Sydney Basin and South East Corner Bioregions.

Many other described and named (but not listed) ecological communities in New South Wales (including potentially Lord Howe Island) are likely to be adversely affected by Myrtle Rust. As with species, current listing status based on threats other than Myrtle Rust is not a sure guide to those most likely to be affected.

4.6.7 Threatened Ecological Communities at risk from Myrtle Rust – other jurisdictions.

Queensland's 1539 Regional Ecosystems (Queensland Herbarium 2018) are not parsed for risk here, but an analysis of Myrtle Rust records against Regional Ecosystem sub-types, vegetation types, and host species distributions, would greatly inform conservation planning at State level.

For the Northern Territory, the level of *A. psidii* naturalisation is currently low (approximately seven localities known), and climatic suitability predictions, for the establishment of *A. psidii* and the potential for Myrtle Rust disease at significant levels, involve much uncertainty. It is too early to forecast more than three specific vegetation communities potentially at risk at the ecological level – Paperbark Forests, Monsoon Vine Forest, and Anbinik (*Allosyncarpia ternata*) forest.

In Victoria and Tasmania naturalisation is too marginal for firm forecasts, the pathogen being confined to date (June 2018) to cultivated situations and the greenlife industries. South Australia and Western Australia are yet to be exposed to the pathogen and relatively few endemic host species are known from other sources. For all four jurisdictions, State-level analysis of the climate-suitability predictive models (particularly those of Kriticos et al. 2013, and Berthon et al. 2018), overlaid with data for Myrtaceae species diversity and distribution, will allow some estimate of those likely to be most at risk. The EPBC-listed TECs and Ramsar Wetlands listed above for these jurisdictions as potentially vulnerable, are necessarily speculative.

4.7 Potential impacts – associated and dependent biota

4.7.1 Summary

Declines of Myrtaceae species due to Myrtle Rust infection have the potential to cause or exacerbate other aspects of environmental decline. One of the most obvious areas of concern is in relation to associated flora and fauna, especially those that maintain a strong or exclusive (obligate) relationship with rust-susceptible species of Myrtaceae. Meaningful predictions are difficult in these early stages of the Myrtle Rust epidemic, given the paucity of Myrtle Rust monitoring and the patchiness of baseline information programs to inform such assessments. Some level of inference, at least of risk, is possible where there is knowledge of the degree and mode of association between the Myrtaceae species of concern and other biota. Associations are often of the form where the Myrtaceae species provides either direct habitat, transitory or critical-stage shelter, or food, for another species. For this review, expert opinion has been sought, and only limited direct literature review conducted, for some of the major groups of associated organisms. In summary, loss of Myrtaceae species from landscapes due to Myrtle Rust is likely to have a variable impact for different groups of biota.

No hard data is available on the current or possible future effects of Myrtle Rust on biota that are closely associated with, or dependent on, myrtaceous species. The following synopsis indicates some of the major biotic groups that are known to be associated with moist-forest Myrtaceae to a greater or lesser degree, and some expert opinions on the plasticity of that relationship.

All such associated biota, in particular circumstances of space and time, may need to be considered as at least theoretically subject to adverse impact, if the Myrtaceae species or communities with which they are associated decline or are extinguished. For example, where Organism A typically lives physically on a Myrtaceous species but can live on non-myrtaceous trees as well (a non-obligate relationship), then loss of the Myrtaceae host may not seriously affect it, but only if those alternative host trees are present within effective movement or dispersal range. If the alternative habitat trees are not present, or not suitably structured (e.g. too young), then Organism A will have nowhere to live and will decline on a local basis. Depending on its overall status, this may contribute to a generalised decline.

The potential spectrum of associations runs from casual to fully obligate use of the host plant, and potentially includes mutualistic relationships of benefit to both species. Vertebrate fauna may utilise myrtaceous plants as habitat (casual, diurnal, seasonal, or life-long), for food (exclusive or not), or for critical life stages (nesting). They may play a mutualistic role for the host plant through pollination, fruit/seed distribution, or control of foliar pests. Epiphytic lichens and bryophytes may contribute to the temperature and moisture relations of the host plant, and to its nutrient inputs.

4.7.2. Vertebrates

A wide range of mammals and birds, and some reptiles and amphibians, utilise Myrtaceae species within the climatic and habitat zones currently or potentially occupied by *A. psidii*.

Those vertebrates utilising Myrtaceae for shelter and nesting sites may be seriously affected by floristic change over time, as other floristically ‘replacement’ flora may not be as functionally suitable or as prevalent. This could be particularly important for species that utilise Myrtaceae ‘monoculture’ species prone to cohort recruitment (e.g. tea-tree thickets) in those cases where seedlings prove to be highly susceptible to Myrtle Rust-mediated mortality. In contrast, the time scales for decline of some other shelter functions (e.g. tree hollows, for tree species that prove to be rust-affected) may be over many decades.

Many vertebrates are dependent on tree hollows for *shelter*, including diurnal shelter and as nesting sites during reproduction. In most Australian forest systems, Myrtaceae species (especially eucalypts) of suitable age provide most of the hollows. The loss (including non-replacement) of hollow-bearing trees is recognised as an actual or potential threatening process in most or all jurisdictions, and is legislatively recognised as a Key Threatening Process in New South Wales. In that State, at least 46 mammals, 81 birds, 31 reptiles and 16 frogs have been identified as utilising hollows, primarily on eucalypts, and of these 40 species are listed as threatened in NSW (http://www.environment.nsw.gov.au/determinations/lossofhollowtreesktp.htm). This syndrome is probably most developed on old-growth eucalypt trees, and other myrtaceous tree genera develop hollows at much lower frequency (although ‘architectural’ concavities at branch/trunk junctions may provide a similar opportunity for at least transitory shelter in some large tree genera, e.g. *Syzygium*). To the degree that Myrtle Rust contributes, along with other factors, to reduced frequency and longevity of hollow-bearing tree species over the longer term, significant decline of these hollow-utilising and hollow-dependent vertebrate species may result.

A range of reptiles and amphibians utilise loose bark (again predominantly on eucalypt species) for shelter, and the same long-term concerns may apply in certain habitats.

Many birds and some mammals (e.g. most ringtail possums) utilise finer branches and foliage of shrub and tree Myrtaceae, among other plants, for diurnal or breeding season nesting sites. In some habitats, e.g. tea-tree dominated associations, Myrtaceae may constitute most or all of the available shelter species, and some such habitats may be susceptible to Myrtle Rust-mediated decline.

Myrtaceae species are utilised as a *food source* by a broad range of vertebrate species, mostly birds and mammals, eating foliage, flowers and their nectar, fruits (mainly of soft-fruited genera), or in rarer instances, plant sap. Most vertebrate fauna that utilise Myrtaceae for food do so on a non-obligate basis, a few mammal species excepted. In the vegetation types most likely to be affected by Myrtle Rust disease, such species are likely to be able to displace onto other food sources, although complete loss of Myrtaceae species, or loss of the resource at critical seasonal or migratory stages or on a whole-site basis, may still have serious effects.

Myrtaceae flowers of all genera are typically significant nectar and pollen sources. A majority of the genera and species most likely to be prone to Myrtle Rust on the East Coast are primarily insect-pollinated, although a number are also facultatively bird- and mammal-pollinated. There are however a wide range of floral visitors, seeking pollen, nectar or smaller prey, beyond actual pollinators. Some Myrtaceae species are also commonly associated with ‘swarming’ events by certain insect pollinators, which may involve co-adaptation and some degree of dependency and may have an ecological role beyond simple food gathering by the insect and pollination of the plant, including a regular if transitory food source for other predators, including some vertebrates.

Several possum and glider species utilise Myrtaceae flowers as a food source, which may be locally or seasonally important. The Australian species of fruit bats (flying foxes -- Megachiroptera, Pteropodidae), are generalist nectarivores and frugivores, but plants of the Myrtaceae family are a key resource driving much of their behaviour and abundance. Markus & Hall (2004) comment that "Australia's four mainland species of flying-fox … traditionally rely on a range of native forest types, including mangroves, dry sclerophyll/eucalypt forest, Melaleuca swamp, and rainforest, for their arboreal roosting and feeding habits … For their typical diet, flying-foxes depend on forests to yield fruit, flowers, pollen and nectar … the nectarivorous component of the flying-fox diet consists mainly of nectar and pollen from plant genera in the families Proteaceae and Myrtaceae, and within the latter particularly the genera *Eucalyptus*, *Corymbia*, *Melaleuca*, *Angophora* and *Syncarpia* … fruits consumed include a wide range of rainforest fruits …". Of the floral resources critical for flying foxes in eastern and northern Australia, the *Melaleuca* swamps are likely to be the most vulnerable to impact from the pandemic strain of *A. psidii*.

The soft-fruited Myrtaceae genera (e.g. *Syzygium*, *Rhodamnia*) often constitute a significant or dominant floristic element (in either density or species richness) in rainforest and some wet sclerophyll habitats, where frugivory is a common syndrome and which are also conducive to Myrtle Rust. Several of these myrtaceous genera have a high proportion of their member species already known to be susceptible to Myrtle Rust infection, and in many cases these are rated as highly or extremely susceptible to the pathogen -- e.g. in *Gossia*, *Rhodamnia*. The high species density of *Syzygium* in the Wet Tropics, and the very high fecundity (and fruit biomass) of its member species, suggests the need for close field study of its frugivorous associates, but noting that we have as yet very little reliable data on Rust impact on *Syzygium* species. Data is also entirely lacking on the effects on palatability of fruits directly infected by *A. psidii*.

A majority of frugivorous (fruit-eating) vertebrates are not exclusively aligned to the fruits of Myrtaceae species. The diets of Flying Foxes (Pteropodidae - three species nationally threat-listed), 'fruit dove' Pigeons (Columbidae – some of which are threat-listed), and the fruit dietary component for the iconic Cassowary [*Casuarius casuarius johnsonii*, listed as nationally Endangered under the EPBC Act), for example, are all broad, including fruits of other plant families and varying with season and habitat – implying adaptive plasticity. However, even herbivore species with a broad forage spectrum may be dependent on particular flowering or fruiting plant species in certain habitats (including migratory way-station sites) or at certain times of year when other resources are scarce. This may be particularly the case in some Myrtaceae-rich rainforest environments. Analysis in the context of the Myrtle Rust threat is lacking, but sufficient data probably exist on the fruit- and flower-related dietary components of Cassowary and some Pigeon species to allow some assessment (not attempted here) of dependency and the risk from Myrtle Rust-related decline.

The use of myrtaceous foliage and sap as a food resource is, among vertebrates, limited to mammals. Many of these also have a fairly broad spectrum of food species and many are not exclusively dependent either on Myrtaceae or on foliage on a sole food source. However, the ubiquity and often dominance of Myrtaceae in Australian ecosystems, especially in wet sclerophyll forest and floodplain open woodlands, may limit the trophic flexibility of even non-obligate species.

Ringtail possums and the Greater Glider (Pseudocheiridae) are highly leaf-dependent. Greater Gliders feed more or less exclusively on eucalypt species, as of course does the Koala *Phascolarctos cinereus*. These taxa are in effect wholly dependent for food on the foliage of an often locally narrow range of Myrtaceae trees. The Ringtails are a little more trophically diverse. The Herbert River Ringtail Possum *Pseudochirulus herbertensis*, for example, is restricted to tropical rainforest in North Queensland, and while not exclusively a Myrtaceae feeder its diet reportedly includes foliage of *Eucalyptus acmenoides*, Cadaghi (*Corymbia torelliana*), Paper-barked Satinash (*Syzygium alliiligneum*), Red Eungella Satinash (*Syzygium/Acmena resa*), and Bumpy Satinash (*Syzygium cormiflorum*) (A. Berger, *Animal Diversity Web*, Regents University of Michigan, http://animaldiversity.org/accounts/Pseudochirulus_herbertensis/, accessed 2 March 2018). All but *E. acmenoides* are already-known hosts of the Myrtle Rust pathogen. Most of the other Glider and possum species (including the Phalangerid possums – cuscuses, brushtail possums, and their relatives) are non-obligate foliovores, although leaves may dominate their diet for much of the year. Some are generalist and not exclusively herbivorous, but make much use of Myrtaceae for some food resources, either directly (for nectar and pollen, e.g. the Eastern and Western Pygmy Possums and the Feathertail Glider), or for the invertebrates which are attracted by Myrtaceae in flower.

All mammals utilising Myrtaceae foliage for food may in some situations be highly dependent upon it, even if they have a more generalist diet. Myrtaceae are in many ecosystems among the dominant and fastest resprouters after fire, and new flush foliage and post-fire coppice growth may be critical seasonal or periodic resources when others are lacking. Loss of the foliage resource, and loss of palatability (not yet investigated) are both potential issues for such species. Analysis of regional diets of these species, and of some less specialist possum species, in Myrtle Rust-prone vegetation types should be undertaken.

4.7.3 Invertebrates

Invertebrate fauna that utilise Myrtaceae cover a very wide range of groups, some of which are poorly known taxonomically and ecologically. While strong or obligate associations with Myrtaceae are known for some species and genera, much of this knowledge relates to woodland or drier sclerophyll vegetation types where Myrtle Rust impact is less likely. For wetter vegetation types, the available knowledge appears to be less well developed and does not appear to have been synthesised yet in a form amenable to analysis of relationships at species level. Records of invertebrate utilisation of a particular species of host plant do not equate to an exclusive relationship.

The mining of data to relate particular floral-feeding and foliage-feeding invertebrates to host Myrtaceae is a very large task, requiring an adequately resourced information assembly project. It is further hampered by a taxonomic and ecological knowledge shortfall for many of the taxonomic groups, too few funded entomologists, and variable reliability of past identification of plant hosts. Nevertheless, some data has been compiled on a taxonomically broad enough scale that would allow future analysis. Invertebrate databases in the State Museums and primary industry departments of New South Wales and Queensland have not been mined for this review, but are likely to contain much information relating larval and adult invertebrates to particular host plant species or genera.

The number of instances of fully confirmed obligate relationships (to one or a defined few host plants) is likely to be low in many invertebrate groups, although higher in the Lepidoptera (butterflies and moths – see e.g. HOSTS database, http://www.nhm.ac.uk/our-science/data/hostplants/), and Coleoptera (beetles). Bellamy et al. (2013) produced an exhaustive work for host plant preferences of the immature life stages of Australian Buprestidae (the Jewel Beetle family), a very speciose group including many conspicuous visitors (as adults) to mass-flowering Myrtaceae (notably *Melaleuca/Callistemon*, *Leptospermum*, and eucalypts). Many of the host plant records provided are likely to have been accurately identified and are nomenclaturally current; for those to genus only, analysis of the original records may allow an inference as to species.

Accumulated CSIRO canopy diversity data from the Wet Tropics is likely to provide a basis for some inferences, although many of the papers located in the course of this review dealt with aggregated invertebrate 'take' from multiple species of host tree. For subtropical and warm-temperate rainforest of the east coast, Williams (2002) reviewed the taxonomic and biogeographic aspects of invertebrates of what is now the Gondwana Rainforests World Heritage Area and adjacent areas; underlying data for that study may provide host specificity data where host plant species is given and nomenclature is brought up to date. Walter et al. (1998) provide a glimpse of the canopy richness for one invertebrate group alone in subtropical rainforest of the Lamington Plateau, Qld. This study, involving only a few species of Myrtaceae among several other families, used a variety of collection methods to assay the richness of the parasitiform mite (Acari: Parasitiformes) fauna, concluding that "a minimum estimate for Parasitiformes in the Green Mountains [section of Lamington] is 500 species, and 2000 for all species of Acari. Given the high spatial turnover of mite species across the Australian tropics (Walter & Proctor 1998) the use of terms like 'hyperdiversity' for mites is not unreasonable".

A pair of papers by Taylor (2004) and Davies & Giblin-Davis (2004) illustrates the potential for discovery of 'new' obligate invertebrate associations, and for potential adverse cascade declines of biodiversity at multiple trophic levels. Several species of flies of the genus *Fergusonina*, and their mutualistic semi-parasite nematodes of the genus *Fergusobia*, together form galls on eight species of the '*Melaleuca leucadendra* complex' (including among others *M. quinquenervia* and *M. viridiflora* – all three are highly susceptible Myrtle Rust hosts). Both invertebrates are dependent on the galls for part of their life cycle, and on each other for its completion. Seven distinct species of fly are involved, all but one specific to single *Melaleuca* hosts; in turn, only two of the melaleucas host more than one fly species. Similar fly-nematode galls, involving still other species of each, have been recorded on other species of *Melaleuca*, and on species of *Eucalyptus*, *Angophora*, and *Syzygium*. Taylor notes that "*Fergusonina* galls are utilised by a complex of parasitoids and gall inquilines", i.e. other insects using the gall as an egg incubation site; these associated insects will themselves have as-yet unexplored ecological roles. While this fly-nematode-Myrtaceae system is unusual at a wider scale, Taylor comments "Given the large number of species of *Melaleuca*, and that only a small number have been extensively surveyed … it is possible that there may be more species yet to be collected. Few collections have been made from the *M. leucadendra* complex in northern and north-western Australia, and from narrow-leaved melaleucas elsewhere." All these living components in a mutualistic system are encompassed in the overarching goals for biodiversity conservation that underlie legislation and strategies in all Australian jurisdictions. There is no predicting what can be learnt from such systems in terms of plant and animal physiology, and ecological management applications (evaluation one of the flies as a possible control insect for *M. quinquenervia* in Florida USA led to the above study).

Myrtaceae lack the domatia (pits on the leaf undersurface) that in some plant families are home to a very diverse microfauna, particularly of mites, often obligate to one or a few host plant species. Nevertheless, the likelihood is that there are many close and some obligate relationships between invertebrates and Australian Myrtaceae species. A corollary is the likelihood of co-decline or co-extinction of these faunal elements, if host plant species decline. Moir et al. (2011) drew attention to this co-extinction risk, providing a decision protocol to identify invertebrate species threatened by coextinction. Moir et al. (2012) point to the risk of loss of dependent insect and other ecto-biota in ex situ and translocation conservation actions. Both studies are highly relevant to assessment and conservation actions relating to Myrtle Rust-mediated declines of host plants.

Few invertebrates have been assessed for extinction risk, and fewer still appear on legislative lists of threatened entities. Given the knowledge gaps, this situation is not easily remedied, but it is here recommended that expert knowledge be elicited to scope the likely *degree* of co-decline and coextinction risk for priority Myrtle Rust-affected species and ecosystems.

4.7.4 Epiphytic non-vascular plants, lichens and fungi

Published syntheses of the species-level host preferences of epiphytic lichens and bryophytes (mosses and liverworts) are lacking. However expert advice solicited for this review indicates that while both groups favour 'permanent-barked' trees, and that some such species will also be favoured because of other features (e.g. leaf surface) or contextual factors like microclimate, there are no general syndromes of correlation between epiphytes of these groups and the plant family Myrtaceae (pers. comms: C. Cargill, Australian National Herbarium, 10 Aug. 2017; Prof. J. Elix, ANU, 10 Aug. 2017). Epiphytic lichens and bryophytes mostly have a low level of host specificity and are unlikely to be severely affected by decline of specific Myrtaceae as long as other habitat species are available with suitable characteristics (e.g. 'permanent' bark and broadly similar bark or leaf surface traits, including pH). Nevertheless, these groups, and epiphytic fungi, may depend on microclimates generated by the density of certain host species on a local basis.

There are a few cases of apparent or suspected strong dependence on Myrtaceae. P. McCarthy (Canberra, pers. comm. 12 Aug. 2017) raises two instances of recently described lichens on Myrtaceae with no other known hosts to date (*Eugeniella farinosa* on *Melaleuca ericifolia* in Tasmania, and *Micarea eucalypti* on *Eucalyptus pauciflora* in Namadgi National Park, NSW). Both these myrtaceous hosts are known as Myrtle rust hosts (Giblin & Carnegie 2014a), albeit only from lab inoculation studies, and both occur in what may be 'at best' climatically marginal areas for A. psiii establishment. The Tea-tree Fingers fungus, *Hypocreopsis amplectens*, which is listed as Vulnerable under the Victorian *Flora and Fauna Guarantee Act* 1988), has a strong relationship with two *Leptopsermum* and one *Melaleuca* species in Victoria, and one non-myrtaceous host (www.fungimap.org.au, accessed 23 Feb 2018). *Microfungal* host specificities are poorly known, and there may be a higher proportion of obligate relationships among these, particularly among those which form symbiotic relationships with Myrtaceae as endo- and ecto-mycorrhizae.

Mining of fungal databases for further close associations should be a mid-term objective in the Myrtle Rust response; as with invertebrates, very few have been assessed for extinction risk, and co-decline/coextinction with myrtaceous hosts is possible.

4.7.5 Epiphytic vascular plants

Epiphytic vascular plants are common on some Myrtaceae species especially in wetter habitats. In general, the moister and warmer the forest, the higher the incidence and diversity of epiphytes. Some are flexible opportunists – there are for example no data to indicate that hemi-epiphytic strangler figs have any obligate relationship to any particular host family, although they may favour some because of suitable bark substrate for germination or structure for growth.

Expert opinions solicited for this review indicate that among *epiphytic and climbing ferns* there are very few if any cases of obligate relationships with Myrtaceae, although large-scale floristic change resulting from Myrtle Rust-mediated decline over time could have some impact on abundance of these types of fern. There may also be strong associations at some sites where only certain trees have desirable host features (permanent bark, etc). (Pers. comms: BJ Wallace 16 Aug 2017; DL Jones 3 Sept 2017; P Bostock 27 Sept 2017).

Epiphytic orchid species appear to have a somewhat higher incidence of very strong (although still rarely fully obligate) relationship with Myrtaceae. In rainforest, floodplain and riparian environments the orchid species may be subject to significant or severe loss of habitat if favoured Myrtaceae species disappear on a local or regional basis. Possible acute examples would include associations dominated by paperbark *Melaleuca* species. While many orchid species appear to have some flexibility in terms of substrate species, they also require the maintenance of local conditions for the symbiotic fungi that they need at various life stages. These in turn may depend on particular bark chemistries or microclimates that could be affected by floristic change.

Despite the low level of fully obligate taxonomic relationship, D.L. Jones (pers. comm.) stresses the potentially significant habitat loss for orchid epiphytes, on either a local or a total basis, if Myrtaceae species that make up large part of the host assemblage were to decline as a result of Myrtle Rust infection. He observes (*in litt*., 3 Sept 2017) that "it would be disastrous if we lost major host species such as *Backhousia myrtifolia*, *Tristaniopsis laurina*, *Melaleuca viridiflora*, *Lophostemon suaveolens* and the various coastal and near-coastal ironbarks [as] habitat trees for epiphytes, even though non-obligate … These species are very significant host trees for a number of epiphytic orchids and their loss would cause a big problem for the orchids, as loss could be inferred to involve decline of those epiphytes in numbers or extent, unless and until suitable non-susceptible host trees can replace those lost."

Jones (*loc. cit.*) also stresses that "orchids need interaction with a [species-]specific mycorrhizal fungus for the seeds to germinate, and in many cases also regular reinfection through the life of the plants, so hosts are not easily replaced. *Backhousia myrtifolia* for example hosts *Sarcochilus australis*, *S. falcatus*, *S. hillii*, *S. parviflorus*, *Plectorrhiza tridentata*, *Tropilis eburnea* and probably others … It also grows in thickets and actually creates congenial conditions for the orchids as well as providing suitable mycorrhizae." (DL Jones in litt., 3 Sept 2017).

BJ Wallace (*in litt*. Sept 2017) notes a number of cases of strong, through rarely or never fully obligate, relationships between epiphytic orchids and certain Myrtaceae. The species information below is as supplied by Dr Wallace. The status of the myrtaceous species as Myrtle Rust hosts is interpolated in [square brackets], along with a tentative inferred estimate (made here) of impact risk for the orchid. The establishment of baseline information and impact data from the field would of course be more reliable than inferences made here.

- *Tropilis aemula* (syn. *Dendrobium aeulum*), Ironbark Orchid, ranges from Moruya NSW north to the Calliope Range in central Queensland; it appears to grow exclusively on *Eucalyptus paniculata* and *E. crebra*. [*E. paniculata* is not to date a known host of Myrtle Rust; *E. crebra* is a known host from lab inoculation only; risk low from this strain of the pathogen].

- *Tropilis eungellensis*, apparently restricted to the Clarke and Connors Ranges in central eastern Qld; said to grow more or less exclusively on the ironbark *Eucalyptus drepanophylla* [a known Myrtle Rust host from lab inoculation only; risk low from this strain of the pathogen].

- *Tropilis radiata*, Brush Box Orchid, grows virtually exclusively on *Lophostemon confertus*, ranging from Wauchope NSW to Eungella in Qld. [*L. confertus* is not to date a known host of Myrtle Rust, and is likely to be fully resistant to the pandemic strain of the pathogen; risk to orchid low].

- The tropical genus *Cepobaculum* (*Dendrobium* segregate) comprises eight species all of which show a preference for growing on *Melaleuca* paperbarks, most particularly *M. viridiflora.* These are:

- *Cepobaculum canaliculatum* (Brown Onion Orchid), distributed on Cape York south to Cooktown area; common, mainly on *Melaleuca viridiflora;*
- *Cepobaculum carronii* (Pink Onion Orchid), distributed on Cape York Peninsula south to the MacIlwraith Range, in more humid areas and uncommon, less dependent on *Melaleuca viridiflora,* often on small-leaf *Melaleuca* spp.;
- *Cepobaculum tattonianum* (Yellow Onion Orchid), distributed from Laura on Cape York south to Rockhampton area; common, more or less exclusively on *Melaleuca viridiflora;*
- *Cepobaculum foelschei* (Slender Onion Orchid), distributed from Cape York Peninsula west to the Kimberley region of WA; common, mainly on paperbark *Melaleuca* spp.;
- *Cepobaculum johannis* (Chocolate Onion Orchid), distributed on Cape York Peninsula, south to the MacIlwraith Range, common, mainly on paperbark *Melaleuca* spp. in more humid areas;
- *Cepobaculum semifuscum* (Fragrant Onion Orchid), distributed from Cape York Peninsula, south to the MacIlwraith Range and Cooktown, locally common, mainly on paperbark *Melaleuca* spp. or other rough-barked species, in more humid areas;
- *Cepobaculum trilamellatum* (Large Onion Orchid), distributed from northern NT to Cape York Peninsula, south to the MacIlwraith Range, locally common, mainly on paperbark *Melaleuca* species but also other rough-barked species, usually in more humid areas such as swamps and by streams.

Melaleuca viridiflora is a known field host of Myrtle Rust, and is rated as Highly Susceptible by Pegg et al. 2014a; the risk to orchids occurring on that species are here tentatively assessed as medium. The above data do not allow risk assessment of the other *Cepobaculum* orchids mentioned by Wallace, but the background data which would allow such assessment are likely to exist in relevant herbaria and survey records.

- Subtribe Aeridinae, the monopodial orchids, have a number of species which commonly are twig epiphytes on myrtaceous trees in rainforests and related vegetation, although none are restricted exclusively to that family. They include: *Plectorrhiza tridentata* (eastern Victoria to Bloomfield River, North Qld); *Papillilabium beckleri* (Illawarra district of NSW to south-east Qld); *Sarcochilus australis* (north-east Tasmania to the NSW/Qld Border Ranges, and north of Sydney occurring only in isolated small populations), often on *Tristania* over streams; *Sarcochilus falcatus* (widespread, relatively catholic but may be strongly associated with Myrtaceae at particular sites [see exemplar plot data below]; *Sarcochilus hillii* (Bega NSW to Fitzroy River Qld), twig epiphyte of warm temperate and dry rainforests, may be strongly associated with Myrtaceae at particular sites [see exemplar plot data below]; *Sarcochilus parviflorus/olivaceus* (Bega NSW to north-east Qld), often on myrtles; *Sarcochilus spathulatus* (Barrington Tops area NSW to the Bunya Mts Qld); *Rhinerrhiza divitiflora*, grows in Littoral and Dry Rainforests on a range of phorophyte [host] species, showing a strong preference for *Backhousia sciadophora* where the two species are sympatric.

- *Tetrabaculum melaleucaphilum* (syn. *Dendrobium tetragonum* in part) favouring (not exclusively) small leaved paperbarks on the North Coast of NSW [Jones 2006:402 says "particularly *M. styphelioides*"], and on *Archirhodomyrus beckleri* and *Choricarpia leptopetala* on the NSW Central Coast and lower Blue Mountains in the Wheeny Creek area. [*M. styphelioides* is a known Myrtle Rust host. *Archirhodomyrtus beckleri* is a known Myrtle Rust host, and while not assigned a susceptibility rating by Pegg *et al*. (2014a), it has since been rated as RT (relatively tolerant) to HS (highly susceptible) by Pegg et al. (2018); the HS rating is certainly appropriate for the populations assignable to the 'southern chemotype', i.e. all those in NSW and south-east Queensland, which are undergoing severe impact from Myrtle Rust – see Pegg *et al*. (2017). *Choricarpia* (now *Backhousia*) *leptopetala* is a known

Myrtle Rust host rated as Highly Susceptible by Pegg *et al*. 2014a. Populations of *Tetrabaculum melaleucaphilum* dependent on the latter two species should be considered as being at high risk.]

- Finally, Wallace notes near 100% association with Myrtaceae hosts of particular local populations (from the Atherton area of North Queensland) of two more widespread orchids: *Oberonia palmicola* on *Acmena smithii, and Eleutheroglosssum fellowsii* (syn. *Dendrobium bairdianum*) on *Syncarpia glomulifera.*
  [*Syzygium* (= *Acmena) smithii* is a known Myrtle Rust host, and is rated by Pegg *et al*. 2014a as being relatively tolerant to moderately susceptible, based largely on subtropical observations. The risk from the pandemic strain of *A. psidii* to this host is probably low, but impact assessment in the North Queensland biome would be advisable. *Syncarpia glomulifera* is a known Myrtle Rust host, but rarely recorded as such; subject to possible impacts of Myrtle Rust at the early germinant stage of this host (as indicated by some records ex cultivation), the risk to *E. fellowsii* on this host is probably low.]

To illustrate the degree to which Myrtaceae species can dominate as orchid hosts on a site basis, Wallace makes available here unpublished research data (Wallace 1983: 113) from an epiphyte recording plot at Long Point, via Hillgrove, NSW (in Oxley-Wild Rivers National Park:

- Plot size: 20 x 30 m; Tree species (number) – 16; Trees over 5 cm d.b.h. – 65.
- *Backhousia sciadophora* individuals – 31 (ie, dominant species in plot).
- Epiphyte species on *B. sciadophora* – 10 (total individuals 257).
- *Sarcochilus falcatus* on *B. sciadophora* – 42, of 153 in plot; *Sarcochilus hillii* on *B. sciadophora* – 69, of 123 in plot; *Plectorrhiza tridentata* on *B. sciadophora* – 25, of 67 in plot.

Some terrestrial orchids may have a strong habitat association with rust-susceptible Myrtaceae. Many orchid species occur in shrublands with (in eastern Australia) *Leptospermum*, *Melaleuca*, and other Myrtaceae as major elements; the effects, of any, of floristic change due to Myrtle Rust are unknown. *Phaius australis*, the southern swamp orchid, is listed as endangered under Commonwealth, NSW and Queensland legislation. It occurs in eastern Queensland and north-eastern New South Wales, usually in coastal wet heath and wetland margins, and is often found beneath stands of Broad-leaved Paperbarks (*Melaleuca leucadendra, M. quinquenervia*) or Swamp Mahogany (*Eucalyptus robusta*); loss or thinning of this overstory could be detrimental to the orchid.

Mistletoes are a class of plant epiphytic parasites – they grown on, and parasitise, other plant species. There are c. 90-100 species of mistletoe in Australia, across three families. Many Australian mistletoe species utilise Myrtaceae hosts, mainly eucalypts, although relatively few are obligately associated with Myrtaceae (most being able to grow on one to many host species of other families). A majority of Myrtaceae/mistletoe associations, and majority of the obligate or near-obligate ones, are in drier country or vegetation types, partly or wholly outside the current and projected naturalisation zone or preferred habitat of Myrtle Rust. Some Myrtaceae-associated mistletoes do occur within the Myrtle rust zone, on both eucalypt and non-eucalypt hosts. Depending on how Myrtle Rust affects these species, and on whether other non-susceptible mistletoe hosts are present in the same areas and able to replace the declining host/s, some mistletoe species may be at local or regional risk. The potential arrival in Australia of other more strongly eucalypt-associated strains of *Austropuccinia psidii* could change the level of threat to Myrtaceae-associated mistletoes in moister ecosystems.

Mistletoes may have a number of strongly associated fauna species in some areas (birds, butterflies, other invertebrates), and may be a primary food source (nectar, fruit, foliage, associated insect assemblages) in seasons when little else is available, although this is more common in drier systems.

Mistletoes are also common nesting and shelter sites for a number of bird and mammal (e.g. ringtail possum) species, and in some habitats may not be easily substituted for in these roles. Watson (2001) postulates that mistletoes, while constituting a negligible proportion of biomass and diversity, nevertheless contribute a disproportionately high level of resource in a number of forest and woodland biomes, to the extent of being a keystone resource. Rust-mediated decline of host plants may therefore cause appreciable cascade effects.

Information on mistletoe species below is largely drawn from information in Downey (1998) and more recent but highly summarised information in Watson (2011), FloraNT (2013-), WA FloraBase (https://florabase.dpaw.wa.gov.au/), and *Australian Tropical Rainforest Plants* edition 6 (https://www.anbg.gov.au/cpbr/cd-keys/rfk/). More detailed analysis of the degree of association between mistletoe species and highly susceptible hosts of Myrtle Rust, taking more recent data and host nomenclatural changes into account, would be a prudent conservation planning step for known or potential areas of Myrtle Rust naturalisation, and especially in the Wet Tropics (c. 45 species),

Mistletoe species that *prima facie* may be of potential concern in the longer term include:

- *Amyema gaudichaudii* utilises only seven or eight species of *Melaleuca/Callistemon* (and one *Acacia*), especially *M. decora* (a known Myrtle rust host), and *M. braceata* (not yet recorded or screened for Myrtle Rust susceptibility); a further three of the *Melaleuca* species are known Myrtle Rust hosts. It occurs on the central NSW coast and in the western Darling Downs of Queensland.
- *Amyema melaleucae* is largely restricted to *Melaleuca* hosts (eight species reported by Downey 1998), in coastal shrublands of SA and WA (areas not yet exposed to Myrtle Rust).
- *Amylotheca dictyophleba* has a broad host range, but at least eight are in the Myrtaceae (Downey 1998) and some are known very susceptible Myrtle Rust hosts; occurs only in wet sclerophyll and rainforest systems of the east coast; the overlap with the naturalised Myrtle Rust pathogen is here estimated as 100%.
- *Benthamina alyxifolia* has a fairly broad host range outside the Myrtaceae, but Downey (1998) cites *Eugenia* sp. and *Callistemon viminalis* as hosts; Watson (2011) adds occurrence on *Syzygium* species. It is restricted to moist forest systems in NSW and Queensland; overlap with the naturalised Myrtle Rust pathogen is here estimated as 100%.
- *Decaisnina biangulata*, a WA endemic (west Kimberley – no Myrtle Rust exposure yet); often on (and restricted to?) *Lophostemon*, *Syzygium*, and *Tristania* species.
- *Dendrophthoe glabrescens* has a broad host range but especially *Eucalyptus*, *Melaleuca, Neofabricia* and *Tristania* species. Overlap with the Myrtle Rust pathogen is partial, in Queensland (parts of coast and some areas of inland rainforest), and potentially in NT and WA.
- *Dendrophthoe odontocalyx* is widespread in Qld, NT, and WA, but has potential future partial overlap with Myrtle Rust in areas where *Melaleuca* species are likely to be main host.
- *Dendrophthoe vitelline* has a broad host range, but Watson (2011) reports "most frequently on *Angophora*, *Eucalyptus* and *Melaleuca* species", albeit usually in open sclerophyll systems; overlap with Myrtle Rust likely to be near-total.
- *Diplatia tomentosa* is Queensland endemic, commonly on *Melaleuca* species in open forest and on rainforest margins (Australian Tropical Herbarium, undated); three of the four hosts listed by Downey (1998) are Myrtle Rust hosts and two (*M. quinquenervia* and *M. leucadendra*) are very susceptible; overlap with the naturalised Myrtle Rust pathogen is here estimated as 100%.
- *Korthalsella arthroclada* is a West Australian species known only from north of Perth on a single host, *Melaleuca lanceolata* (not yet screened for Myrtle Rust susceptibility); WA is not yet exposed to Myrtle Rust.

- *Notothixos incanus* is primarily found on *Melaleuca* and *Callistemon* hosts; eight of the twelve hosts named by Downey (1998) are known Myrtle Rust hosts. It has a patchy range along the NSW and Qld coasts; overlap with naturalised Myrtle Rust is here estimated as 100%.

Other mistletoe species that are in most cases more widespread, but may be of regional concern where they overlap with zones and ecosystems of permanent *Austropuccinia psidii* naturalisation (and depending on impact level on their hosts), include:

- *Amyema bifurcata* has a broad host range, but most are eucalypts, albeit of open forest and woodland systems, which may mitigate rust effects. Areas of current overlap with *A. psidii* include various parts of the east coast; areas of potential overlap exist in the Gulf of Carpentaria coast, Top End, and Kimberley.
- *Amyema pyriformis* is a WA endemic (north-west Kimberley), exclusively on *Eucalyptus* species (*E. rupestris*); WA conservation code Priority 1. The potential for overlap with *A. psidii* is uncertain.
- *Diplatia furcata* has a broad host range in Qld, NSW and NT, but is commonly on Myrtaceae hosts in vine thicket (Australian Tropical Herbarium, undated); several of the hosts listed by Downey (1998) are known Myrtle Rust hosts.
- *Korthalsella rubra* has a broad host range with only partial overlap with Myrtle Rust in NSW, Qld and Victoria, but eastern populations in all three States occur in wet sclerophyll and rainforest systems especially on Myrtaceae hosts (Watson 2011), including the now rapidly declining *Archirhodomyrtus beckleri*.

PART 5: THE RISKS FOR AUSTRALIA FROM MYRTLE RUST DISEASE

BACKDROP:
Australia's Biodiversity Conservation Strategy 2010–2030 (Commonwealth of Australia 2010), *National Targets*:

- By 2015, reduce by at least 10% the impacts of invasive species on threatened species and ecological communities in terrestrial, aquatic and marine environments.

Priority for action 2: Building ecosystem resilience in a changing climate:
2.3 Reducing threats to biodiversity … Outcomes for reducing threats to biodiversity:

- 2.3.1 A reduction in the impacts of priority threatening processes, including habitat loss and climate change;
- 2.3.2 A reduction in the impacts of significant invasive species on biodiversity;
- 2.3.3 An increase in the use of strategic and early interventions to manage threats to biodiversity including climate change;

Target 7: By 2015, reduce by at least 10% the impacts of invasive species on threatened species and ecological communities in terrestrial, aquatic and marine environments.

Australia's Biodiversity Conservation Strategy 2010–2030 (Commonwealth of Australia 2010: 16), Principles: Our efforts to conserve biodiversity must acknowledge and respect the culture, values, innovations, practices and knowledge of Indigenous peoples.

5.1 Risk – further biosecurity breaches ('other strain' arrival)

Australia and the surrounding region currently harbour only one strain of *Austropuccinia psidii*, the C1/C4 'pandemic' strain (Stewart et al. 2017). The arrival of any further strains of *A. psidii* in the Australasian region would escalate the threats posed by this pathogen, for two reasons.

Other strains of the pathogen are likely to have different host ranges, possibly different effects on current hosts, and possibly different environmental tolerances. New strains would be likely to increase the host range, and possibly the geographic range of the pathogen. The arrival in Australia or the region of strains more strongly aggressive on eucalypts would be a development of potentially catastrophic consequence for the Australian environment. The 'pandemic' strain is already known to be capable of infecting some 106 natural eucalypt taxa, although so far a majority are from inoculation screening only. Of the natural infections to date, no eucalypt species declines have been confirmed, although critical life stages remain un-investigated for most eucalypt hosts. Two strongly eucalypt-associated strains (C2, C3) are known from South America, where *A. psidii* has caused major economic damage to eucalypt species and hybrids.

The second aspect of increased threat from new strain arrival (or of further variants of the pandemic strain) is an increased likelihood of recombination events that could result in new hybrid strains, or an increase in the frequency of sexual (recombinant) reproduction providing the pathogen with a stronger pathway to evolve and adapt.

The gross symptoms of disease caused by *A. psidii* are similar for all strains, and molecular (DNA) diagnosis is needed to distinguish them reliably. This greatly reduces the chances of early symptomatic detection post-border of newly arrived strains, and hence any potential for eradication.

Techniques for molecular screening to identify *A. psidii* at the species level, on incoming goods and materials, are available (Langrell et al. 2008) and have on at least one occasion resulted in the interdiction of viable spores on imported goods (Grgurinovic et al. 2006). The current availability of deployable tests for strain-specific identification is unknown, and current understanding of the variance and global distribution of *A. psidii* strains is in any case likely to be incomplete. The deployment of inspection diagnostics on the scale needed to substantially strengthen pre-border and at-border vigilance for new strains is, from a biodiversity conservation point of view, imperative, but must be considered unlikely to occur in practice on resourcing grounds.

The mode of arrival of the pandemic strain of *A. psidii* in Australia is unknown, as it is for most of the countries and regions to which it has spread. There has been no new public analysis of potential pathways for arrival of strains of *A. psidii* since those of Glen et al. (2007) and Plant Health Australia (2009), and no announcement of any tightening of procedures specifically to further restrict new strain arrival or early detection. Domestic quarantine arrangements have been suspended between jurisdictions in which *A. psidii* is established – this is understandable from a single-strain management point of view, but will inevitably mean an easier spread pathway for any new undetected strains arriving.

A process of prioritisation of environmental pests and diseases exotic to Australia is now in train, led by the Commonwealth Department of Agriculture and Water Resources (DAWR), as part of a new emphasis on environmental biosecurity following the recent review of national biosecurity capacity (Craik et al. 2017). It is however unclear whether the prioritisation process will overcome the 'name-based' species-level approach of the past (McTaggart, van der Nest, et al. 2016) and address the 'other strain' issues for pathogens already naturalised, or when – in a long queue of potential threats – the *A. psidii* situation will be addressed. To date there has been no public canvassing of these issues by lead (or environmental) agencies. Given the mobility of this pathogen, the threat is extreme and urgent.

A review of seed importation processes has recently been conducted by DAWR, and limitations placed on all countries where rust is present. Conditions for importing Myrtaceae timber have been relaxed from complete ban to allowed under specified treatment conditions – see Australian Biosecurity Import Conditions website,
(https://bicon.agriculture.gov.au/BiconWeb4.0/ImportConditions/Search/, accessed 03 June 2018).

5.2 Risk – species declines and extinctions

Of the 358 Australian native species so far known to be susceptible to Myrtle Rust disease, some 47 are rated as (or ranging into) the Highly or Extremely Susceptible categories by Pegg et al. (2014a), based on 'natural' infections. That list was based only on Queensland hosts known at the time. Some species at lower ratings on have been upgraded, or had their susceptibility range expanded, by Pegg et al. (2018). Further changes are possible as more data accumulate and the effects of repeated cycles of infection become evident. Several hitherto un-rated species, including some in steep decline, definitely should have high ratings than were applied by Pegg et al. (2014a), for example *Archirhodomyrtus beckleri* southern chemotype (since taken to Highly Susceptible HS by Pegg et al. (2018), while retaining the Relatively Tolerant RT rating for the northern chemotype. Evidence from field observations (see Appendix 1) suggests strongly that *Lenwebbia* sp. 'Main Range P.R.Sharpe+ 4877' should be rated as Extremely Susceptible ES. Others remain to be assessed.

Estimates vary as to the number of known-host species native to the east coast that have their natural distributions mostly or entirely within the current zone of Myrtle Rust naturalisation in NSW and Queensland.

This reviewer (Makinson) estimates that 165 native host *taxa* (i.e. species or subspecies) have natural distributions totally or near-totally within the east coast zone of full *A. psidii* invasive naturalisation in eastern Australia (see Appendix 4). 32 of these taxa are rated (following Pegg *et al*., 2014a) as partly or wholly in the 'Highly Susceptible' or Extremely Susceptible' categories, although the latter number may rise. The unrated 'southern chemotype' of *Archirhodomyrtus beckleri* (accounting for all populations of the species in NSW and south-east Queensland) should certainly be added to either the high or extreme categories, as should *Lenwebbia* sp. 'Main Range (PR Sharpe+ 4877)' (apparently extreme) and *Rhodamnia whiteana* (at least high). A further 15 host species have natural distributions *predominantly* within the current *A. psidii* east-Australian envelope.

Berthon (2018), in the context of analysis of climatic suitability zones for Myrtle Rust, and using aggregated species distributions (i.e. subspecies distributions grouped back into those of the 'parent' species), finds markedly different figures for overlap – the discrepancy is discussed in Section 6.1 below, and Appendix 4.

An undetermined but high number of species that are likely to be susceptible, occur in other parts of Australia that may be climatically suitable for Myrtle Rust establishment.

The assessment and legislative listing of hitherto non-Threatened species, that might now qualify as Threatened due to projected or actual decline caused by Myrtle Rust, has barely begun. In New South Wales two formerly common and widespread species of no conservation concern prior to 2010 have recently been the subject of Preliminary determinations as Critically Endangered under NSW legislation (*Rhodomyrtus psidioides*, *Rhodamnia rubescens*). An undetermined number of species along the east coast, probably in the range of 20-30, would likely qualify for listing in some threatened category due to declines already suffered or projected, but field impact monitoring programs are lacking and only partial evidence is yet available.

Species of highest immediate concern are tabulated in Section 4.4 (Table 3) above, and in more detail in Appendix 1. For many of these species, the decline is likely to accelerate as plant densities drop and flowering fails. The frequency of inbreeding and self-pollinating for those flowers that do emerge is likely to increase, and whatever inbred seed is set from these is likely in most cases to be less genetically healthy than more broadly outcrossed seed, and any successfully established progeny less fit.

Myrtle Rust disease is likely to be the cause of single-agent declines and extinctions among native plants on a scale paralleled in Australia only by *Phytophthora cinnamomi*, and among other biota only by historical land-clearing and, for frogs, the Chytrid fungus.

5.3 Risk – ecosystem and land management impacts

Myrtaceae are a major component of most Australian ecosystems outside the semi-arid zone, and a dominant family in many. Early indications are that the single strain of *A. psidii* present in Australia is already causing substantial floristic and perhaps structural modification to wet sclerophyll ecosystems in south-east Queensland, via direct mortality and loss of reproductive capacity and recruitment. Consequences are likely to include interlinked effects of floristic simplification, increased light levels at ground level, increased invasion of such systems by exotic weeds (incurring extra control costs where addressed), and uncertain potential changes to hydrology, erosion, fire susceptibility, and the conservation status of some Myrtaceae-associated biota (flora and fauna). In other biomes, cohort-recruiting species, if susceptible and subject to high spore loads during recruitment episodes (e.g. post-fire), could see high seedling mortality and effective exhaustion of the soil seed bank, with unpredictable consequences (examples might include some tea-tree species prone to form monocultures).

Of particular concern is the potential for longer-term declines of three of the Broad-leaved Paperbark species that dominate wide areas of floodplain and wetland and river margins in eastern and northern Australia. These species all show some internal variability in susceptibility to Myrtle Rust infection, but range into the Highly Susceptible category and in one case into Extremely Susceptible. Data are only available for one species (*Melaleuca quinquenervia*) but indicate variation in susceptibility in both seedlings and post-fire coppice regrowth, and at within-population and between-population levels. Decline in these species over time could have great effects on river-bank stability, water-table levels, creek and wetland water quality, biomass accumulation and distribution, river and flood-plain shade and evaporative rates, and associated aquatic and terrestrial fauna. See Section 4.6 ‘Ecological impacts’ above for more detail.

The potential for Myrtle Rust to adversely affect wetlands dominated by other, non-broadleaf, melaleucas is uncertain. One system of potential concern is *Melaleuca ericifolia* wetland. *M. ericifolia* is a known host from two separate inoculation trials (Morin et al. 2011, 2012; Sanhu & Park 2013). Its natural range is northern NSW to Tasmania, with the main wetland systems in Victoria and Tasmania).

Other broad vegetation types, encompassing a large set of described but not necessarily Threat-listed ecological communities are also at risk of floristic impact and eco-functional decline in NSW and south-east Queensland: coastal heath and wet heathy woodland; warm-temperate, subtropical, and littoral rainforests; and wet sclerophyll (canopy) to rainforest (lower storeys) transition communities. The heath and heath-woodland communities comprise large vegetational elements within many coastal conservation reserves. The rainforest and rainforest-transition communities and associations are major elements in some conservation reserves and world heritage areas, and have been the subject of particularly high levels of public and private investment in protection and ecological restoration. Myrtle Rust is already causing floristic change and disrupting successional dynamics in regenerating transitional-rainforest systems in regions on either side of the state border.

5.4 Risk – World Heritage Area values

Three World Heritage Areas are likely to already be undergoing levels of impact from permanently established Myrtle Rust: the *Gondwana Rainforests*, *Fraser Island*, and *Wet Tropics WHAs*. Those aspects of impact currently known for these areas are detailed elsewhere in this review.

The *Lord Howe Island Group WHA* has also suffered an incursion (detected October 2016), but thanks to a stringent vigilance system, infections were apparently detected while still confined to cultivated exotic species of Myrtaceae within the village area of the main Island, and therefore amenable to a vigorous eradication program. As at March 2018, there are no reports of infection from any of the five Myrtaceae taxa native (and endemic) to the Island Group, and the disease has apparently been eradicated. The Island Group however remains at permanent risk of re-infection from the Australian mainland (by natural and human-mediated dispersal) and New Zealand (most likely by human-mediated vectors).

The *Greater Blue Mountains WHA* has very few confirmed records of Myrtle Rust (albeit no systematic survey to date), and parts of it may be climatically unsuitable for the year-round presence of the pathogen, although seasonal recolonization could occur rapidly from nearby coastal areas. The highly susceptible known-host species that occur in the GBMWHA are few in number and fairly localised in distribution. However, the possibility of undetected impacts, or future seasonal or recruitment-cohort impacts in the highly Myrtaceae-rich communities of the area, cannot be discounted.

The *Kakadu WHA* has no records of Myrtle Rust to date, although the pathogen is present and apparently full naturalised at least in limited areas (Tiwi Islands, Darwin area, eastern Arnhem Land) that are well within the range of possible spore distribution by natural means. The behaviour of the Myrtle Rust pathogen in the monsoon tropics is not well understood. So far (to June 2018) the pathogen has been moving slowly in both the geographic and host-range senses.

World Heritage Areas have a particular combination of natural and social values that may make conservation responses more than usually complicated.

5.5 Risk – Cultural impacts

Potential cultural impacts of Myrtle Rust relate to both Indigenous and non-Indigenous peoples and communities. The landscapes of the present and past, and very often the small treasured patches and species, are of cardinal importance in sustaining people's connections with the natural environment as individuals and collectively. Traditional Indigenous story lines, and many aspects of colonial and post-colonial history and tradition, are associated with particular species, vegetation types, and landscapes.

The 2015 iteration of the triennial '*Who cares about the environment?*' survey in NSW (NSW Office of Environment and Heritage 2017), the most detailed and reliable longitudinal environmental opinion survey in Australia, reports an overall 73% of respondents were concerned 'a great deal' about environmental legacy for future generations, and 61% concerned 'a great deal' about plants, animals and ecosystems. 97% agreed (70% strongly) that we have a responsibility to look after nature and biodiversity for future generations; 94% agreed (54% strongly) that it is important to know that nature and biodiversity are looked after in NSW; and 94% of respondents expressed concern at the possibility of native plant and animal species in NSW becoming extinct (46% 'very concerned', and 47% 'somewhat concerned'). While noting regional and socioeconomic variation in responses on some issues in this NSW-based survey, there is good reason to think its results are broadly applicable nationwide.

The potential social and cultural impacts of Myrtle Rust have not been addressed to date, and at this stage of the outbreak may be hard to determine. It would be reasonable to expect, over time, loss of some scenic and other amenity values, loss of residents' and visitors valued sense of place, a mourning of familiar species disappeared, in some cases a possible loss of property value. In the event of major decline in paperbark wetlands, and resulting landscape change, a much more distressed response should be expected.

However, the most serious social impacts – if Australia continues to fail to mount a vigorous environmental response, and as declines and extinctions mount and become widely known – may be a loss of faith in Australia's biosecurity arrangements, a loss of faith in the conservation goals of government, and a deterioration in the commitment of bushcare, landcare, and other environmental volunteer groups in the face of unaddressed impacts.

Indigenous cultural impacts

The potential cultural impacts of Myrtle Rust on Indigenous landscape and species values, and on Indigenous enterprises, have not yet been addressed in Australia, nor have Indigenous communities and institutions been widely engaged with by governments in addressing the problem (except in the north, e.g. by staff of the Northern Australia Quarantine Strategy NAQS and Biosecurity Queensland).

Australia's response to date is lagging in this respect compared to Hawaii and New Zealand. In New Zealand, indigenous cultural engagement is an integral part of the national biosecurity strategy (NZ Ministry for Primary Industries 2016), and of the specific Myrtle Rust response since first detection in 2017.

Aboriginal and Torres Strait Islander owned, co-owned, or controlled land is an important part of the matrix in some areas of current Myrtle Rust occurrence, and very large sections of potential future infection. For example, the Githabul People's non-exclusive native title rights and interests have been recognised in nine national parks and 13 state forests in northern New South Wales, including the critical Myrtle Rust impact zone of the Border Ranges and adjacent areas.

In northern Australia and the Torres Strait, staff of NAQS and other DAWR units, QDAF/Biosecurity Queensland (BQ), and the NT Department of Primary Industry and Resources (DPIR, formerly DPIF), have conducted briefings of Indigenous rangers and land management staff. These agencies and their networks have made most of the new detections of Myrtle Rust in the area (Westaway 2016; Westaway 2018 in press; B. Waterhouse, *in litt*. 3 Nov. 2017). The Australian Network for Plant Conservation (NGO), in association with Cairns Regional Council and BQ, conducted a full-day workshop in Mossman in 2011 (prior to arrival of Myrtle Rust in the area), which included some Indigenous council staff and other Indigenous stakeholders. Some other ANPC and primary industry agency workshops in other states have involved small numbers of indigenous stakeholders. These events however have been geared to vigilance and reporting of Myrtle Rust occurrence, and did not constitute consultation on potential impacts as such.

Myrtle Rust impact relevant to Indigenous people and communities may encompass traditional cultural heritage, contemporary continued traditional practices, and Indigenous enterprises, particularly those based on bush product production or exhibition, and ecotourism.

Indigenous peoples continue to use Myrtaceae species for food, medicinal, and other social practices in most parts of Australia, not just in traditional and remote areas. Myrtaceae species form part of the continuing cultural life of those communities. Natural landscapes and vegetation types, and their constituent species, are valued for the traditional stories and continuing custodianships with which they are associated – declines in their integrity have a particular cultural dimension of loss.

Many Aboriginal-run enterprises around Australia are based on natural native-plant products, or incorporate them in their tourism and educational activities. Within the east coast zone currently affected by the Myrtle Rust pathogen, this often includes bush tucker products such as Riberry (*Syzygium luehmannii*) and Midgen Berry (*Austromyrtus dulcis*). Both occur naturally on the NSW North Coast and in south-east Queensland. Both are known Myrtle Rust hosts from natural infections in both States; *A. dulcis* is rated as varying from relatively tolerant to highly susceptible to the disease (Pegg et al. 2014a). Neither species has yet been systematically field-assessed for impact on wild populations, although J. Wills (Queensland Herbarium, pers. comm. 7 June 2018) "Assessed 5 populations that showed minor to major damage. These populations had healthy fruit. Moderate active rust was seen on one population. This species urgently needs further monitoring".

In North Queensland and the Torres Strait, some species of *Syzygium* and a few other genera (e.g. Beach Cherry *Eugenia reinwardtiana*) are both traditional foods and 'demonstration' bush tucker foods for visitors to Indigenous and non-Indigenous ecotourism enterprises and for educational programs in protected areas.

Along the entire coastline from central NSW to the Kimberley, Broad-leaved Paperbark (*Melaleuca*) communities are likely to be of great cultural importance, both for resources provided by the trees themselves and for the associated floral, faunal, and water values (Jackson 2006; Commonwealth Department of Environment 2016). In many of the relevant areas, unresolved issues (e.g. of Native Title, or of joint management arrangements) complicate conservation considerations, and may not be resolved quickly.

In South Australia and western Victoria, the locally native Muntries (*Kunzea pomifera*) fruits are a successful niche crop (mostly cultivated but sometimes still wild-collected), with appeal because of its high antioxidant and vitamin C content. The producers include several aboriginal communities (RIRDC, undated [2014a]). The region of natural occurrence of *K. pomifera* has not yet been exposed to the Myrtle Rust pathogen, but its range includes areas in both States identified as potentially climatically suitable for the disease on some of the predictive models to date (and Myrtle Rust can be a disease of crops even outside its preferred climatic envelope depending on growing conditions). *K. pomifera* is a known host of Myrtle Rust from inoculation screening (Morin et al. 2011, 2012).

A meaningful engagement with Indigenous stakeholders on the potential impacts of Myrtle Rust, is not a one-off exercise, but an evolving process. Species and site values need to be understood in a local context through engagement with traditional owners and custodians; the values attached to a species may be inseparable from broader values of a site or landscape. Engagement also needs to include consultation on the cultural acceptability of possible future species conservation actions – the option of local reinforcement or re-introduction of a severe-decline species with a more disease-resistant genotype would be an example.

Most Aboriginal-run organisations are resource-stretched, and only in some regions are they able to employ full-time staff concerned with natural resource management. In northern Australia, many Indigenous ranger groups are already playing a role in vigilance for general biosecurity and for Myrtle Rust in areas to which it has not yet spread.

A process of engagement with Indigenous stakeholders on the environmental effects of Myrtle Rust could usefully commence with briefings to the Indigenous advisory committees of environment agencies and NRM bodies, and to key staff in each and in some local government bodies, in affected or potentially affected jurisdictions and areas, with subsequent steps to be shaped by their advice.

5.6 Risk – economic impacts (tourism)

No projections are available of the potential impacts of Myrtle Rust on the tourism industry. Indigenous tourism enterprises along the east coast commonly feature native Myrtaceae plants and products in their repertoire, and to the extent these taxa are adversely affected by Myrtle Rust the resources available to these enterprises are reduced.

Wildflower tourism is a significant drawcard in the south-west of Western Australia, and myrtaceous species form a large proportion of the conspicuous flora. However, this is an area of uncertain climatic suitability for the Myrtle Rust pathogen. If the pathogen does invade and naturalise there in seasonally wetter areas, the loss of visual amenity could be significant given the indications of susceptibility in some of the florally conspicuous genera (e.g. *Calothamnus*, *Darwinia*, *Verticordia*), which would compound the loss of attraction resulting from declines already caused by the soil pathogen *Phytophthora cinnamomi* in certain areas (e.g. Stirling Range).

5.7 Risk – economic impacts (bush food and bush products)

A number of small-scale industries along the east coast are based on plant products derived from the Myrtaceae family, the largest dollar product being tea-tree oil (see under 'genetic resources' below), followed by Lemon Myrtle, Aniseed Myrtle, and Riberry products.

Lemon Myrtle (*Backhousia citriodora*) has become "the giant of the Australian native food industry" since the start of commercial cultivation in the 1990s, with a fresh weight leaf harvest of up to 1,000 tonnes p.a., compared with less than 15 tonnes for most other native food crops (AgriFutures 2017). Leaf is used as a culinary herb, tea or spice, and the oil is used as a flavouring agent and in a wide range of personal care products. Commercial production of lemon myrtle in Australia commenced in the mid-1990s. Lemon Myrtle is a host of Myrtle Rust in cultivation and in the wild, and was assigned a medium- to high susceptibility rating by Pegg et al. (2014a). The Lemon Myrtle industry has been hit hard by Myrtle Rust disease, with a number of growers forced to use fungicide treatments and some losing organic certification status as a result, impacting to an undetermined level on their absolute and relative market share. One of the biggest producers has made a costly partial relocation to an irrigated site west of the Great Divide to minimise the disease problem. See further under Section 5.10 'loss of genetic resources' below.

Aniseed Myrtle (*Syzygium anisatum*) production is small and for a niche culinary market. *S. anisatum* is a host of Myrtle Rust, rated as varying from relatively tolerant to highly susceptible (Pegg et al. 2014a), although the selections in commercial cultivation have been seriously impacted by the disease (A. Carnegie, P. Entwistle, pers. comms).

Riberry (*Syzygium luehmannii*) production is small; it is rated as being of moderate susceptibility (Pegg et al. 2014a), but impact on cultivation to date is thought to be minor.

5.8 Risk – economic impacts (eucalypt forestry and plantations, and agroforestry)

A number of economically important eucalypt species (or forestry hybrids or landraces) originating from eastern Australia are affected by *Austropuccinia psidii* in plantations in South America, where the economic losses have at times been large and have sparked intensive resistance breeding programs. Pre-arrival analyses of the risks from the *Austropuccina psidii* pathogen stressed the potential for forestry economic impact on this basis.

Two studies to date have attempted to quantify the potential forestry impacts; both necessarily based their estimates on overseas experience, and treated the disease *in toto*, the different strains and their host preferences being imperfectly understood.

A study for the then Primary Industries Ministerial Council in 2006 (PIMC 2006) estimated a potential 60% to 90% reduction in production in high risk forests, a reduction of total log volume produced in Australia from 9.8-14.8% annually, and a total gross value (mill door) reduction of $170-257 million (on 2006 baseline values).

A second study (Cannon 2011), soon after the arrival of the pathogen in Australia, arrived at a considerably lower figure: "a very broad attempt to quantify the cost of this impact based on a steady estate area and replanting all harvested coupes is a mill door annual loss of $105 million … possibly a worst case scenario." This study however noted the potential for wider geographic incidence of the disease than the 2006 study, noting that much of Australia's temperate plantation regions might be vulnerable on a permanent or occasional basis, and that regeneration rates and forest species diversity could be adversely impacted. It recommended that "it is important that tight quarantine restrictions are maintained to prevent any other strains of the *P. psidii* complex being introduced to Australia."

In Australia, 106 Australia eucalypt species or subspecies are so far known to be susceptible to the 'pandemic' strain of *A. psidii* (84 of them from indoor inoculation studies only). Most show some variability in infection rates. Only two eucalypt species (*E. carnea* and *E. curtisii*) were assigned susceptibility ratings extending into the 'high' category in a study of Queensland host species (Pegg et al. 2014a); dieback of mature trees and young coppice regrowth was noted for both (Pegg et al. 2014b). Since then there have been multiple observations of severe infection on coppice growth of *E. tindaliae* in northern NSW (P. Entwistle pers. comms).

"Very savage" infection on seasonal new growth of *Eucalyptus resinifera* subsp. *hemilampra*, and infection of seedlings and post-fire coppice from trunks and lignotubers, is reported from the Eungella Plateau area near Mackay in Central Queensland by G. Paterson (pers. comm. Sept 2017). This taxon has previously been known as a host only from lab inoculation (Morin et al 2012). The same observer reports *Eucalyptus montivaga* (= *E. andrewsii* in the *Australian Plant Census*) as "hit badly" by Myrtle Rust, including on sucker growth from lignotubers; this taxon has not previously been reported as a host for Myrtle Rust and photo evidence for both these species is as yet lacking. These cases suggest that there is a need for wider survey of eucalypt susceptibility in the field than has been conducted hitherto, across the east coast Myrtle Rust 'zone', and covering seasonal flush and the critical life stages of early germinant seedlings and post-fire coppice regrowth. High susceptibility or mortality at these latter life stages in otherwise relatively tolerant species, could lead to long-term decline being undetected unless baselines are determined and field impact assessments done.

The biological resources of the Australian Myrtaceae for timber production forestry are known to genetic level for a relatively few species, mainly in the eucalypt genera. A much larger body of knowledge to species level exists in the Australian and overseas forestry and silvicultural literature, although the most recent holistic conspectus (in Boland, 2006) is based largely on knowledge generated in the era before modern techniques of genetic and ecological evaluation. Extensive genetic and genomic information for eucalypts now exists, particularly for the species in plantation overseas.

A further area of demonstrated and potential genetic resources is in the selection or development of species for multi-purpose agroforestry use. For Australian-origin species (including a few from Myrtaceae) this has to date been mainly for export purposes to countries where the need has been for combinations of uses including for timber, fuel, fodder, land reclamation, and other purposes. The selection of tree and shrub species for similar multipurpose use within Australia has so far been limited, where simple wild-type selections rather than highly developed stocks are used for general revegetation and ecological restoration. Potential does however exist for a more sophisticated approach to meet coming restoration challenges in relation to staged-succession ecological restoration, mine site rehabilitation, and climate change mitigation strategies.

5.9 Risk – economic impacts (horticulture)

The nursery industry is mostly centred in the eastern parts of Queensland, NSW, Victoria and Tasmania, largely within the established zone of naturalisation of the Myrtle Rust pathogen. Even for indoor production this geographical region means a fairly constant exposure to ambient *A. psidii* spore load, which necessitates constant inspection and when necessary fungicidal treatment for susceptible taxa. It also means a significant probability that plants moving along the supply chain out of that zone will from time to time carry live spores or active infections of *A. psidii* – hence the need for maintenance of domestic quarantine by States not yet affected.

The ornamental horticulture industry is only partly organised under peak bodies, is culturally resistant to detailed surveys, and in any case plant family data does not appear to have been a priority for the industry bodies.

The nursery industry (including growing for forestry, fruit and vegetable, landscaping and ornamental retail supply chains, but excluding turf and cut-flower) generates a total value of production of $1.17 billion, mostly realised domestically with only $5.7M of exports (Horticulture Innovation Australia 2017). However, the use of Myrtaceae species within this sector as a whole is relatively small. Little hard data has been found for this review, but native plant species *in toto* are said to account for only about 10% of sales volume in the ornamental greenlife trade, and within that proportion certain Myrtaceae genera are known to be significant, especially eucalypts, *Callistemon*/*Melaleuca*, and *Chamelaucium*. In the forestry- and landscaping nursery sub-sectors, Myrtaceae species undoubtedly form a much higher proportion.

There is nevertheless considerable activity by plant breeders in the development of Myrtaceae taxa for commercial purposes. The Australian Cultivar Registration Authority (ACRA, https://www.anbg.gov.au/acra/, accessed 14 Sept. 2017), a continuing but increasingly historical list (most entries are prior to c. 2000), has 84 named Myrtaceae cultivars and hybrids out of a total of 450 (19% of total). The Plant Breeders Rights website (https://www.ipaustralia.gov.au/plant-breeders-rights, accessed 14 Sept. 2017) records 273 applications (not all successful) for registration of Myrtaceae breeds. Prominent genera on these registers include *Agonis*, *Callistemon*/*Melaleuca*, *Chamelaucium*, *Leptospermum*, and *Syzygium*, all of which include known Myrtle Rust host species.

However these register figures are a considerable underestimate of the primary selection and breeding activity that goes on in the industry (although of course not all cultivars go through to successful commercial production). For example, the above registers capture only 59 'named' entities from the genus *Callistemon*, yet Wrigley & Fagg (1993 – many more will have been generated since) document 175 named cultivars in that genus. The many horticultural selections developed but marketed under the name of the parent species are also not captured by any consolidated source located to date.

One taxon for which economic value has been published is Geraldton Wax (*Chamelaucium* sp., mostly *C. uncinatum* but possibly involving other undescribed taxa as sources for selections and hybrids). Geraldton Wax accounts for c. 40% of all Australian native cut-flower production, and its farmgate value is placed at more than $20 million per annum (Michael 2011). It is commercially produced in very large overseas, especially in Israel and California (Considine and Webb 1999).

All *Chamelaucium* species are native and endemic to Western Australia, occurring in a coastal zone from Perth to Kalbarri that falls within the Myrtle Rust climatic suitability zone identified by some (but not all) predictive models. *C. uncinatum* was rated as Extremely Susceptible to Myrtle Rust by Pegg et al. (2014a), a judgement confirmed by Tobias et al. (2015) who found very high susceptibility and no indications of resistant genotypes from wild-sourced seedlings across the range of the species. *C. uncinatum* and other species in the genus, several of which are undescribed (https://florabase.dpaw.wa.gov.au/), represent a significant genetic resource for the State and great potential for the horticultural industry.

5.10 Risk – loss of potential new genetic and biological resources:

There is no general strategic conspectus of the genetic resources latent in the Myrtaceae (or any other major group of Australian biota), and such reviews are rare on a global basis. The identification and development of such resources in the past has been on a largely empirical, market-driven basis (e.g. in forestry and horticulture), or to secure intellectual property rights (pharmaceutical screening), rather than on a national-interest basis. Only very recently have the genetic, metabonomic, and other analytical tools become available, now at increasingly low costs, to enable a more strategic approach. As a consequence, we have as yet no real idea of the lost-opportunity economic and social-benefit risks entailed in species declines and extinctions.

5.10.1 Genetic and biological resources related to Indigenous cultural knowledge

Myrtaceae species form a conspicuous part of the Indigenous traditional and continuing pharmacopeia across Australia. Traditional and continuing Indigenous knowledge of the Myrtaceae has been inconsistently addressed scientifically. Aboriginal knowledge of various myrtaceous plant parts and derivatives (leaves, kino, bark, and other) often discriminates between plants of the same species from different places or situations, analogous to (but not necessarily concordant with) phytochemical distinctions between chemotypes within species. Some uses are clearly based on essential oil properties, and some of these have been industrialised and taken up across non-Indigenous society (tea tree and eucalyptus oils being a prime example). Some others have scarcely been investigated, and may not always be amenable to a reductionist approach. The prospects for assessment of biological and genetic resources, where it draws on traditional knowledge or impinges on Aboriginal and Torres Strait Islander tenures, now has to take account of a complex and only partially resolved situation around intellectual and biological property rights, traditional knowledge rights, and competing and imbalanced economic interests. Any future inventory of potential genetic resources of the Myrtaceae (or of other plant families) needs to be based on cultural agreement.

5.10.2 Timber and pulp

Several eucalypt species and hybrids from the moist forests of eastern Australia are known hosts for the eucalypt-associated strains of *Austropuccinia psidii* in South American, and some have been the subject of research there and in Australia into rust-resistance genetics with a view to resistance breeding. These include forestry selections of, and hybrids based on, Tasmanian Blue Gum *Eucalyptus globulus* (globally the most widely grown timber species of Myrtaceae), Flooded Gum *Eucalyptus grandis*, and some other species. A much wider range of eucalypt timber are utilised within Australia, although in very few cases with the research and development effort that has been put into elite clone plantation development in South America and increasingly in China.

More specialist timbers from some non-eucalypt Myrtaceae are also utilised in Australia to varying extents. Brush Box (*Lophostemon confertus*), a key component of some ecological communities on the east coast, is also widely used as an amenity tree, and is apparently highly resistant to the 'pandemic strain' of *A. psidii* present in Australia, with no records of infection either in the wild or in the lab. The susceptibility of *L. confertus* to other strains of *A. psidii* not yet present in Australia, is unknown.

With wild-harvest timber increasingly coming to its limits of extraction, the genetic potential for development of novel plantation hardwood variants (whether grown here or overseas) is very large. The pandemic strain of *A. psidii*, at this early stage of its establishment, does not appear to be posing an existential threat to myrtaceous commercial timber trees or the genetic resource they embody (but noting the lack of information on seedlings and resprout growth for most). Any introduction of further eucalypt-associated strains of the disease would constitute a major threat to this resource.

5.10.3 Essential oils and other secondary metabolites (for medicinal, culinary, cosmetic and other uses)

"The presence of oil glands that produce essential oils is one of the fundamental features of the family Myrtaceae *sens. lat*." [i.e. including Heteropixidaceae] (Wilson 2011). These oils are often complex in their composition (up to c. 100 constituent compounds is not unusual), and are made up of various types of terpene (commonly mono- and sesquiterpenes, less commonly more complex terpenes), triketones, alkyl derivatives, and/or complex aromatic compounds. In rare instances the aromatics can constitute over 90% of the oil volume – e.g. the naturally rare Australian Anise Myrtle *Syzygium anisatum* [formerly *Backhousia/Anetholea anisata]*, which is severely affected by Myrtle Rust. The currently recognised commercial value of a small subset of these oils is usually based on the high levels of particular constituents.

Essential oils are one subset of a very broad class of chemical compounds termed secondary metabolites, which include compounds other than oils, and with a wide array of aromatic, bioactive, or otherwise unusual properties. Essential oils are one of the most commonly exploited sub-classes of secondary metabolites, but a range of other substances are also generated by Myrtaceae. The few of these currently exploited, in a range of applications, hint at the wider potential genetic resources in the family. For example, two species of eucalypt have been commercially cultivated for the production of a flavonoid glycoside (rutin), used in some medical treatments of capillary blood vessels (Wilson, 2011); Stapleton (1981) demonstrated the potential of some species as wool dyes; and water-soluble extracts that inhibit skin-ageing enzymes have been isolated from *Backhousia citriodora* and *Eucalyptus olida* (RIRDC 2012).

These days, almost all essential oils from Australian Myrtaceae are produced from selected lines grown in plantation, in some cases mainly overseas. The range of oils and other secondary metabolites currently produced, and the applications to which they are put, are extremely narrow compared to the actual range of compounds available across the family and their potential for future uses. Most of the extractive industries to date have their origins in former 'bush industry'-scale production and are only in recent decades (for some species) moving to larger scale as new applications and new markets are found. Wilkinson & Cavanagh (2005) pointed out that "of the Australian essential oils, only tea tree (*Melaleuca alternifolia*) and *Eucalyptus* spp. have undergone extensive investigation", and this is true in the sense that most oils and waxes research has been basic, to elucidate constituents, not explore applications. With that proviso, quite extensive survey of the essential oil constituents of Australian Myrtaceae has been done, notably c. 130 papers and books by J.J. Brophy (University of NSW) and various collaborators, and another large body of work on oils and waxes by the late E.V. Lassak (NSW Dept of Agriculture), among others. Some of these have a direct bearing on a conservation response for species already in serious decline due to Myrtle Rust. Phytochemical profiles, taken as indicators of underlying genetic difference, may aid in the identification of infraspecific variants, may inform or contraindicate translocation programs, or be potential correlates of observed infraspecific or infrageneric syndromes of resistance and susceptibility requiring investigation (e.g. Brophy et al. 1995 -- *Backhousia*, Brophy et al. 1996 – *Archirhodomyrtus beckleri*; Brophy et al. 1997 —*Rhodamnia*).

Wilkinson & Cavanagh (2005) themselves investigated antibacterial action in essential oils derived from native plants (including nine Myrtaceae, six of them known hosts of Myrtle Rust), finding that some performed as well or better than tea-tree oil.

The main established industries and some applications are outlined below. These extractive industries have a small producer base, a limited domestic market, and for longer-recognised applications face fierce competition from overseas producers using Australian-origin species from which Australia derives no benefit.

However, some extraordinary and unexpected new potential non-pharmaceutical applications are opening up as a result of advances in organic chemistry and processing technology, providing an opportunity for Australia to derive benefit from entirely new applications – if the biological resources that underlie them are recognised and conserved. Two cases in point from recent Australian-based research illustrate the point, and both relate to a newly recognised suitability of essential oils from native plants for the fabrication of electronic components.

Jacob & Bazaka (2010) demonstrated the generation, from a small sample of plant essential oils and with best results from a tea-tree oil, of superior quality and flexible semi-conducting polymer films, potentially competitive for some large-scale applications with the highly purified and expensive rigid silicon currently used across the electronic and photovoltaic industries. Moreover, the same study indicated that tea-tree derived polymer films are biocompatible in mice, pointing to a potential for use in bio-medical devices such as organ implants. Further research (Bazaka et al. 2011) demonstrates that the technique used to produce the tea tree-derived organic film – pulsed radio-frequency plasma polymerisation – allows the tailoring of surface properties of the film (both surface morphologies and chemical structures) for "prevention of adhesion and proliferation of pathogenic bacteria on the surfaces of in-dwelling medical devices". The possibilities include re-deposition or retention of antimicrobial chemical compounds, including those from the original oil, and this opens up the entire spectrum of antimicrobial properties common across the Myrtaceae.

The second radically innovative use of a Myrtaceae-derived oil, using a similar low-temperature plasma process, is the production of high quality nano-scale graphene films from myrtaceous oil precursors. Graphene has a "rare combination of unique properties highly sought after for a wide spectrum of applications particularly in areas such as electronics, photonics, energy, and environmental sensing" (Jacob *et al*. 2015). Simple exfoliation of graphene from its graphite precursor does not allow the production of large-area films, and alternative methods to date have relied on energy intensive processes and toxic or hazardous catalysts or reagents. The plasma/oil process, which is low-energy, non-toxic, and catalyst-free, "is fast, sustainable, scalable, and potentially low cost" (Jacob *et al*. 2015). As with the previous example, the quality and chemical composition of the oil and its components are critical.

Both the above exploratory studies used the easily available and compositionally consistent tea-tree oil (from *Melaleuca alternifolia*), but in a family with over 2,000 native Australian species, many of which have distinct infraspecific chemotypes, the possibility that even better precursor compounds for these applications, and others yet to be glimpsed, is obvious.

Eucalyptus oil production, once an important bush industry, is now at low levels in Australia compared to overseas production, and within Australia is mostly based on species and located in regions unlikely to be severely impacted by Myrtle Rust for climatic reasons. Nevertheless, the great size of the three eucalypt genera (a combined 900 taxa, with much phytochemical variation) and the long-established and still evolving uses for eucalypt oil and its various component compounds, means that any inventory of myrtaceous genetic resources should take account of threats across those genera, not just to those species currently exploited. The existence of a number of broad-spectrum eucalypt-hostile pathogens not yet in Australia, and not necessarily as restricted in range as the Myrtle Rust pathogen, should be a consideration in such an inventory.

Tea-tree oil is an important regional industry in north-eastern NSW and south-east Queensland. The main tea-tree oil species commercially cultivated in Australia, *Melaleuca alternifolia*, is affected in the wild and in plantation by Myrtle Rust disease, but so far not at a level sufficient to cause major economic or quality problems. A number of other *Melaleuca* species, some also known hosts of Myrtle Rust, are used for oil production overseas, and any decline of the wild reservoirs of genetic variation represents a loss of resource for Australia.

Tea-tree oil has widely documented antimicrobial activity, including anti-fungal properties (e.g. Lis-Balchin et al. 2000; Hammer *et al*. 2003; Sharifi-Rad et al. 2017; an extensive literature database is available at http://www.teatree.org.au/index.php). The commercial tea-tree oil industry is based on selected lines of *Melaleuca alternifolia*, a known host of Myrtle Rust based on considerable regional variation in oil components in this one species alone (Lee et al. 2002). Outbreaks of the disease in plantations have been chronic since 2011-12, but the species (both in the wild and in cultivation) appears to be relatively tolerant of the single strain present in Australia so far, with some damage to growing tips little shoot death and relatively little impact on the quantity or quality of oil production. Tea tree oil is used in many applications, and the current focus on one species does not mean that it is the only one of potential future value for products based on secondary metabolites.

Cajuput oil from *Melaleuca cajuputi*, and Niaouli oil from *Melaleuca quinquenervia* and/or *M. viridiflora*, are produced in much smaller volumes, mostly outside Australia, and are used in a variety of applications including cosmetics and perfumery. Two chemotypes of *M. quinquenervia* are known within Australia (Brophy et al. 2013); no evidence is yet available whether these correlate in any way with the variability reported for Myrtle Rust susceptibility.

A number of species (e.g. *Corymbia citriodora*, *Backhousia citriodora*, and *Leptospermum petersonii*) have high levels of citral and citronella and are used for various insect repellent, perfumery, synthesis of vitamin A, and culinary purposes.

Lemon Myrtle (*Backhousia citriodora*) extracts and powdered leaf, with the oil component as the critical factor, are used in culinary (spice, flavouring), cosmetic, and quasi-medical applications, and the plant is (or was) used as an ornamental in warmer regions. AgriFutures (2017) notes that the oil has antifungal and antimicrobial properties superior to Tea-tree oil, and projects future applications in food preserving and cleaning products. The commercial industry currently comprises about 60 small and medium businesses in north-eastern NSW and south-east Queensland, and one large producer in North Queensland (AgriFutures 2017). Annual production in 2014 was estimated as between 575 and 1,100 tonnes (RIRDC 2014b), with an estimated farm gate value of AU$15 million; lemon myrtle oil production in 2012 was 3—8 tonnes with a farm gate value of AU$500,000. About 90% of lemon myrtle leaf and oil produced in Australia at that time was exported to the European Union and the United States of America (Agrifutures 2017).

The Lemon Myrtle industry has been hit hard by Myrtle Rust, with some growers reported as losing much production, and some losing or foregoing organic certification in order to use fungicidal treatments to maintain production. Both of the main selections of Lemon Myrtle grown clonally in plantation for the industry ("Limpinwood' or 'Line B', and 'Eudlo' or 'Line A'), are affected, although the former appears to be somewhat more tolerant of the disease (AgriFutures 2017). One other production lineage in NSW, not widely grown, is reported (A. Dowell pers. comm. 19 May 2017) as having little or no incidence of Myrtle Rust, although it is unclear whether this is genetically determined tolerance or a result of its very near-coastal situation.

One major Lemon Myrtle producer has relocated part of his production orchard from north-east NSW to a new irrigated inland site in North Queensland, specifically to escape Myrtle Rust, requiring the recruitment of substantial overseas equity (Anon. pers. comm. 2017). The area selected is less amenable climatically to Myrtle Rust, although some local microclimates may harbour it and seasonal outbreaks may still be possible.

Lemon Myrtle is an outstanding case of the need for, and utility of, multi-provenance screening studies for resistance to Myrtle Rust disease – potentially for conservation as well as for production systems. The fortuitous survival of a mid-1990s genepool planting (an array of sampled plants from known provenances across the entire wild range), allowed an assessment of differential levels of Myrtle Rust susceptibility and severity. The plantings were originally established near Beerburrum, Qld, by CSIRO and the Queensland Forestry Research Institute (now part of Agri-Science Queensland) as a research project to help the young industry identify optimal production types; Myrtle Rust was not a consideration at the time, but the survival of the array and most of its documentation allowed its re-use for assessment of Myrtle Rust incidence and severity in 2011-12, soon after the advent of the disease in south-east Queensland (Doran et al., 2012; Lee et al., 2016).

In these studies, significant variation was evident in susceptibility to infection, partially correlated with geographic (populational) origin. The array has since been partly re-propagated and split between two custody sites. As recommended by Doran et al. (2012), further research is now underway (E Lancaster, University of Queensland) directed towards disease-resistance selective breeding for commercial purposes (details not available for this review). However, the parallel *conservation* implications have apparently not been followed through by other agencies. There has been no re-visiting of the wild populations to conduct *in situ* assessment of their conservation status in relation to Myrtle Rust impact. The possibility of utilising this near-unique provenance array for breeding-in disease resistance and eventual rewilding has not been part of the research approach to this point. The longer-term logic of assessing and safeguarding even a proven genetic resource in the wild has not yet penetrated.

Anise myrtle *Syzygium anisatum* (= *Anetholea/Backhousia anisata*) has in recent decades been produced mainly as a culinary flavouring, often in the same plantations as Lemon Myrtle but at lower volumes reflecting its restricted market; in 2010, total annual production was 6-10 tonnes of dried leaf and 0.7-1 tonne of oil (RIRDC 2014c). It too is affected very badly by Myrtle Rust and again several growers have lost or forgone organic certification, or discontinued the species altogether.

5.11 Risk – fruit crops

Many species from the 'fleshy-fruited' genera of Myrtaceae are cultivated globally (Wilson 2011; Mabberley 2009), especially in the Indo-Pacific and south-east Asian regions, and feijoa has been an important emerging introduced crop in New Zealand in recent years. The arrival of *Austropuccinia psidii* in the Indo-Pacific region may have significant impacts on production and the industries around them in some countries – susceptibilities are mostly yet to be determined, and the environmental tolerances of *A. psidii* are uncertain. A few of these introduced tropical species are cultivated in Australia on a small commercial scale, mostly in North Queensland.

Few Australian Myrtaceae are used for fruit cropping, and only on a small scale.

Riberry (*Syzygium luehmannii*) is an east coast rainforest, and is cultivated and wild-harvested on a small scale. It is a significant item in the 'bush tucker' and eco-tourism industries in that region, including Indigenous-run enterprises. *S. luehmannii* is a known host of Myrtle Rust, rated as 'moderately susceptible' (Pegg et al. 2014a).

Midgen Berry (*Austromyrtus dulcis*) is an east coast shrub which similarly features in the bush tucker and home garden repertoire, although not commercialised at this stage. *A. dulcis* is a known Myrtle Rust host, rated as variably 'relatively tolerant' to 'highly susceptible' (Pegg et al. 2014a).

Muntjes or Muntries (*Kunzea pomifera*) grow naturally and are cultivated or wild-harvested mainly in western Victoria and the south-east of South Australia, as a bush-food product. The Myrtle Rust pathogen is not yet present in this region and the climate-suitability models, while varying, mostly suggest that its full naturalisation in that area is only marginally likely except perhaps on the Fleurieu Peninsula. *K. pomifera* is known as a host of the pandemic strain of *A. psidii*, albeit so far only from a laboratory inoculation screening trial (Morin et al. 2011, 2012).

5.12 Risk – honey

The significance of the honey industry in Australian regional economies is illustrated by the recent establishment of an AgriFutures Australia *Honey Bee and Pollination Program* (http://www.agrifutures.com.au/rural-industries/honey-bee-pollination) to support research and development for the beekeeping industry and for the pollination services of bees to horticultural and agricultural crops.

Many Myrtaceae species are important nectar and pollen resources for the honey industry. Among those species known to be strongly susceptible to Myrtle Rust are two Broad-leaved Paperbark species, *Melaleuca quinquenervia* of the mid-east coast, and *Melaleuca leucadendra* of northern Australia (Wrigley & Fagg, 1993). Many eucalypt species are also important but as noted elsewhere few of these are yet rated higher than moderately susceptible.

An emerging specialist area in the Australian honey industry is the potential for production of 'bioactive' honey from bees foraging on certain Australian *Leptospermum* species deemed to produce honey with properties similar or equivalent to the very high-value Manuka honey of New Zealand. New Zealand Manuka honey is produced from bees foraging on *Leptospermum scoparium* and widely used in culinary, para-medicinal, and cosmetic applications. *L. scoparium* also occurs naturally in Australia, and is a known Myrtle Rust host in this country from inoculation trial only (Sandhu & Park 2013), and in New Zealand from a 'natural' outdoor infection (NZ Department for Primary Industries, *Myrtle Rust Stakeholder Update*, 12th September 2017).

However, the comparative bioactivity levels of Australian *versus* New Zealand *L. scoparium* are debated, and other Australian species are being eyed for 'manuka' honey production in Australia. One of the main ones is *Leptospermum polygalifolium* which is widespread along the east coast, but interest is focussing on populations from the NSW Far North Coast and south-east Queensland (a region of heavy Myrtle Rust incidence), where touted as 'magic jelly bush'. *L. polygalifolium* is a known host species of *A. psidii* in Australia, so far from inoculation trial only (Morin et al. 2011, 2012). The above two species have only part of their total distribution within the current east coast Myrtle Rust 'zone'. *Leptospermum whitei, L. liversidgei* and *L. speciosum* are also being mooted by some sources as candidate Australian species for bioactive honey production – all three also occur fully within the east coast Myrtle Rust 'zone'. The first two of these species are also known hosts of the pathogen from 'natural' (outdoor) infection records. *L. liversidgei* is reported by Pegg (in conference, 2017) as undergoing variable, sometimes high impact from Myrtle Rust infection. Three of the above species (*L. polygalifolium*, *L. liversidgei* and *L. whitei*), alone among Australia's c. 90 *Leptospermum* species, are under active monitoring on a limited area basis for post-fire response to Myrtle Rust (G. Pegg, QDAF, research in progress).

The above account sketches only some of the areas of risk and resources that could be lost to the current strain of *Austropuccinia psidii*. The focus here, as elsewhere in this review, has been on the current zone of Myrtle Rust naturalisation in eastern Australia, as the scope of impact in the monsoon tropics and the south-west remains speculative.

PART 6: TOWARDS A CONSERVATION RESPONSE

This section canvasses some general issues relating to species prioritisation – a necessary step for a threat of this magnitude – and the issues of susceptibility and resistance to the Myrtle Rust pathogen that both shape the problem and provide some avenues, even if potential, for effective conservation actions and in some cases, perhaps, eventual recovery. It also looks at specific steps needed as prerequisites, as the current levels of information on species and ecosystem impacts are woefully inadequate, as are currently allocated resources.

The advent of the Myrtle Rust pathogen in Australia in 2010 caught biodiversity agencies, and the wider conservation sector, almost unawares and at a bad time. The substantial pre-arrival synopses on the pathogen (including Glen et al. 2007, and Plant Health Australia 2009) were generated within the plant pathology – biosecurity – primary industry sector, where most of the relevant expertise resides. The awareness crossover between that sector and the environmental sector has historically been poor, except through a rather esoteric biosecurity committee system (Craik et al. 2017) and a few researchers with cross-sectoral interests and concern.

The Myrtle Rust pathogen also arrived at a time of (still continuing) declining levels of staffing, expertise and investment, and continual restructuring, in the conservation agencies in many if not all Australian jurisdictions.

These factors combined with biological features of the pathogen (its high mobility, rapid spread, wide host range, and intractability to management in the wild) to induce a leaden and overly impressionistic fatalism in the front-line environment agencies, that still persists. There is no environmental response plan, no coordinated monitoring of impact, no central information repository, and no mobilisation of funding or human resources to deal with the declines and pending extinctions now under way – an environmental agencies' responsibility. The independent scientific bodies responsible for threatened species listing still tend to see this rapidly unfolding threat through the prism of much slower and more containable threatening processes, with the result that many of the acutely declining species remain unlisted, and almost no new listings have been completed on the basis of this new threat. It is no exaggeration to say that at least two species may well be functionally, if not completely, extinct in the wild before the listing processes for them catch up. The various bodies responsible for threatened species funding have by and large used the same prism, with funds only available for listed species.

Awareness and training programs on Myrtle Rust have been primarily focussed on vigilance (during the pre-arrival and spread stages in any one jurisdiction) and have been delivered mainly by primary industry agencies, with a strong emphasis on production system impacts and stakeholders. The only environmentally oriented awareness and training program has been developed and delivered (in four states at regional centres, 2011 to 2016) by a non-government organisation, the *Australian Network for Plant Conservation Inc*. (Makinson 2011-16), to stakeholders mostly missed by the primary industry training.

There is no silver bullet solution for Myrtle Rust, but equally no room for purely impressionistic pessimism, the current dominant ethos.

This review recommends that:

- 'Salvage' conservation of some of the worst affected species is still possible (extended ex situ conservation, with a program of resistance breeding and eventual reintroduction of some species to the wild);

- Reinforcement of some species and populations with more disease-resistant wild genotypes, through standard translocation and silvicultural selection means, is viable for some taxa;
- Resistance breeding and re-introduction to the wild is technically feasible for some species, and the associated social, ethical and logistical issues are potentially solvable;
- A nationally coordinated impact monitoring effort, drawing in skilled observers well beyond responsible agency circles, is both feasible and a prerequisite to anticipate and minimise slower declines at both the species and ecological system levels;
- Continued exclusion of Myrtle Rust from South Australia and Western Australia is not a lost cause;
- Cultural impacts will occur, and urgent and continuing engagement with cultural stakeholders is vital if these are to be minimised and conservation actions enhanced;
- Stringent exclusion of other strains of *Austropuccinia psidii* from the entire Australasian region is a national imperative;
- A strong national environmental response to Myrtle Rust is in the national interest as necessary preparation for the advent of future invasive environmental pathogens.

These aims, to be realised, are predicated on certain prerequisites:

- Urgent impact surveys for priority species to confirm and modify priorities on the basis of field data (not modelling);
- Urgent germplasm collection for priority species, and storage enablement research as needed;
- Coordination of an environmental response to Myrtle Rust at a national level (preferably involving carriage of the issue through the Environmental Agencies Senior Officers Group), and on a joint basis between the state environmental agencies and NRM bodies, external researchers and community and business stakeholders;
- Prioritisation of Myrtle Rust conservation measures within the overall conservation spend;
- Decoupling, for the purposes of Myrtle Rust actions, prioritisation of species spending from current listing status as Threatened;
- Prioritisation of conservation-directed research on Myrtle Rust within competitive funding streams;
- The establishment of a dedicated and directed (discretionary) government funding stream for those aspects of Myrtle Rust action and research lying outside the normal competitive research funding arrangements;
- The establishment of innovative funding mechanisms to support necessary aspects of the response not prioritised or not easily addressable by governments.

Justifying the feasibility of the first set of points above requires some examination firstly of how species might be prioritised, and secondly of technical capabilities and those features of plant and pathogen biology which provide a practical basis for conservation action.

6.1 A prioritisation of species for conservation action, and issues in prioritisation.

6.1.1 General considerations

Prioritisation of species and ecological communities for directed conservation action and research, needs to be conducted carefully and transparently, both to allow technical and social critique, and to maximise the options for external (non-agency) engagement of expertise and resources.

From the biodiversity conservation point of view, the primary level of prioritisation should be the establishment of need for actions or research, informed by a projection of the consequences of non-prioritisation. In the context of Myrtle Rust, 'need' may be based on current effects (actual declines), anticipated effects, or more general strategic value (actions or research which have generalisable implications with potential to improve the response overall).

A second level of prioritisation, resource and expertise constraints, needs to be clearly downstream of the 'need' level (i.e. a subsequent step), and separately and transparently justified – too often, the two are conflated, and 'lower' priorities disappear altogether. Failure to identify and make publicly available what is not within agency resourcing capacity, or is not for them a priority, obscures the non-prioritised but continuing needs and effectively prevents the engagement of external resources required to address them.

A model approach, from a situation comparable to the Myrtle Rust problem, was followed by the Ontario (Canada) provincial government, in relation to its recovery strategy for the American Chestnut tree in the face of the fungal disease Chestnut Blight. In four pages, the Ontario government described the problem, the management and recovery strategy, and clearly distinguished between *government-led actions* (to be directly performed by government agencies) and *government supported actions* (remaining endorsed needs, open to be met from a variety of external sources). Such an approach maximises the opportunities for non-government researchers, conservation practitioners, and corporate and community engagement and resourcing. It gives a mandate for (approved) action areas across the entire spectrum of identified need. This approach should be followed in Australia.

6.1.2 Species recommended for priority conservation action

45 species are recommended here for the most urgent conservation actions, on the basis of known declines, or known severe infection levels and suspected declines. The evidentiary basis is advanced in Appendix 1.

16 species are known or strongly suspected to be in serious decline on a total or regional basis, and are recommended for the most urgent (2018-19) conservation actions. These actions should include:

- impact surveys to assess decline and establish baselines, combined with
- preliminary survey for disease-resistant populations or individuals, and
- urgent germplasm collection (seed where still available, or vegetative material) to conserve genetically representative material of the declining populations.

Four of these species are recommended for **emergency priority actions** (2018-19 season):

- *Lenwebbia* sp. 'Blackall Range (P.R.Sharpe 5387)'
- *Lenwebbia* sp. 'Main Range (P.R.Sharpe+ 4877)'
- *Rhodamnia rubescens*
- *Rhodomyrtus psidioides*.

12 further species are recommended for **very high priority actions** (by end 2019):

- *Archirhodomyrtus beckleri* (Southern Chemotype), *Decaspermum humile* (Southern Metapopulation), *Eugenia reinwardtiana*, *Gossia fragrantissima*, *Gossia gonoclada*, *Gossia hillii*, *Melaleuca nodosa*, *Rhodamnia angustifolia*, *Rhodamnia dumicola*, *Rhodamnia maideniana*, *Syzygium anisatum*, and *Syzygium hodgkinsoniae*.

A further 29 species, of high known or suspected susceptibility, and suspected decline but for which there are fewer observations of impact, are recommended for **medium priority actions** (pre-end 2020) impact surveys to establish baselines and look for disease-resistant populations or individuals, and in most cases to capture sample germplasm (seed or vegetative) for storage enablement and germination research. These species are:

• *Austromyrtus dulcis*, *Backhousia citriodora* (impact and resistance survey – a germplasm set exists), *Backhousia leptopetala*, *Backhousia oligantha*, *Eucalyptus curtisii*, *Eucalyptus andrewsii* (= *E. montivaga*, Mackay region population), *Eucalyptus resinifera* subsp. *hemilampra* (Mackay region population), *Gossia acmenoides*, *Gossia inophloia*, *Gossia lewisensis*, *Gossia myrsinocarpa*, *Lenwebbia prominens*, *Leptospermum trinervium*, *Lithomyrtus retusa* (NT populations initially), *Melaleuca leucadendra*, *Melaleuca lophocoracorum*, *Melaleuca quinquenervia*, *Melaleuca viridiflora*, *Rhodamnia argentea*, *Rhodamnia australis*, *Rhodamnia costata*, *Rhodamnia longisepala*, *Rhodamnia sessiliflora*, *Rhodamnia spongiosa*, *Rhodamnia whiteana*, *Rhodomyrtus canescens*, *Rhodomyrtus pervagata*, *Stockwellia quadrifida*, and *Syzygium oleosum*.

It is possible, perhaps likely, that other emergency, high, and medium priority species will emerge from ongoing observations in the field.

Six other species for priority precautionary germplasm capture and storage testing:
In addition to the 45 priority species above, the following species are recommended for precautionary germplasm capture, as flagship examples of precautionary action. The first five all occur only in the Lord Howe Island World Heritage Area; all except the *Leptospermum* are known hosts of *A. psidii* from inoculation testing. Allosyncarpia ternata is a Northern Territory endemic of cultural significance, that occurs in and adjacent to the Kakadu World Heritage Area.

- *Leptospermum polygalifolium* subsp. *howense*: NSW (Lord Howe Island endemic)
- *Melaleuca howeana* (Lord Howe Island endemic)
- *Metrosideros nervulosa* (Lord Howe Island endemic)
- *Metrosideros sclerocarpa* (Lord Howe Island endemic)
- *Syzygium fullargarii* (Lord Howe Island endemic)
- *Allosyncarpia ternata* (Northern Territory endemic).

6.1.3 Species prioritisation - Different approaches, different results

Enough data and field observations exist to delineate in broad terms the potential scale of declines likely to occur in the absence of an active conservation management response to Myrtle Rust. It is certain that declines are already underway sufficient to push a considerable number of species into 'threatened' categories for the first time, or to promote low-category threatened species into higher categories. Two to ten taxon extinctions in the wild within the next 5-10 years is not improbable, and over a few decades could climb considerably higher.

Other parts of this review have sought to demonstrate that some options do exist even for the species already in catastrophic decline, although a fair bit of blue sky thinking and uncomfortably interventionist forms of conservation management are likely to be involved, as is a good deal of 'precursor' work to enable any possible long-term recovery actions.

For the most seriously affected species, the overriding priority is to secure germplasm (seed or other) in a storable form – which will require prior enabling research for some. The target levels of germplasm capture need to reflect the natural genetic and geographic ranges of the species, and to provide material for ongoing germinability testing, research, and potentially seed orcharding and translocation, as well as long-term storage. As a matter of precaution, for other species on a slower decline trajectory, or which (e.g. in SA and WA) are not yet exposed to the pathogen, germplasm capture should also be progressively pursued. The eastern Australian experience has demonstrated how the lack of a proactive germplasm capture policy can result in a missed window of opportunity as the disease reduces fruiting levels to near zero in some species.

Conservation with a view to resistance breeding and rewilding -- potential recovery – needs to preserve, as far as possible, the genetic resources and evolutionary potential intrinsic to the wild species. Small captive collections have their role, but as part of a bigger plan.

In a climate of constrained conservation resources, *prioritisation* of species for both precursor and substantive conservation actions is a pragmatic imperative. The paucity of on-ground monitoring of affected species in the wild has hampered the accumulation of data that we need to guide prioritisation, or even a comprehensive picture of which species are, and are not, undergoing significant decline. Field surveys and monitoring are therefore also key elements of a response.

Prioritisation of species for action at this stage of knowledge is necessarily provisional. Species with a high or extreme susceptibility rating and whose home ranges are completely within the east coast Myrtle Rust envelope, but for which field observations are lacking, are legitimate priority targets for urgent survey to determine whether they are undergoing decline or not. The outcome in turn affects their priority for subsequent actions.

Two approaches to prioritisation are possible: modelling and ground-truthing. While not inherently mutually exclusive, the urgency for action for the steeply declining species means that every loss of season before on-ground action is taken, decreases the options for that action and the options for eventual recovery. A sequential approach (e.g. an extended modelling exercise *before* action) is likely to miss the window for some steeply declining species close to extinction. It is important for conservation agencies to register that the ground-truthing approach is not all down to them and their limited resources. The generation of this review has involved inputs of field knowledge from an array of ecological consultants, bush-regenerators (community and professional), land and biodiversity management officers outside the agencies, and motivated and botanically skilled community groups and practitioners. These stakeholders are increasingly conscious of the Myrtle Rust problem and can be expected to be keen to help address it, if given the tools, a sense of purpose, a data repository, and a plan to work to.

The modelling approach, for those species for which time permits, is nevertheless valuable, if (and only if) a certain level of baseline information is available. Modelling potentially allows a longer-range prognosis, that is more desirable for species on a slow trajectory of decline, and it provisionally allows the de-prioritisation of some species altogether on the basis that they are less likely to be affected.

Modelling for Myrtle Rust in Australia has focussed very much on climatic or bioclimatic prediction of the potential distribution and persistence of the pathogen, often with overseas environmental parameters relating to multiple strains of *A. psidii* – see Section 1.4 for discussion. The biological, biogeographic and ecological attributes of the Australia host species have played little or no part in most such predictive models, and while they are valuable and suggestive for regional biosecurity and threat evaluation, these models can provide little prioritisation guidance at the species scale.

A recent exception, which does factor in some host species attributes, is the climatic suitability modelling of Berthon *et al*. (2018), which also uses primarily Australian wild-occurrence data and climatic correlates, and is specific to the 'pandemic strain' of the pathogen. The same paper also constructs a prioritisation table for conservation action, based very largely on their modelled climatic exposure relative to their natural distributions but also factoring in current extinction-risk listing status (in nearly all cases based on pre-Rust assessment). Both suitability mapping and prioritisation were modelled under current climatic conditions and under those projected for 2050. For a brief summary of the predictive distribution aspects of this paper, see Section 2.3 above.

Berthon et al. (2018) identify 23 species as assignable to their Category A and B priority streams, which are defined as non-ordinated relative to each other, and have an associated list of possible actions. *Category A* species are defined as having: Range overlap >80%; Susceptibility Yes or Unknown; and an Existing extinction-risk listing. *Category B* species are defined as: Range overlap >80%; Susceptibility Yes or Unknown; no existing extinction-risk listing. For current climate, Berthon et al.'s priority species (bracketed notes mine – ROM) are:

Category A:
Callistemon genofluvialis (Victorian endemic, listed in Victoria as Vulnerable);
Callistemon kenmorrisonii (Victorian endemic, listed in Victoria as Vulnerable);
Callistemon nyallingensis (Victorian endemic, listed in Victoria as Vulnerable);
Eucalyptus kabiana (Queensland endemic, listed in Queensland as Endangered);
Eucalyptus ornans (Victorian endemic, listed in Victoria as Endangered);
Verticordia apecta (WA endemic, listed as Critically Endangered in WA and by Commonwealth);
Verticordia pityrhops (WA endemic, listed as Endangered in WA and by Commonwealth).

Category B:
Astartea schaueri (WA endemic, not threat-listed);
Astus duomilia [as 'duomilius'] (WA endemic, listed in WA as Priority One flora)
Baeckea pulchella (WA endemic, not threat-listed);
Eucalyptus annettae (WA endemic, listed in WA as Priority Two flora);
Eucalyptus insularis [subspecies not specified] (WA endemic; subsp. continentalis is listed in WA as Endangered);
Eucalyptus rummeryi (NSW endemic; no listings);
Kunzea acuminata (WA endemic, not threat-listed);
Kunzea newbeyi (WA endemic, not threat-listed);
Leptospermum benwellii (NSW endemic, not threat-listed);
* *Melaleuca howeana* (NSW: Lord Howe Island endemic; not threat listed);
* *Melaleuca lophocorcorum* (Queensland endemic, no threat-listings)
Melaleuca ulicoides (WA endemic, not threat-listed);
* *Mitrantia bilocularis* (Queensland endemic, Qld NCA listing as Vulnerable);
* *Rhodamnia longisepala* (Queensland endemic, Qld NCA listing as Endangered);
* *Rhodomyrtus effusa* (Queensland endemic, not threat-listed);
* *Syzygium glenum* (Queensland endemic, Qld NCA listing as Endangered).

Of these species, only those marked with an asterisk* are confirmed or reported Myrtle Rust hosts.

It is here recommended that agencies setting priorities for Myrtle Rust conservation actions take account of the analysis and prioritisation in Berthon et al. (2018)

There are however some issues with this prioritisation method in relation to:

- The limited number of Myrtle Rust records used to generate the model – 651 records, reduced to 276 once adjusted to a 1km^2 grid; (given their other methodological constraints, this was unavoidable for the investigators, given the inadequate national survey and monitoring effort to date, particularly in North and Central Queensland);
- The sinking of infraspecific taxa known to be high-overlap and high-risk back into their 'parent' species, resulting in inflated 'extent of occurrence' estimates for some infraspecific entities best treated separately (e.g. *Archirhodomyrtus beckleri* and *Decaspermum humile*, among others);

- The exclusion from the climate suitability calculations of data derived from species known as hosts only in cultivation out-of-range – this may be methodologically appropriate for the climate-predictive aspects of the study, but results in some curious gaps in the climate suitability maps particularly in North Queensland, and strongly skews the action-priority list;
- The calculation of distributional 'overlap' with known Myrtle Rust locations by means of minimum convex polygon estimation of the 'extent of occurrence' of host species, in the sense of IUCN (2012, 2017), resulting in gross underestimation of the overlap for numerous known hosts.

The last two points in particular, result in the exclusion from Berthon et al.'s priority categories A and B of:

- Numerous species known from open cultivation to be prone to Myrtle Rust infection (some rated in the higher categories), and also known to occur in Myrtaceae-rich wet forest environments that *prima facie* provide near-optimal Myrtle Rust habitat.
- The exclusion from the A/B categories of numerous species known to occur *fully and only* within the Myrtle Rust naturalisation envelope. This exclusion is apparently on the basis of an artifactually low estimate of overlap resulting from the constraints of using EOO, and because of an *assumption of non-continuity* of Myrtle Rust between point records for it (regarded here as a result of inadequate survey for rust incidence).
- The exclusion of a number of species either known or strongly suspected, to be in severe decline.

The categorisation is also influenced by the current threat-listing status of species. As discussed elsewhere in this review, pre-Rust listings may be indicative of the risk of cumulative threats to a taxon, but they have no simple predictive value in relation to further decline caused by this single pathogen – some species assessed as being of 'least concern' have declined more drastically from Myrtle Rust than many listed taxa.

Berthon et al. (2018) do acknowledge (in their Discussion, section 4.2) that "Our use of EOO to estimate species' risk has limitations. EOOs assume a continuous distribution within the polygon, which is unlikely to be the case for many species (Rondinini et al., 2006). Hence, this approach may include areas where the plant species does not occur and cause inaccuracies in the range overlaps calculated here. This result may indicate that there are potential rescue populations outside the range of myrtle rust, but in reality all populations might be distributed within affected areas. As a consequence, higher conservation attention may be required than what was determined based on the overlap threshold of 70%. Conversely, areas of myrtle rust may overlap only with parts of the EOO where a species does not occur, increasing the priority level of host species."

Notwithstanding this disclaimer, Berthon et al.'s overlap analysis does result in gross underestimates of overlap for multiple species, and consequently warps the species prioritisation. Neither of these elements of the paper can be recommended as a basis for conservation planning. For example, *Rhodomyrtus psidioides*, the species for which we have the best documented evidence of catastrophic decline (Carnegie et al. 2016), is assigned an overlap with Myrtle Rust of 28.2% and is assigned to Category C (Berthon et al. 2018, Supplementary Table S3). Category C is broadly defined, but one element is "minor" overlap with Myrtle Rust, and at one point an assertion of "potential refuge populations". The situation of *R. psidioides* is not congruent with either of these parts of the definition. The prescriptions advanced for conservation action for Category C species are acknowledged to need a 'case by case' approach, but the exclusion of known-decline species from the priority Categories A and B, and the inclusion in those of species for which there is no current level of known impact, results in an unsupportable prioritisation. Further examples, among many, of species with underestimated overlap and consigned to Category C are: *Gossia gonoclada* (given

38.2% overlap), *Rhodamnia dumicola* (45.1%), *Rhodamnia rubescens* (18.3%), *Stockwellia quadrifida* (51.8%), and *Syzygium hodgkinsoniae* (5.1%). All of these are in reality total (100%) overlap species, fully within the naturalised distribution of *A. psidii* and endemic only to habitats and vegetation types highly conducive to the pathogen.

6.1.4 Approach to prioritisation of species in this review

Accordingly, for this review a different approach is taken to prioritisation of species for conservation action. No ordination of all known hosts is attempted (much less of all Australian Myrtaceae). Overlap estimates *inform* the production of a priority list (see Sections 4.4 and 6.1.2 above, and Appendix 4). Overlap estimates here are inferred from the general polygon encompassing Myrtle Rust records (including open cultivation), versus the known obligate or preferred habitats of the host species, as well as their gross distributions. It is deliberately assumed here that for moist and near-coastal vegetation types on the east coast north of Moruya (and including high-montane types in North Queensland) *there are no refugia* from Myrtle Rust infection. Primarily, though, species assigned priority in Sections 4.4, 6.1.2 and Appendix 4 are on the basis of documented impacts (published reports) or skilled observer information as to on-ground situations, here considered reliable.

The prioritisation for action of species in this review shown Sections 4.4, 6.1.2, and Appendix 1) applies only to the areas of Australia in which *Austropuccinia psidii* is currently known to be fully naturalised, i.e. NSW, Queensland, and the Northern Territory. It excludes Victoria and Tasmania where no 'wild' records of Myrtle Rust are known, and those States are in the happy position of scoping priorities for precautionary rather than emergency actions. The priority list does however include Lord Howe Island, on the basis of its World Heritage Area status, its down-wind (high risk) location relative to the mainland; and the likelihood that if and when Myrtle Rust does establish there, there is no geographical scope for the five endemic Myrtaceae (four of them known hosts) to 'escape' exposure.

The rationale for the conservation-action priority species presented in Section 6.1.2 of this review is based on the following assumptions:

- An essential continuity of *A. psidii* distribution in moist biomes along the east coast from Narooma NSW to Cape York, Qld, with natural or human-mediated spore transmission across climatically unsuitable terrain being likely to occur on a frequent basis;
- A strong likelihood that infection records for open-cultivated plants (not subject to special horticultural treatment) in north-east NSW and south-east Queensland, that currently form the basis for the known-host status of numerous North Queensland species (in the absence of survey in their home range), allow a high-plausibility estimate that the same species are in fact susceptible in the home range;
- That species known to be undergoing severe infection cycles and observed damage (from credible on-ground reports and/or the few systematic studies to date), especially if given a high susceptibility rating by Pegg et al. (2014a) or Pegg et al. (2018), should be priority candidates for at least field survey and germplasm-capture actions.

This is not to imply that species not so defined, or species occurring in other States with or without *A. psidii* incursion, should not also have conservation actions prioritised and performed, preferably on a precautionary basis and before serious effects manifest. 'Non-prioritisation' of these species and regions in this review does not indicate a lack of need, just a longer window of opportunity. The immediate risk of decline and possible extinction in the east pragmatically dictates that the most urgent conservation steps involve action for those species for which action options may cease to exist in a very few years time. Note also that this does not necessarily mean throwing money at a lost cause – the salvage and recovery options outlined elsewhere in this review are intended to make a case that recovery for severely affected species, while problematic, is not an entirely lost cause – as long as options are kept open for the future through the actions suggested.

6.2 Susceptibility and resistance

Many Australian native species observed with or screened for with Myrtle Rust (i.e. known hosts) show indications of some variation in susceptibility. For other species, screening studies and/or wild surveys have not yet included sites or samples from a meaningful range of source populations (provenances). Simple field observations of asymptomatic individuals or patches may or may not reflect anything more than chance escape at any one time; repeated differential responses within and between populations are more informative. Allowing for the uncertainty, Berthon et al. (2018) conclude that approximately 26% of Australian species investigated for susceptibility show indications of including resistant genotypes, to varying extents.

The terms *resistant*, *susceptible*, and *tolerant,* as applied to plant hosts of pathogens including *Austropuccinia psidii*, are used in different senses in the general and technical literature, and may vary even within the latter. For example, many technical papers define 'resistant plants/species' as "those that show no signs of infection when exposed to the rust" (Berthon *et al*., 2018); for ease of communication this sometimes also termed *immunity* (e.g. Freeman & Beattie 2008). In other cases, plants showing no susceptibility to infection may be termed *non-hosts* or *asymptomatic*, with contextual nuances, and plants or species showing a low-level of symptoms as being *tolerant*, *resistant*, or *low-susceptibility*. Use of the terms must be assessed in context. For the purposes of this review, designation of a species as a *known host* means that completion of the uredinial life cycle has been confirmed, whether in laboratory or glasshouse studies, in cultivation, or in the wild. *Within* that set of known hosts and their constituent populations and individuals, varying degrees of resistance or tolerance of the pathogen (or conversely susceptibility to it) may be shown via expression of symptoms. In this sense, the terms *resistance* and *susceptibility* used with qualifiers are complementary – a highly resistant species has low susceptibility, a non-resistant species has high or extreme susceptibility.

An important qualifier to the above is that the lack of symptoms or a completed rust life cycle on a myrtaceous plant may not mean that it is free of the effects of the pathogen. An important study by Winzer et al. (2018) suggests that even asymptomatic plants subject to *A. psidii* inoculum may undergo reduced growth and biomass, presumably as a result of redirection of energy and physiological processes to fight the disease. If further verified, this finding is likely to prove highly informative for investigation of the disease process and identification of resistance pathways, but it is not a critical factor for urgent conservation measures in the short term (except in relation to quarantine holding periods and vigilance).

An improved understanding of the genetics of resistance to the Myrtle Rust pathogen has led some researchers to speculate about possible some co-evolution of the ancient (Eocene) Gondwanan precursor species of these Australian Myrtaceae, with an ancestor of the Myrtle Rust pathogen (or another pathogen sharing key molecular recognition factors with modern *A. psidii*), and the "retention of ancient *R* genes" [resistance genes] in the modern descendant hosts (Tobias *et al*. 2016; see also Potts *et al*. 2016). This remains a possibility and needs investigation, but it is probably more likely that resistance syndromes to *A. psidii* in Australasian lineages have developed as disease responses to other foliar pathogens, that happen to 'work' to varying degrees against Myrtle Rust infection. The default likelihood, pending deeper research into genomic research, remains that Australian Myrtaceae have evolved almost entirely in isolation from the rust class of pathogens, and have not co-evolved specific defences against them.

Plant disease resistance is unlike that of animals in many details, and analogies can be misleading – plants do not for example have an antigen-antibody system, or mobile immune cells; they rely on chemical signals to mobilise individual cells and tissues to respond to a challenge. Plants and animals do however have in common a dynamic interplay at the physiological and molecular levels, between the host's defence mechanisms and the infective 'strategy' of the pathogen. This reflects the long evolutionary war between hosts and pathogens, in which each have evolved ways of circumventing the other, often only to be countered in turn by a new adaptation.

Understanding the specifics of this interaction is a key to management of the disease. The technical means of achieving this understanding at both genetic and physiological levels have improved greatly in very recent years, and are now starting to be applied to plant diseases. Their further application to Myrtle Rust is a key step in identifying both *constitutive* and *inducible* factors involved in resistance, and hence to the development of resistance genotypes where more traditional selective breeding methods fail or are too slow.

Plants have, at a cellular level, means of detecting invading pathogens and activating *inducible defenses*, which are triggered by pest predation or an invading pathogen; these may involve production of defensive chemical compounds or enzymes hostile to the pathogen, reinforcement of cell walls or leaf cuticle, or may involve deliberate cell suicide to starve the infective agent during its initial establishment phase (the hypersensitive response). Some pathogens are capable of countering these induced responses through interference by a pathogen-produced virulence-effector chemical factor.

Plants may also have *constitutive defences*, sometimes fortuitous in relation to any one pathogen – these are morphological or physiological traits that may serve more than one function and are not necessarily primarily evolved for disease response as such, for example leaf waxes, volatile oils, or other bioactive secondary metabolites that interfere with the pathogen's germination or establishment and growth within the host. Pathogens in turn may have means of suppressing the plant's response (virulence effectors).

It is likely that among those Myrtaceae species (and some within-species populations) that exhibit apparent 'immunity' to *A. psidii* infection, there are some with a 'true resistance' inducible disease response that is highly effective at a very early stage of attempted infection, and others in which the pathogen's inability to establish itself derives from constitutive defences of the plant. Combinations or synergistic interactions between these systems are likely in many cases (see Naidoo et al. 2014 *in toto*, and discussion in Potts *et al*., 2016).

Significant knowledge has been generated on the resistance of some hosts to *Austropuccinia psidii*, including on the frequency and inter- and infra-specific distribution of resistance, its genetics and heritability, and its phylogenetic correlates. This has sometimes involved both essentially empirical silvicultural programs of selection and breeding for phenetic resistance effect, and in others specifically molecular studies to pinpoint the genes and alleles involved in resistance and their likely degree of interaction; reference are given below. The two approaches are synergistic, especially in the use of genetic marker assisted breeding.

Thumma et al. (2013) consider that "Myrtle rust resistance genes are most likely to belong to a class of receptor proteins that contain a nucleotide binding domain (NB) and a leucine rich repeat (LRR)", as this class of NB-LRR proteins in plants commonly confer resistance to a wide range of pathogens and pests. Candidate resistance genes conforming to this pattern (or others known to be implicated in resistance) can be identified by searching the genome of a plant species, genus, or family, where this exists. The sequencing of a genome at the relevant level is thus a prerequisite; fortunately this is becoming a very fast and relatively cheap process using new techniques). Resistance/severity screening of the target species then allows the selection of bulked DNA for analysis of allele frequencies in the resistance genes. In summary, this study (which used only the Australian 'pandemic strain' of *A. psidii*) found "compelling evidence that resistance to myrtle rust is quantitative and likely to be controlled by variation in many genes." The study also found that about 70% of the SNPs identified in *Eucalyptus grandis* were conserved in the rather distantly related *E. dunnii*, i.e. moderate commonality of resistance genetics across a very large genus.

The summary in this study puts the implications more clearly than a paraphrase could:
"Our results strongly suggest that resistance to myrtle rust is controlled by variation in many genes … The good news is that eucalypts, and probably many other Myrtaceous species that have some resistance, are unlikely to suddenly become a lot more susceptible. This is because in order to become significantly more virulent the rust would need to overcome several barriers (genes). It's more likely that the rust will gradually evolve different forms (one gene at a time) that attack a few more genotypes. Another important consequence of the quantitative nature of rust resistance is that breeding for resistance will be slower. Phenotypic screening will take quite a few generations, because selection has to take place on many genes. The most efficient way to build resistance rapidly would be to use marker-assisted selection with many more markers controlling rust resistance. With the markers we have identified we are confident that we could improve the level of resistance in E. grandis from 48% to over 70%. Increasing resistance to 100% would require the identification of many more markers. We consider that using refinements to the methods we have used here that it should be possible to identify most of the molecular variants controlling rust resistance in eucalypts and other Myrtaceous species."

An alternative approach to resistance trait identification and isolation is screening trials (the two approaches are not of course mutually exclusive). Screening trials and breeding/selection programs have a well-established methodology from many decades of use in forestry and horticulture.

Resistant lines of some silvicultural species and hybrids have been developed successfully in South America. Both major gene and additive (gene-complex) modes of disease resistance have been identified for eucalypts, and recent research has greatly advanced the understanding of the genetic basis of the disease response, and some aspects of resistance physiology, in selected taxa of eucalypts (Alfenas et al. 1997; Junghans et al. 2003b; Teixeira et al. 2005; Alfenas et al. 2009; Teixeira et al. 2009; Mamani et al. 2010; Guimarães etal. 2010; Graça, Aun et al. 2011; Zauza et al. 2011; Alves et al. 2012; Carnegie 2012; Miranda et al. 2013; Sandhu & Park 2013; Thumma et al. 2013; Rosado 2013; da Silva et al. 2013; da Silva et al. 2014; Pegg et al. 2014b; Lee et al. 2015; Potts et al. 2016, Butler et al. 2016). David Lee (University of the Sunshine Coast) is also undertaking active research on the selection of Myrtle Rust-resistant eucalypts for plantations and environmental plantings.

The prospects for breeding for resistance to *Austropuccinia psidii* in the three eucalypt genera are well established, with a large body of genomic and transcriptomic data from applied forestry research (Naidoo et al. 2014), the complete genome sequencing of *Eucalyptus grandis* (Myburg et al. 2014), and a single nucleotide polymorphism (SNP) array for *Eucalyptus*.

The body of knowledge from eucalypts has been driven by their economic importance, and the existence of funding sources an institutional arrangement around the timber and forestry sector. A more limited range of studies have been conducted in other tribes and genera (Tobias et al. 2015 -- *Chamaelaucium*; Tobias et al. 2016; Tobias et al. 2018 in press – *Syzygium*; Ribeiro & Pommer 2014 – *Psidium*; see also Doran et al. 2012 re provenance-based resistance in Lemon Myrtle for a possible model species in the Tribe Backhousieae).

Nearly all of these studies have concerned with economically significant species, and have been funded from sources in the primary production orbit. A few studies have managed to also address some species and issues relevant to biodiversity conservation in the wild. As yet, no such study has been commissioned by any body with biodiversity conservation as the primary goal. Some of the eucalypt knowledge, and all of the techniques, will prove useful for Myrtle Rust resistance research and breeding in other tribes of the Myrtaceae. However, if the conservation challenge of Myrtle Rust is to be met, balancing investment is urgently needed, directed specifically to conservation goals for the species and genera most under threat.

Some of the findings are indicative of a generalised resistance syndrome within the eucalypts, and possibly in other genera, but further research is needed to fully open up the possibilities for resistance breeding for both commercial and conservation purposes. Alongside research into direct disease defence traits, those traits and inducible physiological processes correlated with or conferring indirect (constitutive) resistance need to be investigated (Xavier et al. 2001; Moon et al. 2007; Boaretto 2008; Boava et al. 2010; Pizetta 2013; Naidoo et al. 2014; Xavier et al. 2015; Potts et al. 2016). Major gene resistance or constitutive traits are easier to manipulate, but less robust, than additive modes, being more subject to gene-for-gene coevolution with the pathogen.

In the context of a century long battle against White Pine Blister Rust in North America, which has involved the breeding and re-wilding of many disease resistant genotypes and their diffusion back into the wild population, Kinloch (2003) comments that "The identification of major [resistance] genes invites the prospect of gene cloning and transformation of susceptible species and genotypes with desired combinations of resistance. However, this is probably still many years in the future." Thumma et al. (2013) point out that quantitative trait loci (QTLs) "are only useful for screening progeny from specific crosses involving resistant parents", and are of limited use for the breeding populations of forest trees, which typically comprise many [silvicultural] 'families', as the genetic markers associated with the location of resistance genes in one such 'family' are unlikely to correlate in others. However, more specific markers that do relate directly to the locus (location on chromosome) of disease resistance genes on a populational or species basis can be developed, and these open up possibilities for genetic manipulation and resistance engineering. A high degree of genetic 'resolution' can be achieved with the use of single nucleotide polymorphisms (SNPs, pronounced "snips") in association studies to determine linkage to disease-resistance (or other) traits.

Naidoo et al. (2014) provide a review of the genetic tools available for either approach in the context of *Eucalyptus*, including one example of transgenic trait transfer in *Eucalyptus*.

More traditional, and relatively straightforward and uncontentious agricultural and silvicultural selection models can isolate many heritable genes and gene complexes relatively easily, but multi-locus traits (likely to be more robust against evolving disease) are more problematic for transfer, whether by breeding or gene-technological means.

The slowness of reproduction and growth in woody plants is a hindrance to resistance breeding in Myrtaceae, although South American forestry interests have achieved it with eucalypts. Clonal reproduction of individuals with desired traits direct from the wild is technically possible by much faster means, such as somatic embryogenesis (Kinloch 2003; Merkle et al. 2007). In the context of selection for resistance to White Pine Blister Rust, Kinloch (2003) notes: "Somatic embryogenesis is not yet operational for white pines, but is another potentially powerful tool for the future. Resistant phenotypes are often observed, either as individuals or as members of partially resistant families, without any clue of the genetic basis of their resistance. But basic understanding, while most desirable, it is not prerequisite to practical use; the benefits of being able to deploy multiple copies of diverse resistant genotypes, irrespective of the mechanism or inheritance, are obvious. This is especially true of slow growing, non-commercial subalpine species, for which intensive selection and breeding for resistance are not ever likely to happen. Presently, these species must rely on natural selection, perhaps assisted by silvicultural manipulation … One of the major problems of using somatic embryogenesis technology for resistance is to be able to induce embryos from tissues old enough to assess their rust resistance phenotype in the field."

The understanding of Myrtle Rust disease progression and resistance, and the search for weak points of the pathogen potentially open to countermeasures, is also being greatly enhanced by new molecular analysis techniques. These are a set of tools falling under the headings of transcriptomics (DNA to RNA transcription, the starting point for cellular and tissue 'instructions), metabonomics (or metabolomics – the study of chemical products and pathways), and proteomics (study of cell proteins, which among other things convey cellular instructions). These techniques are of extraordinary power, allowing great insight into cellular responses to stress and disease, and elucidation some of the biochemical pathways involved in infection and resistance. Australia is well equipped to use them for conservation purposes. Their potential to facilitate resistance selection, breeding, and/or engineering is expanding rapidly.

Genetic reinforcement of threatened plant populations is not new as a conservation technique, and – subject to careful prior biological and ecological evaluation – is established practice in plant conservation in Australia and abroad (Vallee et al. 2004; Commander et al. in press 2018; IUCN 2013). Generally, it has been by the introduction of whole plants from other populations, without deliberate selection or breeding (much less engineering) for particular traits. For non-threatened species however, the introduction back into wild populations of genotypes manipulated through selection or breeding has been more common (e.g. Kinloch 2003; Sniezko et al. 2014), although historically not with the ecological and ethical care that would be taken today.

A further dimension of resistance studies relates to the potential role of symbiotic microorganisms. Mycorrhizal and soil rhizosphere symbionts are known to confer protection or disease resistance to some soil pathogens, but in the context of Myrtle Rust, the endophytic (within-plant) microflora, of fungi and bacteria, may repay review. Very little is known of these for most plant groups, the best known cases being in the grasses (Selosse et al., 2004), but endophytes are proving to be ubiquitous across the plant kingdom (Wingfield et al., 2017), exercising a variety of physiological and even ecological effects. There are currently no grounds for this microflora to be a major focus of research in relation to Myrtle Rust, but the possibilities of endophytic differences between resistant and susceptible species and populations of Myrtaceae should be borne in mind when those systems are being studied.

The dominant ethos in plant conservation globally, rightly so, is conservation of natural populations in their natural habitats, with the main tools being threat reduction and enhancement of the species' own generative potential. More interventionist forms of conservation, such as translocation to other, less threatened suitable habitat, is always sub-optimal, but acceptably so if it offers a chance to prevent local or total extinction (e.g. many species in WA in response to *Phytophthora*). Even straightforward translocation, whether as reintroduction or reinforcement, is hedged about with genetic, ecological, and often social and ethical considerations. Those can often be satisfied, and have not stopped the use of translocation as a biodiversity conservation technique. Success is not guaranteed, and can only be ultimately judged in the long term, but improved practice means that early failure is far less frequent nowadays, and many cases translocations look set to succeed (see case studies in and linked from Commander 2018, in press).

Myrtle Rust, like chytrid disease in frogs, and devil facial tumour in Tasmanian Devil, is an altogether bigger problem than we are used to in dealing with for environmental pathogens in Australia. In both those cases also, genetic reinforcement is being considered as a conservation option. Natural-habitat refugia from the Myrtle Rust pathogen probably do not exist for most of the seriously affected east coast species, on anything other than a transient timescale. If the need emerges for artificial reinforcement of native forest genotypes (e.g. if more eucalypt-aggressive strains of *A. psidii* arrive in Australia), the technical and particularly social challenges become more formidable. The pathogen's mobility, broad host range, and the high proportion of very susceptible species, mean that for some species we are faced with a difficult choice about highly interventionist conservation practice that no one is happy with. The central question is, which is worse – interventionist conservation, or decline and extinction?

This question is now a real one – Myrtle Rust has already posed it. For some species, the window of opportunity for salvage of representative germplasm has almost closed; for others it will remain ajar for a few years only. The necessary research, social and cultural debates, and development of practice and resources, all necessary before going down the interventionist road, need to commence now.

The conservation implications of Myrtle Rust

The most fundamental problems with the impact of Myrtle rust on wild species in Australia are **the difficulty of containment, and the intractability of the disease to management in the wild**.

The uredinial spores of *Austropuccinia psidii* are both wind-dispersed and easily transported by human and animal vectors. **Containment**, in the sense of prevention of arrival in Rust-suitable biomes by natural (wind/animal) vectors and to some degree by human vectors, is feasible only on large geographical scales where weather systems and patterns of animal movement are unfavourable for natural distribution, and patterns of potential human vectoring are amenable to quarantine control. This is the case with the 'upwind' states of Western Australia and South Australia, and is the rationale for the maintenance of specific domestic quarantine measures for Myrtle Rust by those jurisdictions. The extent of dry and semi-arid country (wholly unsuitable for *A. psidii* except in relatively confined cultivated conditions) between these States and the east coast of Australia is obviously an important factor; narrower rainshadow areas along the east coast have proved no barrier to spread of the pathogen.

Direct management in the wild of the Myrtle Rust pathogen is not feasible by any means currently available, except on the very smallest of scales by the periodic use of fungicides directly applied to plants. Available fungicides are not specific to the *A. psidii*, and hence are likely to have negative effects on beneficial native fungi, and as they are often toxic, to other biota as well. The possibility of direct control measures, applicable in the wild on at least a limited scale (via biological control organisms, RNA interference vaccines, or other novel methods) is at this stage very speculative, but should be scoped by experts – these blue-sky possibilities are canvassed in Section 6.5 below.

6.3 Management and response – the 'no action' option

Once an invasive pathogen is firmly established in the native environment, non-intervention in any process of associated decline is a management option. This may be on the basis of an assessment (or hope) that the pathogen's effects will be minor or regionally confined, or that some or all susceptible native species will adapt and survive, or simply because no management options are identified that satisfy technical, biological, social, or financial/economic imperatives or criteria.

In the case of Myrtle Rust, it is already clear that the effects will not be minor. It is also clear that the pathogen will be substantially confined to regions and biomes of suitable moist climate, but these are very large spatially, and contain a very large number of host species, including many of high susceptibility. Some or many species of moderate susceptibility may very gradually adapt through the decline of susceptible genotypes and the increase of tolerant genotypes; where the former are regionally dominant and isolated from other populations, some acute but gradual declines or extinctions may occur. It is likely that many low-susceptibility hosts will either simply tolerate the disease with little or no decline, but this like all other impacts can only be determined by consistent and long-term monitoring, especially of critical life stages.

What has not been clarified in any public decision-making process or analysis of Myrtle Rust to date, is the full range of options for minimising its impact on wild species and ecosystems, and the constraints on evaluating and exercising those options. The very mobile nature of the spores (defeating containment efforts along the east coast) and the breadth of the host range, have engendered a 'nothing to be done' mentality that has permeated the environmental sector, and has inhibited that sector's uptake of the issue from the initial primary industry-led response. In a climate of contracting resources and expertise in the government agencies, there has been no priority allocated to establishing baseline data for affected flora, nor for field surveys of impact. If not corrected, this will preclude any evidence-based analysis of declines and response options. It will also lead to the closure of an already rapidly narrowing window of opportunity to intervene on behalf of the most severely affected species, and a *de facto* acceptance of un-monitored declines and extinction rather than a considered triage and response.

It is not at this stage possible to predict the precise number of species that are likely to 'go extinct' in the wild on a regional or total basis as a result of Myrtle Rust infection. At least four seem almost certain. Similarly we cannot fully predict which taxa are likely to decline at rates sufficient to either move them from 'not threatened' status to one of the 'threatened' categories (*sensu* IUCN 2012), or promote them from a lower to a higher threatened category (many are likely). Indicative data and field observations are available for a considerable number of species from the NSW/Queensland Myrtle Rust 'zone', but the quantitative data needed for definitive assessment exist only for a relative few – partly because it is still early in the impact process, but more particularly because of the paucity of field studies to date. For the rest of Australia, very little data is available, and for SA and WA the risk of significant decline remains theoretical (although in the south-west of WA it may prove to be anywhere from low to very high depending on which climate suitability model for the pathogen proves to be correct).

It should be noted that the recent agreement by all Australian jurisdictions on a Common Assessment Methodology (CAM), for extinction-risk assessments, imposes a higher requirement for quantitative data than the preceding and varied methods used. In the absence of field surveys and baseline data for most of the species affected by Myrtle Rust (or likely to be so), estimates of current and projected decline remain very unsatisfactory for both listing and management purposes. Even for those few species already listed that are suspected to be in severe rust-related decline, little data on the scale of the Myrtle Rust threat exists – most of the assessments and threat analyses predate the arrival of the pathogen. It should also be noted that there are wide variations in the frequency with which new nominations for 'threatened' listing are made, assessed, and determined in the different jurisdictions – the period from nomination to listing can vary from a few months to more than five years.

The use of existing listing status as a guide to prioritisation of rust-threatened species for conservation action, while consistent with some policy and legislative settings, is at best misleading, and at worst leads to a denial of resources for actions on species that are of higher actual priority but are still unlisted. The first two species level listings for declines entirely attributable to Myrtle Rust have been made under NSW legislation, for the two formerly common and widespread east coast species *Rhodamnia rubescens* and *Rhodomyrtus psidioides*, both closely evaluated and in the process of being listed as Critically Endangered in NSW (and referred to the Commonwealth for possible national listing). A nomination has also been submitted (may 2018) for listing of *Lenwebbia* sp. 'Main Range (P.R. Sharpe+ 4877)' for emergency listing as Critically Endangered in NSW.

The estimates of 45 species of highest priority (for conservation action) in this report (see Section 4 and Appendix 1), if judged to be justified, indicate the risks of a 'do nothing' approach. They suggest the possibility that the number of extinctions in the near future caused by this single strain of the *Austropuccinia psidii* pathogen could exceed those threatened or known to have been caused by *Batrachochytrium dendrobatidis* chytrid disease of frogs, present since the early 1990s and directly implicated in four extinctions and about ten severe declines (Australian Government [2013b]). Myrtle Rust disease, on its current distribution alone, may eventually parallel the 24 Australian bird extinctions since European settlement (*The Action Plan for Australian Birds 2000*, http://www.environment.gov.au/node/14674, accessed 28 Oct 2017), and even approach the levels of endemic mammal extinction over the same time period (29 species, 35% of the world total – Woinarski *et al*., 2015). Over time it is likely to parallel – in threats and declines – the number of species and ecological communities threatened by the *Phytophthora cinnamomi* pathogen (present in Australia for over 100 years).

6.4 Prerequisites to ensure future recovery options for rapid-decline species

A large number of known-host species in eastern Australia fall partly or wholly into the into the Highly or Extremely Susceptible categories established by Pegg *et al*. (2014a) — 48 (29%) of 163 Queensland hosts assessed in that study, and at least two more (*Archirhodomyrtus beckleri* southern chemotype), and *Lenwebbia* sp. 'Main Range P.R.Sharpe+ 4877' have emerged since.

A large number of known-host species in eastern Australia (here estimated at 177 – see Appendix 4) also have their natural distributions totally or near-totally within the zone of *A. psidii* invasion and naturalisation along the east coast (this is here termed 'total overlap'). 36 of these are rated partly or wholly in the Highly or Extremely Susceptible categories of Pegg et al. (2014a), and some new cases of apparently highly susceptible species have emerged since that study (e.g. *Archirhodomyrtus beckleri* southern chemotype; *Rhodamnia longisepala*). A further 22 taxa have natural distributions *predominantly* within the same geographical envelope. All the above numbers may rise as more hosts and life-stage impacts become known and more ratings are assigned; it is less likely that hosts currently rated high for susceptibility will be revised downwards.

The estimates of the 'overlap' summarised above and detailed in Appendix 4 are provisional, and could be methodologically improved. A very much lower estimate of the number of species with 100% overlap is arrived at by Berthon *et al*. (2018), who place it at 13 out of 1285 species or c. 1%. The results of that study however are on a whole-continent basis, are predicated on climatic-suitability modelling, and use an extent of occurrence (*sensu* IUCN 2017) to model host species distributions – hence greatly underestimating the overlap for many taxa. For reasons discussed under 'Species prioritisation' above, the Berthon et al. (2018) methodology for establishing overlap is not accepted for this review.

On the assumption of a minimum 30 rated high-susceptibility species with 100% overlap, hard decline data for a few of them and supporting but non-comprehensive field observations for many (see Part 4 'Impacts' above, and Appendix 1), plus a evidence-based precautionary approach for some additional species not yet formally rated, it is estimated here that at least 45 species require urgent field impact survey if the 'signal' of Myrtle rust-mediated decline is not to be lost (i.e. populations decline or disappear without record).

These same species as priorities for impact survey are also (subject to results of that survey) high priority candidates for germplasm collection, either on an emergency salvage basis (e.g. *Gossia gonoclada*, *Lenwebbia* sp. 'Blackall Range', *Lenwebbia* sp. 'Main Range', *Rhodamnia rubescens*, *Rhodomyrtus psidioides*), or on a precautionary basis, while some wild seed production still continues or at least cutting material is available.

A list of 45 priority species for field impact survey and/or germplasm collection is advanced in Sections 4.4 and 6.1.2 above, and in the adjunct draft action plan. These two steps are absolute prerequisites for:

- a more refined prioritisation of subsequent conservation action;
- the maintenance of any conservation actions at all for many raid decline taxa;
- gaining information of rates of decline and hence modelling future impacts.

6.4.1 Field impact and resistance surveys

All actions noted below as potentially relevant to mitigating declines due to Myrtle Rust, are conditional on an increased understanding of *actual* impacts (or lack thereof) in the field, determination of which requires on-ground surveys. One-off surveys provide a snapshot only, and may sometimes be misleading as to disease presence/absence, severity, and demographic impact.

To enable more informative estimates, some level of monitoring over a time period is needed. 'Before and after' comparisons of the same populations or sites are optimal. The most informative will be a baseline taken before the arrival of Myrtle Rust in a region, and including relevant demographic data on the species of concern. Ecological plots established for quite other research and management-monitoring purposes couple may fill this need, especially when accompanied by a close understanding of the non-Rust pressures also acting on the local Myrtaceae.

In the absence of a pre-rust baseline, consecutive sampling of a site or population during the course of Myrtle Rust decline may also serve as a reliable index of the rate and form of that decline; this was the case with the field studies of Carnegie et al. (2016) and Pegg et al. (2017), where the process of decline and observed symptomology enabled other causes to be ruled out.

Unpublished and 'head' knowledge, where assessed as reliable, may be the main or only means of establishing a baseline for some sites or even species, and should not be downplayed. In some cases, this can be generated from local expert knowledge, as there are many botanically and ecologically skilled practitioners in the non-research community. In other cases, the more optimal quantitative dimension can be added through the records of local consultant ecologists, or through the relocation of vegetation plots floristically assessed for previous research projects. A large network of 'permanent plots' is recorded in the environment agency databases of most or all jurisdictions, World Heritage bodies, and CSIRO, and these could be augmented by the addition of reliably geocoded 'non-permanent' plots from wider literature.

Three data sources should be utilised for the most efficient use of time and energy in planning and executing initial field survey of impacts, and for establishing ongoing monitoring sites for Myrtle Rust:

(1) relocatable floristic research plots and transects, especially those rich in Myrtaceae in general or a targeted species;
(2) populations of target species known from survey and herbarium records;
(3) expert knowledge.

Heim et al. (2018) have demonstrated the feasibility of using optical reflectance spectra derivatives to detect Myrtle Rust infection (or lack thereof) in Lemon Myrtle (*Backhousia citriodora*), via handheld instrumentation and a machine-learning technique. This technique, if developed, is likely to be of most use in production situations, but perhaps also in screening of wild populations, especially where these are relatively uniform in phenology (e.g. post-fire seedling beds).

Sandino et al. (2018) demonstrate a similar capability for more remote (airborne) sensing of healthy and Myrtle Rust-infected *Melaleuca quinquenervia* via spectral analysis. This technique may, for canopy plant stands that are also of a density amenable to calibration, greatly improve monitoring options in the future, especially at habitat scales.

6.4.2 Germplasm capture and storage enablement

A second prerequisite for most high-priority taxa, and a prudent step for known and suspected taxa under (so far) less severe decline, is the collection and storage of *genetically and geographically representative germplasm* (seed or other) *ex situ* – i.e. off site, in dedicated storage facilities like seed banks or dispersed and protected living collections.

The 'representative' factor is essential if the maximum possible range of genetic potential embodied in a species is to be conserved, whether on a precautionary basis or salvaged on an emergency basis. This multi-provenance approach is essential to preserve the capacity of the species (if 'recovered' in the wild) to re-occupy its ecological niche where local adaptation is a factor, and to preserve its overall future evolutionary potential. It is also to ensure that the genetic resources of these species remain available for future human generations and, in the case of successful reintroductions, for the natural environment. Representative sampling does not necessarily require prior research into the genetic variability of a species although careful scoping is needed if this is not available (Offord & Meagher 2009; Maschinski et al. 2012; Maschinski & Haskins 2017).

In addition to geographic and genetic representativeness, the capture of germplasm needs to be on a scale sufficient to allow:

(1) a long-term stored component reflecting that variation;
(2) enough for material for short- and medium-term research on factors where knowledge is lacking for end-use of the germplasm in species recovery actions, e.g. on seed dormancy-breaking triggers; and
(3) enough for medium term use in translocation or in establishing *ex situ* seed production and resistance breeding areas, if these are likely to be required.

The seed biology of some Myrtaceae genera imposes a need for an additional prerequisite layer of enabling research. Stored germplasm, whether as seed or in other forms, is only of use if it can be 'revived' at need and does not give rise to 'unfitness' in the subsequently germinated plant.

Storage tolerance issues: The seeds of a majority of plants are termed *orthodox*, which means that they can in general tolerate a more or less standardised regime of drying and long-term storage in low-temperature conditions, without a significant percentage losing viability, germinability, or fitness. Even with orthodox seed however species-specific tweaks are sometimes needed for best results – e.g. an after-ripening regime before processing. Knowledge gaps for the Australian Myrtaceae in this respect are moderately large.

A minority of plant species (but unfortunately including many of the 'soft-fruited' genera of Myrtaceae most affected by Myrtle Rust) are *non-orthodox*, also termed *recalcitrant*. The seeds of these species are storage-intolerant, for a variety of reasons; they may be naturally short-lived (often the case with rainforest species), they may not tolerate drying, or they may not tolerate low-temperature storage.

In some cases, modified treatments can be found that will enable seed storage, but nearly all such species require some level of individual investigation, usually lasting 1-6 months and requiring healthy fresh seed.

For many non-orthodox species, seed storage as such will prove not to be an option, and germplasm storage for these must be by other means. The alternatives include tissue culture (of either somatic tissue or excised embryo tissue), cryogenic storage of tissues, or permanent whole-plant living collections. All these alternatives are more expensive and more skilled labour-intensive than simple seed storage. A number of the conservation seed banks in Australia affiliated to ASBP are capable of carrying out aspects of storage and revival research on problem species (subject to project funding and staffing levels in the face of competing priorities), as are a number of university units. Fewer institutions are currently equipped for the alternative means of live tissue preservation. A large potential network of public, private, and community facilities exists, which if resourced could provide skilled custodianship of dispersed whole-plant living collections.

Dormancy issues: Once precautionary quantities of orthodox seed are secured, seed can be assayed for the presence of dormancy syndromes and the triggers for dormancy release (to enable germination). Knowledge gaps for dormancy type and release triggers in orthodox-seeded Myrtaceae are moderate, but the procedures for determining these are straightforward and relatively inexpensive, although to test large numbers of new species, beyond existing programs, would be beyond the current labour resources of most Australian conservation seed banks – additional staffing resources as well as simple project funding would be required.

6.5 Techniques available for the Myrtle Rust conservation response

There are very limited prospects for direct control of Myrtle rust disease in the wild. Arrays of techniques are available for the direct control or extirpation of plant fungal diseases in agriculture and other cultivation situations, and in some areas of forestry, whether by environmental manipulation, physical containment, removal of infected stock, biocontrols, or chemical treatments (topical or systemic fungicides). Few of these are applicable to populations of wild or quasi-wild plants on a significant scale, except in forestry, where manipulation of various sorts has been used to deny certain fungal pathogens alternate hosts or vectors. The use of such pathogen-control techniques for the conservation of wild plant biodiversity has been limited (but see Kinloch 2003).

Myrtle Rust poses particular problems because of the mobility of its spores, its extraordinarily wide host range, and the ubiquity of its hosts in Australian ecosystems.

The various options for both direct and indirect control and management are canvassed here, and the pro and con arguments for each are briefly evaluated.

6.5.1 Physical eradication of the pathogen

Eradication of plant pathogens relies on the removal of all plants susceptible to infection (thus denying the pathogen its host), or on the removal or alteration of necessary conditions of life for the pathogen. Means of doing this include biological controls, life-cycle interruption, microclimate manipulation, and the use of chemical controls – although it is rare for any one of these alone to result in total pathogen eradication except on a local and transitory basis. In the case of pathogenic rust fungi in agriculture, all these means have been deployed in various cases. Destruction of infected and often also known-susceptible but non-infected plants often forms part of the first response strategy to an incursion of emergency status.

All rust fungi are essentially parasites (obligate biotrophs), requiring a living plant host when not in one of the dispersive spore stages of their sometimes complex life cycle. Many rusts are *heteroecious*, requiring two quite distinct and often unrelated plant species at different life stages; for agricultural rusts, one of these will be a crop and the other is often a wild plant species. In this case, the complete removal of just *one* of the hosts may stop the disease, unless it has a secondary capability to keep going on the primary host alone, as is the case for Wheat Stem Rust. Attempted eradication of the non-crop host in order to protect the economically valued species may involve huge investment over decades, as for White Pine Blister rust in North America (alternate host, a wild currant species).

The Myrtle Rust pathogen however is apparently fully *autoecious*, requiring only one species of host (or in this case any of a large suite of hosts) throughout its life cycle (Morin et al. 2014; Stewart et al. 2017), and so is not susceptible to control via removal of an *alternate* host. Removal of the Myrtaceae host of course defeats the management aim, whether that is to ensure conservation or continued production.

Eradication, usually by a mix of physical removal of host plants and chemical control of the pathogen itself, remains the optimal goal of a first response to Myrtle Rust incursion in those Australian jurisdictions where it is not yet established (South Australia and Western Australia).

Eradication appears to have succeeded (as at May 2018) on Lord Howe Island, where a strong vigilance regime resulted in apparently very early detection – see next section for details.

More extended containment programs, with the possibility of eradication as an eventual goal, may apply in areas in which the pathogen is only marginally naturalised and limited to hosts in cultivated situations amenable to continued detection and treatment. This is the current strategy in Tasmania, and was for an extended period also in Victoria and New Zealand, although in both the latter cases the eradication goal has now been abandoned as impractical, in favour of containment and management. The feasibility of eradication declines rapidly as time passes.

Fire is often suggested by stakeholders as a possible means of at least local eradication. Unfortunately, fire is not effective in this way, and may be counterproductive as a management tool. Fire in vegetation where there is ‘active’ (sporulating) Myrtle Rust infection will certainly destroy much of the fungus and its spore load, but equally very many of the extremely lightweight spores will be mobilised by fire updraught into the air column before heat kills them, from where they may be distributed to areas far beyond the fire. Moreover, the post-fire vegetation response of seedling germination and re-sprouting will provide a large bed of exactly the sort of young plant tissue that is most vulnerable to reinfection. The likelihood of reinfection from adjacent unburnt areas will usually be high, and the rapid life cycle of the rust will allow it to bulk up long before the regenerating tissues reach an age of lower vulnerability.

Eradication of the now-established ‘pandemic strain’ of Myrtle Rust is not feasible by any means currently or likely to be available, in those coastal areas of NSW, Queensland, and the Northern Territory where Myrtle Rust is fully naturalised.

6.5.2 Containment and exclusion

For soil-borne pathogens, containment methods have been widely employed, especially for *Phytophthora cinnamomi* (Commonwealth of Australia 2014, and references therein). Containment of the Myrtle Rust pathogen, which has airborne spores, is much more problematic. Containment is only likely to be successful in cases of geographic isolation from other areas of infection, coupled with very early detection and a rapid and well-organised response with the aim of eradication. Such a response may with luck enable containment via intensive inspection, the treatment or removal of infected plants, and in some cases by the removal of un-infected potential-host plants to reduce the potential for high spore loads. Early detection is the most crucial success factor, and the use of high-susceptibility known-host plants as sentinels, with a high frequency of inspection, is a key element. Detection early enough to enable containment and eradication is likely to be relatively rare for a very spore-mobile pathogen like *A. psidii*, especially as the pathways for long-distance spread have rarely been determined. The possibility of early detection is enhanced where human-movement routes to a region, and arrival points within it, are one or few, and such movement bottlenecks can greatly assist with inspection and public awareness/education measures directed at minimising transport of spores or the risk of their post-arrival release into the environment. The Lord Howe Island strategy for Myrtle Rust focusses strongly on this aspect, alongside general vigilance.

Containment attempts as part of an eradication effort for Myrtle Rust failed in New South Wales in 2010, although various factors were involved in determining the outcome: the uncontrolled aspects of human-vector dispersal of spores may have played a large role (Carnegie & Cooper 2011), as may a premature halt to national funding of the effort for two months in mid-2010 (Carnegie & Cooper 2011; Cannon 2011), and the existence of a large natural forest infection zone not detected until late in 2010. Subsequent containment efforts in Queensland in 2011 also failed. In both cases the more or less continuous climatic zone suitable for Myrtle Rust establishment along the east coast corresponds largely with other factors that conflict with attempts to contain this (or any other) environmental pathogen. It is the main area of human population, and the main north-south movement corridor for people and goods. It has the highest concentration of host species diversity (for *A. psidii*) anywhere in the eastern half of the continent, and is a major habitat-determined corridor for the north-south movement (foraging or migration) of some long-distance forest birds and mammals (flying foxes).

Conversely, containment measures within an eradication program appear to have succeeded on Lord Howe Island, 600 km east of the NSW coast, where a vigorous vigilance program detected an incursion of Myrtle Rust in October 2016, apparently very early after its arrival. Myrtle Rust was only detected within the village area of the island, where the activation of a strong pre-planned response program was feasible. The response involved rapid survey, and fungicide application to infected plants followed by their destruction (Lord Howe Island Board, 2016; 2017). The outbreak remained confined to cultivated Myrtaceae not native to the Island. The investment in planning reflected the importance of the World Heritage-listed natural values of the island. The Lord Howe Island Group has five endemic Myrtaceae, four of them known to be Myrtle Rust hosts from inoculation screening (Morin 2011; Morin et al. 2012), but no infections on these species have been detected on the island. As at May 2018 the pathogen is regarded tentatively as eradicated there. Lord Howe Island does however remain at constant risk of a new incursion, given its prevailing down-wind position relative to highly infected areas of the mainland, and a high tourist visitation rate with bush-related activities a major attractor. This case illustrates a provisional success of containment as part of an eradication strategy, enabled by a high level of vigilance and a clear pre-existing response plan with adequate administrative and community support – an optimal conjunction.

Successive eastern Australian States followed a mixed *containment and exclusion* strategy as part of the initial response to the arrival of Myrtle Rust. Domestic quarantine measures, infection source tracing, and public and industry awareness campaigns, were used to minimise the risk of human transmission of the pathogen. The strategy failed in this region, probably due to a combination of late detection and uncontrolled elements of human and natural transmission.

Exclusion – prevention of arrival of the pathogen via domestic quarantine measures – remains the strategy for Western Australia and South Australia, backed by a vigilance program and response planning. The onus of public awareness to support continued exclusion of Myrtle Rust has been very much on those States – there has been little complementary public education since 2013 in eastern Australia to help 'contain' the risk there. WA and SA are separated from current zones of *A. psidii* invasion and establishment by large distances of climatically unsuitable habitat (except possibly along the north Australian coast – not determined), and are favoured by a continental climate regime that does not favour wind dispersal from east to west. The intervening regions also have a low incidence or absence of many of the most susceptible host genera. There are few annually migratory transcontinental animal or bird species, although there are a substantial number of birds, particularly waterbirds, which move long distances in response to water and other resource opportunities or absences – these could become vectors for *A. psidii* in some circumstances.

In general however, control of human-mediated pathways assumes prime importance for the prevention of spread to Western Australia and South Australia, the key elements being maintenance of stringent domestic quarantine, supported by vigilance and both general and targeted public education.

In the case of Western Australia, the zones of potential climatic suitability for the establishment of *A. psidii* are in the moister bioregions of the south-west, and possibly in coastal areas of the Kimberley. The potential for naturalisation and persistence of *A. psidii* is not yet known for mediterranean climates (the south-west) and the strongly seasonal monsoon tropics (Kimberley), and predictive climatic suitability models give varying results (see Section 2.3 'Distribution' above). The North Australian Quarantine Service and the Northern Territory and WA agriculture departments collectively maintain a high level of vigilance for Myrtle Rust, among many other pests and diseases, along the northern coastline. The WA environment and agriculture departments do likewise for eastern state pests and pathogens (supplementing normal international vigilance) in the south-west, and both WA Departments have prepared vigilance and response plans specifically for Myrtle Rust. Some targeted education of key community groups and agency personnel has occurred in the south west. Instances of movement of *Backhousia* plant material related to the bush food industry being moved into WA, contrary to domestic quarantine arrangements, were reported to WA biosecurity authorities in 2016; these allegedly involved both internet-based trading and postal dispatch, and transport by either plane or vehicle.

The regulatory and logistical feasibility of within-State containment in Western Australia, should Myrtle Rust arrive in either the south-west or northern region but not the other, and whether this scenario has been evaluated, are not apparent from public documents.

The difficulty of containment does not invalidate its use within a response strategy. However in most cases success is likely only as either part of an immediate and early response to an early detection and as part of an eradication plan. On a larger geographic scale, containment forms the 'inverse' of an *exclusion strategy* applied to other non-infected areas. This is most likely to be successful where:

(a) there is a substantial disjunction between infected and uninfected (but suitable) regions, either in the form of open ocean, or of land wholly unsuitable for Myrtle Rust establishment;

(b) prevailing climatic conditions do not favour the likelihood of wind dispersal of viable spores at high frequency; and
(c) other vectors are controllable to a significant extent (e.g. human-mediated pathways), or do not apply over such distances (e.g. flying fox and bird ranges).

Containment and eradication attempts, even if deemed likely to be only temporarily successful in the face of permanent pathways for recurrent Myrtle Rust pathogen arrival, may also buy valuable time for other preparedness and response measures, in particular the revision of pathway analysis, vigilance procedures, public education, and the securing of bulk wild-plant germplasm from still-healthy populations.

6.5.3 Chemical controls

To date, discussion of known and potential chemical controls for the Myrtle Rust pathogen has focussed on fungicides, which directly reduce the fungal pathogen's viability or growth. There has been little evaluation of the feasibility of resistance promoter chemicals, or of signal disruptors that might interfere with the spore-germination and host-penetration phase of the infection process.

The use of fungicides for control of rust diseases is widespread in agriculture and in some forestry situations. Relatively few fungicidal chemicals are specific to a narrow range of target fungi, most being broad-spectrum and therefore capable of harming beneficial and 'neutral' fungi on and within plants and in soil and the surrounding environment. A number of fungicides are known to be effective for control of *A. psidii*, and most if not all are broad-spectrum in their action. Many but not all are toxic to various classes of organisms other than fungi. Many remain present in their active form inside the plant tissues for some time, usually weeks or months – this is a positive feature where persistent systemic protection is desired, but the active principals or their breakdown residues may be undesirable in other respects. Others are topical, not being deeply incorporated into the host plant tissue and acting on or near the surface – these are less likely to involve long-lasting chemical residues, but also more likely to wash off the plant quickly, necessitating more frequent reapplication.

Chemical residues in host plant tissue may, for commercial crop products, affect saleability and safety or organic certifications. Loss or relinquishment of organic certification, as a result of fungicide use specifically for Myrtle Rust control, has been a major issue for commercial producers of Lemon Myrtle (*Backhousia citriodora*) and Anise Myrtle (*Syzygium anisatum*) in subtropical eastern Australia. This problem is particularly acute given that the culinary and cosmetic niche market sectors for products of both these species have been built strongly around 'natural' and organic branding.

One study of the effectiveness of multiple fungicides for Myrtle Rust control in orchard situations, and of their chemical residue properties, has been conducted to date (Horwood 2013, unpublished) under the *Myrtle Rust Transition to Management Program* (terminated 2015). This study focussed on Lemon Myrtle, as a small but hitherto growing industry. It looked at a number of both single-active ingredient and multi-active ingredient fungicides, only some currently registered for use against Myrtle Rust, finding that: "With the exception of copper oxychloride and mancozeb, all of the fungicides on APVMA permits for the control of myrtle rust reduced disease development in most glasshouse trials, but not equally. The single-active ingredient fungicides that consistently prevented rust development were the demethylation inhibitors [named] … All of the multi-active ingredient fungicides [named] were highly effective. The superiority of triadimenol confirms the results in South America against *P. psidii* on guava (Ruiz et al. 1991, Martins et al. 2011) and *Eucalyptus cloeziana* (Alfenas et al. 1993)." A number of potentially curative agents were also tested and their efficacy determined, as were indications of chemical residue levels over time. Horwood et al. (2013) recommend that "It would be desirable if a wider selection of active ingredients were registered and commercially available".

The use of fungicides for the protection of wild native plant populations is problematic in most cases, due to their often broad-spectrum activity, which may impact on natural and often ecologically beneficial fungi, and their toxic or unknown effects on a wide range of other biota. There are however exceptions. The use of phosphite on a broadacre scale for protection of native Australian plants against the (non-fungal) oomycete pathogen *Phytophthora cinnamomi* is well established and appears to have no toxicity or other side issues (Dieback Working Group [undated]; DPAW 2014). Mostly used in Western Australia, phosphite has been deployed by both aerial spraying and stem injection in a wide range of both common (e.g. Jarrah, *Eucalyptus marginata*) and threatened woody native plant species. Phosphite's mode of action is not entirely understood, but it appears to act partly as a direct fungicide and partly to promote the plant's natural defences against *Phytophthora*. Phosphite is a systemic agent, conferring protection for up to five years in some circumstances.

In another case in NSW, one stand of the iconic Wollemi Pine (*Wollemia nobilis*) was the subject for some years of a soil-drenching program with phosphonate and metalaxyl, to counter the known pathogenicity of two pathogenic *Phytophthora* species present at the site. A sub-optimal situation in many ways, this program yielded only ambivalent results.

For any potential use of fungicides in wild plant conservation, close evaluation is necessary of possible undesirable side kill of native ecto- and endophytic fungi, the possibly toxic effects of the active agents and residues on other biota, and the potentially effects on palatability of the plant for natural herbivores (this last aspect is usually little studied).

Despite these problems, the use of fungicides in the wild, on a limited scale and subject to permit approvals, is of potential benefit in at least two types of situation. Both are likely to be applicable only to small numbers of plants in a spatially compact area. One is as part of disease-exclusion studies, where the aim is to compare the health and survivorship of Myrtle Rust-infected plants with those not infected, under wild rather than artificial conditions. This kind of disease exclusion experiment was central to the study of Carnegie et al. (2016) and helped demonstrate the degree and mode of plant health decline caused by Myrtle Rust. The extension of this form of fungicide use in the wild for other studies to examine the physiology and metabolomics of the disease process, under wild conditions, is feasible. Another potential use of fungicide in the wild, not yet implemented for Myrtle Rust, is for the protection of small numbers of plants on a *pro tem* basis to extend the life or health of individuals of a species of high conservation priority, where the aim is to secure continued reproduction and healthy germplasm for storage. Some small, dense stands of species undergoing severe Myrtle Rust-mediated decline may be relevant for this approach, particularly in species with non-orthodox seeds where time is needed for germplasm storage-enablement research.

Resistance promoters, if found, could fortify the ability of a host plant to prevent Myrtle Rust infection, or to reduce its severity. The potential for identification and deployment of resistance promoter chemicals against *A. psidii* is yet to be evaluated. Such chemicals are known and used against some pathogens for conservation purposes (as with phosphite against Phytophthora), as are rhizobacteria in other cases, but none have yet been identified for Myrtle Rust.

Similarly, the role of topical or systemic chemicals that might act as blockers or signal disruptors at the stage of spore germination and haustorium/mycelium formation, is also largely unevaluated. It is known that this stage of the uredinial life cycle, *A. psidii* depends on an interplay of recognition factors between spore and host plant, probably involving dynamic and synergistic roles for both chemical volatiles and the physical and chemical properties of the surfaces of both organisms (Silva et al. 2012; Xavier et al. 2015; Potts et al. 2016). The potential for infection-process disruptors at this life stage is at present entirely speculative, but warrants urgent investigation as part of deeper studies of the physiology and metabolomics of the Myrtle Rust infection process.

A speculative chemical approach for *A. psidii* control is the development, if feasible, of treatments specifically designed to promote the germination of Myrtle Rust spores in unviable situations, i.e. to stimulate the germination of Myrtle Rust spores by chemical means and on media other than host plant tissue (and outside the laboratory situation). The hypothetical scenarios for use of such a germination-promoter are limited, but might include the disinfection (by abortive germination) of incoming goods as an alternative to possibly less desirable fungicidal treatment or quarantine.

6.5.4 Biological control of the pathogen

The development and safe deployment of biological controls for pests and pathogens is a necessarily lengthy process, with a high proportion of candidate organisms proving unsuitable for various reasons. It is a high-cost area of investment, and Australia currently lacks a dedicated programmatic base for such research, although many non-dedicated institutions have some capability for it and numerous biocontrol evaluation programs are underway for various pest organisms. The only examples of biocontrols developed for agricultural rust pathogens to date appear to be for a fungal hyperparasite on Stem Rust of perennial ryegrass (Gordon & Pfender 2012), and indicative results for bacterial and fungal hyperparasites on Coffee Rust (Haddad *et al*. 2009; Jackson *et al*. 2012).

Features of Myrtle Rust that militate against the effective deployment of a biocontrol include its ability to proliferate very rapidly under suitable weather conditions on amenable hosts (10-12 days from spore germination to a pustule of thousands of uredinial spores). Any biocontrol deployed would have to be able to respond to build-up equally rapidly, unless artificially augmented which would probably be possible only at very small scales. Features of Myrtle Rust (in the sense of the pandemic strain of the *A. psidii* pathogen) potentially favourable to biocontrol include its apparently clonal mode of reproduction (Morin et al. 2014; McTaggart *et al*. 2017), providing a genetically uniform population apart from minor somatic variation (Stewart et al. 2017).

Glen *et al*. (2007) noted a theoretical potential for some bacterial and fungal biocontrols. The bacterium *Bacillus subtilis* in laboratory trials (dos Santos *et al*. 1998) reduced germination of *A. psidii* to very low levels, but no indication of subsequent field trials has been found for this review. Certain strains of the rhizobacterium *Pseudomonas aeruginosa* have been shown to induce systemic resistance in *Eucalyptus grandis × urophylla* (Teixeira et al. 2005); and Glen (2007) cites other unpublished possibilities.

Fungal hyperparasites that infect rust fungi are potential control agents for rusts. Their effects may be direct, affecting germination or sporulation or other aspects of the rust, or indirect, sometimes inducing host-plant resistance to the rust (Prof. R Park, pers. comm. March 2017). The fungus *Fusarium decemcellulare* is known to behave as a hyper-parasite of *A. psidii* (Amorim et al. 1993). An unidentified fungal hyperparasite on *Austropuccinia psidii* has been detected in Australia (M. Moffit, Western Sydney University, pers. comm. March 2017), and is under further study. It is unclear at this stage whether the hyperparasite is a 'true' hyperparasite or a saprotrophic generalist, and whether it may have arrived in Australia with the Myrtle Rust pathogen or was already present. Its potential, and that of other fungal hyperparasites, as a biocontrol for *A. psidii* remains unevaluated.

Viruses that infect pathogenic fungi (mycoviruses) are another biocontrol system with precedents in agricultural disease management. Viral biocontrol has been trialled against the Chestnut Blight pathogen (*Cryphonectria parasitica*) of American Chestnut; the mycovirus in that case reduces the virulence of the pathogen (Jacobs *et al*. 2013). No information has been found on hyperviral infections of *Austropuccinia psidii*.

The likelihood of an effective and environmentally safe biocontrol for Myrtle Rust is low, and it is likely that if one were found its main utility might be in relatively small-scale production orchards and nurseries, and in conservation seed orchards, rather than at large scale in bushland. Nevertheless, the possibilities need to be professionally scoped – see Action 4.3.5 in Recommendations (Section 8, below).

A capacity has recently been developed for the deployment of RNA-interference (RNAi) vaccines for some types of plants against viral pathogens (Wilson & Doudna 2013; Mitter *et al*., 2017a; Niehl et al. 2018). RNA interference "is a natural regulatory mechanism that plays critical roles in growth, development and host defence against viruses and transposons, [and] has proved to be a powerful strategy to engineer disease resistance against viruses, viroids, nematodes, insect pests and fungi in plants" (Mitter *et al.*, 2017a). The technique involves the application to host plants of a pathogen-specific RNA species which is translated by the host plant's own cellular processes into a form that seeks out and 'silences' targeted genes of the pathogen or pest and essential to its life cycle.

The adaptation of this RNAi vaccine process to pests and pathogens other than viruses is in the very early stages, but its application against biotrophic fungal pathogens is feasible in principle (Dang et al. 2011; Duan et al. 2012). The deployment of RNAi vaccines however requires a very detailed knowledge of the genome of the target organism, not yet available for *A. psidii*, to allow the specific targeting of genes unique to that organism and appropriate for silencing; moreover, a multi-gene approach is desirable. The viral genome is simple compared to that of fungi.

The RNAi vaccines developed against viral pathogens to date, and applied by topical (surface) sprays of 'naked' RNA for gradual absorbtion, are prone to washing off and are short-lived in their action. However, the study of this problem has resulted in the development of a technique for delivery of the RNAi vaccine in more durable and effective form by means of an environmentally benign, clay-based nanoparticle vector (Mitter *et al*., 2017b).

RNA interference vaccines are at this stage only a potential tool for a response to the Myrtle Rust pathogen. Their applicability to fungi, their utility in woody plants like Myrtaceae, and the limitations on their use (especially in the wild), all remain to be determined in practice, and use of the technique in the short-term is not at all likely. Nevertheless, their development for control of fungal (including rust) pathogens of crop plants is likely to proceed rapidly, and should be tracked as part of the environmental response to Myrtle Rust. Synergistic exploratory research supported from both the environmental and the production sectors would be productive.

6.5.5 Relocation of host species away from threat, and inter situ interim relocation

In agricultural situations, relocation of production of a susceptible crop to a place less suitable for a pathogen is an option (utilised by at least one major NSW Lemon Myrtle grower in response to Myrtle Rust).

For wild plant species, relocation to a climatically different zone is rarely if ever an effective conservation response, as the survival and long-term viability of the relocated population is unlikely.

Relocation to a natural environment more similar to the 'home' one (but minus the threat that prompted the move) is a viable option for the establishment of at least small, potentially permanent self-sustaining populations. This conservation technique (translocation) is extensively practiced in Australia and elsewhere for threatened species, with variable but improving success but usually at a relatively small spatial and numerical scale (Vallee *et al*. 2004; Menges 2008; Godefroid *et al*. 2011, Commander 2018 in press; J. Silcock work in progress pers. comm.). It relies however on finding an area that is biophysically suitable, of lower-threat status, and whose own conservation values will not be compromised by the translocation. In the case of Myrtle Rust, the mobility of the airborne spores means there are unlikely to be any moist-vegetation refugia from Myrtle Rust inoculum that are suitable over the long-term as permanent translocation recipient sites anywhere along the east coast, and very few inland.

The temporary establishment and maintenance of cultivated or semi-cultivated colonies in lower-threat sites, pending the development of a longer-term recovery process, is a valid conservation option, although not representing a full solution. Sometimes termed *inter situ conservation* (i.e. between *in situ*, the natural site, and *ex situ*, a wholly artificial environment), this form of maintenance may serve multiple roles – e.g. as a holding stage for a genetically diverse sample of a species not amenable to seed storage; as a seed production area; and as a source of material for disease resistance studies. An *inter situ* stage of 'protective custody' of this sort is likely to be necessary for a number of Myrtle Rust-affected species with recalcitrant seeds and which are in severe decline and have essentially ceased producing seed in collectable quantities since 2010. Native Guava (*Rhodomyrtus psidioides*) is a prime example – pending the development of a suitable germplasm storage system, and the possible identification and development of rust-resistant genotypes for rewilding, the continued existence of this species at meaningful levels of its original genetic diversity is likely to be dependent on one or preferably more *inter situ* managed colonies.

Capacity for the hosting and maintenance in good health of *inter situ* plantings of single or multiple species is yet to be surveyed in detail, and would certainly be dependent on the identification of support-funding resources for the hosting bodies. However, a significant number of regional and metropolitan botanic gardens and arboreta, some agricultural research stations, and some universities, all have land area, infrastructure, and some existing staff expertise relevant to this form of interim conservation, as do a small number of commercial producers of bush products. One commercial enterprise is already – with industry grant support – hosting a part-set of Lemon Myrtle provenance clones, and one regional botanic garden (Booderee BG on the NSW South Coast) has secured samples of a local species declining under Myrtle Rust for *inter situ* conservation.

An *ex situ* or *inter situ* custodianship role of this sort, as part of a comprehensive and long-range Myrtle Rust action plan endorsed by environment agencies, is likely to have considerable potential for attracting sponsorship and philanthropic support. See Actions 4.1.3 and 4.1.4 in Recommendations, section 8 below.

6.5.6 Substitution of a declining host species

In agricultural situations, in order to maintain production, the removal of susceptible plants can be followed by their replacement by non-susceptible varieties or breeds of the same species, if these exist, or the substitution of quite different crop species not vulnerable to the pathogen.

For wild plants, the cases where a strategy of alternative species establishment has been followed are mostly in the field of ecological restoration, often in highly modified communities and exercised on relatively small scales. The deliberate replacement of declining species within an otherwise intact natural environment is relatively rare. However in extreme cases, where an ecologically dominant species is effectively extirpated by a pest, pathogen, or other threat process, its deliberate replacement by an alternative species is at least a conceptual option. The concept is now getting significant attention, not in relation to Myrtle Rust but to climate change, where there is a rapidly growing literature on substation strategies (mostly in a regeneration context) that may need to be adopted over coming decades (see. e.g., Gallagher et al. 2015 and references therein).

The goals of a 'species replacement' strategy may include:

- the restoration of either vegetation structure or ecological function to some level of equivalence with the original system, or
- mitigation or reversal of biological or physical deterioration of habitat by establishing a new dominant species and hence a novel ecosystem, or
- support of a flora-dependent species of high conservation value (e.g. koala food-tree plantings).

More usually in practice however, the gap left by a declining former dominant species is filled by a mix of natural regeneration of other species (often including weeds) and a relatively minor level of alternative-species planting.

There are as yet no clear cases of Myrtle Rust impact on dominant species to a level where a need to urgently implement wholesale substitution of an alternative dominant species is apparent. However, the risk of this situation arising is real for certain susceptible species and their associated communities, and it would be prudent to plan for these possibilities. Cases in point include:

- the possible decline (if only on a regional or populational basis) of broadleaf *Melaleuca* species dominant in wetlands (see Section 4.6 'Ecological Community Impacts' above);
- the possible extirpation of post-fire seedling cohorts in some coastal *Leptospermum* species dominant on seaward slopes or dunes; and
- the less immediate possibility of decline of any eucalypt species found to be highly susceptible in the seedling or post-fire life stages, especially if further eucalypt-associated strains of *A. psidii* arrive in Australia.

The substitution of declining species with more resistant ones is not here advocated, although it should be scoped as a contingency issue if keystone species begin to decline radically and local floristic 'adjustment' is unlikely for whatever reason.

6.5.7 Enhancement of disease resistance in host plants, and the re-wilding challenge

In agricultural situations, the loss or removal of susceptible plants can be followed by their replacement by non-susceptible varieties or breeds of the same species, if these exist.

For wild plant species, replacement of natural disease-prone genotypes by more disease-resistant genotypes of the same species (if these exist at the same site) may occur by natural selection, usually operating over many generations. This natural process depends on the genetic basis of the resistance, and may, over many generations, involve a co-adaptive dynamic with host and pathogen each co-evolving in an 'arms race'.

If a host species' distribution is fragmented, regional extinction of vulnerable genotypes may occur along the way. If the disease-resistant genotypes are too rare or too geographically scattered, or not easily inherited, natural selection may not be able to keep pace with the decline caused by the pathogen. This is the case for several (possibly many) east Australian species impacted by Myrtle Rust. The very rapid decline of the previously common *Rhodomyrtus psidioides* (Carnegie et al. 2016) seems certain to outstrip any low frequency of resistant genotype that may exist (no confirmed resistant plants have been identified to date), and lead to the extinction of that species within a very short time-frame in the absence of urgent intervention. The much more restricted *Lenwebbia* sp. 'Main Range' is another example. In other cases where resistant genotypes may be selected for in some populations, the chances of dispersal of that genotype by seed or pollen to other populations may be low or zero, given the high level of fragmentation of many east Australian forest biomes, particularly rainforest.

The selection, breeding and crossing of plant varieties and species, to capture and accentuate desirable traits, is as old as agriculture. Selection and cross-breeding has also been the foundation, for well over a century, of the development of disease-resistance in agricultural crops and silvicultural (forestry) tree species.

Human activities have often had inadvertently selective effects on the genotypes of wild species. However, the deliberate manipulation of genotypes in the wild, or the deliberate introduction of selectively bred or engineered genetic traits into wild populations, is much rarer, at least in cases with a conservation rationale. The ecological risks and ethical issues associated with such an approach are significant. Whereas the aim in agriculture is to produce uniform genetic lineages with desired traits, a modern conservation approach would be almost the opposite - to preserve as full as possibly the natural variation of the species, but to introgress (infuse) into it a single trait that confers resistance to the threat. This is not something to be undertaken lightly – nor, in the face of imminent multiple extinctions, to be rejected out of hand.

For rapid-decline species, we can buy time for the necessary debate and research, if broadly representative germplasm of these species is secured. Without that, the options no longer exist.

There are few cases globally of pathogen resistance traits being 're-wilded' as a conservation action. There are two that bear comparison to the Myrtle Rust situation.

White Pine Blister Rust (*Cronartium ribicola*), exotic to North America, has there caused high mortality for over a century in several economically and ecologically important native pines species logged from wild stands (not plantation). For the first half of that period, management attempts focussed on eradication of obligate non-pine co-host native species (Barberry, *Ribes* spp.). By the 1960s this had given way to White Pine breeding programs, using multiple wild tree genotypes with natural resistance, to reinforce resistance and plant back out into the wild

Sniezko et al. (2014) comment that "The identification and deployment of trees with natural genetic resistance to these rusts is key to restoring and maximizing the ecological role of many of the white pine species as well as the economic utility for white pine and southern pine species used in plantation forestry. Fortunately, genetic resistance to these rusts has been discovered in all pines species studied … Resistance breeding programs, begun over 50 years ago, continue to produce trees with resistance in the U.S. and Canada … The advent of new genomic tools opens up opportunities to gain and apply knowledge in the resistance programs to help ensure healthier forests in the future. … Tree breeding is inherently a long-term endeavour, but the FR [fusiform rust] and WPBR [white pine blister rust] resistance programs have made substantial progress in establishing large base populations, increasing the level of resistance for several species and producing seed for reforestation. Work on some of the high-elevation white pine species has only recently begun, but shows good promise."

American Chestnut (*Castanea dentata*) is the host of the introduced pathogenic fungal disease Chestnut Blight (*Cryphonectria parasitica*). Once a dominant tree in much of eastern North America, and a keystone ecological species providing vast biomass and food resources for animals and humans, American Chestnut has declined catastrophically during the C20th, surviving mainly as suckers on old still-living stumps. It provides a case of decline with certain parallels to some of the Australian species at risk (perhaps *Rhodomyrtus psidioides* in some respects). Not enough blight resistance exists in American Chestnut to make a cis-genic (same species) breeding strategy feasible. However, over several decades a program of orthodox crossing with selected lineages of two more resistant Asian species, followed by multiple backcrossing to American-only lineages, have successfully introgressed resistance traits into American-dominated genomes (in cultivation). Knapp et al. (2014) mention recent success with a breeding line "which should theoretically retain almost 94 % of the American chestnut genes and be highly blight-resistant".

Three other aspects of the American Chestnut case are worth noting in relation to Myrtle Rust in Australia and New Zealand. One is the emphasis laid on achieving a social consensus for what is in effect an ecological restoration program of unusually large scale. Secondly, a significant proportion of funding for the multi-decadal Chestnut recovery program has been raised outside government, in large part through the American Chestnut Foundation (TACF). Finally, the actual deployment of transgenic resistant lines to the wild is being treated as a distinct step requiring its own round of dialogue, debate and consensus-building – consultation is treated as a continuing process.

The above cases concern selection of resistant lineages from the wild types and either simple reinforcement of wild populations, with trait introgression by normal breeding, or artificial breeding to accentuate those traits before re-wilding. Such approaches can be greatly improved by the use of genetic mapping and other techniques in genomics, proteonomics, metabolomics and transcriptomics, without engaging in genetic engineering as such.

Nevertheless, a logical next conceptual step is to consider the options provided by genetic modification techniques, both for their potential ability to much more precisely manipulate only those genes necessary for the resistance trait, and for the compressed time scale of the process. Adams et al. (2002) and Merkle et al. (2007) concisely outline the concepts and techniques as they relate to wild plant conservation, although both areas have advanced far since those papers were published. New genome editing tools, like CRSPR ('crisper'), are very precise, but woody plants in general, the Myrtaceae among them, are not yet subjects for their deployment.

The transfer of major gene resistance (single dominant major genes) is in principle relatively simple, whether by selection, cross-breeding or engineering, but often less robust in the face of pathogen/host coevolution unless it involves a major constitutive trait. Multiple-gene (multi-loci) traits are rather less amenable to manipulation.

As the transgenic (species cross) approach being taken with American Chestnut illustrates, there are complex issues – technical, logistical, and ethical/social – with these approaches. Given the likely steep decline of multiple species due to Myrtle Rust, those issues should be aired in conservation circles and publicly, with a view to dialogue and divorced, to the degree possible, from the entrenched positions that have developed around genetic engineering in the area of food and other commercial products.

The degree of genetic manipulation proposed to meet conservation goals will condition the necessary debate, as well as the technique used. All parties will need clear thinking on whether trait transfer by normal cross-breeding is more or less acceptable, achievable and effective (for conservation) than the same transfer by engineering. Is transgenic breeding or engineering (transfer of traits between different but related species, as with American Chestnut) less acceptable than cis-genic transfer of traits (between different genotypes within the same species)? The issues are heavily laden with values considerations, as well as technical ones.

A paper with great significance for the direction of thinking in relation to Myrtle Rust in Australia is Jacobs et al. (2013), *A conceptual framework for restoration of threatened plants: the effective model of American chestnut (Castanea dentata) reintroduction*. This discusses the interplay between social and ethical concerns, technological choices, and ecological realities in a way that in many respects foreshadows restoration issues for species severely affected by Myrtle Rust, and should be an essential part of the consideration of eventual recovery strategies.

Ideally, and in species with pockets of stronger resistance, simple selection and reinforcement of populations may help stabilise the situation without the hard choices about more interventionist options. But leaving those issues and dialogues to the last moment will guarantee poor outcomes. As Jacobs et al. (2013) point out, the technological, ecological and social 'spheres' have to be in conjunction for landscape scale restoration and recovery projects to work. The recommendation made here is to open that dialogue, on the full range of recovery options, in the specific context of Myrtle Rust-mediated declines. See Actions 4.3.5 and 4.4.1 in Recommendations, Section 8 below.

6.6 Priority subjects for conservation action, research, and strategy

The ultimate goal of biodiversity conservation is to have species secure in their natural habitats, and ecological systems in good functioning mode, both of them with the achievable minimum of 'unnatural' threats. In situ conservation is always preferable, but when a threat process overwhelms both biota and their management, more interventionist options may be able to rescue and restore some species and populations. The above material outlines some of the technical possibilities and social issues involved.

What is clear already for a number of Myrtle Rust-threatened species is that there will be no future management options available, without a rapid implementation of adequately funded, well-directed field survey, germplasm capture (seed or other) and targeted research, and the building of a social and institutional support base around a coordinated national response program. This framework is second nature in the primary industry sector, where this type of threat process is common, but is still unusual in the environment sector.

Certain key areas for an environmental response require a sustained commitment and investment, going beyond the project level approach and the competitive grant system. As with many agricultural threats, a directed and long-term approach to research, actions and stakeholder liaison is needed. This should utilise existing competitive grant funding sources for research and actions (encouraging the setting of Myrtle Rust as a theme where appropriate), but also develop and maintain a discretionary and directed funding source for the many aspects that will not fall under existing grant scheme ambits. A sustained salary component will also be necessary in some areas, especially but not exclusively relating to seed and tissue storage enablement and other forms of germplasm capture and testing.

6.6.1 Establishing initial momentum for a coordinated environmental response

This is the crux of any prospective environmental response to the Myrtle Rust threat. Momentum, mandate, leadership and a large component of at least initial funding are unavoidably responsibilities of governments, although the potential for extra-governmental inputs to all of these should not be discounted. Without these factors, on a concerted national basis, the prospects for an effective response are poor.

The Objectives and Actions under Theme 1 in Section 8 (Recommendations) below, focus on:

- Establishing momentum at governmental level;
- Outreach to key professional organisations, industry bodies, and non-government organisations and stakeholders;
- Expedited use of existing mechanisms for conservation prioritisation and action.

In relation to the first, establishing a line of communication and reportage through the Environmental Senior Officers Group (intergovernmental) to the Meetings of Environment Ministers, seems to be the most promising path of galvanising a coordinated environmental response. All known reportage at this level to date has been through the separate primary industries senior officer and ministerial channels, as those departments led the initial responses. The absence of reportage in the environment stream has contributed to the lack of coherent action and communication.

6.6.2 Biodiversity planning and management instruments

See Objective 1.4 in Section * (Recommendations) below. This subject also relates to various Objectives and Actions under Themes 2 (Awareness and Engagement) and 3 (Impact Assessment).

The scale of Myrtle Rust impacts on native biodiversity in some regions covered by specific biodiversity and heritage planning instruments (frameworks, strategies, management plans) is, or may soon become, so great as to justify either revision or supplementation of existing management plans with Myrtle Rust-specific codicils, unless a review and renewal cycle is already imminent. Cases in point would be:

- The *Border Ranges Rainforest Biodiversity Management Plan* (DECCW 2010a), a joint NSW-Queensland-Commonwealth instrument which covers an area recognised by the Commonwealth as a 'Biodiversity Hotspot', and which is also a region of likely high Myrtle Rust impact on species and potentially ecological communities;
- The *Northern Rivers Regional Biodiversity Management Plan* (DECCW 2010b), a national (Commonwealth-NSW) recovery plan covering an area overlapping with the previous but extending well to the south, and capturing many Myrtle Rust-affected species and ecological communities.

In certain World Heritage Areas already likely to be undergoing significant Myrtle Rust impact and with integrated biodiversity/heritage management plans, similar revision or supplementation should also be considered. These include the Gondwana Rainforests WHA, the Wet Tropics WHA, and potentially the K'gari (Fraser island) WHA.

Extinction-risk and Key Threatening Process listing

See Objective 1.4 in Section 8 (Recommendations) below.

Nearly all species and ecological communities listed in 'Threatened' categories under conservation legislation in the various Australian jurisdictions, were listed on the basis of threats existing before the advent of Myrtle Rust. That pathogen has added an entirely new level of threat for many species, many of which were in the 'least concern' category previously. Review and renewal cycles for legislative 'threatened entity' lists vary greatly, in some jurisdictions being continuous (although not necessarily fast) and in others only on a cycle as long as five years. Some rely largely on public nominations and data provision to trigger an assessment process (although in theory all assessment bodies can auto-nominate entities, not all have the staff-time to prepare the necessarily detailed material for the process).

There are also great discrepancies between Commonwealth (EPBC Act) and State/Territory lists, both for the entities listed and the risk categories to which they are assigned. Very many taxa listed at State level are not yet reflected on the Commonwealth list, even if State-endemic and fully assessed at that level. These discrepancies are gradually being resolved through the 'Common Assessment Methodology' process, but it is likely to be some years before full concordance is achieved. In the meantime, entities not on the Commonwealth lists have not been eligible for Commonwealth threatened entity funding, no matter how dire their actual situation, and the same is often true at State/Territory levels – the bodies that set the parameters for such funding usually show little inclination to anticipate developing extinction risk except as recognised through the slow listing process. Myrtle Rust is a threatening process that is fast-moving in every sense – in geographical spread, host range, and (for many species) in its effects.

Moreover, the extinction risk assessment processes in all jurisdictions lay great stress on evidence levels (e.g. of numerical or geographical decline, among other factors) to justify listings. All jurisdictions allow listing on the basis of projected (future) threats as well as past and current ones, but some evidentiary base is still required. This is fully appropriate, but in the absence of a coordinated field-based impact assessment and monitoring program for Myrtle Rust, the necessary data will accrue either never, or only slowly through the efforts of often un-resourced external stakeholders. This guarantees a tardy and sub-optimal recognition of the unfolding threat in the extinction-risk lists.

It is incumbent on the environment agencies and their expert assessment panels to examine these problems and determine appropriate ways of expediting listings and ensuring that over time, the listing process gets ahead of the curve of Myrtle Rust-mediated declines, rather than lagging some years behind.

6.6.3 Cultural and social impacts, awareness and engagement

See Theme 2 in section 8 (Recommendations) below.

The potential cultural and social impacts of Myrtle Rust on social and cultural values have not been addressed in Australia to date. Three areas of potentially serious social impact from the 'pandemic strain' of the disease are apparent:

- The loss of species and ecological elements, especially in the context of World Heritage Areas and the conservation reserve system;
- Indigenous cultural impacts, on landscape and species values and utilities, and on Indigenous economic enterprises;
- A loss of faith in, and commitment to, Australia's biosecurity and conservation systems, if a vigorous national environmental response is not mounted.

An additional concern is the potential for other strains of the same pathogen, but with a greater affinity for eucalypts arriving in Australia (see Theme 5).

The first challenge above is largely the subject of this action plan and the adjunct *Review of environmental impacts*. The third challenge above is largely in the purview of the peak biosecurity authorities, although a strong and coordinated environmental response to Myrtle Rust will reduce the risk.

The second challenge – Indigenous cultural impacts -- is closely entwined with an environmental response to the pathogen. Indigenous communities and institutions have not been closely engaged with by governments in addressing the problem so far, except by staff of the Northern Australia Quarantine Strategy (NAQS) and Biosecurity Queensland. A particular and essential challenge for governments and the scientific community is to develop meaningful engagement with Indigenous stakeholders over Myrtle Rust impacts and the possible conservation responses.

Myrtle Rust impact relevant to Indigenous people and communities may encompass traditional cultural heritage, contemporary continued traditional practices, and Indigenous enterprises, particularly those based on bush product production of exhibition and ecotourism. Myrtaceae species continue to be used by Indigenous peoples in most parts of Australia, not just those in traditional and remote areas, for food, medicinal, and other social practices. They form part of the continuing cultural life of those communities. Natural landscapes and vegetation types, and their constituent species, are valued for the traditional stories and continuing custodianships with which they are associated – declines in their integrity have a particular cultural dimension of loss. Many Aboriginal-run enterprises around Australia are based on natural native-plant products, or incorporate them in their tourism and educational activities. Finally, Aboriginal owned, co-owned, or controlled land is an important part of the matrix on some areas of current Myrtle Rust occurrence, and very large sections of potential future infection. The consultative process needs to include direct Indigenous input to decision making, and to be an open-ended process. Only a starting approach is recommended here.

The general public, and many bushland-oriented stakeholder groups within it, also stand to lose valued and recognised heritage as a result of Myrtle Rust. This area of social values is highly diverse and harder to address, but stakeholder awareness and impact consultation across the community, especially on a regional and interest-group basis, remains important. As the effects of Myrtle Rust become clearer, environment authorities can expect increased concern.

6.6.4 Information handling and communication

See Objective 3.1 in Section 8 (Recommendations) below, and and relevant Objectives and Actions under Themes 2 (Awareness and Engagement) and 4 (Towards Recovery).

Communication has been a major problem in movement towards an integrated environmental response to Myrtle Rust since 2010. The lead response agencies in each jurisdiction have issued much good extension material in the initial response phase, with on-line brochures, guidance documents, state host lists, and image galleries. These however (in the affected jurisdictions) have tended to become static over time as other disease communication priorities take over – NSW and Queensland host lists have been static since about 2013. They have also tended to have an exclusively State/Territory focus, as is natural for their charter. A PHA-based website (www.myrtlerust.net.au) served as a platform for the Myrtle Rust *Transition to Management Program* (2012-15) with project reports and a few other documents, but has been near-static since. No government agency has been able to maintain a current national host list – this has been achieved through the efforts of researchers in QDAF and NSW DPI and one non-government organisation (ANPC), in recent years working collaboratively through the unofficial Myrtle Rust Environmental Impacts Working Group. There have been no widely promulgated protocols (e.g. evidentiary levels) for the reporting of new host species, and no central reporting point, necessitating laborious tracing and assessment of reports. Researchers, conservation practitioners and the general public have a plethora of web pages to go to, but none which adequately reflect the current state of play and provide comprehensive links and references. A further problem is deep siloing between the plant health / plant pathology, conservation science, and community conservation sectors, and difficulty of access to journals for non-agency and non-university actors. Improved crossover and better information flow is essential.

A single information hub is not necessarily advisable, especially if based in government where websites and their servicing are subject to high churn. A polycentric approach is preferable. A single limited recommendation is made here, but it is also recommended that the lead body for any coordinated national environmental response takes early consideration of communication problems and the need for some support funding to service and strengthen existing hubs.

Only a general recommendation is made here and in the action plan for more effective communications, including to resource some of the existing information hubs playing a key role, and to the volunteer group of scientists maintain the Australian host list.

6.6.5 Field surveys (priority species) and monitoring for impact, resistance, and baseline

See Objective 3.2 in Section 8 (Recommendations) below.

Data to estimate declines and even disease incidence remains very patchy, as there are no integrated monitoring programs in place in NSW or Queensland (though there are some at project level). Field survey of priority species is the only way to accurately determine the level and pace of declines, establish demographic baselines to allow future tracking, detect anomalously resistant populations and individuals, and to prioritise species and actions more precisely than is now possible.

Meaningful data collection requires a standardised approach – suitable disease incidence and severity guidelines exist (see Pegg et al., 2018), but the ecological and demographic metrics have still to be agreed, and the whole package developed into a standard protocol in a form suitable for promulgation to potential data contributors. See draft Action Plan Objective 3.2.

Data once collected, to be validated for quality and available for an integrated response, needs a common repository with some skilled staff time allocation for validation checks, referral of identification issues, and the like. One (or more, connected and interactive) data hubs capable of accepting spatial, disease, and eco-demographic data need to be established. See draft Action Plan Objective 3.2).

The monitoring task ahead of us will far outstrip the capabilities of environmental agency staff alone (unless whole species and ecological communities are simply ignored). The capacity of a targeted, skilled, and motivated citizen science corps is available – concern in these extra governmental conservation and native plant circles runs higher than in some agencies. An integrated monitoring program building an alliance of concern with these partners, if resourced and sustained, can greatly extend the capacity to monitor disease and its effects. See draft Action Plan Themes 2 (Awareness and Engagement) and 3 (Impact Assessment).

6.6.6 Ecological research priorities

See Objective 3.3 in Section 8 (Recommendations) below.

Many ecological communities, and potentially several biomes, are already threatened to varying degrees by Myrtle Rust, with the prospect of many more if the disease spreads further or other strains arrive in Australia.

Three ecological biomes are here recommended as the basis for research programs (not projects): Melaleuca wetlands, Rainforests, and Fire-prone systems (heaths and heathy woodlands) of the east coast (see draft Action Plan Objectives 3.3 and 4.2). These need to integrate not only the host species directly affected, but the ecological consequences of any declines occurring, on floristics, associated flora and fauna, and, in the case of Melaleuca wetlands, aquatic system biota and water quality. Cultural and social impacts are a factor in each.

An overall approach to the structuring, directing, costing and funding of these programs is necessary. It is recommended here (but not in the draft Action Plan) that consideration be given to the use of multidisciplinary scoping studies to develop detailed proposals for each. These should have agency and community interests represented, along with technical expertise, and may perhaps be best convened under an appropriate host body (possibly the Australian Academy of Science, if willing and resourced).

Some elements of each proposed research program are likely to be fundable from existing competitive grant programs, although the success and timing of these, and their scope and relevance within the overall program goals, cannot be predicted. It is therefore recommended that, assuming endorsement of concept for each, discretionary and directed funding be made available for overall coordination within and between the programs, and for their implementation (except where competitive grant sources are able to be utilised in a fully relevant and timely fashion).

Note also the need for a separate research program for recalcitrant seed biology and storage enablement, and other forms of germplasm preservation (see draft Action Plan Objective 4.1), which should be considered as part of the same overall resourcing package.

Each of the four ecological programs recommended below are multidisciplinary and complex. To best effect they would involve collaborations based on expertise and relevance. Construction of optimally detailed and costed proposals for each requires the input of multiple experts in a moderated process within a time frame driven by the needs of each case. It is recommended that an initial funded process occur, of expert and key stakeholder workshops and consultation, to refine the concept of each program and ensure appropriate content and collaborative input. It is suggested that convenorship for these scoping studies be based outside departmental structures. A suitable convenorship vehicle for conducting this initial scoping and refinement process would be the Australian Academy of Science (if willing and resourced); AAS is well-placed to facilitate the multidisciplinary approach required. The need for a social and Indigenous cultural dimension to the scoping and implementation of each research program is stressed.

6.6.7 Germplasm capture and storage enablement research

See Objective 4.1 in Section 8 (Recommendations) below.

For species on a sustained decline towards extinction in the wild and where no resistant populations are known, the choice is between accepting the likelihood of complete extinction, or salvaging germplasm in a form and quantity sufficient for storage-enablement research, establishment of *inter situ* custody and seed production areas, pending eventual deployment in (at this stage hypothetical) recovery programs.

The key point is that without germplasm capture, *there are no recovery options* for species in this situation.

For species with more patchy but still regionally severe declines, germplasm capture from both high- and low-resistant populations is desirable so as not to lose genetic variability, enable research into resistance syndromes, and be able to augment or replace extinct populations with more resistant natural or bred variants without altogether losing local or regional genotypes.

For numerous species known or suspected to be in current steep decline due to Myrtle Rust, the opportunity to secure seed from the wild in meaningful quantities has passed, as fruit set is now small or zero, and likely to be more inbred than normal. This could easily become the case for other highly susceptible species as they become exposed (potentially including, for example, the un-rated five Lord Howe Island endemics). For high-priority species that are still setting some fruit, the annual opportunity for seed collection, if missed, mean another year of decline.

Complicating the issue, many of the species here regarded as highest priority have non-orthodox seeds (not amenable to normal seed bank storage), or their orthodoxy is unknown. Some also have naturally low levels of viable seed. The storage-tolerance problem is solvable for some, but each needs **prior enabling research** to determine – there is no point in large-scale seed banking unless viability and germinability is assured. This enablement research will generally take some months, longer than seasonal fruit remains available, so another year is lost even if storage issues are solved. It also requires moderate initial samples of healthy seed, preferably in the low hundreds, but even this may be unavailable except from cultivation. If no variation on normal seed storage works, other more expensive modes of germplasm capture are necessary if future species recovery options are to be maintained (tissue culture, cryostorage, protected inter-situ live plants). If no seed at all is available, germplasm must be captured via vegetative material and maintained in living collections.

A program of research into rainforest seed biology exists at the Australian Botanic Gardens, Mount Annan (NSW). Within their existing resources that insititution has attempted to prioritise a few non-orthodox or orthodoxy-unknown Myrtaceae species at risk from Myrtle Rust. That program is at staff-time capacity. This and other institutions equipped for the same sort of research would need extra salary funds, not just project funds, to expand the range of species under investigation.

The prioritisation of species presented here is unlikely (for the ‘emergency’ and ‘next highest’ categories) to be altered by field impact surveys, but may result in additions as new impact data comes to light. Establishment of Myrtle Rust in new areas (especially the south-west of Western Australia), would substantially modify these priorities.

Facilitation by response leading bodies of applications for permit variations, to allow greater than normal amounts of germplasm sampling and interstate research collaborations, will be necessary in some cases.

6.6.8 Information assembly gaps

See Objective 4.2 in Section 8 (Recommendations) below.

Apart from rapid field surveys, there are a number of more desk-top information assembly gaps, the filling of which would greatly facilitate the commencement and pace of research programs and conservation actions. These include:

- Identify most effective potential monitoring sites from pre-xisting data (permanent plot and survey records, herbarium and museum data, etc)
- Ecological factors
- Inventory of priority Myrtaceae species in botanical gardens and other collections
- Scope potential locations and funding support for ex situ and inter situ live plant collections and/or seed production areas
- Host life history profiles for action-priority species
- Develop an on-line downloadable (and eventually app-based) atlas of authenticated Myrtaceae seedling images as a field identification aid for priority areas.

6.6.9 Towards recovery – resistance research, resistance breeding, re-introduction, and other strategies

See Objective 4.3 and 4.4 in Section 8 (Recommendations) below.

A closer understanding of susceptibility, resistance and tolerance of *A. psidii* infection in host species is essential for a meaningful conservation response to Myrtle Rust. The genetic basis of these syndromes is partially known in a few genera and species, but un-investigated in most. The physiological mechanisms by which these traits are expressed, blocked or moderated, remain almost entirely un-investigated for this pathogen and its host species, but the means exist to determine them. The mix of induced and constitutive resistance or tolerance traits that exist and are expressed within some species, and between pairs of sister-species in other cases, are potential tools for saving some severely affected taxa.

Some lines of research into resistance syndromes are in train internationally and in Australia. A large body of work and practice in resistance breeding in eucalypts already exists, much of it successfully performed on a phenetic selective basis, rather than a fully genetic approach – both approaches are possible and are fully complementary.

In the eucalypts (see e.g. Potts et al. 2016), some evidence exists that there may be phylogenetic pattern to the distribution of resistance genes (whether operative or not) which would inform disease studies in the wild and resistance breeding strategies. Robust phylogenies exist for some but not all tribes of Australian Myrtaceae. Phylogenetic information may help in determining the potential generalisability of results beyond individual research species, particularly in Tribe Myrteae (*sensu* Wilson et al. 2011), which contains plurality of the high-decline species known to date. Target species will also depend on the outcome of field impact surveys.

The great bulk of genomic and rust-resistance research to date has been on species significant in the silvicultural or horticultural industries. In the absence of dedicated funding for wild-impact research, the thrust of such research will continue to relate to such species. However, these do not correspond at all well with the genera or species undergoing the most rapid decline in the wild. A possible exception is Lemon Myrtle *Backhousia citriodora*, which has not yet been surveyed for Myrtle Rust impact in the wild populations, but which is already the subject of a rust-resistance selection program for plantation purposes, using a fortuitously surviving provenance set.

If a research program along these lines is explored within an *environmental* response program, a focus on threatened biodiversity is important. As with resistance studies in general, synergy with production-sector research is both possible and desirable, but the environmental aspects and species need to be asserted.

Other lines of inquiry are at a very early stage. Some potential directions canvassed here may prove to be dry wells (e.g. biocontrol options, RNA interference vaccines), but enough evidence exists that they deserve expert appraisal of concept and current knowledge, rather than summary dismissal. For that reason, some lines of inquiry are recommended here for expert scoping and feasibility studies only, the results of which would inform decisions about whether or not to proceed with them.

Research into resistance syndromes and novel control methods for environmental purposes will necessarily be dependent on expertise from the plant health, plant pathology, genetics, genomics, transcriptomics, and other sub-disciplines. This expertise is for the most part based in institutions whose primary concerns, priorities and funding streams are not automatically aligned with biodiversity conservation priorities. A viable program of research of these options for addressing the conservation impacts of Myrtle Rust must be structured, funded and mandated in a way that facilitates cross-disciplinary and cross-silo collaboration. The domains of conservation science and plant pathology/plant health science are strongly siloed from each other at present, although both are moderately well integrated with the molecular disciplines. Initial steps towards fostering crossover, likely to be productive of good ideas and potential areas of focus, would be relatively easy to achieve. The sponsoring or facilitation of Myrtle Rust mini-symposia within existing regular conference events, or the convening of specialist cross-disciplinary workshops under the aegis of suitable bodies (e.g. the Australian Academy of Science), would contribute to this process.

The concept of reinforcement of some of the most acute-decline species or their populations, with more *rust-resistant wild-origin genotypes*, is technically feasible. This does not differ in principle from existing translocation reinforcement programs for threatened species – although as with those, a careful assessment of ecological, genetic, and social risk factors is essential. Affected species that show strong variation in resistance and susceptibility within and between populations, are more likely in principle to be amenable to inter-populational reinforcement strategies.

Resistance breeding and/or engineering of resistant genotypes, and their diffusion back into wild populations (or re-introduction where these are no longer extant), are also technically feasible, but more socially and ecologically problematic. There are however global precedents for this approach in pathogen-threatened plant species, that have provided a model for addressing both the technical and social issues. In particular, the conceptual model for the re-establishment in the wild of a cross-bred American Chestnut, resistant to the Chestnut Blight fungus, (summarised in Jacobs *et al*. (2013), provides both an outline of the issues, and a model for addressing them, that has high applicability to the Australian Myrtle Rust challenge.

Both transgenic (cross species) breeding for trait transfer, and (especially) genetic engineering are contentious topics in Australia, although the debate has to date been concerned almost exclusively with production-sector crops and animals and the socioeconomic context of their deployment. The development of a dialogue about the potential applicability of either technique for conservation purposes, directed at preventing extinctions and ecological decline, will not be easy. For the biodiversity conservation sector these are uncomfortably interventionist techniques, with less problematic approaches to be preferred. The latter may be practical for many species in the intermediate impact category, but are unlikely to be so for some severe-decline species. There will in some cases be a stark choice between highly interventionist techniques (assuming the groundwork for these has been laid), or acceptance of extinction. Dialogue, contingency planning and research on *all* options would be the only prudent course.

As a practical matter, genetic modification techniques to date have been expensive and time-consuming. They require laboratory infusion of the modified DNA into cells or tissue, and then tissue culture to rear these into viable plants. These then need to be grown on for testing for the desired new trait, or at a later stage for planting. For woody plants, this slow process is a major problem. A recently developed technique allows direct and minimally invasive transfer of modified DNA into the adult plant reproductive cycle. 'Magnetofection' is the infusion of exogenous (engineered) DNA segments, loaded with magnetic nanoparticles (Fe_3O_4, iron oxide). directly into pollen grains by movement through an applied magnetic field. The DNA fragments pass through the grain pores and internal membranes, and is incorporated into the haploid genome. Treated pollen is then applied manually to target flowers, and the resulting seed contains the modified genes. Further rounds of reproduction are still necessary to achieve pure lines. For species with suitably configured pollen pores, the technique is simple and fast. It is also capable of multi-gene transfer.

The translocation of wild resistant genotypes, or reintroduction of modified genotypes are both medium- to long-range possibilities, and both require extended consideration and preliminary research. Each could play some part as paths back from the brink of extinction for some Myrtle Rust-devastated species. In either case, the preservation (now!) of a wide range of germplasm either in the wild or in tissue banks, is a prerequisite for maximising the available options.

A five-track process is recommended to refine the strategies and issues involved in potential species and ecosystem recovery:

- Assessment of phylogenetic knowledge in the Myrtaceae, to remedy knowledge gaps;
- Basic research on major and multi-gene resistance, constitutive and inducible R-traits, and the prospects for manipulation of genotypes in species of conservation concern;
- Silvicultural selection and breeding for resistance in selected species of environmental significance, informed where possible by existing and parallel genetic and genomic research;
- Exploratory scoping studies into the technical, logistical, and social aspects of reintroduction of resistant genotypes to the wild;
- Scoping studies of other options for management (biocontrol and other).

For eventual research on all tracks, supplies of adequately representative and authenticated germplasm are a pre-requisite if maximum conservation benefit is to be derived (see Recommendations, Objective 4.1, below).

6.6.10 Biosecurity and containment

See Theme 5 Objectives and Actions in Section 8 (Recommendations) below.
Two key national-interest factors are involved:

- Strengthening of national and regional biosecurity and response arrangements against other strains of *Austropuccinia psidii*, and monitoring of emerging genetic variation in Australia.
- Maintenance of domestic biosecurity relating to *Austropuccinia psidii*.

The mode of arrival of *Austropuccinia psidii* in Australia, and in most other areas it has invaded, is unknown. This can lead to a certain fatalism of approach – "I want to be able to tell Estimates that there has been no breach of specific biosecurity rules". The level of threat posed to Western Australia, and to Australia as a whole from eucalypt-associated strains of the pathogen, warrant a serious review and full-node analysis.

PART 7: PLANT PATHOGENS – AN EMERGING THREAT TO WILD BIODIVERSITY IN A GLOBALISED WORLD

Australia's perceptions of the threats to our native biodiversity have evolved in recent decades, reflecting both rapidly improving scientific understanding of those threats, changing public valuation of the environment, and a growing body of policy and investment by government.

However the overall analysis of these environmental threats remains conceptually somewhat narrow, focussed on the 'classical' troika of habitat clearing and fragmentation, feral pests (primarily vertebrate), and environmental weeds. The latter two are often aggregated under a heading of 'Invasive Species', and this is often explicitly stated to include 'diseases' as a distinct category, but rarely with much elaboration. The main conceptual addition to the environmental 'threats' analytical framework in the last two decades has been climate change, both as an aggravating factor for most proximal threats, and as a broad-spectrum threat in its own right. The exploration of 'diseases' (pathogenic invasive organisms) as a distinct and emerging set of environmental threats has had considerable play in general biosecurity circles worldwide, and is routinely addressed in general terms in Australian biosecurity policy, but has had very little study and elaboration within Australia by the environmental sector itself.

Australia's peak policy document for biodiversity conservation, *Australia's Biodiversity Conservation Strategy 2010–2030*, for example, rests for its meta-analysis of threats to terrestrial biodiversity on three main precursors:

- the 'Australia State of the Environment 2006' Report (Beeton et al. 2006),
- 'A national approach to biodiversity decline' (Biodiversity Decline Working Group 2005);
- Australia's biodiversity and climate change: a strategic assessment of the vulnerability of Australia's biodiversity to climate change (Steffen et al. 2009).

Each of these documents presents sophisticated thinking about the threat matrix, and each acknowledges exotic pathogens as part of it. However, none of them presents any (terrestrial) examples other than the two best-known and already fully naturalised cases. 'Dieback caused by the root-rot fungus (*Phytophthora cinnamomi*)' was listed as a Key Threatening Process under the *Environment Protection and Biodiversity Conservation Act* 1999 (EPBC Act) in 2000, and 'Chytridiomycosis (amphibian chytrid fungus disease)' was listed as a Key Threatening Process under the EPBC Act in 2002.

In none of these foundation analyses is any implication drawn from those two prior cases, that certain broad-spectrum pathogens (i.e. pathogens with the potential to affect many native species) may constitute a particular class of threat process, distinct in some respects from other invasive species categories. The proposition is advanced here that the threat from such pathogens does require a distinct and more complex level of preparedness and response. Microbial invasive organisms, especially pathogens not obligately dependent on an exotic vector, are more difficult to exclude from Australia, and less easy to detect, contain or eradicate once naturalised. In some cases, they have a greater potential (than other classes of invasive organisms) to cause simultaneous declines or extinctions in many native species in a short time frame. Detailed scoping of the potential further threat from such pathogens is not specifically identified as a need in any of these documents. Neither do these documents evaluate the preparedness of the environmental agencies for this class of invasive organism.

The above observation is not to detract from the importance of those documents in other respects, but the relative lack of attention that they gave to the pathogens threat has, together with longstanding institutional and investment settings, helped to perpetuate an unpreparedness in the environmental agencies in respect of policy, planning, and expertise for this class of invasive organism. Biosecurity, including environmental biosecurity, has traditionally been funded and run via primary industry agencies. Funding streams have been disproportionately slanted towards economic species, and funding capacity for the environmental side has not been developed. Expertise on pathogens has traditionally rested with primary industry bodies agencies and with universities, not with the environmental agencies (except, after many years of slow development, for the two pathogens noted above). In the absence in these foundational documents of any scoping, other than at a general level, of the potential impact of pathogens on native biodiversity, there was no internal mechanism to drive later biodiversity policy into a more proactive and anticipatory approach, and not enough cross-over with the plant and animal pathology sector to provide a corrective flow of knowledge.

There had however been early warnings of the looming threat to biodiversity posed by broad-spectrum pathogens for some years. The Australian Academy of Sciences (1996), in the context of a general review of quarantine arrangements, noted that:
"To date, Australia has been fortunate in that few introduced diseases have moved on to native Australian species: *Phytophthora cinnamoni* in Western Australia is a major exception. A number of exotic diseases are known that will attack Australian native species. These include various diseases of Myrtaceous species that will attack Australian species in the same family. A particularly good example is that of *Puccinia psidii* (guava rust) which attacks a range of eucalypt species growing in plantations in Brazil and other South American countries. In those situations epidemics of the pathogen cause substantial defoliation. In South-East Asia, several canker diseases, unknown in Australia, have been found in plantations of *Eucalyptus camaldulensis*. In some plantations in Vietnam the effect of these is so great that plants are reduced from a forest tree to a multi-stemmed mallee form. None of these pathogens currently occur in Australia but their arrival could have substantial and irreversible effects on natural communities."

Yet even as late as 2005, in a global review of the theoretical mechanisms of disease-induced extinction, de Castro & Bolker (2005: 120) found that "There are very few cases where disease has been implicated as the direct cause in the global extinction of a species … In fact, we have found no examples of the complete extinction of a species in the wild which can be attributed to a pathogen with certainty." They did however note "from the empirical literature" numerous cases in which "disease has either threatened species or driven local populations extinct. … We have found only a single recent reference to a plant species threatened with extinction by a disease. The Florida torreya (*Torreya taxifolia*) suffered a severe population reduction during the 1950s, probably as a result of a fungal disease (Schwartz et al. 1995). The present population is composed of small, sexually immature trees, not producing seeds. All the models applied to its population dynamics predict the extinction of the species (Schwartz et al. 2000). Two other plant pathogens have also caused dramatic and widespread declines in their hosts: the chestnut blight (*Endothia parasitica*) … and the Dutch elm disease (*Ophiostoma ulmi*)."

Smith et al. (2006) interrogated both available literature and the background documentation to the IUCN Red List of Threatened Species. They found that "infectious disease was listed as a contributing factor in <4% of species extinctions known to have occurred since 1500 (833 plants and animals) and as contributing to a species' status as critically endangered in <8% of cases." However they also identified 'temporal' problems (largely a lack of baseline data against which to assess declines, plus the recent nature of many apparent cases of emerging infectious diseases), and methodological problems (lack of resolution of threat factors) in the IUCN list of the day.

An accumulating body of global work has since pointed to a growing likelihood of extinctions as a result of invasive pathogens, particularly fungal diseases with a broad host range.

Fisher et al. (2012), reviewing emerging fungal and 'fungal-like' threats to animal, plant and ecosystem health on a global basis, noted recent cases of exceptionally severe impacts from such pathogens on a variety of plant and animal groups. They concluded that "the lack of disease-related IUCN red list records is due to a lack of baseline data on the incidence of pathogens in natural systems compounded by inadequate disease diagnostics, reporting protocols and a lack of centralized recording mechanisms. Hence, the true numbers of extinctions and extirpations caused by fungi and oomycetes are likely to be greater as we have not been able to categorize the probably high levels of species loss in major plant … or animal outbreaks. … fungi remain the major cause (65%) of pathogen-driven host loss after this correction. Our estimates are probably conservative owing to the cryptic nature of most disease-driven species impacts.".

As reports continued to accumulate of the involvement in species declines and extinctions of emerging infectious diseases (EIDs), particularly those caused by fungal or 'fungus-like' pathogens, a strong correlation emerged with global change factors of recent origin. These included in particular the accelerated level of 'globalisation' of trade and the volume and speed of international movement of people and goods since about 1995, and the legacy of a century of forest plantation tree movements (Wingfield et al. 2001). Bebber (2015 – for general crop pests and pathogens) and Helfer (2014 – specifically for rusts of crops and wild species) attempted reviews of the potential trajectory of plant pathogens under global change, both generating rather more unknowns than knowns.

Graça et al. (2013) itemised some of the most concerning cases: "Examples of emerging infectious diseases of woody plants as a result of pathogen introduction include Dutch elm disease caused by *Ophiostoma* spp. (Brasier 2001), chestnut blight caused by *Cryphonectria parastica* (Anagnostakis 1987), dogwood anthracnose caused by *Discula destructiva* (Carr & Banas 2000), pitch canker caused by *Fusarium circinatum* (Gordon et al. 2001), white pine blister rust caused by *Cronartium ribicola* (Kinloch 2003), and sudden oak death caused by *Phytophthora ramorum* (Greunwald et al. 2012)."

Focussing on rust fungi, Stewart et al. (2017) noted that "The movement of pathogens has increased due to the importation of wood products and live plant trade (Wingfield et al. 2001; Stenlid et al. 2011; Santini et al. 2013; Roy et al. 2014). As obligate pathogens, rust fungi are likely moved via live plant materials and their pathways of entry can elude the detection of infected plant materials, especially those with latent stages of infection (Rossman 2009)." … "Prevention of introduction and detection/eradication before establishment occurs is arguably the best measure for reducing damage from invasive rust pathogens (Santini et al. 2013; Roy et al. 2014)."

A particular threat to Australia relates to exotic-origin pests and diseases of *Acacia* and eucalypt species. Burgess & Wingfield (2017) examined emergent eucalypt pathogens overseas, and concluded that "vigilant biosecurity is required to protect the biodiversity of native forests and the sustainability of eucalypt plantations", the latter including (at 2008) some 20M ha of trees. Plantation at this scale represents not only a huge investment in wood products, but also a substantial part of the developing carbon trading economy. Burgess & Wingfield (2017) consider seven scenarios: " (1) native pathogens in native forests, (2) introduced pathogens in native forests, (3) introduced pathogens in exotic plantations, (4) host shifts where endemic pathogens have adapted to infect exotic plantation trees, (5) native pathogens in native plantations in Australia, (6) introduced pathogens of exotic plantation trees moving into endemic forests outside Australia, and (7) introduced pathogens in native eucalypt plantations."

A daunting range of exotic and potentially broad-spectrum plant pathogens are of particular environmental concern to Australia and its neighbours. These include strains of the bacterium Xylella

(*Xylella fastidiosum*), the oomycete Sudden Oak Death (*Phytophthora ramorum*), several forms of the fungus Ceratocystis (*C. fimbriata* and several recent segregate species), and a number of mutualisms of Australian host plants grown overseas (notably *Acacia* species) with exotic insect pest and pathogen partners, with potential for these to arrive together in Australia. These are tips of the iceberg.

The degree to which Australia mounts an environmental response to Myrtle Rust – successful in part, or not – will largely determine our future preparedness for these and other future threats to our unique natural heritage.

PART 8: RECOMMENDATIONS

Recommendations made here have been informed by many colleagues and collaborators in Australia and New Zealand, including participants in an expert workshop held in Canberra in December 2017, funded by the Plant Biosecurity CRC and the Commonwealth Government's National Environmental Science Program.

The recommendations made in this review have a level of implementational detail, some elaborated in the recommendations themselves but for the most part in Section 6.6 above. This implementational detail is recommended for eventual consideration by the agencies that will be key stakeholders in any coordinated environmental response to Myrtle Rust, and by other stakeholders seeking to contribute to such a response.

That implementational detail is however provisional, and is not an optimal part of the essential first step in *gaining momentum* towards such a coordinated response, via a conceptual action model suitable for consideration by the key agencies. Accordingly, a 'higher-level' document (*Myrtle Rust in Australia – a draft Action Plan*) has been developed for a public consultation phase, and is published by the Plant Biosecurity CRC separately but adjunct to this review. That draft Action Plan is the result of a synthesis of the main recommendations of this review with input (gratefully acknowledged) from colleagues in the Plant Biosecurity CRC, the Commonwealth Department of Environment and Energy, and the Queensland Department of Agriculture and Fisheries.

Two overarching recommendations are made here, with subordinate recommended actions grouped under five 'themes' grouping related actions to the degree possible, while recognising that many actions are interdependent across themes:

Overarching recommendation 1: **Establish momentum, funding and leadership for a coordinated national environmental response to Myrtle Rust**

- *Theme 1: Enabling the response*
- *Theme 2: Awareness and engagement*

Overarching recommendation 2: **Adopt a coordinated and long-term national environmental response to Myrtle Rust**

- *Theme 3: Impact assessment*
- *Theme 4: Towards recovery*
- *Theme 5: Biosecurity*

The overarching recommendations, themes, numbered Actions, and priority levels, are all as presented in the separate draft Action Plan. Not all subordinate comments, implementation recommendations, and suggested sub-actions made here are included in the draft Action Plan, but are offered to inform discussion of it, and hopefully assist its adoption and implementation.

A careful mapping of stakeholders to themes and actions is strongly advised. It is not anticipated that biosecurity and environment agency players have as yet an adequately developed understanding of, or linkage to, the potentially active stakeholders who could be brought into play in support of a coordinated environmental response. Close liaison in this respect is recommended with those non-government organisations and working alliances which have played a proactive and largely autonomous role in relation to Myrtle Rust awareness and information flow to date, including the Myrtle Rust Environmental Impacts Working Group, the Australian Network for Plant Conservation, and the Invasive Species Council.

Overarching recommendation 1: Establish momentum, funding and leadership for a coordinated national environmental response to Myrtle Rust

THEME 1: ENABLING AN EFFECTIVE AND COORDINATED NATIONAL RESPONSE

OBJECTIVE 1.1: ESTABLISH AND RESOURCE LEADERSHIP

Action 1.1.1: Establish and resource an interim steering and liaison committee
(HIGH priority, Year 1)

Comments and implementation:
An effective and coordinated response to the environmental threat posed by Myrtle Rust requires leadership from across government environmental agencies. It also requires a whole-of-government commitment to allow coordination with, and expertise to be drawn from, other agencies. The threat of biodiversity decline and ecological loss posed by Myrtle Rust impinges on several areas of government responsibility.

Arrangements will undoubtedly evolve as a response takes shape, but an essential first step is to establish an interim coordination body with lines of reporting and liaison within the environmental apparatus of governments, and with involvement and cooperation of other key agencies. Myrtle Rust has previously been reported via primary industry and biosecurity inter-agency channels, through senior officer to Ministerial Council level when that still existed, but has not to date had a similar line of reportage on the agendas of corresponding inter-agency senior officer bodies on the environmental side of government (currently the Environmental senior Officers Group, ESOG). Such a line of reportage is recommended as essential for the development of a specifically environmental response.

The environmental response also requires consistent outreach to, and dialogue with, key non-government stakeholders, either directly or through secondary channels.

OBJECTIVE 1.2: ESTABLISH A COLLABORATIVE RESPONSE

ACTION 1.2.1: Secure engagement and commitment from key stakeholders to the environmental response
(HIGH priority, ongoing)

Comments and implementation:
An effective response to the environmental threat posed by Myrtle Rust requires engagement and commitment of expertise by key relevant stakeholders. These include government environmental agencies, natural resource management bodies, the non-government environmental sector, research institutions, the biosecurity apparatus, primary industry agencies and corporate bodies.

Much of Australia's plant pathogen expertise resides in primary industry agencies and corporate bodies, and some universities, which have informed the general biosecurity response since 2010 and have generated most of the limited research on environmental impacts to date. Their continued engagement in a developing environmental response is crucial. The continued availability of research staff expertise and time from primary industry agencies, for research in progress and to guide the formation of wider research and monitoring programs, is essential.

Direct involvement of, or very close liaison with, certain non-government stakeholders with a key potential role in implementation of a response strategy is recommended, including the Australian Seed Bank Partnership (ASBP) for germplasm issues, one or more of the non-government organisations involved with awareness and information flow since 2010 (e.g. Australian Network for Plant Conservation; Invasive Species Council), and key professional bodies (e.g. Ecological Society of Australia, Australian Systematic Botany Society, Australasian Plant Pathology Society, Botanic gardens Australia-New Zealand, and others).

OBJECTIVE 1.3: ESTABLISH FUNDING ARRANGEMENTS

ACTION 1.3.1: identify funding needs and options
(HIGH priority, Years 1-3)

Comments and implementation:
A coordinated and comprehensive environmental response to Myrtle Rust will require dedicated, directed and discretionary resourcing to ensure priority research and actions in a timely manner, and to complement existing sources of competitive funding. Industry levies help to fund biosecurity and research and the development of responses to invasive pathogens in the agricultural sector. Equivalent levy-based sources of funding do not exist for research and actions in the environment sector.

Funding allocation for some high priority areas needs to include a salary component for additional staff. For example, the conservation seed banks grouped under the Australian Seed Bank partnership are already committed to staff capacity, and simple project funding will not help meet the need for seed collection, storage enablement, and testing.

Attention should also be given to the development of innovative funding mechanisms, alongside dedicated government funding, particularly as public awareness grows of the threat to Australia's natural heritage. Joint government-private-public foundation or trust models should be actively investigated to support aspects of the response that are not easily covered from other sources. North American (and other) models for such entities, and their potential effectiveness in addressing species and ecosystem decline and recovery, should be assessed for applicability to the Australian Myrtle Rust situation.

OBJECTIVE 1.4: EXPEDITE LEGISLATIVE MECHANISMS

ACTION 1.4.1: Expedite listing of species and ecological communities at serious risk from Myrtle Rust
(HIGH-MEDIUM priority, ongoing)

Comments and implementation:
The rapid environmental impacts of Myrtle Rust have outstripped Australia's legislative extinction-risk assessment systems. Amongst the species now in severe decline are species that are unlisted or were non-threatened up until this point.
In the absence of coordinated monitoring, and of quantitative baseline information, many species at risk remain 'data deficient' for optimal extinction-risk assessment, even though in many cases Myrtle Rust impact and decline are known or strongly suspected. Baselines for impact assessment can be retrospectively established where pre-existing permanent plots or transects exist (see recommended Action 3.2.2 below), or where high reliability information can be provided from other sources (see recommended Action 2.1.2 below)

Identification, prioritisation, and funding of impact assessment and conservation actions for the species most affected by Myrtle Rust should not be based on or limited to pre-existing listing status, although that is one factor for consideration. Nevertheless, formal extinction-risk assessment and listing, where necessary on a precautionary ('projected decline') basis, remain important instruments. The assessment and listing of species at severe risk from Myrtle Rust will assist in tracking impact, mobilise the gathering of data, raise awareness, mandate research and conservation actions, assist in establishing Myrtle Rust in the thematic prioritising of competitive grant schemes, and assist external (non-government) fundraising to support conservation actions.

ACTION 1.4.2: Consider other expedited instruments to focus on the threat of Myrtle Rust
(HIGH priority, ongoing)

Comments and implementation:
The legislative recognition of environmental 'key threatening processes' is provided for in some but not all jurisdictions. Alternatives include advice statements to Ministers, and policy and strategy statements. This Plan recommends consideration of expedited adoption of instruments of these sorts to recognise the Myrtle Rust threat and establish a momentum for planning and skills sharing and development, among key responders. These instruments also contribute to raising the level of public and sectoral vigilance and monitoring for Myrtle Rust and its effects, and to priority setting for research and its funding bodies. They provide an additional mandate for conservation actions and seeking external (non-government) funding to support them. Such instruments also help focus public awareness on the environmental biosecurity in general.

Where environment agencies are in a position to advise on the thematic deployment of competitive-grant or discretionary conservation research and action funding, it is recommended that consideration be given to promoting the setting of Myrtle Rust issues as an eligible objective, without limitation of eligibility to already-listed species/communities.

Conservation and heritage Management Plans for severely affected areas should be evaluated for any necessary changes in the light of the Myrtle Rust threat, and necessary codicils added unless plan review is pending in the near future. This applies particularly to such plans for World Heritage Areas and conservation regions in north-eastern NSW, south-eastern Queensland, and the wet Tropics.

THEME 2: AWARENESS AND ENGAGEMENT

OBJECTIVE 2.1: MAXIMISE SOCIAL COMMITMENT TO AND PARTICIPATION IN RESPONSE

ACTION 2.1.1: Raise awareness of Myrtle Rust and the environmental response
(HIGH-MEDIUM priority, Ongoing)

Comments and implementation:
The potential impacts of Myrtle Rust on social and cultural values have not been addressed in Australia to date. Three areas of potentially serious social impact from the 'pandemic strain' of the disease are apparent:

- The loss of species and ecological elements, especially in the context of World Heritage Areas and the conservation reserve system;
- Indigenous cultural impacts, on landscape and species values and utilities, and on Indigenous economic enterprises;

- A potential for loss of faith in, and commitment to, Australia's biosecurity and conservation systems, if a vigorous national environmental response is not mounted.

Increased public and key sectoral awareness of Myrtle Rust will aid vigilance, reporting and monitoring efforts, and the pursuit of wider funding sources for essential research and conservation actions. It will also complement and support the stronger national emphasis on environmental biosecurity awareness recommended in the Priorities for Australia's biosecurity system report of 2017. We should take advantage of the rare 'good news' stories to support the holistic response, for example, the early detection and apparently successful eradication of Myrtle Rust from Lord Howe Island in 2017.

Given that the mode of arrival of the pandemic strain of *A. psidii* in Australia remains unknown, increased public and sectoral awareness of the risk posed by further introductions of other strains of sub-strains of the pathogen will assist exclusion measures.

ACTION 2.1.2: Engage key non-government stakeholders in the response
(HIGH priority, ongoing)

Comments and implementation:
In order to raise awareness of Myrtle Rust most effectively, it will be important to pay close attention to key stakeholder sectors as well as taking a 'general public' approach. The environmental response should take full advantage of the existence of strongly motivated and appropriately skilled sectoral interests in the non-government area, with a strong stake in an effective environmental response to Myrtle Rust. These include conservation non-governmental organisations, expert native plant growers, foresters, natural resource management bodies, World Heritage Area management and stakeholders, parts of the scientific community and their professional organisations, the environmental and ecological consultancy sector, and other commercial and community sectors (e.g. bush regeneration bodies) with relevant expertise and interests.

Such bodies may play a key role in data-gathering, and in awareness and skills transfer to support professional, para-professional and citizen science contributions to the vigilance and monitoring efforts.

There is potential for certain professional bodies to act as convenors or moderators of any necessary preliminary scoping studies (e.g. to determine costings, priorities, and optimal collaborations within the recommended research programs), or to advise on overall progress of the environmental response. They may also play an important role is supporting the development and profile of novel funding mechanisms to support the response. Organisations with potential in these respects include, but are not limited to, the Australian Academy of Science, the Australasian Plant Pathology Society, the Ecological Society of Australia, among others.

ACTION 2.1.3: Seek Indigenous stakeholder input and participation in the response
(HIGH priority, Year 1 and ongoing)

Comments and implementation:
Myrtle Rust impacts are highly relevant to Indigenous people and communities in the regions of risk. Decline due to Myrtle Rust can affect cultural heritage values, continued traditional practices, and indigenous enterprises, particularly those based on bush product production and ecotourism. Myrtaceae species continue to be used by Indigenous peoples in most parts of Australia, not just those in traditional and remote areas, for food, medicine, and other social uses – they form part of the continuing cultural life of those communities. Natural landscapes and vegetation types, and

their constituent species, are valued for the traditional stories and continuing custodianships with which they are associated – declines in their integrity have a particular cultural dimension of loss. Many Aboriginal-run enterprises are based on natural native-plant products, or incorporate them in their tourism and educational service activities. Indigenously owned or controlled lands are a major part of the landscape matrix for some areas of current and projected Myrtle Rust occurrence.

Recommended sub-actions include:

- A briefing program for relevant Aboriginal and Torres Strait islander organisations, researchers, and environmental managers, key Indigenous advisory panels, NRM/EA Indigenous network meetings, and peak regional and other bodies as appropriate. Briefings should cover the known and potential environmental impacts of Myrtle Rust, hear Indigenous views on proposed response elements, seek their guidance on (and at local levels involvement in) monitoring programs, and to strengthen lines of communication on the environmental response. Report-back mechanisms should be established to the national steering and liaison group (when established) and other environmental response peaks.

- Ensure Indigenous stakeholder prior awareness and approval of, and where appropriate involvement in, ongoing Myrtle Rust research and its outcomes, especially ecological impact research in rainforest, Melaleuca wetland, and coastal heath biomes, and in the monsoon tropics and south-western Australia if the disease establishes in those regions.

- Ensure research and field action project personnel under any integrated response are acquainted with guidelines on cultural and land-access protocols for areas and species concerned.

- Seek agreement of Indigenous peak organisations and relevant key stakeholder to facilitate a flow of knowledge and concerns to and from Indigenous communities and enterprises that may be impacted by Myrtle Rust.

- Review relevant domestic and international cultural engagement models with applicability to Myrtle Rust engagement, including Hawaiian and New Zealand examples.

Overarching recommendation 2: Adopt a coordinated and long term national environmental response to Myrtle Rust

THEME 3: IMPACT ASSESSMENT

OBJECTIVE 3.1: ESTABLISH INFORMATION HUB/S AND DATA VALIDATION PROTOCOLS

ACTION 3.1.1: Establish a Myrtle Rust data hub and one or more information repositories.
(HIGH priority, Year 1 & 2)

Comments and implementation:
Communication and information flow have been major problems in movement towards an integrated environmental response to Myrtle Rust since 2010. Myrtle Rust information is currently fragmented between specialist journals, government agencies (not all is on websites), individual researchers, and field ecological managers. Lead (primary industry) agency websites contain much good material but in some States it is increasingly static and becoming outdated. The national host list is audited, maintained and published by an unofficial and un-resourced linkage group of scientists and an NGO.

No single agency or other information repository is currently equipped to receive, validate and store the range of information needed for a fully informed environmental response to Myrtle Rust. An effective and integrated impact survey and monitoring program needs a clear line of reportage and reporting standards (see next Action), and a capacity to quality-check and forward incoming information. An information clearing house is needed, capable of receiving, validating, storing and disseminating the full range of incoming data and images resulting from impact monitoring and new host reporting. This information would include disease incidence and severity data, and host species ecological and demographic data and images. The information clearing house needs to be able to interact with related and complementary biodiversity and pest data systems.

A single information repository is not necessarily optimal, especially if based in government where websites and their servicing are subject to high churn. A polycentric approach for the permanent storage of information may be preferable, as long as nodes are serviced, linked, and accessible. It is recommended that the lead body for any coordinated national environmental response takes early consideration of communication problems and the need for some support funding to service and strengthen existing hubs.

OBJECTIVE 3.2: ASSESSMENT OF MYRTLE RUST IMPACT ON PRIORITY SPECIES

ACTION 3.2.1: Standardise impact assessment methods and monitoring protocols
(HIGH priority, Year 1)

Comments and implementation:
Protocols for recording Myrtle Rust incidence, severity and symptomology are well established but not yet widely promulgated outside specialist circles. The additional host plant demographic and ecological data requirements are likewise straightforward but not yet codified. A synthesised set of protocols, adaptable for both professional and skilled non-professional use (separate modules may be desirable), is a prerequisite for effective impact monitoring and assessment. It is not proposed that this should preclude differing protocols for specialist research, but compatibility of data, to the

extent possible, should be a priority for all parties. Similarly, interchange compatibility with general pest, vegetation condition, and native species reporting systems (e.g. AusPestCheck and state environment monitoring systems) must be ensured.

Development and promulgation of core protocols is a 'low hanging fruit' action that with a small allocation of resources could be undertaken quite quickly and easily under the guidance of key stakeholder groups.

ACTION 3.2.2: Identify most effective potential monitoring sites
(MEDIUM priority, Year 1-3)

Comments and implementation:
Assessment and monitoring of Myrtle rust impact and declines, and survey for resistant plants, requires a combination of a systematic approach and 'opportunity knocks' observations. Assessment of decline requires a pre-Rust or present-day baseline; the most time-effective monitoring will also, where possible, use sites where multiple target species are closely co-located. These elements of a systematic approach are best achieved by pooling and analysis of potential best monitoring sites from pre-existing permanent plot/transect data and other species occurrence records, currently held in environment and forestry agencies, World Heritage and NRM organisations, herbaria, CSIRO, and some local government bodies. Integration of selected sites into existing agency and citizen science monitoring programs, to extend the reach of the monitoring effort, is recommended where feasible.

ACTION 3.2.3: Rapid field surveys
(VERY HIGH priority, Year 1-3)

Comments and implementation:
Few of the species known or suspected of being at serious short-term risk of decline from Myrtle Rust have been surveyed fully and systematically for rust impact, possible resistant populations, and germplasm collection. Forty-five species are recommended as priorities for systematic field assessment, to enable more informed conservation actions and adjustment of priorities: four on an emergency basis, twelve on an urgent (Year 1) basis, and 29 on a medium priority basis (years 1-3). These species are the same as listed under Action 4.4.1 (Germplasm capture) below.

Non-government and citizen science monitoring and vigilance efforts are a crucial extension of government capabilities in risk areas not yet affected by Myrtle Rust. Within affected areas, citizen science contributions in infected areas may provide valuable data beyond the scope of government monitoring programs, and have already done so, for both high and lower priority species which may nevertheless be undergoing cumulative decline. Citizen science network development should focus on groups and individuals of likely high skill and reliability, to ensure quality data. For the most part these will be among the following groups: staff of environment and NRM agencies and some local councils; eco-consultants; bush regeneration businesses and community groups; some staff and volunteers at regional botanic gardens; some members and interest groups in native plant societies; and some independent professionals in bush-related disciplines and employment. The potential east coast network of likely reliable people in these categories runs into the hundreds. Activation of this network has been hindered by the lack of monitoring standards and tools, a responsive central reporting point and data repository, lack of a coordinated environmental response (see other recommended Actions). Long-term stability and continuity of any CS program is essential.

ACTION 3.2.4: Undertake quantified field impact and resistance studies
(HIGH priority, Ongoing)

Comments and implementation:
Fully quantified studies of species and ecosystem effects (e.g. Carnegie et al. 2016, Pegg et al. 2017), have been central to the current state of knowledge of Myrtle Rust impacts, are highly desirable for identifying conservation actions and priorities (particularly if they cover the whole of a species range), and bolster the high data requirements of extinction-risk listing assessments. They also lend themselves to eligibility for competitive research grants and, sometimes, student projects, although the latter rarely allow for the necessary extensive field work, and impose a time frame and learning curve that does not accord with the need for action on fast-decline species. To the extent that progress can be made on funding from those sources, fully quantified studies on selected species may not compete for funding with the rapid status surveys recommended above. Exceptions (if not funded from elsewhere) are the multi-species and ecological research programs recommended below (Action 3.3.1). Open-round funding sources should be encouraged to set Myrtle Rust effects as a theme, and to require successful applicants to ensure compatibility with the common data collection protocol and data repository. Actions and projects under this heading may overlap with recommended ecological research programs (Theme 4).

Detailed research on Myrtle Rust's progressive impact on individual species is valuable, but is unlikely to be feasible for each of the large number of species involved. However, selected species studies should be supported for exemplar species in several groups. For example, these could shed light on differential resistance to disease at sub-specific levels, gauge the risk to keystone ecological species (such as Broad-leaved Paperbarks), or provide generalisable models in other groups.

OBJECTIVE 3.3: ASSESSMENT OF MYRTLE RUST IMPACT ON ECOLOGICAL COMMUNITIES AND FUNCTION

ACTION 3.3.1: Continue and expand research programs in priority ecosystems
(HIGH-MEDIUM priority, Year 1-2 and ongoing)

Comments and implementation:
Ecological communities with high proportions of susceptible Myrtaceae and suitable climatic conditions have the highest potential for loss of ecological function due to Myrtle Rust impacts. Three ecological systems are here recommended for dedicated research programs (multi-project). Ecological research in these communities will accumulate impact and resistance data for multiple host species, and will help to anticipate the effects that rust-mediated decline of host species may have on other flora and fauna. It will also provide a broad evidence base for ecosystem-level planning for Myrtle Rust impacts.

Priority ecological systems as at 2018 are east coast rainforests, coastal heath/woodlands, and *Melaleuca* wetlands.

It is recommended that discretionary and directed funding be made available for the scoping and implementation of these programs and for overall coordination within and between them. A multidisciplinary approach is recommended, encompassing plant health, plant ecology, Myrtaceae-associated or dependent flora and fauna, and broader ecological considerations such as hydrology or ecological niche closure. Interdisciplinary scoping will be necessary to identify optimal collaborations and critical elements.

Construction of optimally detailed and costed proposals for each requires the input of multiple experts in a moderated process within a time frame driven by the needs of each case. It is recommended that an initial funded process occur, of expert and key stakeholder workshops and consultation, to refine the concept of each program and ensure appropriate content and collaborative input. It is suggested that convenorship for these scoping studies be based outside departmental structures. The need for a social and Indigenous cultural dimension to the scoping and implementation of each research program (see Actions 2.1.1, 2.1.3) is stressed.

A Melaleuca Wetland impact research program should focus initially on *Melaleuca quinquenervia* systems (to dovetail with existing QDAF research), but with extension study of *M. viridiflora* and *M. leucadendra* systems. The program should include:

- screening metapopulations for differential susceptibility;
- securing baseline information on demographics;
- bulk germplasm collection from resistant populations;
- close monitoring of disease behaviour in currently marginal areas of occurrence;
- wetland melaleuca ecology/biology, dependent and associated fauna, herbivore/pathogen interactions, hydrology/aquatic systems, and erosion;
- cultural heritage components (Indigenous and non-); economic impact.

A rainforest impacts research program should address both warm-temperate/subtropical rainforest systems (NSW and south-east Queensland, to dovetail with existing QDAF research), and tropical rainforest systems (Wet Tropics). The program should include:

- screening metapopulations of susceptible species for differential susceptibility;
- a focus on regeneration dynamics as affected by Myrtle Rust and synergistic pressures;
- securing baseline information on species demographics (note the availability of extensive permanent plots and data for both regions of focus);
- assessment of need and opportunity for germplasm capture for ex situ conservation and research;
- assessing potential impacts on rainforest ecology/biology, dependent and associated fauna, and current management systems;
- cultural heritage aspects (Indigenous and non-Indigenous).

A coastal heath and heathy woodland research program should focus on north-east NSW and South-east Queensland. The program should include:

- screening metapopulations for differential susceptibility,
- a focus on regeneration dynamics (especially after fire) as affected by Myrtle Rust and synergistic pressures;
- securing baseline information on species demographics;
- assessment of need and opportunity for germplasm capture for ex situ conservation and research;
- assessing potential impacts on dependent and associated fauna, and current management systems;
- cultural heritage aspects (Indigenous and non-Indigenous).

THEME 4: TOWARDS RECOVERY

OBJECTIVE 4.1: GERMPLASM CAPTURE

ACTION 4.1.1: secure future options for species in current or projected decline through germplasm capture
(VERY HIGH-HIGH priority, Year 1-2)

Comments and implementation:

Decline of species means loss of genetic variation, including distinct genotypes that may be significant for ecological reasons or as future genetic resources. Preservation of genetic variation is a conservation goal; where this cannot be done in the wild, it can be approximated by germplasm capture.

For some species in severe and uniform decline due to Myrtle Rust, germplasm capture is now the only option to avoid the high likelihood of complete extinction. Without germplasm capture, there are no future options for preservation or recovery of such species.

Four species are recommended for **emergency priority** germplasm capture

- *Lenwebbia* sp. 'Blackall Range (P.R.Sharpe 5387)', *Lenwebbia* sp. 'Main Range (P.R.Sharpe+ 4877)', *Rhodamnia rubescens*, *Rhodomyrtus psidioides*

Twelve species known or strongly suspected to be in serious decline on a total or regional basis are recommended as a **very high priority** (Year 1-2) for germplasm capture, concurrent with impact and resistance surveys:

- *Archirhodomyrtus beckleri* (Southern Chemotype), *Decaspermum humile* (South Queensland form), *Eugenia reinwardtiana*, *Gossia fragrantissima*, *Gossia gonoclada*, *Gossia hillii*, *Melaleuca nodosa*, *Rhodamnia angustifolia*, *Rhodamnia dumicola*, *Rhodamnia maideniana*, *Syzygium anisatum*, and *Syzygium hodgkinsoniae*.

These species are recommended for urgent germplasm collection from multiple provenances. Some no longer produce fruits in collectable quantities and will have to be secured as vegetative material for propagation and seed production. *M. nodosa* is likely to have orthodox seeds, and should be collected in bulk as soon as practicable. The remainder are known or likely to have non-orthodox seed, and smaller initial research batches are needed for (as yet unfunded) storage enablement research.

A further 29 species, of high known or suspected susceptibility to Myrtle Rust, and suspected decline but for which there are fewer observations of impact, are recommended for **medium priority** (pre-2021) conservation actions, including some for bulk collection (*Eucalyptus*, *Leptospermum*, *Melaleuca*) and the others for the preliminary capture and testing of at least sample germplasm (seed or vegetative) for storage enablement and germination research (see Action 4.1.2). These species are:

- *Austromyrtus dulcis*, *Backhousia citriodora* (top-up as needed of existing germplasm set), *Backhousia leptopetala*, *Backhousia oligantha*, *Eucalyptus curtisii*, *Eucalyptus andrewsii* (= *E. montivaga*, Mackay region population), *Eucalyptus resinifera* subsp. *hemilampra* (Mackay region population), *Gossia acmenoides*, *Gossia inophloia*, *Gossia lewisensis*, *Gossia myrsinocarpa*, *Lenwebbia prominens*, *Leptospermum trinervium*, *Lithomyrtus retusa* (NT populations initially), *Melaleuca leucadendra*, *Melaleuca quinquenervia*, *Melaleuca viridiflora*, *Melaleuca lophocoracorum*, *Rhodamnia argentea*, *Rhodamnia australis*, *Rhodamnia costata*, *Rhodamnia longisepala*, *Rhodamnia sessiliflora, Rhodamnia spongiosa*, *Rhodamnia whiteana*, *Rhodomyrtus canescens*, *Rhodomyrtus pervagata*, *Stockwellia quadrifida*, and *Syzygium oleosum*.

A further six species, currently just outside the known range of Myrtle Rust but at risk of impact in the near future, are recommended for **medium priority** (2018-20) precautionary collection of germplasm as flagships of the environmental response in World Heritage Areas:

- *Allosyncarpia ternata* (NT, including Kakadu WHA); *Leptospermum polygalifolium* subsp. *howense*, *Melaleuca howeana*, *Metrosideros nervulosa*, *Metrosideros sclerocarpa*, and *Syzygium fullargarii* (the last five all Lord Howe Island endemic species).

The Lord Howe Island species are geographically relatively simple to collect, and all bar *S. fullargari* have orthodox (storable) seed. The medium priority assigned reflects the high risk but current lack of known Myrtle Rust infection. However, an early start with these species, given their WHA context, would be likely to greatly assist the momentum of the overall national response.

Facilitation by response leading bodies of applications for permit variations, to allow greater than normal amounts of germplasm sampling and interstate research collaborations, will be necessary in some cases.

Seed is the most efficient and easiest form of germplasm to gather and store. Many Myrtle Rust affected species have storage tolerant seeds, and capture of representative samples from the wild requires only extra resourcing of the seed banking effort. However, many others, particularly rainforest species, have storage intolerant seeds, and prior research is needed to enable seed storage (see next Action).

Among the species undergoing the most drastic declines due to Myrtle Rust, we know that several are no longer producing seed due to foliage and stem damage and stress. For these species, we have missed the window for seed collection, and we must capture and grow vegetative material from which protected seed production areas can be established later.

In South Australia, Western Australia, Lord Howe Island and parts of the Northern Territory, proactive germplasm capture before Myrtle Rust arrives is recommended as a high priority for the species considered most at risk. This action could be undertaken quite quickly and easily under the guidance of key stakeholder groups. Enough germplasm should be collected and stored to allow for screening, future resistance research, conservation translocation and long-term seed bank reserve.

ACTION 4.1.2: Seed storage-enablement research; determine alternative germplasm storage options for storage intolerant species

(VERY HIGH priority, Year 1 and ongoing)

Comments and implementation:

Many priority species, particularly of rainforests, have seeds known or suspected not to be amenable to normal seed bank storage (storage intolerant or non-orthodox, or just short-lived). Some also have naturally low levels of viable seed. Species by species testing is needed to determine whether storage can be enabled by modified treatment, or to determine alternative germplasm storage options for fully storage intolerant species. This is a prerequisite for bulk germplasm capture and storage for these species – there is no point in large-scale seed banking unless viability and germinability is assured. This enablement research will generally take some months per species , longer than seasonal fruit remains available, so another year can be lost even if storage issues are solved. It also requires moderate initial samples of healthy seed, preferably in the low hundreds, but even this may be unavailable except from cultivation. If no variation on normal seed storage works, other more expensive modes of germplasm capture are necessary if future species recovery options are to be maintained (tissue culture, cryostorage, protected inter-situ live plants). If no seed at all is available, germplasm must be captured via vegetative material and maintained in living collections.

A program of existing research into rainforest seed biology exists at the Australian Botanic Gardens, Mount Annan (NSW), and within existing resources has attempted to prioritise a few non-orthodox or orthodoxy-unknown Myrtaceae species at risk from Myrtle Rust. That program however is at staff-time capacity. This and other Australian Seed Bank Partnership institutions equipped for the same sort of research would need extra salary funds, not just project funds, to expand the range of species under investigation.

ACTION 4.1.3: Inventory of priority Myrtaceae species in botanical gardens and other collections
(HIGH priority, Year 1)

Comments and implementation:
Some species in severe decline no longer produce fruit and seed in the wild in collectable quantities. For these species, authenticated cultivated specimens that can be protected if necessary by periodical fungicidal treatment may represent the only source of seed for storage research, representatives of populational genomes, and for long-term preservation of the species. In extreme cases, these specimens may be the last of their kind in years to come. A national inventory of specimens of priority species in botanical gardens and other public or private collections is required. Resourcing for the maintenance of priority species ex situ holdings should be enabled.

The inventory action could be undertaken quite quickly and easily under the guidance of key stakeholder groups, particularly the *Council of Heads of Australian Botanic Gardens* and *Botanic Gardens Australia New Zealand Inc*.

ACTION 4.1.4: Scope potential locations for ex-situ and inter-situ live plant collections and/or seed production areas
(MEDIUM priority, Year 1-5)

Comments and implementation:
For species where little or no seed is available or which are not amenable to seed storage, seed production programs may be required. For some other species, standing collections of live plants will be useful for resistance research and breeding programs. In both of these cases, host sites with suitable horticultural conditions will be needed, amenable to fungicidal control of rust as necessary. Some regional and metropolitan botanic gardens, universities, and arboreta, if resourced, are among the candidate sites, although hosting need not be limited to existing botanical facilities as long as sites can be serviced and monitored effectively. The potential for commercial and private host-sites, and sponsorship, should be explored. Early development and utilisation a one or a few such sites for progeny sets of the 'emergency' salvage species would be useful and a positive contribution to the momentum of the environmental response.

The scoping action could be undertaken quite quickly and easily under the guidance of key stakeholder groups.

OBJECTIVE 4.2: IMPROVE UNDERSTANDING OF AFFECTED SPECIES

ACTION 4.2.1: Assemble host life history profiles for priority species
(MEDIUM priority, Year 2+)

Comments and implementation:
Substantial botanical and ecological knowledge exists for many of the species at risk, including forestry species. However, this knowledge is fragmented and has not been indexed or assembled. Assembling directories of relevant host-species literature, data references and links will facilitate and expedite research, conservation planning and rapid surveys for Myrtle Rust-affected species (going beyond current priority species). It will also ensure conservation planners not necessarily familiar with the full range of resources will have the fullest possible information to inform decisions.

Target information would include: longevity and reproductive maturity age; recruitment pattern; vegetative reproductive capacity; flowering and fruiting characters and phenology; breeding systems; seed biology data and protocols; seedling images to aid field identification; germplasm alternatives to seed.

This action could be undertaken progressively, if resourced, under the guidance of key stakeholder groups.

ACTION 4.2.2: DEVELOP ONLINE ATLAS OF AUTHENTICATED MYRTACEAE SEEDLING IMAGES
(MEDIUM priority, Year 2+)

Comments and implementation:
In many species, very young seedlings may be particularly vulnerable to *A. psidii* infection (and are known to be so for some species). Seedling identification during field monitoring of impacts (post-fire or not) can be problematic, especially in Myrtaceae-rich vegetation where multiple species are germinating simultaneously. Most printed and interactive plant identification tools are geared to adult plant stages and lack seedling images. Some recent on-line and electronic identification aids for rainforests contain seedling images, but other biomes are deficient. An on-line atlas of downloadable Myrtaceae seedling images for all Rust-susceptible biomes, coupled with lists of species known to occur in particular regions, would facilitate the involvement and accuracy of field monitoring personnel. Crowd-sourcing of images could complement the limited seedling image holdings of the public institutions, subject to expert authentication. State and Commonwealth Herbaria, with staff resource assistance, might be best equipped to initiate, coordinate, and authenticate, with inputs from others as above. A pilot project for a defined regional area (e.g. Border Ranges/Lamington; wallum communities) would allow proof of concept.

OBJECTIVE 4.3: EXPLORE RESISTANCE AND CONTROL

General issues:
A closer understanding of susceptibility and resistance in host species is essential for a meaningful conservation response to Myrtle Rust. Their genetic and physiological bases, and the mix of induced and constitutive resistance traits that exist within some species and between pairs of sister-species in other cases, are potential tools for saving some severely affected species. Some research is in train internationally and in Australia. A large body of work and practice for eucalypts exists. Most genomic and resistance research to date has been on species of economic significance. However, these do not correspond well with the species undergoing the most rapid decline in the wild, with

the possible exception of *Backhousia citriodora* (subject of a resistance selection program for plantation use, but not yet evaluated for impact in the wild).

A research program within an environmental response program focussed on threatened biodiversity is needed. The Myrtle Rust pathogen is now a global problem, and Australian research efforts should be resourced adequately to allow strong international collaborations to develop and be maintained.

ACTION 4.3.1: Assessment of selected species for variation in levels of resistance/tolerance
(HIGH priority, ongoing)

Comments and implementation:
Some significantly affected species are known to have varied levels of tolerance of the disease within or between populations, and others may do so. Initial determination of resistant genotypes can occur through field survey and screening trials. An understanding of resistance variation and its heritability, through screening tests and molecular techniques, will shed light on resistance genetics and physiology. It will also enable an estimation of natural versus assisted regeneration potential, and inform potential selective breeding strategies. There is strong potential for cross-over of environmental and production sector research in this area, but environmental priorities need to be specifically asserted and funded.

ACTION 4.3.2: Augment knowledge of phylogenetic relationships within Myrtaceae
(MEDIUM priority, Year 2-4)

Comments and implementation:
Susceptibility to Myrtle Rust does not have a straightforward relationship with phylogeny (the evolutionary lineages in the Myrtaceae family), but there is partial correlation. Some lines of research also suggest the possibility of phylogenetically correlated resistance gene-complexes, not always expressed, which may inform resistance studies and breeding. Completion and integration of phylogeny for the family in Australia and New Zealand would facilitate targeted research on resistance and its management implications. Tribes recommended for particular focus are Kanieae, Melaleuceae, Myrteae, and Sygygeae. Genera for particular focus include *Archirhodomyrtus*, *Austromyrtus*, *Decaspermum*, *Eugenia*, *Gossia*, *Lenwebbia*, *Lithomyrtus*, *Melaleuca*, *Pilidiostigma*, *Rhodamnia*, *Rhodomyrtus*, *Syzygium*.

ACTION 4.3.3: Review and identify priorities for resistance research
(HIGH priority, Ongoing)

Comments and implementation:
The wide host range of *A. psidii* and the search for better understanding of rust resistance traits and their potential deployment, dictate a spread of research effort across the affected species. Some of the most severely affected species show no patterns of resistance, but close relatives may, and cross breeding or trait transfer may prove to be an option. Other species that are severely but less uniformly affected, and play a key ecological role (e.g. wetland *Melaleuca* species), require resistance research to shed light on whether populations have a natural capacity to reverse decline over time, or require assisted reinforcement with resistant genotypes.

The underlying biology of both the rust and its hosts, and their infective and defensive processes, require parallel research. This should be supported on an internationally collaborative basis – *Austropuccinia psidii* is now a global concern. Dimensions of this basic research include genetic/genomic, metabolomic, physiological, and constitutive and inducible defence traits/processes, and other host-pathogen interactions.

There is strong potential for cross-over of this research area with production sector efforts, but environmental species need their own priority. Specialist scoping is needed to determine priorities and the best lines of investigation.

ACTION 4.3.4: Review and identify priorities for silvicultural selection and breeding for resistance
(HIGH-MEDIUM priority, Ongoing)

Comments and implementation:
The selection and breeding of eucalypt genotypes resistant to *A. psidii* for plantation timber species is well-established in South America. The identification and deployment of such genotypes in other genera, and for conservation purposes in the wild, raises more complex issues (e.g. avoidance of genetic bottlenecking, and ecological considerations) but is feasible in principle and for some species may be the best option. Specialist evaluation of options is needed.

ACTION 4.3.5: Explore potential for novel Myrtle Rust controls through reviews and scoping studies
(MEDIUM priority, Ongoing)

Comments and implementation:
While no quick fix is to be expected, especially for wild plant populations, some lines of potential biological control have been identified in the scientific literature, and others under investigation for other plant diseases may have implications for Myrtle Rust control. These include bacterial, viral, and fungal hyperparasite organisms, RNA interference vaccines, and novel fungicides. Some of these, if developed but unsuitable or impractical for use in the wild, may nevertheless be deployable for Myrtaceae in production systems, and in ex-situ conservation seed production areas.

OBJECTIVE 4.4: EXPLORE REINFORCEMENT/REINTRODUCTION STRATEGIES FOR AFFECTED SPECIES

ACTION 4.4.1: Explore species recovery options for species and ecosystems in decline
(MEDIUM priority, Year 2-5)

Comments and implementation:
For some species in acute decline due to Myrtle Rust, the only likely path back from the brink of extinction will be through translocation or introduction/reintroduction of rust-resistant genotypes, whether these are of wild origin or modified. Translocation is a well-established conservation tool, although success is not guaranteed. There are fewer global precedents for modification of genotypes of wild species as a response to pathogens (e.g. by selection or cross-breeding followed by 're-wilding'), but there are some models and much potential.

Stakeholder consultations and production of an initial issues paper on the ecological, genetic, social and ethical factors of deployment of rust-resistant wild and modified genotypes, are recommended.

THEME 5: BIOSECURITY

OBJECTIVE 5.1: PREVENTION OF ARRIVAL OF NEW STRAINS OF *AUSTROPUCCINIA PSIDII*

ACTION 5.1.1: Continue pre-border and border vigilance for all strains of A. psidii
(VERY HIGH priority, ongoing)

Comments and implementation:
Australia currently has only one strain of the *A. psidii* pathogen. Introduction of further lineages of the same strain may increase the likelihood of recombinant evolution and adaptation of the pathogen. Introduction and establishment of other strains may increase the potential of the pathogen to infect a still wider range of hosts, show wider climatic tolerances, and add to its adaptive potential. Two further strains in South America show a strong affinity for eucalypt species grown there, and have caused serious damage to them in plantation. The continued exclusion of any further strains of *A. psidii* from the Australasian region is a national imperative, requiring a both a national and a regional approach for biosecurity vigilance and response.

ACTION 5.1.2: Review potential pathways of entry of different strains of A. psidii into Australia
(HIGH priority, Year 1-2)

Comments and implementation:
The progressive establishment of the pandemic strain of Myrtle Rust in the Asia-Pacific region, a different strain in South Africa, and the potential for future emergence of yet other strains from the Americas, necessitate continued reappraisal of potential arrival pathways and measures for prevention and early detection.

ACTION 5.1.3: Establish an Asia-Pacific Myrtle Rust network
(MEDIUM priority, Year 2 and ongoing)

Comments and implementation:
A. psidii can spread by human, animal and wind vectors within the Asia-Pacific region. Given this, the regional exclusion of new strains, early warning of new recombinant or mutational genotypes within the region, and collaborative research and monitoring arrangements, should all be priorities in the interests of national environmental biosecurity and Myrtaceae production systems.

ACTION 5.1.4: Promote and contribute to coordinated international Myrtle Rust collaborative biosecurity and biological research network
(HIGH priority, ongoing)

Comments and implementation:
Screening of more Australian plant species against *A. psidii* and against different strains of the pathogen overseas provides valuable data on susceptibility and resistance. This information can inform risk appraisal, predictive threat models, resistance studies, and breeding trials. A greater emphasis on screening environmental (non-commercial) species will help to refine our understanding of conservation threats and priorities.

Internationally collaborative research on fundamental features of *A. psidii* and its interactions with host species will inform resistance studies and applications and the conservation and production sector responses.

OBJECTIVE 5.2: MAINTAIN DOMESTIC QUARANTINE

ACTION 5.2.1: Vigorously maintain current quarantine arrangements for Western Australia and South Australia
(VERY HIGH priority, ongoing)

Comments and implementation:
Predictive bioclimatic models differ but show some areas of Western Australia and South Australia are potentially suitable for Myrtle Rust establishment. More than half of Australia's Myrtaceae species occur in Western Australia, over 1000 of them in the south-west, which is the region considered most likely to be favourable for establishment of the Myrtle Rust pathogen. Current domestic biosecurity arrangements for human vectors, coupled with bioclimatic separation, have so far successfully prevented spread of the pathogen to these states. It is crucial to maintain domestic biosecurity arrangements to continue to exclude *A. psidii* from these states.

ACTION 5.2.2: Ongoing review and identification of potential risk pathways for entry of Myrtle Rust to Western Australia and South Australia
(HIGH priority, Ongoing)

Comments and implementation:
The establishment of the Myrtle Rust pathogen in the Northern Territory, and its partial naturalisation in Victoria and Tasmania, are widening the potential area of domestic origin for transmission to as-yet unaffected states and regions. Continual reappraisal is needed of the evolving potential arrival pathways, and measures for prevention and early detection.

OBJECTIVE 5.3: MONITOR FOR CHANGES IN PATHOGEN POPULATION

ACTION 5.3.1: Develop strategies to monitor for changes in the Australian and regional A. psidii populations
(HIGH priority, Ongoing)

Comments and implementation:
There is a need for continued monitoring for genetic change in the population of *A. psidii* in Australia and the broader Asia-Pacific region. This will allow the detection of new genotypes and pathotypes emerging through mutation, recombination, or the arrival of new strains not otherwise detected.

Species recommended for priority conservation action

45 species are recommended here for the most urgent conservation actions, on the basis of known declines, or known severe infection levels and suspected declines. The evidentiary basis is advanced in Appendix 1.

16 species are known or strongly suspected to be in serious decline on a total or regional basis, and are recommended for the most urgent (2018-19) conservation actions. These actions should include:

- impact surveys to assess decline and establish baselines, combined with
- preliminary survey for disease-resistant populations or individuals, and
- urgent germplasm collection (seed where still available, or vegetative material) to conserve genetically representative material of the declining populations.

Emergency priority

Four of these species are recommended for **emergency priority actions** (2018-19 season):

- *Lenwebbia* sp. 'Blackall Range (P.R.Sharpe 5387)'
- *Lenwebbia* sp. 'Main Range (P.R.Sharpe+ 4877)'
- *Rhodamnia rubescens*
- *Rhodomyrtus psidioides*.

Very high priority

12 further species are recommended for **very high priority actions** (by end 2019):

- *Archirhodomyrtus beckleri* (Southern Chemotype), *Decaspermum humile* (Southern Metapopulation), *Eugenia reinwardtiana*, *Gossia fragrantissima*, *Gossia gonoclada*, *Gossia hillii*, *Melaleuca nodosa*, *Rhodamnia angustifolia*, *Rhodamnia dumicola*, *Rhodamnia maideniana*, *Syzygium anisatum*, and *Syzygium hodgkinsoniae*.

Medium priority

A further 29 species, of high known or suspected susceptibility, and suspected decline but for which there are fewer observations of impact, are recommended for **medium priority actions** (pre-end 2020) impact surveys to establish baselines and look for disease-resistant populations or individuals, and in most cases to capture sample germplasm (seed or vegetative) for storage enablement and germination research. These species are:

- *Austromyrtus dulcis*, *Backhousia citriodora* (impact and resistance survey – a germplasm set exists), *Backhousia leptopetala*, *Backhousia oligantha*, *Eucalyptus curtisii*, *Eucalyptus andrewsii* (= *E. montivaga*, Mackay region population), *Eucalyptus resinifera* subsp. *hemilampra* (Mackay region population), *Gossia acmenoides*, *Gossia inophloia*, *Gossia lewisensis*, *Gossia myrsinocarpa*, *Lenwebbia prominens*, *Leptospermum trinervium*, *Lithomyrtus retusa* (NT populations initially), *Melaleuca leucadendra*, *Melaleuca lophocoracorum*, *Melaleuca quinquenervia*, *Melaleuca viridiflora*, *Rhodamnia argentea*, *Rhodamnia australis*, *Rhodamnia costata*, *Rhodamnia longisepala*, *Rhodamnia sessiliflora*, *Rhodamnia spongiosa*, *Rhodamnia whiteana*, *Rhodomyrtus canescens*, *Rhodomyrtus pervagata*, *Stockwellia quadrifida*, and *Syzygium oleosum*.

Six other species for priority precautionary germplasm capture and storage testing:

In addition to the 45 priority species above, the following species are recommended for precautionary germplasm capture, as flagship examples of precautionary action. The first five all occur only in the Lord Howe Island World Heritage Area; all except the *Leptospermum* are known hosts of *A. psidii* from inoculation testing. Allosyncarpia ternata is a Northern Territory endemic of cultural significance, that occurs in and adjacent to the Kakadu World Heritage Area.

- *Leptospermum polygalifolium* subsp. *howense*: NSW (Lord Howe Island endemic)
- *Melaleuca howeana* (Lord Howe Island endemic)
- *Metrosideros nervulosa* (Lord Howe Island endemic)
- *Metrosideros sclerocarpa* (Lord Howe Island endemic)
- *Syzygium fullargarii* (Lord Howe Island endemic)
- *Allosyncarpia ternata* (Northern Territory endemic).

AUTHOR'S AFTERWORD

An environmental threatening process of the breadth and scale of Myrtle Rust by rights should have had a multidisciplinary and cross-agency task force working on contingency planning for environmental impacts, and implementing baseline and impact monitoring to track its effects. It's not too late. New Zealand provides an example in this respect. An eight-years-in review like this one would have been much more robust had the nettle been seized in 2010-12. In Australia, there has been contingency planning in some jurisdictions but, until this review, no overview of the biodiversity impacts and their implications. What monitoring has occurred, has been the results of efforts by a very few researchers in primary industry agencies of New South Wales and Queensland, an equally few university-based researchers, concerned environmental agency staff and botanists, and a dispersed network of other government and non-government skilled observers and conservation practitioners. These people have collectively provided much of the information on which the impacts analysis and projections in this review have been based. Any errors or omissions are of course down to the author.

In the course of preparation of this review and the adjunct draft action plan, some respected colleagues have criticised the lack of 'spread' in priority ratings applied to proposed actions in the Action Plan – where, they ask, are the low priorities? Governments and funding bodies after all do not like everything to be high on the priority scale. The species proposed for conservation actions in this review, out of a total of 358 known-host native taxa, number 45. The number of hosts and the number of species of immediate conservation concern can be expected to rise in the future.

The 'low' priorities in this review and action plan are the other 313 known-host species, and the several hundred others, notably in western Australia, that may be at future risk. Regrettably, high priorities here and now, are the price of eight years without an integrated national environmental response and impact monitoring.

Western Australians and South Australians, in particular, may be disappointed that more extrapolation is not applied to their floras. Unfortunately, predictive modelling for Myrtle Rust spread is inconsistent in its outputs, making impact prediction hard – although at least parts of the Fleurieu Peninsula and the south-west of WA are common to most or all models. In any case, those States are for now pursuing the best possible course, with rigorous exclusion and vigilance programs, and environmental contingency planning that was lacking in eastern Australia in 2010 and since.

The immediate species and ecosystem priorities are in the east. The recommended institutional and funding arrangement settings, and the recommended research, will, if implemented, have direct benefit for other jurisdictions if Myrtle Rust impacts become comparably severe there.

Finally, as a conservation botanist and plant taxonomist with limited acquaintance, prior to 2010, with the world of death and destruction that is the daily round for plant health and plant pathology specialists, I want to thank colleagues on both sides of that divide, and in the third domain of conservation practice in the community, for help with this review and their commitment to conserving Australia's plant heritage. We should talk more.

Bob Makinson

Australian Network for Plant Conservation Inc.
25 May 2018

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Providers of information by direct personal communications (pers. comm's) cited in this review, including interviews by phone or in person, and information provided in written form (*in litt*.), are included below, except for two respondents who requested anonymity.

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APPENDIX 1: Species of high priority for conservation action (East Coast and Northern Territory)

Allosyncarpia ternata

Distribution: NT (endemic).

Legislative extinction-risk listings: nil.

Susceptibility rating/s: Morin et al. (2012) in inoculation screening noted a range of symptoms (severity scores 1—5) across replicates. Berthon *et al*. (2018) render this as Low to Medium susceptibility. No wild or open cultivation records of infection are known to date.

Resistant individuals or populations known/suspected: unknown.

Germplasm: nil or low in storage; non-orthodoxy for storage is likely but to be confirmed.

Geog. overlap (Berthon et al., 2018): 0%

Geog. overlap (Makinson, here estimated): No estimate made.

Impact quantified: No – no wild infection recorded to Jan. 2018.

Impact indicative: No – no wild infection recorded to Jan. 2018.

Priority for conservation actions (Berthon et al. 2018): Non-priority

Priority for conservation actions (here recommended): HIGH PRECAUTIONARY

Prioritisation rationale: *A. ternata* (Anbinik) occurs in the Arnhem land 'Stone Country', along the western and northern edges of the Arnhem Plateau, where it is the largest tree species and sometimes dominant in fire-protected gorges and on scree slopes where it effectively forms a closed-canopy rainforest (Russell-Smith et al. 1993); patches also occur as a gallery forest dominant on flat land along drainage lines issuing from the plateau (Dempster 2014; Warddeken Land Management [2012]). Where *A. ternata* is dominant, there are few other competing tree species present, and structural replacement (in the event of its decline) would be highly problematic. It often abuts, and is a marginal constituent of, the Arnhem Plateau Sandstone Shrubland Complex which is listed under the Commonwealth EPBC Act as an Endangered Ecological Community (http://www.environment.gov.au/biodiversity/threatened/communities/pubs/111-listing-advice.pdf). *Allosyncarpia ternata* has strong cultural significance to the Bininj people of the region (Dempster 2014). "*Allosyncarpia* is taxonomically significant as a monospecific genus, and *A. ternata* is a keystone monsoon forest plant endemic to the specialised geology of the sandstone plateau in western Arnhem Land" (Westway 2016).

Flowering and seed production does not occur every year, with mast years occurring at 2-3 year intervals (Fordyce et al. 1997). Seeds germinate immediately after falling and few seeds are viable after 3 weeks (Fordyce 1997, citing own unpublished data); the species is capable of resprouting from lignotuber after fire (Fordyce et al. 1997).

The species has an unusual strategy of episodic seedling growth (Fordyce et al., 2000): "Individual seedlings may produce, each wet season, a number of fast-growing stems, which then die back in the following dry season. As a result, mean annual above-ground growth during this life stage is negligible. With each wet season, however, the seedling extends its below ground parts – a large lignotuber and a deep root system. After a number of years, when the lignotuber has grown large enough to sustain massive shoot growth, when a suitable light gap becomes available, and presumably when roots reach reliable dry-season water supplies, the seedling grows rapidly." The potential for this growth strategy to be significantly affected by Myrtle Rust remains unknown. Wet season monitoring of this seasonal flush on young plants is likely to be difficult but desirable.

The spread of Myrtle Rust in the NT since first detection on the Tiwi Islands and in Darwin in 2015 has been gradual (relative to the east coast experience). Myrtle Rust was detected for the first time in Arnhem Land in May 2017, but in the eastern part of the region, and Bathurst Island in the same month (J. Westaway, Commonwealth Department of Agriculture & Water Resources, pers. comm. Dec. 2017). Eventual dispersal to western and northern Arnhem Land seems likely to be only a matter of time.

The shrub species *Dichapetalum timoriense* (family Dichapetalaceae) is largely or wholly restricted to the understorey of *Allosyncarpia ternata* forests; while apparently not currently listed under NT legislation (and not listed Federally), Kerrigan (2004) regarded it as qualifying for Vulnerable status. Any decline of the *Allosyncarpia* overstorey would be likely to adversely affect *D. timoriense*.

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available; Wet season monitoring of seedling flush)
- Germplasm storage enablement research (prerequisite for germplasm capture).
- Secure germplasm (high quantity, geographically and genetically representative).

Archirhodomyrtus beckleri

Distribution: NSW, Qld. Two disjunct chemotypes (cryptic taxa?) are known (Brophy et al, 1996). The Southern chemotype occurs from Kin Kin in Queensland (c. 26^{o} 16' S) south to the Williams River NSW (c. 32" 12' S). The Northern chemotype occurs from Eungella, Qld (c. 21" 11' S) north to at least Mt Lewis (c. 16^{o} 30’ S).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: A. beckleri was first reported as a host of *Austropuccinia psidii* from screening tests in South America by Zauza *et al*. (2010), using seed stated to be of ‘NSW’ provenance (and therefore the southern chemotype); 98.25% of the sample plants were found to be ‘resistant’ (S0 or S1on the susceptibility scale of Junghans *et al*. 2003a). However the fungal isolate used (UFV-02, or Race 1, of Junghans et al. 2003b) is assignable to the ‘C2/C3 Eucalypt/Rose Apple Brazil/Uruguay’ (Graca *et al*. 2011, 2013; Stewart *et al*. 2017), a different strain to the C1/C4 ‘pandemic biotype’ strain now present in Australia (Stewart *et al*. 2017) – the level of resistance cited for the sample is therefore not applicable to wild populations afflicted with the pandemic strain of the pathogen.

Pegg *et al*. (2014) assigned no susceptibility rating to *A. beckleri* and indeed the species was found to be not infected at sites (Queensland – most or all in south-east?) checked in the field for that study.

Berthon *et al*. (2018) synthesised the above reports into a ‘Medium’ susceptibility rating for the whole species.

However, after a slow start, the southern chemotype of *A. beckleri* has now been observed in severe decline in south-east Queensland and north-eastern NSW (details below).

Resistant individuals or populations known/suspected: None known in southern chemotype. Northern chemotype: data deficient, but may be tolerant – no adverse field reports from North Queensland are known; A. Ford (CSIRO, pers. comm. Sept. 2017) reports no infection of this species in two plots examined in that month on Windsor Tableland, despite numerous other infected species in area, and only minor infection seen elsewhere in northern Queensland in recent years. WJF McDonald (pers. comm. Sept. 2017) has visited populations at Eungella Qld in recent years and has not noticed Myrtle Rust as a problem, an observation confirmed by local ecological consultant G.

Paterson (pers. comm., Sept 2017). Further field checks of the northern chemotype populations are nevertheless desirable.

<u>Southern chemotype</u>: highly susceptible – high impact and severe decline in SE Qld (Pegg et al. 2018), and in NE NSW (Murwillumbah to border – L. Weber pers. comm. Aug. 2017), no resistant specimens noted by those observers. J. Halford (Brisbane Botanic Gardens, pers. comm. May 2017) reports that a population at Kin Kin (south-east Qld) is "OK, both adults and juveniles" in early 2017, but it is unknown whether this reflects resistance or simply non-infection that season.

Germplasm: J. Halford (Brisbane Botanic Gardens, pers. comm. May 2017), reports that one good-sized seedlot is held in the BBG seed bank, from a single population (of the southern chemotype).

Geog. overlap (Berthon et al., 2018): 10%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: Yes, for two southern chemotype locations: Pegg *et al*. (2017) report 44% and 79% adult tree death at the main two study sites in the Tallebudgera valley of SE Qld.

Impact indicative: Several reports of severe infection levels and defoliation in SE Queensland and in NE NSW. L. Weber (pers. comm. Aug. 2017) reports severe decline in north-eastern NSW (Murwillumbah to the border, e.g. Crystal Creek NSW) and on the Queensland side; Mr Weber also confirms Pegg *et al*.'s (2014) observation that this species was not widely infected in the first few years after Myrtle Rust arrival. D. Binns (pers. comm. July 2017) reports "a lot of dieback" seen in a single site in the Bucca area north of Coffs Harbour NSW, affecting both young and adult trees but to date with no observed whole-plant mortality; the biggest effects seemed to be on regeneration area edges. K. Kupsch (pers. comm., May 2017) reports stands in the Upper Burringbar/Mullumbimby NSW area are "very badly infected and badly defoliated". By contrast, R. Kooyman (pers. comm. May 2017), possibly based on observation of higher-altitude populations in NE NSW, reports no infection seen. For the northern chemotype, J. Wills (Queensland Herbarium, pers. comm. 25 May 2018) reports that examination at multiple sites in May 2018 showed no signs of infection.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH (southern chemotype locations)

Prioritisation rationale: Clear decline across much of the range of the southern chemotype; *A. beckleri* is (with *Gossia hillii q.v.*) a key species in subtropical rainforest regeneration in the NE NSW SEQ region.

Conservation actions here recommended:

<u>Northern chemotype</u>:

- Field impact survey (use quantified occurrences e.g. permanent plots where available), then re-evaluate.

<u>Southern chemotype</u>:

- Germplasm storage enablement study (prerequisite for germplasm capture).,
- Secure germplasm (high quantity, geographically and genetically representative). (dependent on enablement),
- (Possible) Investigate options for inter-situ live collections (fungicide-protected) for regional populations.
- (Possible) Secure germplasm or inter-situ for presumed-resistant lineages.

Austromyrtus dulcis

Distribution: Qld, NSW

Legislative extinction-risk listings: No listings

Susceptibility rating/s: Relatively Tolerant to Highly Susceptible (Pegg et al. 2014); Medium to High susceptibility (Berthon et al. 2018).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Likely to be non-orthodox.

Geog. overlap (Berthon et al., 2018): 23%.

Geog. overlap (Makinson, here estimated): Total.

Impact quantified: nil.

Impact indicative: J. Wills (Queensland Herbarium, pers. comm. 7 June 2018) "assessed 5 populations that showed minor to major damage. These populations had healthy fruit. Moderate active rust was seen on one population. This species urgently needs further monitoring".

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM (demonstrative, precautionary)

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available).

Prioritisation rationale: *A. dulcis* (Midgen Berry, Midyim) is a species of Indigenous cultural significance, both traditionally and as a bush-food in Indigenous ecotourism. It is also a significant horticultural (garden) species. Impact survey of this species, which occurs from Valla NSW to Fraser Island Qld, would open the way to wider Indigenous community involvement in the monitoring of Myrtle Rust impacts.

Backhousia citriodora (Lemon Myrtle)

Distribution: Qld (endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Medium to High susceptibility (Pegg *et al*. 2014); Resistant to Highly Susceptible (*Berthon et al, 2018*).

Resistant individuals or populations known/suspected: Yes – significant inter- and intra-provenance variation for foliar infection levels (Doran *et al*. 2012; Lee *et al*. 2016; E Lancaster, Univ. of Queensland, work in progress).

Germplasm: A living (whole-plant) set, dating from 1995-6 and representing all wild populations known at that time (Doran et al. 2012), supplemented by recollection from some sites and at least two new Queensland populations (Lee et al., 2016), survives and is being maintained in orchard. House et al. (1996) report that seed germination is slow (occurring through the wall of the indehiscent fruit), seed viability is very low (3%), although this may vary on a populational basis. The species is prone to reproduction by root-suckering, and some populations may be mostly or fully clonal (Lee et al. 2016) with little viable seed produced.

Geog. overlap (Berthon et al., 2018): 8.5%.

Geog. overlap (Makinson, here estimated): Total.

Impact quantified: Yes, in commercial cultivation and provenance screening trials (E. Lancaster Univ. of Queensland, work in progress; Lee et al. 2016). The effects of Myrtle Rust on commercial plantings have been significant to severe, with one major producer relocating to an inland irrigated property to escape the pathogen. However, no quantitative data on impact in the wild is available. For the Mackay (Qld) region, ecological consultant Grant Paterson (Aurecon Australasia, pers. comm. 28 Sept. 2017) notes that *B. citriodora* is patchily widespread in the area (>100 locations), and apparently very prone (as elsewhere) to occurring in clonal patches which seem to exhibit differing levels of tolerance of Myrtle Rust; while infection is common, with some noticeable reduction of flowering, there is still a reasonable floral show and fruiting levels remain "OK". Mr Paterson is unsure whether there has been any reduction in seedling establishment, noting that there were in any case not many seedlings anyway before Myrtle Rust arrival, and noting the difficulty of telling seedlings from suckers (the latter probably accounting for most 'recruits').

Impact indicative: Many reports of severe impact in commercial and domestic horticultural situations.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Evaluate data from multi-provenance genepool (CSIRO/commercial/RIRDC) to inform populational conservation priorities;
- Field impact survey (use quantified occurrences e.g. permanent plots where available) of wild populations to compare with ex situ provenance set.
- Possible priority candidate for scoping resistance breeding and rewilding (breeding selection already underway CSIRO/UQ/commercial).

Prioritisation rationale: *B. citriodora* is one of Australia's relatively few success stories in commercial native plant orchard cropping, having secured a strong niche market for culinary, cosmetic, and other products. It also demonstrates significant variation in resistance to Myrtle Rust, now being analysed and utilised, via resistance selection and breeding, for its commercial applications. Yet the underlying natural resource (the wild populations) have not been evaluated for Myrtle Rust impact, and the resistance traits identified have not been evaluated for their conservation utility. The available ex situ gene pool and the known resistance traits make this an excellent candidate for reinforcement of any declining wild populations with more resistant stock (subject to wild-population genetic variation sampling for traits other than rust resistance, yet to be done). As much of the resistance screening work has been done, this species constitutes a 'low-hanging fruit' for the proposed conservation actions.

Rainforest expert WJF McDonald (pers. comm. Sept 2017) notes that Lemon Myrtle is (uniquely) co-dominant in some of the Whitsunday region (Qld) rainforests, e.g. the Conway-Dryander footslopes forests; he reports that the species in that region however has a distinctly different appearance to the main-stem bark, being more reddish and almost smooth, as compared to south-east Queensland populations where duller coloured and of almost ironbark roughness. Clones from the Dryander region had high indices of stem and foliar rust infectivity compared to other provenances in the screening trials of Doran et al. (2012), and was assigned a mid-range severity rating by Lee et al. (2016). Decline, if confirmed, in a community where the species is co-dominant, could be expected to have more severe cascading effects on other biota than in communities where it is less floristically significant.

Backhousia leptopetala (= *Chorcarpia leptopetala*)

Distribution: NSW, Qld

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly Susceptible (Pegg et al. 2014; Berthon et al. 2018);

Resistant individuals or populations known/suspected: None known, surveys lacking.

Germplasm: undetermined.

Geog. overlap (Berthon et al., 2018): 19.5%.

Geog. overlap (Makinson, here estimated): Total.

Impact quantified: No (surveys lacking).

Impact indicative: One only (surveys lacking): G. Leiper (pers. comm. 22 May 2017) reports that a population at Pimpama (Gold Coast, Qld) regularly "gets hammered by MR but comes back OK"; observation on fruit set and recruitment are however lacking.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available).

Prioritisation rationale: A High priority for basic impact survey is here recommended, based on the high-susceptibility rating of the species and the only available field impact observation.

Backhousia oligantha

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Endangered

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014; Berthon et al. 2018).

Resistant individuals or populations known/suspected: None known, surveys lacking.

Germplasm: Presumed non-orthodox; not studied to date for storage potential.

Geog. overlap (Berthon et al., 2018): 4%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: NO

Impact indicative: No reports

Priority for conservation actions (Berthon et al. 2018):

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available).
- Germplasm storage enablement study (prerequisite for germplasm capture and use).

Prioritisation rationale: *Backhousia oligantha* occurs disjunctly in the Biggenden and Rockhampton regions, with very small areas of occurrence in both cases. The degree of exposure to *A. psidii* spores in the Rockhampton rainshadow area is uncertain (Myrtle Rust occurrence records from this region are scanty, although its wet forest habitat would favour exposure). A Medium priority for basic impact survey is here recommended, based on the high susceptibility rating of the species, its

Endangered status (pre-dating the advent of Myrtle Rust), its very restricted areas of occurrence, and the apparently complete absence of impact assessment to date.

Decaspermum humile (Southern metapopulation)

Distribution: NSW, Qld. The species exists in two metapopulations (G. Guymer, Queensland Herbarium, *in litt*. 2016): the 'Northern Queensland population' occurs in the Cape York Peninsula and north-east Queensland north from Townsville – Myrtle Rust field observations for this variant are lacking. The Southern metapopulation occurs in south-east Queensland and down the NSW coast to about Wyong.

Legislative extinction-risk listings: No listings ('Least concern' under Qld NCA)

Susceptibility rating/s:

- Pegg et al. (2014): Southern metapopulation (as '*Decaspermum humile*'): Extremely Susceptible; Northern metapopulation (as 'North Queensland form'): Relatively Tolerant.
- Aggregated (whole species), (Berthon et al., 2018): Resistant to Highly Susceptible.

Resistant individuals or populations known/suspected: None known, surveys lacking.

Germplasm: presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 7%.

Geog. overlap (Makinson, here estimated): Near-total.

Impact quantified: Yes, for south-east Queensland (Southern Metapopulation): Pegg et al., 2017 report it in serious decline – at the primary assessment site the species showed 100% branch dieback, 48-86% branch death, 95%+ crown transparency, and tree death more than doubling over a 12-month interval (2016-7) from 36% to 73%.

Impact indicative: Few other observations. Marc Russell (Conservation Partnerships Officer, Sunshine Coast Regional Council; pers. comm. Sept. 2017) reports the local *D. humile* [part of the southern metapopulation] as among the ten most severely affected species in the region. Two observers in NSW report nil or minor infection levels noticed, but these observations were not in context of a survey targeting either *D. humile* or Myrtle Rust.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available) for areas not covered by Pegg et al. (2017).

Germplasm: storage enablement study (prerequisite for *Germplasm:* capture).

Prioritisation rationale: A Very High action priority is here assigned for the southern metapopulation, due to the very severe and rapidly accelerating decline documented for south-east Queensland, the need for storage enablement research, and the prominent floristic role played by the species in some regenerating rainforest communities.

Eucalyptus andrewsii subsp. andrewsii (not fully confirmed as a host, photo of infection lacking).

Distribution: NSW, Qld.

Legislative extinction-risk listings: No listings

Susceptibility rating/s: None assigned to date. This new host report emerged during consultations for this review, and is yet to be considered by the Myrtle Rust Environmental Impacts Working Group. The report concerns only the northern disjunct population near Eungella Qld (G. Paterson, Aurecon Australasia, pers. comm. 28 Sept. 2017), under the synonymous Queensland-preferred name *E. montivaga*. Morin et al. (2011) report *E. andrewsii* as a host from inoculation testing; it was not recorded as a 'natural' infection host from Queensland in Pegg et al. (2014). Berthon et al. (2018) include *Eucalyptus andrewsii* (subspecies unspecified) on their Australian host list, referencing Morin et al. 2012; however the only mention of *E. andrewsii* in that 2012 paper is in a footnote to Supplementary Table S1, where it is stated that seed for the study was "Supplied as *Eucalyptus andrewsii* Maiden, but identified as the related species *E. campanulata*, which is recognized by some as *Eucalyptus andrewsii* subsp. *campanulata* (R.T.Baker & H.G.Sm.) L.A.S.Johnson & Blaxell". The *Australian Plant Census* (accessed 19 Jan. 2018) recognises *E. campanulata* at species rank, as do the Queensland Plant Census 2017 and the NSW Herbarium PantNet site (both accessed 19 Jan. 2018) – the only two states of occurrence of *E. andrewsii*. It therefore appears that as at January 2018, and pending investigation of the Eungella report, there is no fully confirmed occurrence of infection on *E. andrewsii*.

Resistant individuals or populations known/suspected: Not known.

Germplasm: Presumed orthodox.

Geog. overlap (Berthon et al., 2018): not applicable.

Geog. overlap (Makinson, here estimated): minor only, but may be of regional significance.

Impact quantified: No.

Impact indicative: Severe infection reported, including on (post-fire?) sucker growth from lignotubers, in Eungella Plateau population, Qld (G. Paterson, Aurecon Australasia, pers. comm. Sept. 2017).

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM (initially Eungella population only).

Conservation actions here recommended:

- Field survey of disjunct Eungella Plateau population, especially for post-fire impacts; if significant, extend field survey to southern populations in potentially rust-compatible climatic areas (south-west of Gladstone and west of Maryborough).

Prioritisation rationale: *E. andrewsii* is one of very few eucalypts (along with *E. resinifera* subsp. *hemilampra* and *E. tindaliae*) for which significant impact has been reported in the wild. Most populations of *E. andrewsii* (New England Blackbutt), a significant timber species, are in climatic areas less likely to be prone to Myrtle Rust establishment, e.g. western New England (NSW) and adjacent areas in southern Queensland. The more northerly Queensland populations, being disjunct, may be considered as being of conservation significance. Confirmation of high susceptibility of resprout growth may be informative for conservation of these populations and of use in determining resistance/susceptibility traits and mechanisms in *Eucalyptus* as a whole.

Eucalyptus curtisii

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Near-threatened.

Susceptibility rating/s: Relatively Tolerant to Highly Susceptible (Pegg et al. 2014); Medium to High susceptibility (Berthon et al. 2018).

Resistant individuals or populations known/suspected: Yes (susceptibility range in Pegg et al. 2014).

Germplasm: Orthodox.

Geog. overlap (Berthon et al., 2018): 12%

Geog. overlap (Makinson, here estimated): Partial (the largest populations are probably fully within the Myrtle Rust zone). The exposure of higher-altitude and inland populations, and of the disjunct Central Queensland populations, is uncertain.

Impact quantified: No.

Impact indicative: No.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available) in south-east Queensland coastal populations (Gold Coast to Sunshine Coast) and Townsville.

Prioritisation rationale: As one of the few mainland eucalypts to rate (partially) as highly susceptible, and as already near-threatened by processes other than Myrtle Rust, field impact study would allow determination of trend. Confirmation of significant susceptibility in the wild may be informative for conservation of the species and of use in determining resistance/susceptibility traits and mechanisms in *Eucalyptus* as a whole

Eucalyptus resinifera (subsp. hemilampra)

Distribution: NSW, Qld.

Note: the taxonomic distinctiveness of subsp. *hemilampra* is not universally accepted – see Bean (2003).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Resistant to Medium Susceptibility (Berthon et al., 2018) – this rating is based only on the ex situ inoculation testing reported in Morin et al. (2012).

Resistant individuals or populations known/suspected: Not known, although the inoculation tests (Morin et al. 2012) indicated a range of response.

Germplasm: Orthodox.

Geog. overlap (Berthon et al., 2018): 8% (whole species, subsp. *resinifera* and subsp. *hemilampra*).
Geog. overlap (Makinson, here estimated): (subsp. *hemilampra* only): Total? The aggregated species *E. resinifera* (subsp. *resinifera* plus subsp. *hemilampra*) also spans NSW and Qld, but with less overlap (many more populations in areas likely to be less prone to Myrtle Rust).

Impact quantified: No.

Impact indicative: G. Paterson (Aurecon Australasia, pers. comm. Sept. 2017), for the disjunct northern population on Eungella Plateau, Qld, reports "very savage" infection on new seasonal growth each year, and on seedlings and post-fire epicormic growth.

Priority for conservation actions (Berthon et al. 2018): Category C (whole species).

Priority for conservation actions (here recommended): MEDIUM (subsp. *hemilampra* only).

Conservation actions here recommended:

- Field survey of disjunct Eungella Plateau population, especially for post-fire impacts; if significant, extend field survey to southern populations in rust-compatible climatic areas.

Prioritisation rationale: This is one of very few eucalypts (along with *E. andrewsii* Eungella population, and *E. tindaliae*) for which significant impact has been reported in the wild, albeit to date only at one site. The Eungella population, being somewhat disjunct, may be considered as being of conservation significance in its own right. G. Paterson (pers. comm. as cited above) notes that the Eungella Plateau population of *E. resinifera* is part of the habitat for important local populations of Greater Glider and Yellow-bellied Glider, and that while *E. resinifera* is probably not a significant food source for Greater Glider, it is a preferred food source (nectar, foliage, sap) for the local Yellow-bellied Glider; eventual decline of E. resinifera could adversely affect these mammal species. In addition, confirmation of high susceptibility of resprout and seedling growth in *E. resinifera* may be informative for conservation of these populations and of use in determining resistance/susceptibility traits and mechanisms in *Eucalyptus* as a whole.

Eugenia reinwardtiana (Beach Cherry)

Distribution: Qld, WA; Malesia, Pacific Islands.

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Extremely Susceptible (Pegg et al. 2014); Highly Susceptible (Berthon et al. 2018).

Resistant individuals or populations known/suspected: Most observer reports indicate heavy impact, but a few indicate differential impact between morphological forms. An exception is a report from G. Paterson of Mackay Qld (pers. comm. 28 Sept. 2017) who notes two forms in the area (see below) with apparent differential levels of rust severity; he also reports that 'volunteer' progeny of one individual (an 'elite clone' of the larger-leaved form, with 'massive' fruit that he had in cultivation, and which he destroyed in 2016 due to repeated severe rust infection cycles), germinated from fallen seed over the last few years, survive and show no effects of Myrtle Rust for the last two years, despite a heavy spore load in season from strongly infected *Syzygium jambos* and other species nearby. G. Leiper (Conservation Officer, Native Plants Queensland; pers. comm. 22 May 2017) reports a single plant in cultivation on the Gold Coast doing "ok' despite ample rust in the surrounding area.

Germplasm: Presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 5% (national).

Geog. overlap (Makinson, here estimated): Near-total on east coast (Maryborough Qld to Cape York); western Cape York Peninsula uncertain, WA (Kimberley coast) uncertain but likely.

Impact quantified: No (no survey).

Impact indicative: Many reports of severe infection. Aaron Bean (Mackay Regional Botanic Gardens, Mackay Regional Council, Qld; pers. comms Sept 2017) reports that "the only plant that is a sure loser in the myrtle rust battle is *Eugenia reinwardtiana* this species suffers all year, ours at the [botanic] garden have not gained any new growth in more than a year and a half", and that wild populations in the Mackay area are "just as bad as in cultivation … one population under observation has put out no new growth at all this season." Expert native plant grower and ecologist Gary Sankowsky of Tolga, North Queensland (pers. comm. 30 Aug. 2017) reports "repeated infections (every year) on new leaves, flowers and fruits" on the wild native form of the species, and feels that this species is likely to become regionally extinct in the near future.   G. Paterson (ecological consultant, Mackay Qld, pers. comm. 28 Sept. 2017) reports that *E. reinwardtiana* is "the most seriously affected native species in the Mackay region … In the first season of Myrtle Rust presence (2012-13), the infection level was devastating … 50% foliage loss overall, and 100% of new growth lost". Mr Paterson notes that there are two forms of *E. reinwardtiana* in the Mackay region, 'large-leaved' and 'small-leaved' – the former is noticeably more prone to severe Myrtle Rust effects. The two forms can occur fully sympatrically, literally side-by-side, and some of both are in remote locations, implying that both may be of natural occurrence in the area, not introduced. Mr Paterson has seen individual plants of great stature on Gloucester Island, with trunks c. 150cm diam., almost certainly hundreds of years old. In North Queensland, J. Wills (Queensland Herbarium, pers. comm. 25 May 2018) reports active rust and some tip dieback on a small-leaved form in the Musgrave River area, with immature green fruits not infected but old black fruit apparently dead (rust impact inferred).

E. reinwardtiana is (oddly) not known to be native in the Northern Territory, but specimens in open cultivation there have been recorded as early and highly susceptible Myrtle Rust hosts on Melville island and in Darwin (Westerway 2016), and more recently in north-eastern Arnhem Land (P Westaway *in litt*., 4 Dec. 2017).

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available) – complex, many populations with some morphological variation; some populations may be of transplanted stock of Australian or non-Australian origin. The infraspecific taxonomy has not been investigated to date.
- Indigenous stakeholder consultation: The fruits of *E. reinwardtiana* are edible (palatability apparently varying with form), and Indigenous cultural significance in some areas is likely – consultations are needed to confirm this.

Prioritisation rationale: Severe infection levels and reported loss of growth in several areas of occurrence. Possible Indigenous cultural significance (to be confirmed). Reported differential levels of rust susceptibility in some individuals and populations, giving a potential basis for resistance breeding for recovery.

Gossia acmenoides

Distribution: NSW, Qld

Legislative extinction-risk listings: NSW: one 'endangered population' listing under the former NSW *Threatened Species Conservation Act* (the southernmost and disjunct Sydney Basin metapopulation); listing to be re-evaluated under the new NSW *Biodiversity Conservation Act* and the national Common Assessment Methodology (CAM).

Susceptibility rating/s: Highly Susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected:

Germplasm: Presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 18%
Geog. overlap (Makinson, here estimated): Total.

Impact quantified: No (no targeted impact surveys).

Impact indicative: Scanty reports indicate severe infections, but no decline data are available. NSW Scientific Committee (2014) describes Myrtle Rust as “potentially the most severe threat” to the Sydney Basin metapopulation of the species, and cites observations of infection and loss of new growth on cultivated plants in the Southern Sydney/Illawarra region, and on wild plants. K. Mills (2015, and in pers. comm. October 2015) reports one of the few Illawarra plants as having most new shoots infected. Brush Turkey Enterprises (2011) identified *G. acmenoides* as one of the species “affected dramatically” on the Blackall Range (Sunshine Coast hinterland, Qld) very soon after arrival of the pathogen in the area. T. Taylor (Griffith University, PhD student, pers. comm. 15 May 2017) reports evidence of Myrtle Rust at all *G. acmenoides* sites visited, with “crowns thin in most cases”, and states that *G. acmenoides* and *G. hillii* are the priority cases for conservation action in *Gossia*.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)

Prioritisation rationale: High priority is assigned on the basis of the high susceptibility rating and because of the apparent absence of any targeted assessment to date.

Gossia fragrantissima

Distribution: NSW, Qld

Legislative extinction-risk listings: Qld NCA: Endangered; NSW BCA: Endangered; Commonwealth EPBCA: Endangered.

Susceptibility rating/s: Medium Susceptibility (Pegg et al. 2014); Medium (Berthon et al., 2018).

Resistant individuals or populations known/suspected: no data available.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al. 2018): 52%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no survey).

Impact indicative: Only one report to date: J. Wills (*Queensland Herbarium pers. comm. 7 June 2018) assessed 8 populations across the species range, including the only population on the Sunshine Coast; no active rust was found or, damage that could be attributed to Myrtle Rust. The Sunshine Coast population had healthy fruit and flowers in January 2018”.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field survey (precautionary); use quantified occurrences e.g. permanent plots where available.

- Precautionary germplasm capture.
- Germplasm storage enablement research.

Prioritisation rationale:

Notwithstanding the one favourable report cited above, *G. fragrantissima* remains a High priority for targeted impact survey and germplasm capture and storage enablement, because of the rare and endangered status of the species prior to the arrival of Myrtle Rust; survey is need to ascertain whether that status has been exacerbated since.

Gossia gonoclada

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Endangered; Commonwealth EPBCA: Endangered

Susceptibility rating/s: Highly Susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: T. Taylor (Griifith Uni, pers. comm. May 2017) reports possibly two less susceptible genotypes at Logan (Qld). G. Leiper (pers. comm. May 2017) reports a colleague's [name redacted here] cultivated specimen as producing a lot of fruit in early 2017, although this may have been fortuitous escape rather than resistance to infection.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 38%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: Yes (T. Taylor, Griffith Uni, work in progress; Taylor 2013 ined. [thesis]; Taylor et al. 2017).

Impact indicative: Yes, several reports. T. Taylor (pers. comm.) reports some adult mortality (but notes a probable strong interaction with drought stress), no observation of seed set (mature fruit) in visits to multiple sites, no signs of recruitment at Logan (Qld) population in recent years. Defoliation due specifically to Myrtle Rust is hard to estimate in drought years as leaf-drop is a normal drought response in this species – the interaction however contributes to stress and mortality. Taylor remarks that outcrossing in the surviving plants of *G. gonoclada*, because of distance between plants and their asynchronous flowering, is probably at very low levels, and forecasts a further reduction in pollen flow for this preferentially outcrossing species, hence likely further decline in seed set and progeny fitness. Shapcott & Playford (1996) note that the rate of germinable seed set was already low prior to the arrival of Myrtle Rust, and that the fitness of selfed progeny was lower than for outcrossed progeny. Taylor (pers. comm. as cited) also suggests that *G. gonoclada* is long-lived and slow-maturing, likely requiring >20 years to reach fecund stage, complicating recovery potential – this observation is supported by G. Leiper (pers. comm. May 2017) based on observation of a seed-grown cultivated specimen now 30 years old which has never flowered, in contrast with cutting-grown specimens which tend to flower after a few years. Leiper also reports that a conservation seed orchard of the species at Loganlea was "smashed' by Myrtle Rust, and that four of ten specimens planted as part of conservation works at Tygum Lagoon, Waterford, died.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field situation known (T. Taylor Griffith Univ. and collaborators, including unpublished data).
- *Germplasm:* storage enablement study (prerequisite for *Germplasm:* capture).

- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected).

Prioritisation rationale: Some conservation actions for *G. gonoclada*, including translocation and augmentation plantings, have been in train since the 1990s. In 1996, less than 30 natural plants were known; augmentation resulted in a higher population for some years, but the Millennium Drought and then Myrtle Rust has eroded the situation and the species is now very marginal, and would almost certainly qualify for Critically Endangered status under an IUCN-type assessment (IUCN 2012). The possible existence of differential levels of susceptibility to Myrtle Rust allows some hope for selective breeding, but the time-scale is necessarily long and maximum germplasm capture is needed for best effect.

Gossia hillii

Distribution: NSW, Qld

Legislative extinction-risk listings: No listings as threatened; 'least concern' under Qld NCA.

Susceptibility rating/s: Highly to Extremely Susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: Neither Pegg et al. (2017) not T. Taylor (Griffith University, pers. comm. May 2017) have observed resistant plants in their research areas, and none are reported elsewhere.

Germplasm: Presumed non-orthodox, although two seed lots are held at Brisbane Botanic Garden seed bank (J Halford, pers. comm. May 2017). *G. hillii* is capable of resprout from basal and remote (T. Talor pers. comm.) suckers, and while these are also attacked by Myrtle Rust they may provide a source of germplasm for a few seasons after fruit production has ceased.

Geog. overlap (Berthon et al., 2018): 7%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: Yes, on a regional basis (Pegg et al., 2017). In a regenerating Myrtaceae-rich community in transition from wet sclerophyll (emergent canopy) towards rainforest (lower stories), *G. hillii* was a mid-storey element (25%). Tree deaths for *G. hillii* doubled from 2016 (18%) to 2017 (38%). Branch death on *G. hillii* in the understorey was 34% and in the mid-storey 43%; exhibition of rust-related branch dieback was 97% in the understorey and 100% in the midstorey. Mid-storey crown transparency was just under 95%. *G. hillii* occurs from the coastal hinterland into montane regions – the sites of decline observed by Pegg et al. (2017) are at <100 m a.s.l., and more elevated populations may or may not reflect the trend.

Impact indicative: Yes, multiple reports of severe impact in SE Qld, NE NSW, and North Queensland. T. Taylor (Griffith University, pers. comm. May 2017) reports that it is hard to find *G. hillii* now at her research sites, and regards *G. hillii* (along with *G. acmenoides*) as a priority case for conservation action in *Gossia*.

J. Halford (Brisbane Botanic Garden, pers. comm. May 2017) reports *G. hillii* "very badly hit by Myrtle Rust" in the Kin Kin (Qld) area, with "many mature trees dead, no fruit on survivors ... Formerly many seedlings <30cm tall, now none; carpet of seedlings under one tree now gone." On the Sunshine Coast, [Anonymous, pers. comm. Aug. 2017) reports *G. hillii* as "very susceptible both in cultivation and [in] local recruits in the wild". Queensland rainforest expert WJF McDonald (pers. comm. Sept 2017) reports "Situation dire – most trees seen (even big ones) almost totally defoliated, many dead. This is the case both on Lamington Plateau, and on Main Range up near Killarney." Liu Weber (pers. comm. Aug. 2017) reports *G. hillii* "hit badly by Myrtle Rust" on both sides of the NSW/Qld border. M. Russell (Conservation Partnerships Officer, Sunshine Coast Regional Council, *in* *litt*. Sept. 2017) regards *G. hillii* as one of the ten most seriously affected species in that part of Queensland. Myrtaceae horticulturalist K. Kupsch (pers. comm., May 2017) reports local stands of *G. hillii* in the Mullumbimby area of NSW as "annihilated". Ecological consultant A. Benwell (pers. comm. Aug. 2017) reports *G. hillii* a little further south as "hit quite hard, adults (3-4 m high) killed", but with some fruit still observed in previous season. In North Queensland, J. Wills (Queensland Herbarium, pers. comms. 25 May and 7 June 2018) has assessed "25 populations from across its distribution and all have been severely impacted with many already dead and gone"; for North Queensland, Wills reports extensive damage at multiple sites on life stages from seedlings to large trees.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available) at locations not already studied
- *Germplasm:* storage enablement study (prerequisite for *Germplasm:* capture).
- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.
- Secure germplasm or inter-situ for presumed-resistant lineages.

Prioritisation rationale:

Gossia hillii occurs from north east Queensland into north eastern New South Wales, and is a frequent and ecologically significant understory tree and rainforest margin tree, playing a role in pioneering the advancing rainforest front and in closing the mid-storey canopy in rainforest-trending regenerating systems. In such situations it often grows with the equally declining *Archirhodomyrtus beckleri*, and the loss of two species with similar roles in these systems is likely to compound the ecological impact. Observations from central and north-east Queensland are lacking, but in south-east Queensland and north-east NSW this species is in very serious decline as a result of Myrtle Rust.

Gossia inophloia

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Near-threatened

Susceptibility rating/s: Extremely Susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: no reports.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 47%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no surveys).

Impact indicative: G. Leiper (Conservation Officer, Native Plants Queensland, pers. comm. May 2017, numerous personal observations) sums up as 'no hope' without intervention. M. Russell (Conservation Partnerships Officer, Sunshine Coast Regional Council, *in litt*. Sept. 2017) regards *G. inophloia* as one of the ten most seriously affected species in that part of Queensland. Ecologist R. Kooyman (pers. comm. May 2017) reports "total defoliation" at one site in the Maleny Gorges (Qld) area in the Sunshine Coast hinterland. An anonymous Myrtaceae grower on the Qld Sunshine Coast (pers. comm. Aug. 2017) reports *G. inophloia* in varying cultivated situations (street and garden) as seriously affected, with many plants dead or removed due to decline. These reports span much of the species core range (Mt Glorious to Kin Kin area); no reports are available on the isolated inland population south of Yarraman. J. Willis, Queensland Herbarium, pers. comm. 7 June 2018) "assessed 11 populations from across its range and all have been severely impacted, with confirmed mortality. One population of 4 individuals growing in the shaded understorey at Mary Cairncross seemed to be unaffected in January 2018".

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- *Germplasm:* storage enablement study (prerequisite for *Germplasm:* capture).
- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.

Prioritisation rationale:

Gossia inophloia is a high priority species for conservation action due to its extreme susceptibility to Myrtle Rust, and the (albeit few) reports of serious infection levels.

Gossia lewisensis

Distribution: Qld (endemic).

Legislative extinction-risk listings: No listings

Susceptibility rating/s: Medium to High Susceptibility (Pegg et al. 2014); S* ["susceptible but severity not recorded"] (Berthon et al. 2018).

Resistant individuals or populations known/suspected: no data (no surveys).

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 55%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No.

Impact indicative: A. Ford (CSIRO, pers. comm. Sept 2017) reports infection in three of four plots on Windsor Tableland FNQ in that month. J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018) "assessed 4 populations on Mt Lewis. All were severely impacted. Stephen McKenna [NQ botanist] confirmed that many had died from the same populations that he visited 2 years prior".

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)

Prioritisation rationale:

Despite (and because of) the lack of field observations to date, *G. lewisensis* should be investigated for infection levels and impact. It has a susceptibility rating of MS-HS (albeit probably based largely on observations in cultivation at southern latitudes). It is a constituent of the Wet Tropics World Heritage Management Area flora. It has a distribution and habitat strongly favouring potential Myrtle Rust impact, and is of very limited geographical extent (Mt Spurgeon-Mt Lewis area and the Windsor Tableland, at 850-1200 m a.s.l., as a tree in rainforest understorey habitat (Australian Tropical rainforest plants website: http://keys.trin.org.au/key-server/data/0e0f0504-0103-430d-8004-060d07080d04/media/Html/taxon/Gossia_lewisensis.htm, accessed 11 Jan. 2018).

Gossia myrsinocarpa

Distribution: Qld (endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Medium to High Susceptibility (Pegg et al. 2014); Medium to High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: no data

Germplasm: Non-orthodox

Geog. overlap (Berthon et al., 2018): 7%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No.

Impact indicative: A Ford (CSIRO Tropical Forest Research Centre, Atherton, pers. comms. Sept 2017) reports infection in four of four plots on Windsor Tableland FNQ in Sept. 2017, and more generally that this species "gets hammered" both in the wild and in cultivation in the Atherton area. Queensland rainforest expert W.J.F. McDonald (pers. comm. Sept. 2017) comments that "it is rare to see it with a full crown any more". J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018) "Assessed 20 populations across its range and all showed signs of infection, with the majority showing active rust and severe damage"; in North Queensland, Wills notes infection at multiple sites on seedlings to small trees, with severe tip dieback and branch death in some, but also significant variation, with a few sites containing apparently healthy trees flowering and fruiting.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)

Prioritisation rationale:

Gossia myrsinocarpa is a constituent species of the Wet Tropics World Heritage Area flora, although it also occurs in central Queensland. The susceptibility rating, distribution and wet forest habitat make it a strong candidate for potential decline. Its presence in CSIRO permanent plots in the Wet Tropics facilitates impact monitoring in that region (if resourced).

Lenwebbia prominens

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Near-threatened

Susceptibility rating/s: Highly Susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: No – variable impact reported (e.g. by Anonymous, Myrtaceae grower, Sunshine Coast, pers. comm. Aug. 2017), but no pattern or consistency yet detected).

Germplasm: Presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 56%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no targeted surveys to date).

Impact indicative: Yes, reports of moderate to severe infection. Queensland rainforest expert W.J.F. McDonald (pers. comm. Sept 2017) reports a population with significant rust damage on Lamington Plateau (O'Reilly's). Ecologist Liu Weber (pers. comm. Aug. 2017) has seen this seen growing next to *Lenwebbia* sp. 'Main Range', and while the *L. prominens* does get infected on new growth, it is not faring as badly as the other.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available) unless unpublished Qld data proves adequate
- *Germplasm:* storage enablement study (prerequisite for *Germplasm:* capture).
- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.
- Secure germplasm or inter-situ for presumed-resistant lineages.

Prioritisation rationale:

Reports of impact for *L. prominens* are scanty, but it is here recommended for targeted impact survey because of its high susceptibility rating, its total overlap with the Myrtle Rust naturalisation zone (except possibly at its highest altitudes), and because any resistance traits identified in it may contribute to the managed conservation and resistance breeding for other *Lenwebbia* species in more severe decline. W.J.F. McDonald (pers. comm. Sept 2017) reports a population overlapping a permanent plot at O'Reilly's on Lamington Plateau (the 'Earthwatch site'), so a pre-MR baseline is available for at least that site.

Lenwebbia sp. 'Blackall Range' (P.R. Sharpe+ 5387)

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Endangered.

Susceptibility rating/s: Relatively Tolerant (Pegg et al. 2014), recategorized as Highly to Extremely Susceptible (Pegg et al. 2018); Medium (Berthon et al. 2018). Field reports (see below) suggest this species was a possible 'late starter' and is now in serious decline.

Resistant individuals or populations known/suspected: Some indications (G. Morgan, pers. comm. 15 Sept. 2017) that the Eudlo National Park population is less infection-prone and may be more resistant than most others.

Germplasm: Presumed non-orthodox. G. Morgan (pers. comm. Sept. 2017) reports that a small sample (n = 16) of fresh seed showed near-100% germinability.

Geog. overlap (Berthon et al., 2018): none assigned (*L*. sp. 'Blackall Range' is omitted from Berthon et al.'s Supplementary Table S3, which gives overlap estimates).

Geog. overlap (Makinson, here estimated): Total.

Impact quantified: Yes, unpublished. G. Morgan (Sunshine Coast Council) reports his unpublished data showing no rust present at one site in October 2013, only establishing on the species there in May 2014. By June 2015 at the same site there was significant adult mortality (including plants to 8 m tall), and numerous surviving plants were in decline. A two-year monitoring study (covering 100 plants at six sites, out of a total for the species of c. 14) commenced in October 2015. Mr Morgan reports "a majority of plants severely affected, marked decline overall, including numerous adult deaths, but considerable site variability". Flowers and fruits were only observed at two locations, both in very low numbers. Recruitment is hard to gauge, as seedlings are difficult to distinguish from suckers. Pegg et al. (2018) report that 85% of trees assessed in 2014 had a crown transparency rating of greater than 50%, and 51% of these trees with >80% crown transparency. All trees assessed at the Doonan Reserve had transparency rates >75%; the Eudlo sites sampled has the lowest crown transparency at that time, consistent with the G. Morgan observations above.

Impact indicative: M. Russell (Conservation Partnerships Officer, Sunshine Coast Regional Council, *in litt*. Sept 2017) regards *L*. sp. 'Blackall Range' as one of the ten worst rust-affected species in the LGA (to which it is endemic).

Priority for conservation actions (Berthon et al. 2018): none assigned (*L*. sp. 'Blackall Range' is omitted from Berthon et al.'s Supplementary Table S3, which gives priorities).

Priority for conservation actions (here recommended): EMERGENCY

Conservation actions here recommended:

- *Germplasm:* storage enablement study (prerequisite for *Germplasm:* capture).;
- Secure germplasm (high quantity, geographically and genetically representative). (subject to enablement);
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations;
- investigate and secure reported resistant germplasm.

Prioritisation rationale:

Lenwebbia sp. 'Blackall Range' is listed in Queensland as Endangered, has low total numbers and a restricted and patchy distribution (only occurring in the Sunshine Coast LGA), and from unpublished data appears to warrant a susceptibility rating of at least High. Unpublished data shows significant adult plant mortality. Fruiting has reportedly almost ceased. The species is prone to regenerate by both sucker growth and aerial rooting (G, Morgan pers. comm.), and these traits are likely to allow capture of conservation germplasm for a moderate period of time in the absence of fruit.

Lenwebbia sp. 'Main Range' (P.R. Sharpe+ 4877)

Distribution: Qld (endemic).

Legislative extinction-risk listings: nil.

Susceptibility rating/s: none assigned. However, field reports (see below) suggest this species is extremely susceptible across its very limited range.

Resistant individuals or populations known/suspected: None observed.

Germplasm: Presumed non-orthodox. Seed probably no longer available in the wild due to extensive defoliation and flowering failure.

Geog. overlap (Berthon et al., 2018): none assigned (species not treated).

Geog. overlap (Makinson, here estimated): Total.

Impact quantified: No.

Impact indicative:

Priority for conservation actions (Berthon et al. 2018): none assigned (species not treated). *Priority for conservation actions (here recommended)*: EMERGENCY

Conservation actions here recommended:

- Secure germplasm likely to be vegetative only available, and not for long.
- Propagate and establish a protected set ex situ with strong clonal control; breed for fruit to enable seed storage testing.
- *Germplasm:* storage enablement study.

Prioritisation rationale:

Lenwebbia sp. 'Main Range' (P.R. Sharpe+ 4877) is a narrow Border Ranges endemic, occurring around the southern edge of the Lamington Plateau (Gondwana Rainforests WHA) in Queensland and extending into NSW (e.g. Limpinwood Nature Reserve). A majority of plants are reportedly on the NSW side of the border (L. Weber pers. comms 2017, 2018). The species has only recently been recognised as occurring in NSW. It is restricted to the edge of cloud-forest habitats on cliff edges and faces and on steep rocky ridgelines. L. Weber (pers. comms 2017, 2018) and J. Mallee (NSW NPWS, pers. comm. Feb. 2018) report extensive defoliation since 2016 across all parts of the population they have been able to access, with all plants in such poor condition it was hard to find suitably healthy material for cuttings for supply to the Australian Botanic Gardens Mount Annan; two struck cuttings are held by TABGMA as at February 2018.

Leptospermum polygalifolium subsp. howense

Distribution: NSW (Lord Howe Island endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: None assigned. This subspecies is not a known host, but an unspecified subspecies (highly unlikely to have been subsp. *howense*), was the basis of the 'known host' record for *L. polygalifolium* deriving from inoculation testing (Morin 2011; Morin et al. 2012). No wild infection records for L. polygalifolium have yet been reported in either Australia or New Zealand.

Resistant individuals or populations known/suspected: unknown

Germplasm: Presumed orthodox.

Geog. overlap (Berthon et al., 2018): 8% (whole species)

Geog. overlap (Makinson, here estimated): 100% (subsp. howense)

Impact quantified: Nil impact recorded to date.

Impact indicative: Nil to date.

Priority for conservation actions (Berthon et al. 2018): Category C (whole species)

Priority for conservation actions (here recommended): HIGH PRECAUTIONARY (subsp. howense only) – see rationale below.

Conservation actions here recommended:

- Secure germplasm in high quantity and genetically representative, for conservation and research.

Prioritisation rationale: *L. polygalifolium* subsp. *howense* is one of a suite of five taxa endemic to Lord Howe Island (four of them known hosts from inoculation screening) that are here recommended for precautionary conservation action (large-scale germplasm collection). The Lord Howe Island Group is a World Heritage Area with a high degree of floral endemicity (one of the main bases of its WHA declaration). This taxon is ecologically significant in its habitat. *L. polygalifolium* subsp. *howense* is a significant species ecologically on Lord Howe Island, present in at least seven of the total 26 plant communities recognised for the Island Group in that classification. It is also an important structural element of the ecological community Gnarled Mossy Cloud Forest, which is listed under NSW legislation as Critically Endangered.

Myrtle Rust was detected on cultivated plants on Lord Howe Island in 2016, but detection and response seems to have occurred very early in the invasion process and as at January 2017 no infections of LHI wild native plants have been found, and it appears likely that Myrtle Rust has been eradicated. There is however a constant risk of renewed arrival either by human agency or by wind distribution of spores from the Australian mainland or (New Zealand or New Caledonia). Precautionary conservation action via the securing of germplasm for the future is prudent, given the indefinite risk of re-infection, the known susceptibility of four of the five endemic Myrtaceae, the World Heritage values, and the positive demonstrative effect on public biosecurity awareness that a coordinated action set would promote.

Leptospermum trinervium

Distribution: Qld, NSW, ACT, Vic.

Legislative extinction-risk listings: nil.

Susceptibility rating/s: MS (Pegg et al., 2018).

Resistant individuals or populations known/suspected: undetermined.

Germplasm: Orthodox

Geog. overlap (Berthon et al., 2018): 12.8%

Geog. overlap (Makinson, here estimated): PARTIAL (MOST?)

Impact quantified: In part – preliminary results of studies of multi-species responses after fire in coastal heathy systems of north-east NSW (Pegg et al., 2018, further publication pending) indicates high Myrtle Rust impact on *Leptospermum trinervium.* They report: "*Leptospermum trinervium* was not present in any of the study plots. However, observations by the authors identified significant levels of *A. psidii* infection and dieback on epicormic regeneration of this species. All 20 trees assessed showed some level of branch epicormic regrowth dieback caused by *A. psidii*. Of these, 10 had greater than 50% of branches showing evidence of dieback". They go on to state that *L. trinervium* "was identified as a species on which *A. psidii* could have significant impacts, particularly with regards to regeneration following disturbance. *Austropuccinia psidii* infection on new flush growth and juvenile stems initially resulted in defoliation followed by shoot and branch dieback and complete death of all coppice shoots on some trees. Of the trees assessed all showed some level of decline as a result of repeated infection. Further studies on this widespread species are required."

Impact indicative: P. Entwistle (pers. comm. 16 May 2017) reports that post-fire re-sprouts of this species are particularly susceptible. Coppice growth on adult plants that survive fire become severely infected, with growth-form effects (distortion and retardation of growth) that Mr Entwistle feels are likely to permanently damage the development of affected individuals. No seedlings have been observed by Mr Entwistle yet in these post-fire situations, but the monitoring program during which the above observations were made did not include seedlings in the data targets. Mr Entwistle thinks it possible that post-fire seedling emergence may well have occurred, with the germinants being infected and dying at a very early stage, too early to easily identify.

Priority for conservation actions (Berthon et al. 2018): Category C.

Priority for conservation actions (here recommended): MEDIUM

Prioritisation rationale: *L. trinervium* is a floristically significant component of the coastal and sub-coastal heathy systems where it occurs, and is sometimes the locally dominant shrub. Its ecological function role is not fully determined but is likely to be significant.

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available; Germplasm storage enablement research (prerequisite for germplasm capture).
- Secure germplasm (high quantity, geographically and genetically representative).

Lithomyrtus retusa

Distribution: Qld, NT, WA.

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: S* [“susceptible, but severity not recorded”] (Berthon et al. 2018).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Uncertain, probably orthodox. Some seed of Northern Territory origin is held at the Australian Seed Bank in Canberra (Wirf 2015). Broadhurst et al. (2016) (citing Cowie & Liddle 2014) states that the related NT species *L. linariifolia* may have short-lived seed (*L. linariifolia* is not recorded as a Myrtle Rust host species). Snow and Guymer (1999a) reported that attempts to germinate seven *Lithomyrtus* species were unsuccessful.

Geog. overlap (Berthon et al., 2018): 0.7%

Geog. overlap (Makinson, here estimated): Partial only.

Impact quantified: No.

Impact indicative: *Lithomyrtus retusa* was among the first species detected with Myrtle Rust in the Northern Territory, on Melville Island in May 2015, and at that time had not been recorded as a host elsewhere. The pathogen was affecting hundreds of adult plants at a severe level (Westaway 2016). In July 2015, *L. retusa* was found infected at a lighter level on the mainland at Berry Springs, and in July 2017 on Bathurst Island (P. Westaway, pers. comm. 4 Dec. 2017). Myrtle Rust was also detected in north-eastern Arnhem land in May 2017 (Westaway pers. comm.) but on other species to date. Westaway (in press) reports that the affected populations on Melville Island, which in 2015 displayed disease symptoms of “minor distortion and abscission of young foliage and dieback of severely infected branch tips”, were by mid-2017 including many dead and dying shrubs, and that mortality “may consist of a substantial proportion of the *L. retusa* population in places”. The Berry Springs (mainland) plants, relatively lightly infected in 2015, “were observed in June 2017 to have deteriorated considerably in the interim with plants now showing significant levels of infection, abundant leaf tip damage and even some branch death leaving some shrubs half dead”. Westaway (in press) notes that infection levels and spore loads on Melville Island adjacent to *Acacia mangium* plantations "may pose a potential quarantine issue for export of wood products".

As at January 2018 there are still no reports of infection of the species from its extensive Queensland populations, although may well reflect lack of both targeted and casual survey rather than absence of disease.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey in NT including for recruitment-stage impacts (use known occurrences e.g. permanent plots where available); use existing ranger resources on-country? Completion of development of NT Cybertracker Myrtle Rust app (S. Saynor, CDU) recommended (some financial support needed for programmer; use Lithomyrtus as test case for app.)
- Seed biology and germplasm storage tolerance research – some *Lithomyrtus* have low seed set, and storage tolerance is undetermined.
- Note: a precautionary approach would also include surveys for disease incidence and impact for *Lithomyrtus linariifolia* (not yet a known Myrtle Rust host), which is listed as Vulnerable under the Northern Territory *Parks and Wildlife Conservation Act* 2000 and which often occurs on the margins of stands of *Allosyncarpia ternata* (Kerrigan 2004; Broadhurst et al. 2016), another species here noted as of concern.

Prioritisation rationale: The Northern Territory observations of *Lithomyrtus retusa* (Westaway 2016; 2018 in press) suggest that it is highly susceptible to Myrtle Rust infection, and that significant damage is occurring in some populations. The species is relatively widespread in the NT and across northern Australia, and not all populations may be in areas or sites not conducive to frequent or prolonged rust infection; nevertheless an early appraisal of impact is clearly warranted. The absence of reports from north Queensland is as likely to reflect lack of investigation as absence of disease.

Melaleuca howeana

Distribution: NSW (Lord Howe Island endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: S* ["susceptible, but severity not recorded"] (Berthon et al. 2018); known host from inoculation testing (Morin 2011; Morin et al. 2012).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Presumed orthodox.

Geog. overlap (Berthon et al., 2018): 100%

Geog. overlap (Makinson, here estimated): Total if rust establishes on Lord Howe Island.

Impact quantified: No records of wild infection to date.

Impact indicative: No records of wild infection to date.

Priority for conservation actions (Berthon et al. 2018): Category B

Priority for conservation actions (here recommended): HIGH PRECAUTIONARY

Conservation actions here recommended:

- Secure germplasm in high quantity and genetically representative, for conservation and research.

Prioritisation rationale: *Melaleuca howeana* is one of a suite of five taxa endemic to Lord Howe Island (four of them known hosts from inoculation screening) that are here recommended for precautionary conservation action (large-scale germplasm collection). The Lord Howe Island Group is a World Heritage Area with a high degree of floral endemicity (one of the main bases of its WHA declaration). This taxon is ecologically significant in its habitat. *M. howeana* is the dominant element of vegetation community no 5 'Tea Tree shrubland on exposed rocky slopes', delimited in Sherringham et al. (2016), which is there identified as having (in the absence of Myrtle Rust) a Low threat status, and which provides nesting habitat for four seabird species. *M. howeana* is also present in at least four other vegetation communities identified in that classification. It is also the only food plant available to the only wild population of the Lord Howe Stick Insect (or Phasmid; *Dryococelus australis*) on Balls Pyramid, which is listed as Critically Endangered under the Commonwealth EPBC Act, and as Endangered under NSW legislation (the relationship is however not obligate – the phasmid utilised many other plants before becoming extinct on the main Lord Howe Island).

Myrtle Rust was detected on cultivated plants on Lord Howe Island in 2016, but detection and response seems to have occurred very early in the invasion process and as at January 2017 no infections of LHI wild native plants have been found, and it appears likely that Myrtle Rust has been eradicated. There is however a constant risk of renewed arrival either by human agency or by wind distribution of spores from the Australian mainland or (New Zealand or New Caledonia). Precautionary conservation action via the securing of germplasm for the future is prudent, given the indefinite risk of re-infection, the known susceptibility of four of the five endemic Myrtaceae, the World Heritage values, and the positive demonstrative effect on public biosecurity awareness that a coordinated action set would promote.

Melaleuca leucadendra

Distribution: Qld, NT, WA

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Relatively Tolerant to Highly Susceptible (Pegg et al. 2014); Medium to High susceptibility (Berthon et al. 2018).

Resistant individuals or populations known/suspected: G. Pegg (QDAF, unpublished data, pers. comm., Dec 2017) has identified provenance (populational) variation in seedling resistance to Myrtle Rust ranging from c. 10% to c. 70%.

Germplasm: Orthodox.

Geog. overlap (Berthon et al. 2018): 1%

Geog. overlap (Makinson, here estimated): Partial in Qld (potentially near-total over whole range if Myrtle Rust naturalises across the monsoon tropics).

Impact quantified: No, but work is in progress in a number of Queensland populations (G. Pegg, Queensland Department of Agriculture and Fisheries).

Impact indicative: Very few observations.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available); needs to dovetail with work in progress led by G. Pegg (QDAF).
- Fund and implement an integrated biological and ecological research program on Myrtle Rust impacts and conservation responses for the three Broad-leaved Paperbark species (*M. leucadendra*, *M. quinquenervia*, *M. viridiflora*).

Prioritisation rationale: *M. leucadendra* is one of three broad-leaved paperbark species that are keystone ecological species in several communities (wetlands and riparian) in eastern and northern Australia, and which play a major biophysical role and have strong Indigenous cultural significance. Pro-active survey of the species for disease incidence, severity and impact would provide advance warning of possible decline in these key ecosystems, and put affected jurisdictions on the front foot in the identification and selection of more resistant genotypes for remedial conservation.

Subject to initial field survey outcomes, the three broad-leaved paperbark species *M. leucadendra*, *M. quinquenervia*, and *M. viridiflora* should be the joint subjects of an integrated impact study.

Melaleuca lophocoracorum

Distribution: North Queensland (very restricted, Ravenshoe area)

Legislative extinction-risk listings: nil.

Susceptibility rating/s: none yet applied.

Resistant individuals or populations known/suspected: Data deficient, but on report of some resistance in cultivated seedlings (see below).

Germplasm: Presumed orthodox.

Geog. overlap (Berthon et al., 2018): 100%

Geog. overlap (Makinson, here estimated): TOTAL

Impact quantified: No.

Impact indicative: There are no reports from wild populations. However Mr A. Ford (CSIRO, pers. comms and *in litt*., 2017) reports ex situ mortality in cultivated seedlings of *Melaleuca lophocoracorum* ("many killed, others survived, and remain alive after in-ground planting"). The latter species has not hitherto been reported as a host, and is exceedingly rare in the wild near Ravenshoe.

Priority for conservation actions (Berthon et al. 2018): none applied.

Priority for conservation actions (here recommended): MEDIUM

Prioritisation rationale: *M. lophocoracorum* is a newly reported host (A. Ford, CSIRO, pers. comms and *in litt*., 2017). It does not appear on the Australian host list at Appendix 3 to this review only because the preferred evidence levels of the gatekeeper Myrtle Rust Environmental Impacts Working Group (i.e. photographic evidence or direct pathologist inspection) are not yet available. However the identification of the host by Mr Ford, his description of unambiguous *A. psidii* infection symptoms, and his report of severe seedling mortality in cultivation, are all considered here to be highly reliable. These observations, coupled with the extremely restricted range of the species and its rarity within that range, justify urgent field survey to confirm host status, determine disease impact, and secure germplasm.

Conservation actions here recommended:

- Field impact and resistance survey (use quantified occurrences e.g. permanent plots where available;

- Secure germplasm (high quantity, geographically and genetically representative).

Melaleuca nodosa

Distribution: NSW, Qld

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly to Extremely Susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: Differential levels of apparent susceptibility are reported (P. Entwistle pers. comm.) on the North Coast of NSW between two regional morphological forms in north-eastern NSW – a 'coastal' form (tending to smaller habit (usually c. 1m tall) with thicker, hairless, sub-succulent leaves rounded in cross-section, and occurring in wallum heath and adjacent communities), and a 'North Coast inland' form (a taller plant up to 6-7 m prior to the advent of Myrtle Rust, with thin flat hairy leaves, occurring in somewhat drier shrubby woodlands). Mr Entwistle regards the latter form as rather more susceptible to Myrtle Rust infection and severity of impact. The forms may represent cryptic taxa.

Germplasm: Presumed orthodox.

Geog. overlap (Berthon et al., 2018): 9%

Geog. overlap (Makinson, here estimated): Partial in NSW; partial in Qld.

Impact quantified: None published, but work is in progress by G. Pegg (QDAF) and collaborators in north-eastern NSW including in post-fire plots. Pegg (unpublished data, pers. comm., Dec 2017) notes severe defoliation, sometimes severe branch dieback, and nodular stem swellings, following Myrtle Rust infection, and on a preliminary basis assesses the overall impact on this species as moderate to high, with an indirect impact (through branch abortion and loss of plant resources) on flowering and fruiting.

Impact indicative: P. Entwistle (pers. comm. 16 May 2017) reports reduced flowering and severe habit distortion of the 'North Coast inland' form across several populations; he also reports consistent heavy infection and damage on resprouts and epicormic shoots after fire. He notes apparent different levels of MR susceptibility, with the Inland form rather more susceptible, and for that form reports structural (habit) change, with the pendulous-branched semi-weeping shape of larger plants now (since the advent of Myrtle Rust) rare across several populations, as a result of tip-death of new shoots limiting their elongation. The damage has also reduced flowering levels, although *M. nodosa* has some ability to produce flowers (and new shoots) on older wood, and these old-wood inflorescences may now make up a greater proportion of total flowering. Finally, Mr Entwistle notes that post-fire re-sprouts and epicormic shoots of both forms of *M. nodosa* are prone to severe Myrtle Rust infection. Seedling susceptibility, and any change in recruitment frequency, are not known.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Resources for the continuation of the Pegg et al. multi-species post-fire study on the NSW North Coast, which is already well advanced, are not assured – deployment of resources to enable its completion should be a priority for this species (ahead of broader geographic survey).

- Field impact survey (use quantified occurrences e.g. permanent plots where available) of selected sites in other regions (NSW and Qld) at coastal altitudes, and (Qld) eastern Darling Downs.
- Investigate reported differential impacts/resistance on coastal and hinterland forms
- Seek taxonomic reappraisal of possible cryptic sub-taxa.
- The above actions need to dovetail with (and reinforce on a wider geographical basis) work in progress by G. Pegg (QDAF) and collaborators on multiple species in fire-prone systems on the NSW North Coast.

Prioritisation rationale: Significant Myrtle Rust impact on *Melaleuca nodosa* on a regional basis (NSW Far North Coast) is clear. *M. nodosa* is a significant element of many coastal heath and shrubby woodland ecosystems at coastal altitudes in NSW and Queensland; the impacts of myrtle Rust across this biome are unknown except for the above region. *M. nodosa* also occurs on and west of the ranges, where it is less likely to be impacted by Myrtle Rust – these truly inland occurrences are not here regarded as priority for investigation.

Melaleuca quinquenervia

Distribution: NSW, Qld; (also Indonesia, New Guinea, New Caledonia).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Relatively Tolerant to Extremely Susceptible (Pegg et al. 2014); Low to High susceptibility (Berthon et al. 2018).

Resistant individuals or populations known/suspected: YES (G. Pegg, unpublished data).

Germplasm: Orthodox.

Geog. overlap (Berthon et al. 2018): 6%

Geog. overlap (Makinson, here estimated): Near-total.

Impact quantified: Yes, in part (G. Pegg, unpublished data and work in progress in north-east NSW and Queensland). Pegg (pers. comm. Dec. 2017) reports, on a preliminary basis, 30% of adult trees in study sites as fully resistant or tolerant of the pathogen, and 40% as highly susceptible, with significant variation between sites. Among highly susceptible trees, adult death may occur after as little as 18 months exposure to infection in cases where ambient conditions favour sustained disease levels. For juveniles and saplings, Myrtle Rust symptoms were identified on all sampled, with varying levels of severity and impact – 41% with relatively low impact (symptoms restricted to foliage), 26% moderate impact (symptoms on foliage and juvenile stems causing foliage loss and some dieback), and 33% severe impact (foliage and stem dieback). The juvenile data suggests, pending more complete data, that even in some populations with a high proportion of resistant or tolerant adults, cumulative juvenile mortality and slowed growth may have significant successional impacts over time. Seedling resistance does however vary markedly with provenance, ranging from 5% to c. 80%; it is unclear how closely this correlates with adult tolerance. Flowering rates of adults are affected by Myrtle Rust, with trees exhibiting low-severity symptoms losing much flowering capacity in the first year but recovering significantly in the second; trees with moderate and severe symptoms show a greatly reduced flowering rate on a sustained basis. Lose of floral (and therefore seed) capacity is significant for the species, but loss of the floral resources of pollen and nectar are a major problem for many invertebrate and some vertebrate species which utilise them on a large-scale basis in season; declines in the invertebrate component especially may have cascade effects on other associated fauna. Some *M. quinquenervia* communities are fire-prone, with coppice regeneration playing an important recovery role; initial data from the above project indicates a strong interaction of rust damage and insect attack on coppice regrowth – where these were uncontrolled, survival averages <30%, but where controlled improves to >80%.

The known high impacts of Myrtle rust on this species in Florida USA (and compounding rust/insect/host interactions there) are well documented and should inform Australian investigations.

Impact indicative: YES, variable reports, some indicating high to very high infection levels (often uneven within a site), and significant reductions of flowering and seeding.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended: Field impact survey (use quantified occurrences e.g. permanent plots where available); needs to dovetail with work in progress led by G. Pegg (QDAF).

- Fund and implement an Integrated biological and ecological research program on Myrtle Rust impacts and conservation responses for the three Broad-leaved Paperbark species (*M. leucadendra*, *M. quinquenervia*, *M. viridiflora*).

Prioritisation rationale: *Melaleuca quinquenervia* is a keystone ecological species in several communities (wetlands and riparian), with Indigenous cultural significance and a major biophysical role. Subject to field impact survey outcomes for its two northern congeners, the three broad-leaved paperbark species *M. leucadendra*, *M. quinquenervia*, and *M. viridiflora* should be the joint subjects of an integrated impact study, and large-scale germplasm collection undertaken in the light of results. Possible candidate for translocation of resistant lineages and/or for resistance breeding and rewilding if projected impacts warrant this. Impact modelling desirable for known susceptible populations. Note existing work in progress by G. Pegg and collaborators – this needs reinforcement and resources to deal with large scope of the species and known high variability of susceptibility.

M. leucadendra, *M. quinquenervia*, and *M. viridiflora* should be the joint subjects of an integrated impact study.

Melaleuca viridiflora

Distribution: Qld, NT, WA.

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly Susceptible (Pegg et al. 2014); High (Berthon et al., 2018).

Resistant individuals or populations known/suspected: undetermined.

Germplasm: Orthodox.

Geog. overlap (Berthon et al., 2018): 1.5%

Geog. overlap (Makinson): not estimated.

Impact quantified: No, but G. Pegg (QDAF) presents preliminary data on ex situ susceptibility trials of seedlings from multiple provenances across the range, showing strong variation in resistance varying from <10% to >70%. Further development of this research program, which is highly desirable, is not funded.

Impact indicative: Very few reports of infection (but minimal survey). J. Wills (Queensland Herbarium, pers. comm. 25 May 2018) reports damage varying from minor to moderate at multiple sites (seven populations) in North Queensland in May 2018.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available); needs to dovetail with work in progress led by G. Pegg (QDAF).
- Fund and implement an integrated biological and ecological research program on Myrtle Rust impacts and conservation responses for the three Broad-leaved Paperbark species (*M. leucadendra*, *M. quinquenervia*, *M. viridiflora*).

Prioritisation Rationale: *M. viridiflora* is a keystone ecological species in several communities (wetlands and riparian), with Indigenous cultural significance and a major biophysical role. Subject to field impact survey outcomes for it and its congeners *M. leucadendra* and *M. quinquenervia* (*q.v.*), all three broad-leaved paperbark species should be the joint subjects of an integrated impact study, and large-scale germplasm collection guided by the results.

Metrosideros nervulosa

Distribution: NSW (Lord Howe Island endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: S* [“susceptible, but severity not recorded”] (Berthon et al. 2018); known host from inoculation testing (Morin 2011; Morin et al. 2012).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Presumed orthodox.

Geog. overlap (Berthon et al., 2018): 40%

Geog. overlap (Makinson, here estimated): Total if rust establishes on LHI.

Impact quantified: No wild infections recorded to date.

Impact indicative: No wild or open-cultivation infections recorded to date.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): HIGH PRECAUTIONARY

Conservation actions here recommended:

- Secure germplasm in high quantity and genetically representative, for conservation and research.

Prioritisation rationale: *Metrosideros nervulosa* is one of a suite of five taxa endemic to Lord Howe Island (four of them known hosts from inoculation screening) that are here recommended for precautionary conservation action (large-scale germplasm collection). The Lord Howe Island Group is a World Heritage Area with a high degree of floral endemicity (one of the main bases of its WHA declaration). This taxon is ecologically significant in its habitat. *Metrosideros nervulosa* (Mountain Rose) is co-dominant in Community 13c ‘Fitzgerald – Mountain Rose low closed forest’ of Sherringham et al. (2016), who note that this community provides nest-burrow sites for Providence Petrels (*Pterodroma solandri*). The species is a major dominant tree in the ecological community Gnarled Mossy Cloud Forest, which is listed under NSW legislation as Critically Endangered.

Myrtle Rust was detected on cultivated plants on Lord Howe Island in 2016, but detection and response seems to have occurred very early in the invasion process and as at January 2017 no infections of LHI wild native plants have been found, and it appears likely that Myrtle Rust has been eradicated. There is however a constant risk of renewed arrival either by human agency or by wind distribution of spores from the Australian mainland or (New Zealand or New Caledonia). Precautionary conservation action via the securing of germplasm for the future is prudent, given the indefinite risk of re-infection, the known susceptibility of four of the five endemic Myrtaceae, the World Heritage values, and the positive demonstrative effect on public biosecurity awareness that a coordinated action set would promote.

Metrosideros sclerocarpa

Distribution: NSW (Lord Howe Island endemic)

Legislative extinction-risk listings: No listings

Susceptibility rating/s: S* (Berthon et al. 2018); known host from inoculation testing (Morin 2011; Morin et al. 2012).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Presumed orthodox.

Geog. overlap (Berthon et al., 2018): 50%

Geog. overlap (Makinson, here estimated): Total if rust establishes on LHI.

Impact quantified: No wild infections reported to date.

Impact indicative: No wild or open cultivation infections reported to date.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): HIGH PRECAUTIONARY

Conservation actions here recommended:

- Secure germplasm in high quantity and genetically representative, for conservation and research.

Prioritisation rationale:

Metrosideros sclerocarpa is one of a suite of five taxa endemic to Lord Howe Island (four of them known hosts from inoculation screening) that are here recommended for precautionary conservation action (large-scale germplasm collection). The Lord Howe Island Group is a World Heritage Area with a high degree of floral endemicity (one of the main bases of its WHA declaration). This taxon is ecologically significant in its habitat. It is the dominant species of the very restricted vegetation type 'Community 22 - Hill Rose – Forky-tree forest of rocky creeks and slopes' of Sherringham et al. (2016). It is also a constituent of Community 15 'Blue Plum – Curly Palm – Scalybark – Forky-tree closed forest on rocky slopes and gullies' of the same classification, which is endemic-dominated and provides nest-burrow sites for Providence Petrels (*Pterodroma solandri*).

Myrtle Rust was detected on cultivated plants on Lord Howe Island in 2016, but detection and response seems to have occurred very early in the invasion process and as at January 2017 no infections of LHI wild native plants have been found, and it appears likely that Myrtle Rust has been eradicated. There is however a constant risk of renewed arrival either by human agency or by wind distribution of spores from the Australian mainland or (New Zealand or New Caledonia). Precautionary conservation action via the securing of germplasm for the future is prudent, given the indefinite risk of re-infection, the known susceptibility of four of the five endemic Myrtaceae, the World Heritage values, and the positive demonstrative effect on public biosecurity awareness that a coordinated action set would promote.

Rhodamnia angustifolia

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Endangered

Susceptibility rating/s: Extremely susceptible (Pegg et al. 2014); Highly susceptible (Berthon et al. 2018).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Presumed non-orthodox. Seed set may be low; no seedlings seen by Snow & Guymer (1999b), who also report apparently significant levels of insect predation on seed. The species does however produce suckers at and near the base, providing an additional option for germplasm collection.

Geog. overlap (Berthon et al., 2018): 50%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (surveys lacking).

Impact indicative: Very few observations, none decisive

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots if available).
- Urgent precautionary securing of seed or vegetative germplasm.
- Seed storage enablement research.
- Investigate options for inter-situ live collections (fungicide-protected).

Prioritisation rationale:
The Extreme susceptibility rating conferred by Pegg et al. (2014), the very limited area of occurrence (c. 60 ha) and low numbers (19 reported by Snow & Guymer 1999b, a few more subsequently), and the Endangered threat status even prior to the advent of Myrtle Rust, all combine to make targeted survey a priority.

Rhodamnia argentea

Distribution: NSW, Qld

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Medium to High susceptibility (Pegg et al. 2014); Medium to High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: None reported.

Germplasm: Non-orthodox. One small seed batch is held at Brisbane Botanic Garden (J. Halford, pers. comm. May 2017).

Geog. overlap (Berthon et al., 2018): 18%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no surveys).

Impact indicative: Very few reports. Ecological consultant A. Benwell (pers. comm. Aug 2017) reports seeing only light infections in north-eastern NSW; however, G. Lieper (Conservation Officer, Queensland native Plant Society, pers. comm. May 2017) reports a population at The Head, east of Killarney Qld, very badly hit in 2016, with no fruit produced. M. Russell (Conservation Partnerships Officer, Sunshine Coast Regional Council, *in litt*. Sept. 2017) regards *R. argentea* as one of the ten species most seriously affected by Myrtle Rust in that region. J. Wills (Queensland Herbarium, pers. comm. 7 June 2018) "assessed 7 populations from across its range. Damage varied from minor to moderate. Active rust was severe on 3 of the populations".

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): medium

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available); dependent on results, then …
- Germplasm storage-enablement study (prerequisite for germplasm capture).
- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.

Prioritisation rationale:

Rhodamnia argentea ranges into the High susceptibility category, and of the two reports on wild infection available for this review, one indicates significant impact (loss of season's fruit) for one population. Urgent field survey to determine impact level would allow more confidence for extended actions.

Rhodamnia australis

Distribution: Qld, NT

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014); Medium to High susceptibility (Berthon et al. 2018).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 2%

Geog. overlap (Makinson, here estimated): Total in Qld; uncertain in NT.

Impact quantified: No (no surveys).

Impact indicative: No data. The lack of field observations reflects the paucity of observers and lack of planned survey in the area of occurrence (Cape York Peninsula and NT Top End).

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for germplasm capture).

Dependent on outcomes of the above, then

- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.

Prioritisation rationale:

High susceptibility (in common with most or all other species in the genus), and apparent occurrence in habitat suitable for Myrtle Rust (albeit uncertain in the NT) make precautionary survey of at least some sites prudent.

Rhodamnia costata

Distribution: Qld (endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014); Medium to High susceptibility (Berthon et al. 2018).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 9%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No

Impact indicative: No impact data as such, but infection levels can be high. A. Ford (CSIRO, pers. comm. Sept 2017) reports infection in three of four plots on the Windsor Tableland. Rainforest plant expert G. Sankowsky (pers. comm. Aug. 2017) reports this species (and *R. spongiosa* and *R. blairiana*) all with "extraordinary levels of Myrtle Rust sporulation – golden clouds of dust [spores]" on one visit, but on subsequent visit in a different season no sign of active rust. W.J.F. McDonald (pers. comm. Sept. 2017) has seen infection in wild populations in both Central and North Queensland, but has not noted any major defoliation to date.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for germplasm capture).

Dependent on outcomes of the above, then

- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.

Prioritisation rationale: *R. costata* may be one of the species able to 'push through' severe bouts of infection and maintain a growth flush beyond the peak level of rust frequency, but this may not be the case at all sites and does not preclude 'slow burn' decline. High susceptibility (in common with most or all other species in the genus), and apparent total occurrence in habitat suitable for Myrtle Rust, make precautionary survey of at least some sites prudent.

Rhodamnia dumicola

Distribution: Qld (endemic)

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014); Medium to High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: unknown.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 45%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no surveys).

Impact indicative: Rainforest expert W.J.F. McDonald (pers. comm. Sept. 2017) regards *R. dumicola* as "a cot case – I have not seen any in recent times that haven't been very, very badly defoliated, although not quite dead."

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- *Germplasm:* storage enablement study (prerequisite for *Germplasm:* capture). (precautionary).

Prioritisation rationale: High susceptibility (in common with most or all other species in the genus), endemicity to a habitat and zone (NSW border to Miriam Vale) which is replete with highly susceptible species and therefore high spore load, plus the only field observations available for this review, make precautionary survey of at least some sites prudent.

Rhodamnia longisepala   NEW HOST REPORT

Distribution: Qld endemic (very restricted, Windsor Tableland, FNQ)

Legislative extinction-risk listings: Qld NCA: Endangered

Susceptibility rating/s: not assigned. This species is reported as a new host (A. Ford, CSIRO Atherton, pers. comm. Sept. 2017). Host status has not yet been assessed by the Myrtle Rust Environmental Impacts Working Group.

Resistant individuals or populations known/suspected: unknown.

Germplasm: Assumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 100%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No.

Impact indicative: A. Ford (CSIRO, pers. comm. Sept 2017) reports severe infection, Windsor Tableland.

Priority for conservation actions (Berthon et al. 2018): Category B

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Refer to MREIWG for addition to national host list.
- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for germplasm capture).
- Secure germplasm (high quantity, geographically and genetically representative).
- If warranted, investigate options for inter-situ live collections (fungicide-protected).

Prioritisation rationale:

The identification of the host species is by a leading expert (Ford), and the identification of infection symptoms as Myrtle Rust infection is here assessed as highly reliable. The sole report of severe infection, coupled with the extremely narrow distribution of the host (known only from the Windsor Tableland, where numerous other species known to be prone to heavy infection) make an urgent conservation assessment prudent.

Rhodamnia maideniana

Distribution: NSW, Qld

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Extremely susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: none reported.

Germplasm: Non-orthodox. K. Kupsch (pers. comm. May 2017) notes that some populations (mainly in NSW?) tend to be relatively small-habit sprawling shrubs in non-fire environments, and that the species (at least in populations with this habit) can naturally self-propagate by layering, but do not sucker.

Geog. overlap (Berthon et al., 2018): 67%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: regional data indicating serious decline is available. Pegg et al. (2017) report on impact at sites in south-east Queensland and far north-east NSW. At the primary Queensland site, *R. maideniana* was co-dominant in the understorey and on forest edges, and while whole-branch death was at low levels, branch dieback was 100% (and averaged 93% across all sites), with much epicormic shooting (an indicator of stress) and 'witch's broom' clusters of dead shoots at branch tips; crown transparency at the primary site was 91% in 2016 (up from 69% in 2014). No whole-plant adult deaths were recorded within the study transects in 2014, but mortality was 30% in 2016.

Impact indicative: Several reports of severe infection, e.g. L. Weber (Qld, pers. comm.) "hammered on new growth, flowers and fruits". Queensland rainforest expert W.J.F. McDonald (pers. comm. Sept 2017) reports "heavy defoliation wherever seen, but hanging on; no full mortality seen … Cautiously, some indications of regrowth on some plants, possibly a function of reduced Rust incidence during current dry spell". A Sunshine Coast Myrtaceae grower (Anonymous, pers. comm. Aug. 2017) regards *R. maideniana* as the "worst of all *Rhodamnia*" for infection in open cultivation. Myrtaceae horticulturalist K. Kusch (pers. comm. May 2017) reports *R. maideniana* in the wild in far north-eastern NSW as severely hit with extensive defoliation. Ecologist L. Weber (pers. comm. Aug. 2017) concurs, reporting *R. maideniana* as "severely hammered [by Myrtle Rust] on new growth, flowers and fruits, from Alstonville [NSW] to the Queensland border". Ecologist A. Benwell (pers. comm. Aug. 2017), for the same general region, reports the species as hit very badly, with adults killed.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for germplasm capture).
- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.

Prioritisation rationale: *Rhodamnia maideniana* is rated as extremely susceptible to Myrtle Rust. It occurs entirely within the current zone of permanent Myrtle Rust naturalisation, and in a region rich in other highly susceptible Myrtaceae, ensuring a relatively constant inoculum source at most if not all locations. Serious decline has been quantitatively demonstrated in the core part of the species' range, and observer reports from other areas suggest this is general.

Rhodamnia rubescens

Distribution: NSW, Qld

Legislative extinction-risk listings: NSW BCA: A preliminary determination under NSW legislation has been made to list this previously unlisted (widespread, common, 'least concern') species as Critically Endangered as a direct result of Myrtle Rust-mediated decline (NSW Scientific Committee 2017a -- http://www.environment.nsw.gov.au/resources/threatenedspecies/determinations/PDRhodrubesCR.pdf). As this is a cross border species (with Queensland), listing is subject to the nationally agreed Common Assessment Methodology, and the timeframe for a national assessment and listing is not yet clear.
Susceptibility rating/s: Highly to Extremely susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: None confirmed. There are repeated reports of isolated plants with no or low infection (often in otherwise cleared paddocks) – these may be artifacts of microclimate or locally low spore-load. Some ability to 'push through' infection with late flush is reported by various respondents, and there are occasional reports of low-infection patches still flowering (e.g. at Kin Kin, Qld, J. Halford pers. comm. May 2017), but these not necessarily 'resistant'.

Germplasm: Non-orthodox? (under study, NSW PlantBank).

Geog. overlap (Berthon et al., 2018): 18%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: Yes. Carnegie et al. (2016) conducted a whole-of-range study (43 sites), finding all infected, a mean crown transparency of 76% (against an estimated 'normal' of 30-35%), and adult mortality, while variable, averaging 12% (to Oct. 2014, increased since). Lack of fruiting and seedling recruitment was evident across the sites. Data collection for that project terminated in October 2014, at which time the sites had had a maximum of four years exposure to the pathogen (less for many). Carnegie (pers. comm. Dec. 2017) reports that revisits to some of the sites in 2017 have shown mortality has increased to 50% in some. Pegg et al. (2017) report a slower but steady increase in mortality at one site in the Tallebudgera Valley (Qld) with 25% adult mortality in 2014, and 30% in 2016.

Impact indicative: There are many reports of severe decline, and some of apparent local extinction. There are also frequent reports of ability to persist for a few years on late flush and late stem shoots (after the main seasonal rust cycle has waned); however the trend is sharply downwards in all regions of occurrence. Towards or at the upper end of the altitudinal range of the species, at The Head (near Killarney, Qld, at 700-800m a.s.l.), G. Leiper (Conservation Officer, Native Plants Queensland, pers. comm. May 2017) reports *R. rubescens* (and the co-occurring *R. whiteana* and *R. argentea*) "smashed by Myrtle Rust in 2016", with none of the three species setting any fruit. Near the southern end of the range, at Booderee National Park NSW (Jervis Bay), Stig Pedersen of Booderee Botanic Gardens (pers. comms Sept. 2017) reports one of two populations under observation in the Park as 100% dead. At the northern end, W.J.F. McDonald (pers. comm. Sept. 2017) reports the situation as dire, but still struggling – the current dry spell could aggravate decline ... Still seeing some shrub-sized specimens, but most adults long dead". Ecologist R. Kooyman (pers. comm. May 2017) confirms extensive infection and "heavy damage" in the NSW Rainbow Region. M. Russell (Sunshine Coast Regional Council, *in litt*. Sept. 2017) rates *R. rubescens* as among the ten most seriously rust-affected species in the region. And so on.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): EMERGENCY

Conservation actions here recommended:

- *Field survey and monitoring*: for resistant individuals or populations.
- *Germplasm:* storage enablement study (prerequisite for seed banking) – in train at NSW PlantBank.
- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) sampled from regional populations, as seed production resources.
- Candidate for exploratory resistance breeding or engineering.

Prioritisation rationale:

The steep decline across the whole of the range of *Rhodamnia rubescens* is well documented. While some plants in many populations survive yearly bouts of infection and maintain some new growth, many do not, and the cumulative mortality rate is compounded by lack of fruiting in most populations in most years, and apparent cessation of seedling recruitment at nearly all locations for which appropriate seasonal reports are available. No signs of resistance at populational level have emerged, although there are sporadic reports of individuals (and very rarely small populations) with low or no infection incidence – possibly by chance. Effective extinction in the wild of this formerly common species within a very few years is likely.

Rhodamnia sessiliflora

Distribution: Qld (endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Medium to Extremely susceptible (Pegg et al. 2014); Medium to High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: none reported.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 46%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no surveys).

Impact indicative: A. Ford (CSIRO, pers. comm. Sept 2017) reports infection in three of four plots on Windsor Tableland FNQ. J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018) reports active rust infection at multiple sites in North Queensland, on seedlings to small trees, with severe tip dieback and branch death in some, but also significant variation; overall, he "assessed 20 populations and most showed severe damage. Four populations had no signs of infection or active rust" and were flowering and fruiting.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for future germplasm capture).

Prioritisation rationale:

Rhodamnia sessiliflora is rated as having variable medium to extreme susceptibility, but this range of response has not been proven in the wild. Its range (Townsville area to Cape Tribulation area, and sea-level to 1,000 m alt.) is at these latitudes totally overlapped by that over Myrtle Rust, in Myrtaceae-rich systems where spore load can be expected to be high. Prudent conservation management dictates a need for impact survey and seed storage enablement against future need.

Rhodamnia spongiosa

Distribution: Qld endemic

Legislative extinction-risk listings: No listings

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014); High (as '*Rhodamnia glauca*, syn. *R. spongiosa*') in Berthon et al. (2018).

Nomenclatural note: Berthon et al. (2018) publish a new Australian Myrtle Rust host list. They have chosen to follow the generic and species names accepted in the international catalogue *The Plant List* (The Plant List 2013), which differs from Australian botanical usage and taxonomic views at some points. This leads them to follow an assignation by Scott (1979) of *R. spongiosa* to synonymy under the name *R. glauca*, a species with a New Guinean type specimen. Snow (2007, 2012) however explicitly maintains the name and type of *R. spongiosa* for the Australian populations. The *Australian Plant Census* (APC -- https://www.anbg.gov.au/chah/apc/) recognises the Australian taxon as *R. spongiosa*, as does the Queensland Herbarium (Queensland Plant Census 2017, https://data.qld.gov.au/dataset/census-of-the-queensland-flora-2017 . This approach is followed here.

Resistant individuals or populations known/suspected:

Germplasm: Non-orthodox

Geog. overlap (Berthon et al., 2018): 3.7% (as '*Rhodamnia glauca*')

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no surveys).

Impact indicative: A. Ford (CSIRO, pers. comm. Sept. 2017) confirms "very heavy infection levels with twig death" in Lake Tinaroo region (FNQ, 700 m a.s.l., repeated observations), but the growth flush outlasts the infection surge and plants recover. Ford also documents infection in four out of four plots at Windsor Tableland in spring 2017. J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018) "assessed 14 populations from Danbulla/Lamb Range, Wongabel and Lake Eacham and they have all been severely impacted. Using CSIRO permanent plots and QFS plots located at Downfall Creek and Danbulla I can confirm that many have died due to MR infection".

Priority for conservation actions (Berthon et al. 2018): Category C (as '*Rhodamnia glauca*')

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available), including CSIRO permanent plots.
- Germplasm storage enablement study (precautionary, pending survey outcomes; enablement is a prerequisite for any future germplasm capture).

Prioritisation rationale: *R. spongiosa* occurs in four or five metapopulations along the Queensland coast from Bundaberg to north of Lockhart. The largest metapopulation occurs largely within the Wet Tropics World Heritage Management Area. Actual impact data is lacking, but in view of the high susceptibility of the species and the scanty reports of infection, targeted impact survey is desirable.

Rhodamnia whiteana NEW HOST REPORT

Distribution: NSW, Qld

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: none assigned. This species is reported as a new host (G. Leiper, Conservation Officer, Native Plants Queensland, pers. comm. May 2017). Host status has not yet been assessed by the Myrtle Rust Environmental Impacts Working Group.

Resistant individuals or populations known/suspected: G. Leiper (pers. comm. May 2017) reports a population NNW of Killarney Qld, at 900m a.s.l. in west-facing Dry Rainforest, as untouched by Myrtle Rust and fruiting heavily in May 2017, while elsewhere in the same area (The Head, at 700-800m a.s.l.), *R. whiteana* and co-occurring *R. rubsecens*, and *R. argentea* were all heavily infected and with no fruit set. It is undetermined if this represents resistance, an altitude or microclimate effect, or fortuitous absence of inoculum. J. Wills (Queensland Herbarium, pers. comm. 7 June 2018) "Assessed 4 populations at Mt Mistake and Queen Mary Falls Rd, and all were infected with minor-moderate damage. Fruit was not assessed".

Germplasm: Non-orthodox. The higher altitude population noted above may be a source of seed not available elsewhere.

Geog. overlap (Berthon et al., 2018): 47%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No

Impact indicative: Yes (G. Leiper, pers.comm., May 2017), see above.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- *Germplasm:* storage enablement study (prerequisite for germplasm capture).

Prioritisation rationale: *Rhodamnia whiteana* is restricted in distribution, occurring only in the Caldera region of far north-eastern New South Wales, the Border Ranges, and north to Glenrock State Forest in Queensland – Myrtle Rust is heavily naturalised through most or all of this region. Impact survey is strongly advised.

Rhodomyrtus canescens

Distribution: Qld (endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014); High (Berthon et al., 2018, as '*R. trineura*').

Nomenclatural note: Berthon et al. (2018) publish a new Australian Myrtle Rust host list. They have chosen to follow the generic and species names accepted in the international catalogue *The Plant List* (The Plant List 2013), which differs from Australian botanical usage and taxonomic views at some points. This leads them to follow the relegation by Scott (1978), in a general revision of the genus, of *Rhodomyrtus canescens* to subspecies status as *R. trineura* subsp. *canescens.* Guymer (1991) however in a revision of the *R. trineura* complex, reinstates *R. canescens* at species rank. The *Australian Plant Census* (APC -- https://www.anbg.gov.au/chah/apc/) recognises *R. canescens* C.T.White & W.D.Francis as a species, as does the Queensland Herbarium (Queensland Plant Census 2017, https://data.qld.gov.au/dataset/census-of-the-queensland-flora-2017 . This approach is followed here.

Resistant individuals or populations known/suspected: None reported.

Germplasm: Presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 5.9% (as '*Rhodomyrtus trineura*' – the apparent inclusion in this overlap estimate of both subspecies of *R. trineura* as well as *R. canescens* leads to a major underestimate of overlap).

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no survey).

Impact indicative: J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018) report having assessed five populations at Baldy Mountain and Mt Lewis, four of which showed severe damage and active rust infection on seedlings to small trees, with severe tip dieback and branch death. One population showed minimal infection or damage and was flowering and fruiting.

Priority for conservation actions (Berthon et al. 2018): species omitted

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- *Germplasm:* storage enablement study (prerequisite for germplasm capture).

Prioritisation rationale: *R. canescens* occurs in the Wet Tropics area of North Queensland, from the Tully Falls National Park north to Mount Lewis National Park, in wet sclerophyll and rain forest, at 500—1200 m a.s.l. It is highly susceptible to Myrtle Rust, is a constituent of the Wet Tropics World Heritage Management Area flora. The lack of impact reports indicates lack of survey, not necessarily absence of disease and its effects. Impact survey to establish a baseline is highly desirable.

Rhodomyrtus pervagata

Distribution: Qld (endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Medium to High susceptibility (Pegg et al. 2014); Medium to High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: none reported.

Germplasm: Presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 51%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no surveys).

Impact indicative: A. Ford (CSIRO Atherton, pers. comm. Sept 2017) reports infection in four of four plots on Windsor Tableland FNQ. J. Wills (Queensland Herbarium, pers. comms 25 May and 7 June 2018) "Assessed 13 populations and all showed severe damage and active rust" on seedlings to small trees. "5 individual plants showed no signs of infection and were fruiting heavily".

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (precautionary – prerequisite for any future germplasm capture).

Prioritisation rationale: *Rhodomyrtus pervagata* is distributed from just north of Townsville to north of Cape Tribulation, and is a constituent of the flora of the Wet Tropics World Heritage Management Area. It grows in Myrtle Rust-prone habitat (upland and montane rainforest at 350-1250 m a.s.l.). It is favoured by disturbance and is a characteristic component of rain forest regrowth (Australian Tropical Rainforest Plants information system, http://keys.trin.org.au/key-server/player.jsp?keyId=41, accessed 13 Jan. 2018) – the effect of any decline of this species on rainforest system regeneration dynamics is of concern.

Rhodomyrtus psidioides

Distribution: NSW, Qld

Legislative extinction-risk listings: NSW BCA: A preliminary determination under NSW legislation has been made to list this previously unlisted (widespread, common, 'least concern') species as Critically Endangered as a direct result of Myrtle Rust-mediated decline (NSW Scientific Committee 2017b -- http://www.environment.nsw.gov.au/resources/threatenedspecies/determinations/PDRhodpsidCR.pdf). As this is a cross border species (with Queensland), listing is subject to the nationally agreed Common Assessment Methodology, and the timeframe for a national assessment and listing is not yet clear.

Susceptibility rating/s: Extremely susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: Myrtaceae horticulturalist K. Kupsch (pers. comm. May 2017) reports one apparently disease-tolerant plant at Mooball NSW, while all others in the area have died. No others known despite wide survey and reportage.

Germplasm: Non-orthodox; one batch of several hundred seeds is held at the Queensland Seed Bank (Brisbane Botanic Garden), but testing on a duplicate batch at the Millennium Seed Bank (UK) shows a relatively low level of viability; it is understood that testing is underway to evaluate cryogenic storage options (J. Halford, Brisbane Botanic Garden, pers. comm. May 2017). Queensland rainforest expert W.J.F. McDonald (pers. comm. Sept. 2017) is of the opinion that *R. psidioides* is (pre-Myrtle Rust) mostly clonal from suckers, especially in regrowth situations. There are reports of surviving resprout plants in various areas; ecological consultant A. Benwell (pers. comm. Aug. 2017) reports apparent juveniles (suckers or suppressed seedlings) to 10cm tall, free of infection in a re-locatable littoral rainforest site south of Ballina.

Geog. overlap (Berthon et al., 2018): 28%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: Carnegie et al. (2016) conducted a whole-of-range study (18 sites), finding all infected, a mean crown transparency (CT) of 95% (against an estimated 'normal' of 25-35%), with 82% of plants sampled having >90% CT. Adult mortality averaged 57%, and "all but three sites had exceptional levels of mortality" not plausibly attributable to any other cause. Lack of fruiting and seedling recruitment was evident across the sites; persistent sucker regrowth was often noted but failing after re-infection. Data collection for that project terminated in October 2014, at which time the sites had had a maximum of four years exposure to the pathogen (less for many). One of the same sites (in the Tallebudgera valley of south-east Queensland, and where *R. psidioides* had been locally common prior to 2010) was monitored subsequently as part of a more regionally focussed study (Pegg et al., 2017) – in 2014 "96.7% of *Rhodomyrtus psidioides* trees assessed at Ryans Road were dead, increasing to 100% in 2016. No evidence of root sucker regeneration or seedling germination was found at spots where *R. psidioides* trees had been killed by *A. psidii*. *Rhodomyrtus psidioides* at Ryans Road has been replaced by other species including the noxious weeds lantana (*Lantana camara*) and wild tobacco (*Solanum mauritianum*)".

Impact indicative: There are many reports of severe decline and local extinction. Queensland rainforest expert W.J.F. McDonald (pers. comm. Sept. 2017) regards *R. psidioides* as "an absolute goner … all I see is dead trees – haven't seen a live one in 3 or 4 years other than one weak stem sucker on a large, otherwise defoliated specimen on Lamington Plateau" (where until the advent of Myrtle Rust it dominated several regrowth areas around O'Reillys). Lamington Plateau and many other sites of occurrence of *R. psidioides* in NSW and Queensland, are part of the Gondwana Rainforests World Heritage Area. M. Russell (Sunshine Coast Regional Council, Qld; pers. comm. Sept. 2017) reports *R. psidioides* as one of the ten most seriously affected species in that area.

There are frequent reports of suckering for a year or two after rest of the plant is dead, although these too are soon infected (these are now the only source of germplasm at a rapidly dwindling number of sites). Ecologist D. Binns (pers. comm. July 2017) on the far north coast of NSW has noted some surviving specimens growing as understorey in disturbed Camphor Laurel forest. D. Holloman (NSW NPWS, pers. comm. July 2015) reports discovery of healthy low plants (probably suckers) under a heavy Bitou Bush infestation at Wamberal Lagoon (NSW Central Coast), an area where all adult *R. psidioides* had been killed by Myrtle Rust by 2014 or earlier. These two observations suggest that emergency salvage of vegetative germplasm may still be possible for apparently extinguished sites if overlying vegetation is dense enough to intercept spore load – *R. psidioides* is very shade tolerant. Ecologist R. Kooyman (pers. comm. May 2017) reports a large population (although fragmented by recent clearing) with no evident infection at c. 900m a.s.l. at Green Mountain on Lamington Plateau, Qld, where co-dominant in regrowth (the relationship of this observation in time and spatially with that of McDonald, above, is not clear, but it is possible that parts of Lamington Plateau may be partial altitudinal refugia for this taxon).

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): EMERGENCY

Conservation actions here recommended:

- Field survey of furthest-inland populations (escarpment) for remaining fruiting populations.
- Very urgent - Germplasm storage enablement study (prerequisite for seed banking) – in train at MSB UK (E. Bremer); also at NSW PlantBank (K. Sommerville).
- Very urgent - Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) sampled from regional populations, as seed production resources.

Prioritisation rationale: *Rhodomyrtus psidioides* is well documented as being in catastrophic decline across its range, with survivors being exceptional and almost certainly fortuitous in most cases. The window for seed collection from the wild has long passed (absent the long-term development of seed orchards), and only vegetative germplasm can now be collected from the wild. Surviving plants in cultivation, especially if with a known wild source, have acquired exceptional conservation value and should be protected with fungicide treatments where possible, as they may be vital sources of seed (even if selfed) for propagation, storage testing, and the capture of what remains of this species' genetic diversity. This formerly common species is the starkest case of rapid decline as a result of Myrtle Rust, and should be a lead candidate for emergency salvage to avoid total extinction.

Stockwellia quadrifida

Distribution: Qld (endemic).

Legislative extinction-risk listings: Qld NCA: Near-threatened

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014); High (Berthon et al. 2018).

Resistant individuals or populations known/suspected:

Germplasm: Storage tolerance etc undetermined.

Geog. overlap (Berthon et al., 2018): 52%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: No (no surveys).

Impact indicative: J. Wills (Queensland Herbarium, pers. comm. 25 May 2018) reports one observation of active rust on a wild seedling t Mt Bartle Frere. No other reports located for this review (reflects low number of rapporteurs in area and lack of targeted monitoring programs).

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for germplasm capture if warranted).

Prioritisation rationale:

Stockwellia quadrifida is of restricted distribution in north-east Queensland, in upland rainforest on the south-eastern edge of the Atherton Tableland and the Bellenden Ker Range, probably in a very limited altitudinal range from 600-750 m (Australian Tropical Rainforest Plants information system, http://keys.trin.org.au/key-server/player.jsp?keyId=41, accessed 13 Jan. 2018). Impact survey is warranted by the high susceptibility rating and the restricted area of occurrence, in a Myrtaceae-rich area that is fully within a zone of full naturalisation of Myrtle Rust.

Syzygium anisatum (= Anetholea anisata, Backhousia anisata)

Distribution: NSW (endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Relatively Tolerant to Highly Susceptible (Pegg et al. 2014); Medium to High (Berthon et al. 2018).

Resistant individuals or populations known/suspected: unknown (no survey).

Germplasm: Presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 68%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: High impact to the species selections grown in commercial cultivation occurred very rapidly after spread of Myrtle rust to the production areas in 2010-11 (Carnegie & Lidbetter, 2011). No data are available on the levels of infection/resistance in wild populations.

Impact indicative: Nil reports.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for germplasm capture).
- Secure germplasm (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations.

Prioritisation rationale: *Syzygium anisatum* is naturally rare and of restricted and patchy distribution, occurring only in the Nambucca and Bellinger valleys on the NSW North Coast (http://plantnet.rbgsyd.nsw.gov.au, accessed 13 Jan. 2018). Despite the damage done to commercial plantings, and the standing of the species as the source of an economic resource (albeit minor), no impact survey has been conducted on the wild populations.

Syzygium fullargarii

Distribution: NSW (Lord Howe Island endemic).

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: S* [“susceptible but severity not recorded”] (Berthon et al. 2018); known host from inoculation testing (Morin et al. 2011).

Resistant individuals or populations known/suspected: No data.

Germplasm: Presumed non-orthodox.

Geog. overlap (Berthon et al., 2018): 50%

Geog. overlap (Makinson, here estimated): Total if rust establishes on Lord Howe Island.

Impact quantified: No wild infection reported to date.

Impact indicative: No wild infection reported to date.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): HIGH PRECAUTIONARY.

Conservation actions here recommended: (precautionary – World Heritage Area, significant flora)

- Germplasm storage enablement study (prerequisite for future germplasm capture).
- Secure germplasm as precaution (high quantity, geographically and genetically representative).
- Investigate options for inter-situ live collections (fungicide-protected) for regional populations. if seed storage not enabled.

Prioritisation rationale: *Syzygium fullargarii* is one of a suite of five taxa endemic to Lord Howe Island (four of them known hosts from inoculation screening) that are here recommended for precautionary conservation action (large-scale germplasm collection). The Lord Howe Island Group is a World Heritage Area with a high degree of floral endemicity (one of the main bases of its WHA declaration). This taxon is ecologically significant in its habitat.

Syzygium fullargarii is a dominant element of vegetation community no 14 'Scalybark – Blue Plum – Curly Palm closed forest of sheltered slopes or valleys', delimited in Sherringham et al. (2016), who identify the conservation significance of the community as "A community dominated by endemic species and which provides nesting habitat for Providence Petrels (*Pterodroma solandri*). It is threatened by weed infestation where it is adjacent to cleared paddocks and Settlement areas, and dieback from exposure of the edge of the forest by clearing." In the event of Myrtle Rust naturalisation and significant impact on this species (loss of crown cover, mortality), these threatening processes for the whole community would be likely to be aggravated.

Myrtle Rust was detected on cultivated plants on Lord Howe Island in 2016, but detection and response seems to have occurred very early in the invasion process and as at January 2017 no infections of LHI wild native plants have been found, and it appears likely that Myrtle Rust has been eradicated. There is however a constant risk of renewed arrival either by human agency or by wind distribution of spores from the Australian mainland or (New Zealand or New Caledonia). Precautionary conservation action via the securing of germplasm for the future is prudent, given the indefinite risk of re-infection, the known susceptibility of four of the five endemic Myrtaceae, the World Heritage values, and the positive demonstrative effect on public biosecurity awareness that a coordinated action set would promote.

Syzygium hodgkinsoniae

Distribution: Qld, NSW

Legislative extinction-risk listings: Qld NCA Vulnerable; NSW BCA Vulnerable; Commonwealth EPBCA Vulnerable.

Susceptibility rating/s: not formally rated by Pegg et al.(2014); S* ["susceptible but severity not recorded"] based on its inclusion (as a 'natural' infection in NSW) in the Australian host list of Giblin & Carnegie (2014b). Results of a study by Pegg et al. (2017 – see below) suggest it may merit rating as of medium to high susceptibility.

Resistant individuals or populations known/suspected: no data.

Germplasm: Non-orthodox.

Geog. overlap (Berthon et al., 2018): 5%

Geog. overlap (Makinson, here estimated): Total

Impact quantified: Partial. Pegg et al. (2017), for a regenerating Myrtaceae-rich wet sclerophyll/rainforest community in the Tallebudgera Valley of south-east Queensland, found this species to be moderately frequent both as large (to 20 m tall) paddock residuals, and in the remnant and regenerating mid-storey rainforest association, although not frequent enough to be adequately captured in their Myrtle Rust monitoring plots for statistical analysis. "All juvenile (saplings) trees had very high incidence (90±--100%) of rust infection on new shoots and expanding foliage. Dieback on all branches is likely to have been caused by past infection episodes … with symptoms typical of *A. psidii* infection evident. The impact of *A. psidii* on mature *S. hodgkinsoniae* trees was less obvious as foliage/crown density levels were high with trees examined having a low transparency recorded. However, the presence of branch dieback, dead growing tips on most branches and epicormic shoots was evidence of stress. These epicormic shoots were infected by *A. psidii*. Despite the level of dieback, fruit was present on one of the trees. No evidence of *A. psidii* infection was identified on the fruit at the time". Pegg et al. conclude that "the impact of *A. psidii* is likely to push *S. hodgkinsoniae* closer to extinction but more extensive assessments across its range are required".

Impact indicative: No other data or observations found.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): VERY HIGH

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available)
- Germplasm storage enablement study (prerequisite for future germplasm capture).
- Secure germplasm as precaution (high quantity, geographically and genetically representative).

Prioritisation rationale: *Syzygium hodgkinsoniae* is a relatively rare large-tree constituent of subtropical and tropical rainforests, occurring from the Richmond River in north-east NSW to the Kin Kin – Maleny area in south-east Queensland, and with a very disjunct northern population near Kuranda and Gordonvale in North Queensland. In view of the susceptibility and impact demonstrated at the Tallebudgera study site, and the pre-existing vulnerable status, Pegg et al.'s recommendation for further assessments should be actioned.

Syzygium oleosum

Distribution: Qld, NSW

Legislative extinction-risk listings: No listings.

Susceptibility rating/s: Highly susceptible (Pegg et al. 2014); Resistant to High susceptibility (Berthon et al. 2018). Berthon et al.'s (2018) inclusion of a 'resistant' end of the susceptibility range is based on the varied symptoms demonstrated in glasshouse inoculation tests by Morin et al. (2012), a situation which does not well reflect susceptibility in the field. The Pegg et al. (2014) rating is more likely to reflect the field situation, although necessarily based on the limited data available at the time (and still not improved upon).

Resistant individuals or populations known/suspected: Uncertain.

Germplasm: Presumed non-orthodox

Geog. overlap (Berthon et al., 2018): 10%

Geog. overlap (Makinson, here estimated): Near-total

Impact quantified: Very limited data at regional level (Tallebudgera Valley, south-east Queensland) was captured by Pegg et al. (2017), but from a very small sample at one site – infection was noted on new growth flush, and a low (relative to other Myrtaceae species at the same site) level of branch dieback (<25%).

Impact indicative: G. Sankowsky (Tolga, north Queensland, pers. comm. Aug. 2017) is familiar with the species both in cultivation and in the wild in that area, and has not seen Myrtle Rust infection on *S. oleosum*. Ecologist R. Kooyman (pers. comm. May 2017) reports some infection level seen in north-eastern NSW.

Priority for conservation actions (Berthon et al. 2018): Category C

Priority for conservation actions (here recommended): MEDIUM

Conservation actions here recommended:

- Field impact survey (use quantified occurrences e.g. permanent plots where available).

Prioritisation rationale: *Syzygium oleosum* is widespread, occurring from the Central Coast of NSW to Australia to the Cairns area of North Queensland (where it occurs at up to 1200m a.s.l.), in rain forest, wet sclerophyll forest near rain forest margins, and in sheltered situations in eucalypt forest (Australian Tropical Rainforest Plants information system, http://keys.trin.org.au/key-server/player.jsp?keyId=41, accessed 13 Jan. 2018). It seems to play a significant role in the maintenance and possible expansion of rainforest association edges where other factors favour this. The genus *Syzygium* overall shows a very wide range of susceptibility to the strain of Myrtle Rust currently present in Australia, with species ranging from highly resistant to highly susceptible – the genetic and physiological correlates of this variation are not understood, and there is a need for identification of actual incidence, severity and impact on *Syzygium* species in the wild to cast some light. The inclusion of *S. oleosum* in this priority set is largely on the basis of its high susceptibility rating, and the impact shown in the regional study cited above.

APPENDIX 2: Reference codes used in Appendix 3 (Revised Australian Host List).

AgVic2018: Myrtle Rust. Agriculture Victoria. http://agriculture.vic.gov.au/agriculture/pests-diseases-and-weeds/plant-diseases/shrubs-and-trees/myrtle-rust, accessed 26 Jan. 2018.

B2018: Berthon K, Esperon-Rodrigueza M, Beaumont LJ, Carnegie AJ, Leishman MR (2018) Assessment and prioritisation of plant species at risk from myrtle rust (*Austropuccinia psidii*) under current and future climates in Australia. *Biological Conservation* 218: 154–162.

C2016: Carnegie AJ, Kathuria A, Pegg GS, Entwistle P, Nagel M, Giblin FR (2016) Impact of the invasive rust *Puccinia psidii* (myrtle rust) on native Myrtaceae in natural ecosystems in Australia. *Biological Invasions* 18: 127–144. DOI 10.1007/s10530-015-0996-y

CL2011: Carnegie AJ & Lidbetter JR (2011) Rapidly expanding host range for *Puccinia psidii sensu lato* in Australia. *Australasian Plant Pathology* 41: 13–29. DOI 10.1007/s13313-011-0082-6

DPIPWE2018: Plant species affected by myrtle rust in Tasmania. Department of Primary Industries, Parks, Water and Environment (Tasmania). http://dpipwe.tas.gov.au/biosecurity-tasmania/plant-biosecurity/pests-and-diseases/myrtle-rust/plant-species-affected-by-myrtle-rust-in-tasmania, accessed 26 Jan. 2018.

GC2014: Giblin F & Carnegie AJ (2014b) Puccinia psidii (Myrtle Rust) – Australian host list. Version current at 24 Sept. 2014. http://www.anpc.asn.au/resources/Myrtle_Rust.html

LBP2015: Lee DJ, Brawner JT, Pegg GS (2015) Screening *Eucalyptus cloeziana* and *E. argophloia* populations for resistance to *Puccinia psidii*. *Plant Disease* 99: 71-79.

LHIB2016: Lord Howe Island Board (2016) Business Paper: Detection, containment and eradication of Myrtle Rust, Lord Howe Island. Board Meeting: November 2016 Agenda Number: 12 (vi).

M2011: Morin L, Aveyard R, Lidbetter J (2011) Myrtle rust: host testing under controlled conditions. Report number C2010/9785. CSIRO, Canberra.

M2011(LHI): Morin L (2011) Testing the susceptibility of key plant species endemic to Lord Howe Island to myrtle rust. Unpublished report, August 2011, CSIRO Ecosystem Sciences, Canberra.

M2012: Morin L, Aveyard R, Lidbetter JR, Wilson PG (2012) Investigating the host-range of the rust fungus *Puccinia psidii sensu lato* across tribes of the family Myrtaceae present in Australia. *PLoS ONE* 7(4): e35434. doi:10.1371/journal.pone.0035434

MREIWG2: Minutes and actions, meeting of Tuesday 4th October 2016. Myrtle Rust Environmental Impacts Working Group. [unpublished]

P2014: Pegg GS et al. (2014) *Puccinia psidii* in Queensland, Australia: disease symptoms, distribution and impact. *Plant Pathology* 63(5): 1005–1021

P2017: Pegg G et al. (2017) Impact of *Austropuccinia psidii* (myrtle rust) on Myrtaceae-rich wet sclerophyll forests in south east Queensland. *PLoS ONE* 12(11): e0188058. https://doi.org/10.1371/journal.pone.0188058

P2018: Pegg G, Carnegie A, Giblin F, Perry S (2018) Final Report – Managing myrtle rust in Australia CRC2063. Plant Biosecurity Cooperative Research Centre, Bruce ACT. http://www.pbcrc.com.au/publications/pbcrc2206

PBL2014: Pegg, Brawner & Lee (2014) Screening Corymbia populations for resistance to Puccinia Psidii. *Plant Pathology* 63(2): 425–436

Potts2016: Potts BM, Sandhu KS, Wardlaw T, Freeman J, Li H, Tilyard P, Park RF (2016) Evolutionary history shapes the susceptibility of an island tree flora to an exotic pathogen. *Forest Ecology and Management* 368: 183–193. http://dx.doi.org/10.1016/j.foreco.2016.02.027

R2015: Roux J, Germishuizen I, Nadel R, Lee DJ, Wingfield MJ, Pegg GS (2015) Risk assessment for *Puccinia psidii* becoming established in South Africa. *Plant Pathology* 64: 1326–1335.

SP2013: Sandhu KS & Park RF (2013) Genetic basis of pathogenicity in *Uredo rangelii*. National Myrtle Rust Transition to Management (T2M) Program; Final Report, Project PHA 4.1. http://myrtlerust.net.au/documents/

T2015: Tobias, Park, Külheim & Guest (2015) Wild-sourced *Chamelaucium uncinatum* have no resistance to *Puccinia psidii* (myrtle rust). *Australasian Plant Disease Notes* 10.

T2017: Taylor T, Morin L, Pegg G, Zalucki J (2017) The threat of Myrtle Rust to the conservation of the endangered tree, *Gossia gonoclada* (Myrtaceae) in south east Queensland. *Australasian Plant Conservation* 25(3): 6-8.

W2016: Westaway JO (2016) The pathogen Myrtle Rust (Puccinia psidii) in the Northern Territory: First detection, new host and potential impacts. *Northern Territory Naturalist* 27: 13-28

APPENDIX 3: Australian Host List

Infection reference codes in the following table are keyed to full citations in Appendix 2. In the same column, personal communication respondents are as listed in Acknowledgements section.

Legend:

Note: the codes and categories applied to indicate extinction risk in official lists vary with jurisdiction, in some cases even for equivalent categories (hence E, e, EN); they are rendered here as they appear the jurisdictional lists relevant to each taxon.

Extinction Risk	
CR	critically endangered
r or R	rare
E or EN	Endangered
V or VU	Vulnerable
Near-Thr	Near Threatened
T	Threatened
Susceptibility Rating	
RT	Relatively tolerant
MS	Moderate susceptibility
HS	High susceptibility
ES	Extreme susceptibility

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Agonis flexuosa	ES (P2014, P2018)	Natural (Qld, NSW, Tas, Vic); Inoculation	M2011, M2012, GC2014, P2014, AgVic2018, DPIPWE2018		Aust native, endemic: WA
Allosyncarpia ternata		Inoculation	M2011, M2012		Aust native, endemic: NTerr
Angophora costata [subsp. uncertain]		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW. (subsp. costata Qld, NSW; subsp. euryphylla Qld, NSW)
Angophora floribunda		Natural (NSW); Inoculation	M2011, M2012	Vic (Advisory): r (rare)	Aust native, endemic: Qld, NSW. Vic
Angophora subvelutina		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW
Archirhodomyrtus beckleri [southern chemotype]	HS (P2018, inferred)	Natural (Qld, NSW)	P2014, P2017; NSW: Weber, Kupsch pers comms		Aust native, endemic: Qld, NSW
Asteromyrtus brassii	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native , non-endemic: Qld, New Guinea
Asteromyrtus magnifica		Inoculation	M2011, M2012		Aust native, endemic: NTerr
Austromyrtus dulcis	RT-HS (P2014, P2018)	Natural (Qld, NSW, ACT, Vic); Inoculation	M2011, M2012, GC2014, AgVic2018		Aust native, endemic: Qld, NSW
Austromyrtus tenuifolia	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: NSW
Backhousia angustifolia	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Backhousia bancroftii	RT (P2014, P2018)	Natural (Qld, NSW)	P2014		Aust native, endemic: Qld
Backhousia citriodora	MS-HS (P2014, P2018)	Natural (Qld, NSW, Vic); Inoculation	M2011, M2012, GC2014, AgVic2018		Aust native, endemic: Qld
Backhousia enata	RT-MS (P2018)	Natural (Qld, NSW)	GC2014		Aust native, endemic: Qld

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Backhousia gundarara (Synonyms: Backhousia sp. sp. Prince Regent W. O'Sullivan & D. Dureau WODD 42); 'B. bundara' in error.)	RT (Qld, in cult) (P2014, P2018)	Natural (Qld)	P2014	WA: Priority 2	Aust native, endemic: WA
Backhousia hughesii	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, B2018		Aust native, endemic: Qld
Backhousia leptopetala (Synonym: Choricarpia leptopetala)	HS (P2014), amended to RT-HS (P2018)	Natural (Qld, NSW)	P2014		Aust native, endemic: Qld, NSW
Backhousia myrtifolia	MS (P2014), amended to RT-MS (P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014		Aust native, endemic: Qld, NSW
Backhousia oligantha	HS (P2014), amended to MS-HS (P2018)	Natural (Qld)	P2014, B2018	Qld: E	Aust native, endemic: Qld
Backhousia sciadophora	RT (P2014, P2018)	Natural (Qld, NSW)	P2014		Aust native, endemic: Qld, NSW
Backhousia subargentea (Synonym: Choricarpia subargentea)	RT (P2018)	Natural (Qld)	P2014	NSW: E	Aust native, endemic: Qld, NSW
Backhousia tetraptera (Synonym: Backhousia sp. 'Mt. Stuart')		Natural (NSW)	GC2014		Aust native, endemic: Qld
Baeckea gunniana			GC2014		Aust native, endemic: NSW, ACT, Vic, Tas
Baeckea leptocaulis			GC2014		Aust native, endemic: Tas
Baeckea linifolia	MS (P2014)	Natural (Qld)	P2014	Vic (Advisory): r (rare)	Aust native, endemic: Qld, NSW, Vic
Barongia lophandra		Natural (NSW)	GC2014	Qld: V	Aust native, endemic: Qld
Beaufortia schaueri		Inoculation	M2011, M2012		Aust native, endemic: WA
Beaufortia sparsa		Inoculation	M2011, M2012		Aust native, endemic: WA

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Callistemon citrinus (Synonym: Melaleuca citrina)		Inoculation	M2011, M2012, SP2013		Aust native, endemic: Qld, NSW, Vic
Callistemon formosus (Synonym: Melaleuca formosa)	RT (P2018)	Natural (Qld)	P2014	Qld: near-thr	Aust native, endemic: Qld
Callistemon linearifolius (Synonym: Melaleuca linearifolia)		Inoculation	M2011, M2012	NSW: V	Aust native, endemic: NSW
Callistemon linearis (Synonym: Callistemon rigidus)		Natural (NSW)	GC2014		Aust native, endemic: NSW
Callistemon pachyphyllus (Synonym: Melaleuca pachyphylla)	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, NSW
Callistemon pallidus (Synonym: Melaleuca pallida)		Inoculation	SP2013		Aust native, endemic: Qld, NSW, ACT, Vic, Tas
Callistemon pinifolius (Synonym: Melaleuca linearis var. pinifolia)		Natural (NSW)	GC2014		Aust native, endemic: NSW
Callistemon polandii (Synonym: Melaleuca polandii)	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Callistemon salignus (Synonym: Melaleuca salicina)	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, NSW; Vic(naturalised)
Callistemon sieberi (Synonym: Melaleuca paludicola)	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW, ACT, Vic, SA
Callistemon sp. 'Rock of Gibraltar' (LM Copeland 3618)		Natural (ACT)	MREIWG2		Aust native, endemic: NSW

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Callistemon viminalis (Synonym: Melaleuca viminalis)	MS-HS (P2014, P2018)	Natural (Qld, NSW, Vic); Inoculation	M2011, M2012, SP2013, GC2014, AgVic2018	WA: Priority 2	Aust native, endemic: Qld, NSW, SA, WA
Callistemon viridiflorus (Synonym: Melaleuca virens)		Inoculation	SP2013		Aust native, endemic: Tas
Calothamnus gilesii		Natural (ACT)	MREIWG2		Aust native, endemic: WA
Calothamnus quadrifidus [subsp. sensu WA Florabase uncertain]		Natural (NSW); Inoculation	M2011, M2012, GC2014	WA: subsp asper Priority 2; subsp. teretifolius Priority 4	Aust native, endemic: WA
Calothamnus quadrifidus subsp. Asper (Synonym: Calothamnus asper)		Natural (ACT)	MREIWG2	WA: Priority 2	Aust native, endemic: WA
Calothamnus torulosus		Natural (ACT)	MREIWG2		Aust native, endemic: WA
Calytrix tetragona		Inoculation	GC2014		Aust native, endemic: Qld, NSW, ACT, Vic, Tas, SA, WA
Chamelaucium uncinatum	ES (P2014, P2018)	Natural (Qld, NSW, ACT, Vic); Inoculation	M2011, M2012, SP2013, P2014, T2015, MREIWG2, AgVic2018		Aust native, endemic: WA
Corymbia citriodora [subsp. citriodora and subsp. uncertain]		Inoculation	M2011, M2012, PBL2014		Aust native, endemic: Qld, NSW; naturalised in WA, SA? Vic
Corymbia citriodora subsp. variegata	RT (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, PBL2014, P2014		Aust native, endemic: Qld, NSW
Corymbia ficifolia		Inoculation	M2011, M2012, SP2013,		Aust native, endemic: WA
Corymbia ficifolia x C. ptychocarpa	RT (P2018)	Natural (Qld)	P2014		Hybrid,both parents Aust native, both WA
Corymbia gummifera		Natural (Qld); Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW, Vic
Corymbia henryi	RT (P2014, P2018)	Natural (Qld); Inoculation	M2011, M2012, PBL2014, P2014		Aust native, endemic: Qld, NSW

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Corymbia intermedia		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW
Corymbia maculata		Inoculation	M2011. M2012		Aust native, endemic: NSW, Vic
Corymbia tessellaris		Natural (Qld); Inoculation	M2011, M2012		Aust native, non-endemic: Qld, NSW, New Guinea
Corymbia torelliana	RT (P2014, P2018)	Natural (Qld; Inoculation)	M2011, M2012, P2014, PBL2014		Aust native, endemic: Qld
Corymbia variegata [= citriodora] x C. torelliana		Inoculation	M2011, M2012, PBL2014		Hybrid, both parents Aust natives: variegata Qld, NSW; torelliana Qld
Darwinia citriodora	MS (P2014, P2018)	Natural (Qld); Inoculation	M2011, M2012, P2014		Aust native, endemic: WA
Darwinia glaucophylla		Inoculation	M2011	NSW: V	Aust native, endemic: NSW, Vic
Darwinia procera		Natural (Qld, NSW); Inoculation	M2011		Aust native, endemic: NSW
Decaspermum humile [Southern metapopulation]	ES (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014, P2017		Aust native, endemic: Qld, NSW
Decaspermum humile [Northern metapopulation] (Synonym: D. humile ('North Queensland form'))	RT (P2014, P2018)	Natural (NSW)	P2014		Aust native, non-endemic: Qld, New Guinea
Eucalyptus agglomerata		Natural (NSW); Inoculation	M2011, M2012, SP2013	Vic (Advisory): r (rare)	Aust native, endemic: NSW, Vic
Eucalyptus amygdalina	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus archeri	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus argophloia		Inoculation	M2011, M2012, LBP2015	Comm: V; Qld: V	Aust native, endemic: Qld
Eucalyptus baileyana		Inoculation	SP2013		Aust native, endemic: Qld, NSW
Eucalyptus barberi	HR-VS (Potts2016)	Inoculation	Potts2016	Tas: r (rare)	Aust native, endemic: Tas

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Eucalyptus baueriana [subsp. uncertain]		Inoculation	SP2013	Vic (Advisory): subsp. deddickensis e, subsp. thalassina e.	Aust native, endemic: NSW, Vic. (subsp. baueriana NSW, Vic; subsp. deddickensis Vic; subsp. thalassina Vic)
Eucalyptus brookeriana	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Vic, Tas
Eucalyptus burgessiana		Inoculation	SP2013		Aust native, endemic: NSW
Eucalyptus camaldulensis (subsp. uncertain)		Inoculation	SP2013	NSW: E pop'n (Hunter Valley)	Aust native, endemic: Qld, NSW, Vic, SA
Eucalyptus camaldulensis subsp. simulata		Inoculation	GC2014, R2015		Aust native, endemic: Qld
Eucalyptus camfieldii		Inoculation	M2011	Comm: V; NSW: V	Aust native, endemic: NSW
Eucalyptus campanulata (Synonym: E. andrewsii subsp. Campanulata)		Inoculation	M2012		Aust native, endemic: Qld, NSW
Eucalyptus camphora [subsp. uncertain]		Inoculation	SP2013	NSW: E (subsp. relicta]	Aust native, endemic: Qld, NSW, ACT, Vic
Eucalyptus carnea	RT-HS (P2014, P2018)	Natural (Qld)	GC2014		Aust native, endemic: Qld, NSW
Eucalyptus cephalocarpa		Inoculation	GC2014		Aust native, endemic: NSW, Vic
Eucalyptus cinerea		Inoculation	SP2013		Aust native, endemic: NSW, ACT
Eucalyptus cladocalyx		Inoculation	M2011, M2012, SP2013		Aust native, endemic: SA
Eucalyptus cloeziana	RT (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, SP2013, GC2014, LBP2015		Aust native, endemic: Qld
Eucalyptus coccifera	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus conveniens x E. tetragona		Inoculation	SP2013		Hybrid, both parents Aust native, both WA
Eucalyptus cordata subsp. cordata	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Eucalyptus cordata subsp. quadrangulata [Note: Potts2016 do not distinguish subspecies in main paper, but do in the Supplementary Table S1].	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus cornuta		Inoculation	SP2013		Aust native, endemic: WA
Eucalyptus crebra		Inoculation	SP2013		Aust native, endemic: Qld, NSW
Eucalyptus curtisii	RT-HS (P2014, P2018)	Natural (Qld)	GC2014	Qld: Near-Thr	Aust native, endemic: Qld
Eucalyptus dalrympleana subsp. dalrympleana	HR-VS (Potts2016)	Inoculation	Potts2016	SA: R (rare)	Aust native, endemic: Qld, NSW, ACT, Vic, Tas, SA
Eucalyptus deanei (Synonym: Eucalyptus brunnea)		Natural (NSW); Inoculation	SP2013 (as both E brunnea and E. deanei), GC2014		Aust native, endemic: Qld, NSW
Eucalyptus delegatensis	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: NSW, ACT, Vic, Tas
Eucalyptus diversicolor		Inoculation	M2011, M2012		Aust native, endemic: WA
Eucalyptus dunnii		Inoculation	M2011, M2012, SP2013	Qld: V	Aust native, endemic: Qld, NSW
Eucalyptus elata		Natural (NSW); Inoculation	SP2013, GC2014		Aust native, endemic: NSW, Vic
Eucalyptus fastigata		Inoculation	SP2013		Aust native, endemic: NSW, ACT, Vic
Eucalyptus forrestiana		Inoculation	SP2013		Aust native, endemic: WA
Eucalyptus gillii		Inoculation	SP2013		Aust native, endemic: NSW, SA
Eucalyptus globoidea		Inoculation	SP2013		Aust native, endemic: NSW, Vic
Eucalyptus globulus [subsp. uncertain]		Inoculation	SP2013		Aust native, endemic: NSW, Vic, Tas, SA
Eucalyptus globulus subsp. Globulus (Synonym: Eucalyptus globulus [sens. strict.])	HR-VS (Potts2016)	Inoculation	M2011, NM2012, Potts2016	Vic (Advisory): r (rare)	Aust native, endemic: NSW, ACT (naturalised), Vic, Tas, SA, WA (naturalised)

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Eucalyptus globulus subsp. bicostata (Synonym: Eucalyptus bicostata)		Inoculation	M2011, M2012	SA: V; Tas: r (rare) [as globulus subsp. pseudoglobulus].	Aust native, endemic: NSW, Vic, SA. (ACT naturalised)
Eucalyptus gomphocephala		Inoculation	M2011, M2012		Aust native, endemic: WA
Eucalyptus goniocalyx [subsp. uncertain]		Inoculation	GC2014	SA: V [subsp. exposa]	Aust native, endemic: NSW, ACT, Vic, SA
Eucalyptus grandis	RT-MS (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, SP2013, P2014		Aust native, endemic: Qld, NSW
Eucalyptus guilfoyleii		Inoculation	SP2013		Aust native, endemic: WA
Eucalyptus gunnii subsp. gunnii	HR-VS (Potts2016, (as 'E. gunnii')	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus gunnii subsp. divaricata	HR-VS (Potts2016, (as 'E. gunnii')	Inoculation	Potts2016	Comm: E; Tas: e	Aust native, endemic: Tas
Eucalyptus haemastoma		Inoculation	M2011, M2012		Aust native, endemic: NSW
Eucalyptus jacksonii		Inoculation	SP2013		Aust native, endemic: WA
Eucalyptus johnstonii	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus laevopinea		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW
Eucalyptus lehmannii		Inoculation	SP2013		Aust native, endemic: WA
Eucalyptus longirostrata		Inoculation	M2011, M2012		Aust native, endemic: Qld
Eucalyptus marginata subsp. marginata		Inoculation	M2011, M2012		Aust native, endemic: WA
Eucalyptus megacarpa		Inoculation	SP2013		Aust native, endemic: WA
Eucalyptus microcorys		Inoculation	SP2013		Aust native, endemic: Qld, NSW
Eucalyptus moluccana		Inoculation	M2012, SP2013		Aust native, endemic: Qld, NSW
Eucalyptus morrisbyi	HR-VS (Potts2016)	Inoculation	Potts2016	Comm: E; Tas: e	Aust native, endemic: Tas
Eucalyptus nebulosa	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus nitens		Inoculation	M2011, M2012		Aust native, endemic: NSW, Vic
Eucalyptus nitida (Synonym: Eucalyptus ambigua (disputed synonym))	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Eucalyptus obliqua	HR-VS (Potts2016)	Inoculation	M2011, M2012, Potts2016		Aust native, endemic: Qld, NSW, Vic, Tas, SA
Eucalyptus occidentalis		Inoculation	M2011, M2012, SP2013		Aust native, endemic: WA
Eucalyptus olida		Natural (NSW, Vic); Inoculation	M2011, M2012, GC2014, AgVic2018		Aust native, endemic: NSW
Eucalyptus ovata [var. ovata]	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: NSW, Vic, Tas, SA
Eucalyptus pauciflora subsp. pauciflora	HR-VS (Potts2016)	Inoculation	Potts2016	SA: V	Aust native, endemic: Qld, NSW, Vic, Tas, SA
Eucalyptus pellita		Inoculation	M2011, M2012, R2015		Aust native, endemic: Qld
Eucalyptus perriniana	HR-VS (Potts2016)	Inoculation	Potts2016	Tas: r (rare); Vic Advisory List: r (rare)	Aust native, endemic: NSW, ACT, Vic, Tas
Eucalyptus pilularis		Natural (NSW); Inoculation	M2011, M2012, SP2013, GC2014		Aust native, endemic: Qld, NSW
Eucalyptus planchoniana	RT-MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Eucalyptus populnea [subsp. uncertain]		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW
Eucalyptus pryoriana (Synonym: Eucalyptus viminalis subsp. Pryoriana)		Inoculation	GC2014		Aust native, endemic: Vic, Tas
Eucalyptus pulchella	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus punctate (Synonym: Eucalyptus biturbinata)		Inoculation	M2011 (as E. biturbinata), M2012		Aust native, endemic: Qld, NSW
Eucalyptus pyriformis x E. macrocarpa		Inoculation	SP2013		Hybrid, both parents Aust native, both WA

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Eucalyptus radiata subsp. radiata	HR-VS (Potts2016)	Inoculation	Potts2016	Tas: r (rare)	Aust native, endemic: Qld, NSW. ACT, Vic, Tas
Eucalyptus regnans	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Vic, Tas
Eucalyptus resinifera [subsp. uncertain]		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW
Eucalyptus resinifera subsp. hemilampra		Natural (Qld); Inoculation	M2012; G. Paterson pers. comm. re Qld N,. needs validation.		Aust native, endemic: Qld, NSW
Eucalyptus risdonii	HR-VS (Potts2016)	Inoculation	Potts2016	Tas: r (rare)	Aust native, endemic: Tas
Eucalyptus robusta		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW
Eucalyptus rodwayi	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus rubida [subsp. rubida]	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: NSW, Vic, Tas
Eucalyptus saligna		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW
Eucalyptus siderophloia		Natural (NSW); Inoculation	M2012, GC2014		Aust native, endemic: Qld, NSW
Eucalyptus sieberi	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: NSW, ACT, Vic, Tas
Eucalyptus smithii		Inoculation	M2011, M2012		Aust native, endemic: NSW, Vic
Eucalyptus subcrenulata	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus tenuiramis	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus tereticornis [subsp. uncertain]	RT (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, SP2013, P2014, GC2014	subsp. rotunda: Qld: near-thr	Aust native, non-endemic: Qld, NSW, Vic, New Guinea
Eucalyptus tindaliae	MS (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014, GC2014		Aust native, endemic:Qld, NSW
Eucalyptus torquata		Inoculation	SP2013		Aust native, endemic: WA

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Eucalyptus urnigera	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus urophylla		Inoculation	GC2014		EXOTIC Malesia (Indonesia, Timor Leste)
Eucalyptus vernicosa	HR-VS (Potts2016)	Inoculation	Potts2016		Aust native, endemic: Tas
Eucalyptus viminalis [sens. str.; = subsp. viminalis]	HR-VS (Potts2016)	Inoculation	Potts2016	SA: R	Aust native, endemic: NSW, ACT, Vic, Tas, SA
Eucalyptus wandoo subsp. wandoo		Inoculation	M2011, M2012		Aust native, endemic: WA
Eucalyptus websteriana x E. crucis		Inoculation	SP2013	[WA: E. crucis subsp. crucis T-EN, subsp. praecipua T-EN; Comm: subsp. crucis E]	Hybrid, both parents Aust native, both WA
Eucalyptus websteriana x E. orbifolia		Inoculation	SP2013		Hybrid, both parents Aust natives, webs WA; orbi SA, WA, NT.
Eucalyptus woodwardii		Inoculation	SP2013		Aust native, endemic: WA
Eucalyptus xerothermica		Inoculation	GC2014		Aust native, endemic: WA
Eucalyptus youngiana x E. macrocarpa		Inoculation	SP2013		Hybrid, both parents Aust natives: youn SA, WA; macr WA.
Eugenia natalitia (Synonym: Eugenia capensis subsp. natalitia+B261)	MS (P2018)	Natural (Qld)	P2014		EXOTIC: Southern Africa
Eugenia reinwardtiana	ES (P2014, P2018)	Natural (Qld, NSW, NTerr)	P2014, W2016		Aust native, non-endemic: Qld, WA, SW Pacific
Eugenia uniflora	MS (P2018)	Natural (Qld)	P2014		EXOTIC S America (naturalised Qld, NSW)
Eugenia zeyheri (Synonym: Eugenia capensis subsp. zeyheri (as this in B2018))	MS (P2018)	Natural (Qld)	GC2014		EXOTIC: S Africa
Gossia acmenoides	HS (P2014, P2018)	Natural (Qld, NSW)	P2014; K.Mills *in litt*. Oct 2015	NSW: E (pop'n)	Aust native, endemic: Qld, NSW

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Gossia bamagensis	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Gossia bidwillii	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Gossia floribunda	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Gossia fragrantissima	MS (P2014, P2018)	Natural (Qld, NSW)	P2014	Qld: E; NSW: E; Comm: E	Aust native, endemic: Qld, NSW
Gossia gonoclada	HS (P2014, P2018)	Natural (Qld, NSW)	P2014, Taylor2017	Qld: E; Comm: E	Aust native, endemic: Qld
Gossia hillii	HS-ES (P2014, P2017, P2018)	Natural (Qld, NSW)	P2014, P2017		Aust native, endemic: Qld, NSW
Gossia inophloia (Synonym: Austromyrtus inophloia)	ES (P2014, P2018)	Natural (Qld, NSW, ACT, Vic); Inoculation	M2011, M2012, P2014, MREIWG2	Qld: Near-Thr	Aust native, endemic: Qld
Gossia lewisensis	MS-HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Gossia macilwraithensis	MS-HS (P2014), amended to MS (P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Gossia myrsinocarpa	MS-HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Gossia pubiflora		Natural (NSW)	GC2014		Aust native, endemic: Qld
Gossia punctata	MS (P2014, P2018)	Natural (Qld, NSW)	P2014		Aust native, endemic: Qld, NSW
Homorathus croftianus		Natural (ACT)	MREIWG2	NSW: Endangered	Aust native, endemic: NSW
Homoranthus flavescens		Natural (ACT)	MREIWG2		Aust native, endemic: NSW
Homoranthus melanostictus	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Homoranthus montanus		Natural (ACT)	MREIWG2	Comm: V; Qld: V	Aust native, endemic: Qld
Homoranthus papillatus	MS (P2014, P2018)	Natural (Qld)	P2014	Qld: V	Aust native, endemic: Qld

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Homoranthus prolixus		Natural (NSW, ACT)	GC2014, MREIWG2	NSW: V; Comm: V	Aust native, endemic: NSW
Homoranthus virgatus	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, NSW
Hypocalymma angustifolium [subsp. uncertain]	RT (P2014, P2018)	Natural (Qld)	P2014	WA: T-VU [subsp. Hutt River (S. Patrick 2982)]	Aust native, endemic: WA
Kunzea ambigua		Inoculation	M2012 (as 'K. ambigua hybrid'), SP2013		Aust native, endemic: WA; Vic (naturalised)
Kunzea baxteri		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW, ACT; Tas (naturalised)
Kunzea ericoides		Inoculation	M2011, M2012		Aust native, endemic: Qld, NSW, ACT, Vic, SA; Tas (naturalised)
Kunzea pomifera		Inoculation	M2011, M2012		Aust native, endemic: Vic, SA
Lenwebbia lasioclada	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Lenwebbia prominens	HS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: Near-Thr	Aust native, endemic: Qld, NSW
Lenwebbia sp. Blackall Range (PR Sharpe 5387)	RT (P2014); amended to RT-ES (P2018)	Natural (Qld)	P2014	Qld: E	Aust native, endemic: Qld
Lenwebbia sp. Main Range (P.R.Sharpe+ 4877)	Unpubl. field reports suggest ES	Natural (Qld, NSW)	[L. Weber, J. Mallee, G. Pegg, pers. comms 2018]		Aust native, endemic: Qld, NSW
Leptospermum barneyense	RT (P2018)	Natural (Qld)	MREIWG2	Qld: V	Aust native, endemic: Qld
Leptospermum brachyandrum		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW
Leptospermum continentale 'cv. Horizontalis'		Inoculation	M2012		Aust native, endemic: NSW, ACT, Vic, SA
Leptospermum deuense		Natural (ACT)	MREIWG2		Aust native, endemic: NSW

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Leptospermum glaucescens		Inoculation	SP2013		Aust native, endemic: Tas
Leptospermum grandiflorum		Inoculation	SP2013		Aust native, endemic: Tas
Leptospermum juniperinum		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW
Leptospermum laevigatum		Inoculation	M2011, M2012		Aust native, endemic: NSW, Vic, Tas; naturalised in SA, WA, Qld
Leptospermum lanigerum		Inoculation	SP2013		Aust native, endemic: NSW, Vic, Tas, SA
Leptospermum liversidgei	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Leptospermum luehmannii	RT (P2014, P2018)	Natural (Qld)	P2014	Qld: V	Aust native, endemic: Qld, NSW
Leptospermum madidum [subsp. uncertain]	MS (P2014, P2018)	Natural (Qld, NTerr)	P2014, W2016		Aust native, endemic: subsp. madidum: Qld, NTerr. subsp. sativum: Qld, WA, NTerr
Leptospermum madidum subsp. sativum		Natural (Qld)	Pegg, unpubl. data	WA: Priority 3	Aust native, endemic: Qld, WA, NTerr
Leptospermum morrisonii 'cv. Burgundy'		Inoculation	M2011, M2012		Aust native, endemic: NSW
Leptospermum myrsinoides		Inoculation	GC2014		Aust native, endemic: NSW, Vic, SA
Leptospermum nitidum		Inoculation	SP2013		Aust native, endemic: Tas
Leptospermum petersonii	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, NSW; Vic (naturalised)
Leptospermum polygalifolium [subsp. uncertain]		Inoculation	M2011, M2012		Aust native, endemic: Whole species: Qld, NSW, LHI, ACT. subsp. polygalifoilum: Qld, NSW, ACT. subsp. cismontanum: Qld, NSW. subsp. howense: NSW(LHI only). subsp. montanum: Qld, NSW. subsp. transmontanum: Qld, NSW. subsp. tropicum: Qld.
Leptospermum polygalifolium x L. scoparium		Inoculation	M2011, M2012		Hybrid, both parents Aust native endemic: polyg: Qld, NSW, LHI; scop NSW, Vic, Tas.
Leptospermum riparium		Inoculation	SP2013		Aust native, endemic: Tas

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Leptospermum rotundifolium		Natural (NSW)	GC2014		Aust native, endemic: NSW; naturalised in Vic, Tas..
Leptospermum rupestre		Inoculation	SP2013		Aust native, endemic: Tas
Leptospermum scoparium		Inoculation	SP2013		Aust native, non-endemic: NSW, Vic, Tas; New Zealand
Leptospermum scoparium x L. macrocarpum		Inoculation	GC2014		Hybrid, Aust native parents: scop: NSW, Vic, Tas, NZ; macr NSW
Leptospermum semibaccatum	RT (P2014), amended to RT-MS (P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Leptospermum spectabile		Natural (NSW)	GC2014		Aust native, endemic: NSW
Leptospermum trinervium	MS (P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014, GC2014	Vic(Advisory): r	Aust native, endemic: Qld, NSW, ACT, Vic
Leptospermum whitei		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW
Leptospermum wooroonooran		Natural (ACT)	MREIWG2	Qld: rare	Aust native, endemic: Qld
Lindsayomyrtus racemoides	RT (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014, GC2014		Aust native, endemic: Qld
Lithomyrtus obtusa	RT (P2018)	Natural (Qld, NSW)	GC2014		Aust native, endemic: Qld
Lithomyrtus retusa		Natural (NTerr)	W2016		Aust native, endemic: Qld, WA, NTerr
Lophomyrtus bullata		Natural (NSW)	GC2014		EXOTIC: New Zealand
Lophomyrtus obcordata		Natural (Vic)	MREIWG, AgVic2018		EXOTIC: New Zealand
Lophomyrtus x ralphii		Natural (NSW, Tas, Vic)	GC2014, AgVic2018, DPIPWE2018		EXOTIC (hybrid): New Zealand
Lophostemon suaveolens	RT (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012 (no infection), P2014, GC2014		Aust native, endemic: Qld, NSW
Melaleuca alternifolia		Natural (NSW); Inoculation	M2011, M2012, SP2013, GC2014		Aust native, endemic: Qld, NSW
Melaleuca argentea		Natural (NSW)	GC2014		Aust native, endemic: Qld, WA, NTerr

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Melaleuca armillaris [subsp. uncertain]		Natural (NSW)	GC2014	Vic (Advisory): r [subsp. armillaris]; SA: R [subsp. akineta]	Aust native, endemic: subsp. armillaris: NSW,Vic, Tas (naturalised in ACT, SA, WA). subsp. akineta: SA
Melaleuca biconvexa		Natural (NSW); Inoculation	M2011, GC2014	NSW: V; Comm: V	Aust native, endemic: NSW
Melaleuca cardiophylla		Inoculation	GC2014		Aust native, endemic: WA
Melaleuca cheelii	RT (P2018)	Natural (Qld)	F. Giblin in litt. 2016		Aust native, endemic: Qld
Melaleuca comboynensis	RT-MS (P2018)	Natural (Qld)	Pegg, unpubl. data		Aust native, endemic: Qld, NSW
Melaleuca decora		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW
Melaleuca ericifolia		Inoculation	M2011, M2012, SP2013		Aust native, endemic: NSW, Vic, Tas
Melaleuca fluviatilis	HS (P2014, P2018)	Natural (Qld, NSW)	P2014		Aust native, endemic: Qld
Melaleuca gibbosa		Inoculation	SP2013		Aust native, endemic: Vic, Tas, SA
Melaleuca howeana		Inoculation	M2011(LHI), M2012		Aust native, endemic: NSW (LHI only)
Melaleuca leucadendra	RT-HS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, WA, NTerr
Melaleuca linariifolia	RT (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, GC2014		Aust native, endemic: Qld, NSW; naturalised in Vic, WA)
Melaleuca nervosa	HS (P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, WA, NTerr
Melaleuca nesophila	RT (P2014, P2018)	Natural (Qld, NSW, ACT)	P2014, GC2014, MREIWG2		Aust native, endemic: WA; naturalised in Vic, SA.
Melaleuca nodosa	HS-ES (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, NSW
Melaleuca pustulata		Inoculation	GC2014	Tas: r	Aust native, endemic: Tas
Melaleuca quinquenervia	RT-ES (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, SP2013, P2014, GC2014		Aust native, non-endemic: Qld, NSW; Indonesia, New Guinea, New Caledonia

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Melaleuca saligna	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Melaleuca sapientes		Natural (ACT)	MREIWG2		Aust native, endemic: WA
Melaleuca sieberi		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW
Melaleuca squamea		Inoculation	GC2014	SA: R	Aust native, endemic: NSW, Vic, Tas, SA
Melaleuca squarrosa		Inoculation	SP2013	SA: R	Aust native, endemic: NSW, Vic, Tas, SA
Melaleuca styphelioides		Natural (NSW)	GC2014		Aust native, endemic: Qld, NSW; naturalised Vic
Melaleuca viridiflora	HS (P2014, P2018)	Natural (Qld, NSW)	P2014		Aust native, endemic: Qld, WA, NTerr
Metrosideros carminea		Natural (Vic)	GC2014, AgVic2018		EXOTIC: New Zealand
Metrosideros collina	RT (P2014, P2018)	Natural (Qld, NSW, Vic); Inoculation	M2011, M2012, SP2013, P2014, GC2014, AgVic2018		EXOTIC: South Pacific
Metrosideros collina x villosa	RT (P2014, P2018)	Natural (Qld)	P2014		EXOTIC hybrid: South Pacific
Metrosideros excels (Synonym: M. tomentose)		Natural (NSW, Vic); Inoculation	M2011, M2012, SP2013, GC2014, AgVic2018		EXOTIC: New Zealand
Metrosideros kermadecensis	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		EXOTIC: New Zealand
Metrosideros nervulosa		Inoculation	M2011 (LHI), M2012		Aust native, endemic: NSW (LHI only)
Metrosideros sclerocarpa		Inoculation	M2011 (LHI),M2012		Aust native, endemic: NSW (LHI only)
Metrosideros thomasii	RT (P2014, P2018)	Natural (Qld)	P2014		EXOTIC: New Zealand
Metrosideros vitiensis 'Fiji Fire'		Natural (NSW - LHI)	LHIB2016		EXOTIC: South Pacific

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Mitrantia bilocularis	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V	Aust native, endemic: Qld
Myrciaria cauliflora (Synonym: Plinia cauliflora)	RT (P2014, P2018)	Natural (Qld)	P2014		EXOTIC Brazil
Myrtus communis	MS-HS (P2014, P2018)	Natural (Qld, NSW, Vic)	P2014, GC2014, AgVic2018		EXOTIC Meditteranean
Neofabricia myrtifolia	RT-MS (P2018)	Natural (Qld); Inoculation	B2018		Aust native, endemic: Qld
Osbornia octodonta	RT (P2018)	Natural (Qld); Inoculation	GC2014		Aust native, endemic: Qld, WA, NTerr
Pilidiostigma glabrum	RT-MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, NSW
Pilidiostigma rhytispermum	RT-MS (P2018)	Natural (NSW)	GC2014		Aust native, endemic: Qld
Pilidiostigma tetramerum	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Pilidiostigma tropicum		Natural (NSW)	GC2014		Aust native, endemic: Qld
Pimenta dioica		Inoculation	M2011, M2012		EXOTIC Central America
Psidium guajava		Natural (NSW)	GC2014		EXOTIC Central & South America
Regelia velutina		Inoculation	M2011, M2012		Aust native, endemic: Qld
Rhodamnia acuminata	RT (P2014, P2018)	Natural (Qld, ACT)	P2014, MREIWG2		Aust native, endemic: Qld
Rhodamnia angustifolia	ES (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: E	Aust native, endemic: Qld
Rhodamnia arenaria	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Rhodamnia argentea	MS-HS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic:Qld, NSW
Rhodamnia australis	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NTerr
Rhodamnia blairiana	RT-MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Rhodamnia costata	HS (P2014), amended to RT-HS (P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Rhodamnia dumicola	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Rhodamnia glabrescens	MS (P2014, P2018)	Natural (Qld)	P2014	Qld: Near-Thr	Aust native, endemic: Qld
Rhodamnia longisepala NEW HOST reliably reported, preferred evidentiary level lacking; further field investigation needed.		Natural (Qld)	A. Ford (CSIRO) pers. comm.	Qld: E	Aust native, endemic: Qld
Rhodamnia maideniana	ES (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, NSW
Rhodamnia pauciovulata	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: Near-Thr	Aust native, endemic: Qld
Rhodamnia rubescens	HS-ES (P2014, P2018)	Natural (Qld, NSW, ACT)	P2014, C2016, P2017, MREIWG2	NSW: Critically Endangered (prelim. Det.)	Aust native, endemic: Qld, NSW
Rhodamnia sessiliflora	MS-ES (P2014, P2018)	Natural (Qld, ACT)	P2014, MREIWG2		Aust native, endemic: Qld
Rhodamnia spongiosa [treated as R. glauca in Berthon et al. 2018]	HS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Rhodamnia whiteana NEW HOST reliably reported, preferred evidentiary level lacking; further field investigation needed..		Natural (Qld)	G. Leiper (Native Plants Qld) pers. comm.		Aust native, endemic: Qld

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Rhodomyrtus canescens (Synonym: R. trineura subsp. canescens [e.g. in Berthon et al. 2018])	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Rhodomyrtus effusa	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Rhodomyrtus macrocarpa	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Rhodomyrtus pervagata	MS-HS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Rhodomyrtus psidioides	ES (P2014, P2018)	Natural (Qld, NSW, ACT)	CL2011, P2014, MREIWG2, C2016, P2017	NSW: Critically Endangered (prelim. Det.)	Aust native, endemic: Qld, NSW
Rhodomyrtus sericea	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Rhodomyrtus tomentosa	MS-HS (P2014, P2018)	Natural (Qld)	P2014		EXOTIC: SE Asia
Rhodomyrtus trineura subsp. capensis	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Ristantia pachysperma	MS-HS (P2018)	Natural (Qld, NSW)	GC2014		Aust native, endemic: Qld
Ristantia waterhousei	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V	Aust native, endemic: Qld
Sphaerantia discolor	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V	Aust native, endemic: Qld
Stockwellia quadrifida	HS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V	Aust native, endemic: Qld
Syncarpia glomulifera [subsp. uncertain]		Natural (Qld, NSW); Inoculation	CL2011, M2011, M2012		Aust native, endemic: Qld, NSW. (subsp. glomulifera Qld, NSW; subsp. glabra NSW)
Syzygium alatoramulum		Natural (Qld)	B2018; Pegg unpublished data		Aust native, endemic: Qld
Syzygium alliligneum		Natural (NSW)	GC2014		Aust native, endemic: Qld

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Syzygium angophoroides	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, WA, NTerr
Syzygium anisatum (Synonym: Backhousia anisata, Anetholea anisata)	RT-HS (P2014, P2018)	Natural (Qld, NSW, Vic); Inoculation	CL2011, M2011, M2012, P2014, GC2014, AgVic2018		Aust native, endemic: NSW
Syzygium apodophyllum	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Syzygium aqueum	RT (P2014, P2018)	Natural (Qld)	P2014	Qld: V	Aust native, non-endemic: Qld; Malesia, SE Asia, India
Syzygium argyropedicum	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Syzygium armstrongii	RT (P2014, P2018)	Natural (Qld, NTerr)	P2014, W2016		Aust native, endemic: NTerr
Syzygium australe	RT-MS (P2014, P2018)	Natural (Qld, NSW, Vic); Inoculation	CL2011, M2011, M2012, GC2014, AgVic2018		Aust native, endemic: Qld, NSW
Syzygium bamagense	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium banksii	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Syzygium boonjee	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium buettnerianum		Natural (NSW)	GC2014	Qld: Near-Thr	Aust native, non-endemic: Qld; New Guinea, Solomon Is.
Syzygium bungadinnia		Natural (NSW)	GC2014		Aust native, endemic: Qld; ?New Guinea
Syzygium canicortex	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Syzygium claviflorum (Synonym: Acmena claviflorum)	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NTerr (Bathurst Is.)

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Syzygium cormiflorum	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium corynanthum	RT (P2014), amended to RT-HS (P2018)	Natural (Qld, NSW)	P2014, GC2014, P2017		Aust native, endemic: Qld, NSW
Syzygium cryptophlebium (Synonym: Syzygium wilsonii subsp. Cryptophlebium)	MS (P2014, P2018)	Natural (Qld)	P2014, Pegg unpubl data 2016		Aust native, endemic: Qld
Syzygium cumini	MS (P2014, P2018)	Natural (Qld)	P2014		EXOTIC: SE Asia; (naturalised in Qld)
Syzygium dansiei	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium endophloium	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Syzygium erythrocalyx	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium erythrodoxum		Natural (NSW)	GC2014		Aust native, endemic: Qld
Syzygium eucalyptoides [subsp. uncertain]	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, WA, NTerr
Syzygium eucalyptoides subsp. eucalyptoides	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, WA, NTerr
Syzygium fibrosum		Natural (Qld); Inoculation	M2011, M2012, B2018		Aust native, endemic: Qld, NTerr
Syzygium floribundum (Synonym: Waterhousea floribunda)	RT (P2014, P2018)	Natural (Qld); Inoculation	M2011, M2012, P2014, SP2013		Aust native, endemic: Qld, NSW
Syzygium forte subsp. forte	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NTerr
Syzygium forte subsp. potamophilum	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld, WA, NTerr

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Syzygium francisii		Natural (Qld); Inoculation	M2011, M2012; Mrussell SCRC pers. comm. re Qld natural		Aust native, endemic: Qld, NSW
Syzygium fullagarii		Inoculation	M2011 (LHI), M2012		Aust native, endemic: NSW (LHI only)
Syzygium glenum		Natural (NSW)	GC2014, B2018	Qld: E	Aust native, endemic: Qld
Syzygium graveolens (Synonym: Acmena graveolens)		Natural (NSW)	GC2014		Aust native, endemic: Qld
Syzygium hedraiophyllum (Synonym: Waterhousea hedraiophylla)	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Syzygium hemilamprum [subsp. uncertain] (Synonym: Acmena hemilampra)	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, subsp. hemilamprum non-endemic, Qld, NSW, NTerr, New Guinea; subsp. orophium endemic, Qld.
Syzygium hodgkinsoniae	RT-HS (P2018)	Natural (Qld, NSW)	GC2014, P2017	Qld: V; NSW: V; Comm: V	Aust native, endemic: Qld, NSW
Syzygium ingens (Synonym: Acmena ingens)	RT (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, NSW
Syzygium jambos	ES (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, SP2013, P2014, GC2014		EXOTIC: SE Asia
Syzygium kuranda	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium luehmannii	MS (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, SP2013, P2014, GC2014		Aust native, endemic: Qld, NSW
Syzygium macilwraithianum	RT (P2014), amended to RT-HS (P2018)	Natural (Qld)	P2014	Qld: V	Aust native, endemic: Qld

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Syzygium maraca	RT (P2014, P2018)	Natural (Qld, NSW)	GC2014; F. Giblin 2016 in litt. (re Qld).		Aust native, endemic: Qld
Syzygium megacarpum		Natural (NSW)	GC2014		EXOTIC: Hawaii
Syzygium minutiflorum	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust. native, endemic: NTerr
Syzygium moorei	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V; NSW: V; Comm: V	Aust native, endemic: Qld, NSW
Syzygium mulgraveanum (Synonym: Waterhousea mulgraveana)	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V	Aust native, endemic: Qld
Syzygium nervosum	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: WA, NTerr, Christmas Is.
Syzygium oleosum	HS (P2014), amended to RT-HS (P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014, GC2014		Aust native, endemic: Qld, NSW
Syzygium paniculatum	RT (P2014, P2018)	Natural (Qld, NSW, Vic)	P2014, GC2014, AgVic2018	NSW: E; Comm: V	Aust native, endemic: NSW
Syzygium polyanthum		Natural (NSW)	GC2014		EXOTIC: Malesia
Syzygium pseudofastigiatum	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium puberulum	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, non-endemic: Qld; Malesia
Syzygium resa (Synonym: Acmena resa)		Natural (NSW)	GC2014		Aust native, endemic: Qld
Syzygium rubrimolle	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V	Aust native, endemic: Qld
Syzygium sayeri		Natural (NSW)	GC2014		Aust native, endemic: Qld
Syzygium smithii (Synonym: Acmena smithii)	RT-MS (P2014, P2018)	Natural (Qld, NSW, Vic); Inoculation	M2011, M2012, SP2013, P2014, AgVic2018		Aust native, endemic: Qld, NSW, Vic
Syzygium suborbiculare	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld, WA, NTerr

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Syzygium tierneyanum	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, non-endemic: Qld; New Guinea, Malesia
Syzygium trachyphloium		Natural (NSW)	GC2014		Aust native, endemic: Qld
Syzygium unipunctatum (Synonym: Waterhousea unipunctata)	MS (P2014), amended to RT-MS (P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Syzygium velarum		Natural (NSW)	GC2014	Qld: V; Comm: V	Aust native, endemic: Qld
Syzygium wilsonii [subsp. uncertain]	RT (P2014, P2018)	Natural (Qld, NSW)	P2014		Aust native, endemic: Qld
Syzygium wilsonii x luehmannii (Synonym: S. luehmannii x wilsonii)	RT (P2018)	Natural (Qld, NSW); Inoculation	SP2013, GC2014		Hybrid, both parents Aust native, wils Qld, leuh NSW
Syzygium xerampelinum	MS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Thaleropia queenslandica		Natural (Qld)	B2018; Pegg in. litt. 2018		Aust native, endemic: Qld
Thryptomene calycina		Inoculation	M201, M2012	Vic(Advisory): r	Aust native, endemic: Vic, SA
Thryptomene saxicola	RT-MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: WA
Tristania neriifolia	MS (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014, GC2014		Aust native, endemic: NSW
Tristaniopsis collina		Natural (NSW)	GC2014		Aust native, endemic: NSW
Tristaniopsis exiliflora	HS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld
Tristaniopsis laurina	RT (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, SP2013, P2014 , GC2014		Aust native, endemic: Qld, NSW, Vic
Ugni molinae		Natural (NSW, Tas)	GC2014, DPIPWE2018		EXOTIC: S. America
Uromyrtus australis		Natural (NSW)	GC2014	Comm: E; NSW: E	Aust native, endemic: NSW
Uromyrtus lamingtonensis		Natural (NSW)	GC2014	Qld: V	Aust native, endemic: Qld, NSW
Uromyrtus metrosideros	MS (P2018)	Natural (NSW)	GC2014		Aust native, endemic: Qld

Species	Susceptibility Rating and source	Infection records	Selected infection references	Extinction risk legislative listings	Native/exotic; natural distribution
Uromyrtus tenella (Previously reported (GC2014, B2018) as Austromyrtus sp 'Lockerbie Scrub'; redetermined as Uromyrtus tenella by Gordon Guymer 20 Sept. 2016, MREIWG Minutes 04 Oct. 2016.)	RT (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014		Aust native, endemic: Qld
Verticordia chrysantha		Inoculation	M2011, M2012		Aust native, endemic: WA
Verticordia plumosa [var. uncertain]		Inoculation	M2011, M2012	Comm: vars ananeotes, vassensis - both. EN]; WA: var. ananeotes T-CR,; var. vassensis T-EN.	Aust native, endemic: WA
Verticordia plumosa x Chamelaucium uncinatum		Natural (NSW)	GC2014		Hybrid, both parents Aust native, both WA
Xanthostemon chrysanthus	RT-MS (P2014, P2018)	Natural (Qld, NSW); Inoculation	M2011, M2012, P2014, GC2014		Aust native, endemic: Qld
Xanthostemon formosus		Natural (NSW)	GC2014	Comm. E; Qld:E	Aust native, endemic: Qld
Xanthostemon fruticosus	HS (P2018)	Natural (Qld)	MREIWG2		EXOTIC: Phillipines
Xanthostemon graniticus		Natural (NSW)	GC2014	Qld: Vulnerable	Aust native, endemic: Qld
Xanthostemon oppositifolius	HS (P2014, P2018)	Natural (Qld, NSW)	P2014, GC2014	Qld: V; Comm: V	Aust native, endemic: Qld
Xanthostemon youngii	MS (P2014, P2018)	Natural (Qld)	P2014		Aust native, endemic: Qld

APPENDIX 4: A categorisation of the distributional overlap of host species and the Myrtle Rust pathogen.

The geographic ranges of Australian native plant taxa known to be hosts of *Austropuccinia psidii*, the causative pathogen of Myrtle Rust disease, are here tabulated, by State/Territory and subordinate descriptive regions. Known-host hybrids of native parentage are excluded from the tables below; their susceptibility (see Appendix 3) may or may not be informative about their parent species.

A categorisation is advanced of the degree of overlap between each host taxon, and the approximate geographic extent of full naturalisation of the Myrtle Rust pathogen to date in New South Wales and Queensland.

The overlaps in Victoria and Tasmania (where *A. psidii* is only marginally naturalised so far, and confined to cultivation) are flagged as 'uncertain', as are those for South Australia and Western Australia where *A. psidii* has not yet arrived, and in most cases those for the Northern Territory where the pathogen is known from a few locations only and has unclear potential for spread. The various climatic suitability models that are discussed in Part 2.3 of this Review do show some level of consensus in predicting climatic suitability for the pathogen in parts of SA and WA (e.g. the Fleurieu Peninsula in SA, and the south-westernmost three to five IBRA bioregions in WA), but differ in detail; they lack consensus for the monsoon tropics. Predicting overlap on the basis of these discrepant modelling results for these areas, at this stage of the epidemic, would be a very uncertain exercise.

358 native Australian taxa (excluding hybrids) are known hosts of *A. psidii*. On the categorisation advanced here:

- 177 native natural host taxa (excluding hybrids) have natural distributions **totally or near-totally** within the current zone of full Myrtle Rust naturalisation in eastern Australia.
- Of these, 36 have susceptibility ratings partly or wholly in the 'Highly Susceptible' or Extremely Susceptible' categories (*fide* Pegg et al., 2014, except for three ratings assigned here on the basis of subsequent observations). Many taxa are yet to have ratings assigned as observations are scanty.
- A further 22 host species have natural distributions **predominantly** within the current Myrtle Rust east-Australian geographic envelope.

Taken together with susceptibility ratings where these have been applied, recorded impacts on wild populations where these are available, and data on seed biology and seed-storage tolerance characteristics of each host insofar as these have been determined, the degree of distributional overlap between pathogen and its host species provides a basis for the prioritisation of conservation actions advanced in Part 6 of this Review and in the adjunct draft Action Plan.

Problems in estimating overlap

The bioclimatic range of the Myrtle Rust pathogen in eastern Australia is the subject of a recent paper by Berthon et al. (2018). From the climatic suitability model outputs, they derive an analysis of overlap with host species distributions, which in turn informs a categorisation of species for conservation action. As discussed in Part 6.1 of this review, there are significant problems with the method used by Berthon et al. (2018) to calculate overlap. Their overlap estimates are both misleadingly precise and seriously at odds with the *known* degree of exposure to the pathogen for some species, and with any reasonable projection of exposure for many more, particularly those that are endemic to rainforest biomes on the east coast. In most such cases the degree of exposure of host to pathogen is much underestimated in that study. Partly as a result of this, their resulting categorisation of species for priority action is also very discrepant with the pattern of known declines – deficient though our knowledge of these still is.

Berthon et al. (2018) made an understandable decision to tightly constrain the set of records of Myrtle Rust occurrence and its hosts deemed admissible for the purpose of calculating areas of climatic suitability. The absence of any systematic monitoring program in bushland across the east Australian infection zone since the initial emergency responses of 2010-13, has left us with a very suboptimal level of presence/absence observations of the disease, and many of the records that do exist are from cultivated situations, which are explicitly excluded from Berthon et al.'s (2018) data set. The pursuit of a rigorous methodological basis for the climatic suitability modelling thus resulted in a relatively small set of accepted records. The extrapolation from that climatic model of secondary results, for both overlap and conservation action priority, are where the problems lie.

Note that Berthon et al's (2018) Supplementary Table S3 presents their calculated overlap (and conservation prioritisation) for *all* Australian Myrtaceae, not just known hosts of *A. psidii*. For that reason, it may be taken as a basis for predictive planning for as-yet unaffected areas and species. In view of the problems outlined below, it should be so used only with caution.

The general climatic suitability zone predictions made for *A. psdii* under current and future climates are not disputed here. The derived estimates of overlap, and of prioritisation for conservation action, *are* disputed here.

A core problem is the estimation of host species distribution (for matching against Myrtle Rust climatic suitability cells) by means of the minimum convex polygon 'extent of occurrence' (MCP-EOO), in the sense of IUCN (2012, 2017). EOO is an established metric within the IUCN method for general extinction-risk assessment, which method is designed for application to all biota (motile organisms as well as sedentary ones like plants). The use of EOO as an index is balanced in the IUCN assessment method by being one element of a rule set, encompassing a range of other metrics. The purpose of EOO within the IUCN rule set is "to measure the degree to which risks from threatening factors are spread spatially across the taxon's geographical distribution. The theoretical basis for using EOO as a measure of risk spreading is the observation that many environmental variables and processes are spatially correlated, meaning that locations that are close to each other experience more similar (more correlated) conditions over time than locations that are far away from each other. These processes include both human threats (such as diseases …) and natural processes" (IUCN 2017:46). However, "EOO is not intended to be an estimate of the amount of occupied or potential habitat, or a general measure of the taxon's range. Other, more restrictive definitions of "range" may be more appropriate for other purposes, such as for planning conservation actions" (loc. cit.).

EOO defines host species distribution by a minimum convex polygon around the totality of its distribution, so as to encompass *all* accepted sites; in the context of Berthon et al. (2018), that *total area* enclosed (regardless of the proportion that is actually suitable for the host species) is then compared to the separately modelled climatic suitability cells. For many species other than those existing at only one location (and these, for the most part, are the only ones assigned a 100% overlap in the above study), the method results in a marked underestimation of host species exposure to the pathogen. The 'dead ground' (unsuitable for the host and perhaps the rust as well) in the often very large EOO, masks the fact that the host species exists naturally only within a fraction of the polygon area – a particular vegetation type or local habitat, sometimes determined by very localised climatic factors resulting from of topography or aspect or vegetation, that may be spatially well below the threshold for recognition within the climate characterisation of that cell as a whole. Moreover, the MCP-EOO metric captures, as part of the nominally suitable range for the host species, the areas between metapopulations of the host that are devoid of that species for other reasons -- historical or stochastic.

Berthon et al. do in fact acknowledge (in their Discussion, p. 161) that "use of EOO to estimate species' risk has limitations", but the distributional overlap estimates presented in their Supplementary Table S3 may well be taken at face value by conservation planners, as might the derived conservation action categories (in the same Table), which are assigned in large part on the basis of the calculated overlaps. The problem is compounded for some taxa by a decision to aggregate known hosts of *infraspecific* taxonomic rank back into the much larger 'parent species' distribution for the purpose of EOO calculation (whether the other taxonomic element/s of the species are known hosts or not, or occupy drier country than the known-host entity). All these factors together lead to underestimation of overlap for many, and probably most, species in that study.

Cases in point are the two best-documented instances of Myrtle Rust-caused decline. Carnegie et al. (2016) field-surveyed impact across the ranges of both *Rhodomyrtus psidioides* (18 sites) and *Rhodamnia rubescens* (43 sites), finding Myrtle Rust infection present at all sites. Both are species of warmer rainforest types and rainforest margins, extending marginally into wet sclerophyll forest, along the NSW and south-east Queensland coasts and hinterland, extending to the foot of the Tablelands escarpment. These vegetation types are also ideal habitats for *A. psidii* infection and persistence, assuming the presence of suitably susceptible hosts. Berthon et al. (2018) assign overlap estimates of only 28.2% for *Rhodomyrtus psidioides*, and 18.3% for *Rhodamnia rubescens*. A more empirical and less model-determined categorisation, giving due weight to this known habitat, considering the overall spread of Myrtle Rust occurrence records and the mobility of spores, might assume (as here) an essential continuity of *A. psidii* spore distribution over time across the entire point-based distribution of those hosts, and might conclude that both species clearly merit a rating of 'total' overlap, with the intervening large regions captured by a minimum convex polygon-EOO approach being irrelevant to the estimate, as long as they fall within a general complex (non-convex) polygon of Myrtle Rust (not host) occurrence and potential spore spread.

An alternative categorisation of overlap

Determining a method for estimating the exposure of host plant distributions to a threatening process – and whether host EOO is or is not a useful tool for that purpose -- requires thinking about the *nature* of the threatening process, especially its ability to disperse, and the conditions under which it can establish and persist – which may be very local within a less suitable broader landscape. Myrtle Rust differs from many other threatening processes, except some insect pests, in its very high fecundity (rapid production of very large quantities of urediniospores), and its extreme mobility over both local and regional spatial scales (in this case by wind, and by ubiquitous human and assumed animal vectors). These vectors are not of course random – winds have patterns, humans may move selectively between high risk sites (think tourists and national parks), and some of the suspected animal vectors such as flying foxes and moist-forest birds move selectively and thoroughly between Myrtaceae-rich vegetation patches over large spatial scales.

Exact causes of inter-regional spread of *Austropuccinia psidii* have rarely been determined on either global or sub-continental scales. The 2005 arrival in the Hawaiian islands is thought likely to have been via imports of nursery stock or cut foliage from mainland USA (Loope & La Rosa 2008; Loope 2010). It is highly likely that the arrival of Myrtle Rust on Raoul Island (in the Kermedec Islands group, c. 1,100 km NE of New Zealand's North Island), some months prior to detection of the pathogen on North Island, was by natural means, most probably wind dispersal from the Australian coast. Raoul Island is subject to very low levels of controlled human visitation, by conservation agency staff only. The pathway of arrival in Australia by which the pathogen successfully established in or prior to 2010 is unknown, although a prior interdiction of viable spores on a timber import shipment had been made (Grgurinovic et al. 2006). Once established in NSW, however, dispersal within the Australian east coast corridor was both very rapid and strongly human mediated

(Carnegie and Cooper 2011; Pegg et al. 2014), with natural vectors (wind and animal) probably playing a role of 'filling in the gaps' – for the possible role of fruit bats (flying foxes) as vectors, see Review section 1.5.3, 'Spore dispersal and spore longevity'). What is apparent from the east Australian experience is the overall speed of advance (e.g. in Queensland, 18 months from the Gold Coast to Daintree – Pegg et al. 2014), and its spatial 'thoroughness' of establishment on suitable hosts in suitable habitats. Carnegie et al. (2016), for example, found no sites in their all-of-range surveys of two widespread species to be without infection in the period up to October 2014. A categorisation of species exposure to *A. psidii* needs to take account of the pathogen's very high level of mobility.

The categorisation of 'overlap' attempted here is more empirical and less methodologically rigorous than that of Berthon et al. (2018). It is hampered by the same paucity of wild-occurrence records. It does not attempt to calculate precise degrees of exposure of host species distributions to the pathogen, except at the 'top of the scale' for total or near-total overlap. It is also based on a polygon approach, although in this case the single polygon is applied to the pathogen occurrence records, not those of the hosts, and is a complex (not simple convex) polygon, extending from the southernmost report in NSW north to the Torres Strait islands, and defined along the uncertain western margin as detailed below.

It has not been thought useful here to attempt to define a buffer area around particular known point occurrences of Myrtle Rust disease that might notionally correspond with spore dispersal distance, and to use this to infer absence of the pathogen outside that buffer. As discussed above, this is because the pattern of *A. psidii* spread since 2010, and its occurrence in widely separated areas of mesic vegetation, suggest an ability to override (whether by natural means or by human vectors) large distance separations between outbreaks, and the likelihood of exposure to spores (with or without successful establishment) of intervening areas. A strong secondary reason is that, given the absence of any broad systematic vigilance and recording system for Myrtle Rust (with the exception of short-lived public report collection during the establishment phases in NSW 2010-11 and Queensland 2011-12), an absence of point data for Myrtle Rust *within* most of the 'naturalisation zone' here defined, is more likely to represent lack of observations rather than absence of the rust, with the possible exception of some strong rain-shadow areas in Central Queensland.

Within the Myrtle Rust distributional zone defined below, the working assumption behind this categorisation is that *A. psidii* spore distribution is more or less ubiquitous over time, although varying in spore load intensity according to weather, seasonal, and between-year conditions. In other words, within the east coast corridor, *there are no refugia* in which host plants remain entirely unexposed to *A. psidii* inoculum, except on a transitory basis. Moreover, within that zone, *A. psidii* is highly likely to persist over most winters in all moister vegetation types. There are of course areas of drier vegetation or cleared land in which Myrtle Rust is less likely to establish or persist, even on high-susceptibility hosts if these are present, but these areas are here assumed to still be within the zone of exposure to spores, i.e. the 'overlap' zone, even if recolonization is required. The western margin of the Myrtle Rust zone of occurrence, in drier or higher locales, can also be expected to fluctuate somewhat in terms of frequency, duration, and persistence of the pathogen.

The rationale for the categorisation of overlap (or 'exposure') presented here is based on the following assumptions:

- An essential continuity of *A. psidii* infection – or at least periodic arrival of dispersing spores -- in moist biomes of whatever scale, along the east coast and hinterland from Narooma NSW to Cape York, Qld;
- A strong likelihood that open-cultivated plants (not subject to special horticultural treatment) in north-east NSW and south-east Queensland, that currently form the basis for the known-host status of numerous moist-habitat North Queensland species (in the absence of survey in

their home range), allow a high-plausibility estimate that the same species are susceptible to infection in the home range.

The prioritisation presented here applies only to the areas of Australia in which *A. psidii* is currently known to be fully naturalised, i.e. NSW (including Lord Howe Island), Queensland, and to some degree the Northern Territory. Host distributions are characterised for the other jurisdictions, but predictive models are insufficiently concordant to allow a firm basis for species-by-species exposure estimates.

Characterising the Myrtle Rust 'naturalised zone':

Total data on point occurrences of Myrtle Rust disease in Australia has not so far been assembled (the initial data sets gathered by Berthon et al. 2018 would have come close – but these are not all in the public domain in raw or consolidated form). Even the two largest repositories of data, held by NSW DPI (mainly for the establishment phase 2010-13) and Queensland DAF (mainly for the corresponding phase 2012-14) have not so far been made publicly available either individually or in integrated form.

This preliminary analysis has therefore been made based on a generalised definition of the established (fully naturalised) zone of Myrtle Rust in eastern Australia, i.e. eastern areas of NSW and Queensland. This zone has been defined by a combination of the generalised maps available on websites of the above two departments; more detailed distributional statements and maps of point occurrences in published papers (especially Carnegie & Lidbetter 2011, Pegg et al. 2014), and observations made available by experts and experienced field spotters (Angus Carnegie, Phil Craven, Darren Crayn, Peter Entwistle, Graeme Errington, Andrew Ford, Gordon Guymer, Phil Hurle, Richard Johnstone, David L. Jones, Catherine Jordan, Rob Kooyman, Glenn Leiper, Bill McDonald, Kevin Mills, Grant Paterson, Stig Pederson, Geoff Pegg, Peter Richards, Garry Sankowsky, Barbara Waterhouse, and Lui Weber, among others). The inferences drawn from their observations are those of the author.

The current distribution of Myrtle Rust in Australia is described in section 2.3 of this Review. It is briefly restated here for the three jurisdictions in which full naturalisation has been reported.

QUEENSLAND: *Austropuccinia psidii* is fully naturalised along most of the Queensland coast from the NSW border almost to the tip of Cape York Peninsula, but with some apparent breaks in distribution in drier areas, e.g. the Rockhampton rain-shadow. These do represent a climatically less suitable area and a probably much reduced frequency of infections in dominant drier vegetation types with fewer highly susceptible species, but the Myrtle Rust pathogen is very probably present across these regions in suitable small habitats, or at low levels, or simply not reported. In south-east Queensland it extends inland into the eastern part of the Darling Downs (Warwick – Toowoomba), with one outlying record towards Chinchilla (Pegg et al. 2014, Fig. 3). Further north the inland limit is data deficient and very poorly defined; it seems highly unlikely that *A. psidii* is absent from the patchy but frequent moister vegetation scattered from the Bunya Mountains north through Gayndah, Monto, Biloela, and on to Mount Morgan inland from Rockhampton; on a provisional basis the line described by these locales is here treated as a western boundary. Elsewhere in central Queensland *A. psidii* is well established in the Mackay region, including the Eungella Plateau (and its presence in suitable habitat patches in the adjacent ranges is assumed likely), and around Proserpine. From Townsville north, records indicate presence right through the Wet Tropics and on to Cape York and Torres Strait. The inland extent west from Townsville is highly uncertain and may not be extensive, but further north *A. psidii* is solidly established east of the line Ravenshoe – Atherton – Mareeba and on to Mount Lewis and Mount Spurgeon, and then scattered records (little monitoring) up the east side of the Cape York Peninsula to Bamaga. Myrtle Rust disease is not so far reported from the western side of the Cape York Peninsula or in the Gulf country, but no targeted monitoring is known to have occurred there. There is one reported location known to this reviewer from west of the Great Dividing Range, on the Walsh River north-west of Chillagoe, a tributary of the Mitchell River system which flows to the Gulf of Carpentaria (on *Melaleuca leucadendra* – P. Entwistle pers. comms 2014, 2015).

NEW SOUTH WALES AND A.C.T.: *A. psidii* is naturalised along most of the NSW coast, from the Queensland border south to the Moruya area. South of Moruya it is known only from infections of established garden and street plantings, almost to the Victorian border. Myrtle Rust disease reports are largely confined to the east of the tablelands escarpment in NSW. In areas where the escarpment is less marked and the Great Dividing Range is lower, it extends well inland (e.g. up the Hunter Valley to about Mount Royal, and in the Clarence River valley inland to at least Mallanganee west of Casino and the Tabulam region); in principal these areas may provide a bridge for natural dispersal of the pathogen to the much more limited suitable habitats on the western side of the Great Divide, although human agency may be a higher risk to these. *A. psidii* and outbreaks of Myrtle Rust disease may extend onto the eastern part of the Tablelands division in places; occasional reports indicate a presence at altitudes assignable to eastern edge areas of the Northern Tablelands (NT) sub-division, in higher-altitude patches of vegetation types that normally occur in the coastal division. Occurrences in the eastern parts of the Central Tablelands division are infrequent and appear to be marginal.

The few Myrtle Rust records west of the Great Divide in NSW (all from cultivated situations, e.g. Canberra, Orange) are here excluded from the naturalisation zone, although an autumn 2016 outbreak in Canberra (P. Hurle, ANBG, *in litt*. Sept 2016) demonstrates an ability of the pathogen to reach that area (possibly by human vectors), and establish at least on a seasonal basis. Also excluded here are certain areas either on warmer parts of the Tablelands or actually west of the Great Divide with potentially Rust-suitable mesic vegetation types, and Myrtaceous species, such as the Mount Kaputar area and some of the western gorges. This is not to say that those areas are not at risk of full, partial, or occasional establishment of the pathogen.

LORD HOWE ISLAND (NSW) has had one outbreak of Myrtle Rust in October 2016, where it was detected early on cultivated plants only. Subject to further monitoring, eradication is considered likely to have succeeded (Lord Howe Island Board, 2016, 2017; H. Bower pers. comm. Feb. 2018). Lord Howe Island remains at high risk of reinfection from mainland Australia and New Zealand, and is here considered within the naturalisation zone for species categorisation purposes.

NORTHERN TERRITORY: Myrtle Rust was first detected in the NT in May 2015, on both cultivated and wild native species on Melville Island (Tiwi Islands group). Later in 2015 it was detected in the greater Darwin area, and subsequently on Bathurst Island, and in May 2017 in eastern Arnhem Land at Gapuwiyak (J. Westaway, DAWR, *in litt*. Sept. 2017). Spread has been slow, and host range remains restricted, so far as is known.

Regional characterisation

The broad zone of Myrtle Rust occurrence in NSW and Queensland can be defined by defining the boundary of bushland and open-cultivation records. However, in order to relate this broad picture of Myrtle Rust occurrence to the usually finer-scale distributions of the host species, the use of more or less consistent regional descriptors is needed. These are not to be taken as necessarily *defining* the bioclimatic envelope suitable for *A. psidii* establishment, only for describing it in terms meaningful for thinking about the threat geographically in relation to host species.

The IBRA (version 7, DSEWPaC 2013) bioregions in eastern Australia, although defined in part by climate and floristics, do not correspond particularly well with the observed pattern (and apparent stabilisation) of *A. psidii* establishment to date. The IBRA version 7 *sub-regions* are at a scale which would be more descriptively useful, but the sparseness of the occurrence data set at this point would not populate all sub-regions likely to be exposed to spore load, and in any case would require a fully consolidated and validated data set. It is nevertheless recommended that a future integrated recording system for Myrtle Rust make use of the IBRA sub-regions on a national basis – their utility will become more relevant as the occurrence data improves.

NEW SOUTH WALES: the NSW *Botanical Divisions* (mapped and described in Harden 2000) have been used here, in conjunction with the above data sources, as the units for describing the distribution of host species. The three coastal divisions conveniently approximate the Myrtle Rust 'zone' of naturalisation to date (correlating strongly with climatic suitability), and also correspond well to floristic patterns that mean many coastal host species do not occur in other divisions.

QUEENSLAND: The IBRA version 7 biogeographic regions (DSEWPaC 2013) do not provide a particularly convenient level of description for current Myrtle Rust record distribution, given the limitations of the occurrence data set and the climatic and vegetational breadth of those regions. The Queensland Pastoral Districts (Bostock & Holland 2017), widely used for botanical distribution description, are also for the most part too broad for convenience – most of those which do capture some *A. psidii* occurrence extend much too far inland to be useful shorthand descriptors of its distribution, although the Moreton and Wide Bay pastoral districts combined do encompass most, but not all, of the 'south east Queensland' unit used here.

'South-east Queensland' (SEQ) is here defined as south and east of a line running roughly Bundaberg – Gayndah – Bunya Mtns – Toowoomba – Warwick – Killarney. Drier areas and vegetation types in the west of this area may be free of Myrtle Rust disease expression (although not necessarily of *A. psidii* spore load) except on an occasional basis, although the possibility of spread into the western Darling Downs cannot be excluded.

'Central Queensland' (CQ) is also here broadly defined: Bundaberg to about Mackay, with an uncertain and probably geographically complex extent inland. A working assumption has been made here that the Myrtle Rust pathogen is more or less continuously distributed along the CQ coast, at least over time. In practice there may be some genuine climatically related gaps in the expression of disease. These, if large, would probably equate to low local atmospheric spore load, corresponding with areas of drier (rainshadow) regional climate and correlated floristic types. However as discussed above, no or low infection does not equate to zero spore load, and these apparent gaps in infection records (where not simply due to lack of inspection) have proved no impediment to the rapid dispersal across them of the disease front and wide establishment of Myrtle Rust in the period 2011-14. It is unlikely that the pockets of moister vegetation that these areas harbour are not exposed to *A. psidii* spore load at least on an intermittent basis. Some allowance (as 'uncertain' areas) has been made for this lack of precision in the Table A4.3 below.

'North East Queensland' (NEQ) is defined as Bowen to Cape York (and the Torres Strait islands) and east of the Great Dividing Range. 'Cape York Peninsula' (CYP) region as used descriptively here corresponds to the northern two-thirds of the Cook Pastoral District and thus overlaps the NEQ component as above (which includes the Wet Tropics) – CYP in this sense includes all west of the Great Dividing Range and north of a line roughly Normanton to Ravenshoe. The likelihood of exposure of host species to *A. psidii* in the western half of CYP is flagged uniformly as 'uncertain', because of an almost complete lack of observations of (or searches for) Myrtle Rust in that area, and because of the complex vegetation types – although quite a few known hosts do occur there.

NEW SOUTH WALES: The NSW standard botanical subdivisions (defined in Harden 2000, and used for all the State's plant species in the National Herbarium of NSW *PlantNet* information system, http://plantnet.rbgsyd.nsw.gov.au/), provide a useful set of geographic units for this exercise.

Myrtle Rust records are largely confined to the Coastal Division, which comprises the subdivisions of North Coast (NC), Central Coast (CC), and South Coast (SC). The coastal divisions include not only immediately coastal areas, but extend inland to the escarpment that runs north-south parallel to the coast (note that this escarpment is mostly well east of the Great Dividing Range). The western boundary of these coastal botanical subdivisions extend up the escarpment to some extent (up to 600 m a.s.l. in the southern part of the State, and up to 900 m a.s.l. in the north – Harden 2000). It is in some cases known, and in others here inferred, that the Myrtle Rust occurrence extends into the escarpment country and *across* the coarsely mapped coastal division boundary (into the Tablelands division as mapped) along river valleys and gorges where these are at coastal division altitude and are known to have Rust-suitable vegetation types and hosts. The entire southern flank of the Border Ranges is here assumed to be within the Myrtle Rust 'zone'.

Remaining botanical divisions and subdivisions in NSW, used to show the non-coastal parts of host species distributions, are Tablelands (Northern = NT, Central CT, Southern ST), Western Slopes (NWS, CWS, SWS), Western Plains (NWP, SWP), and Far Western Plains (NFWP and SFWP). Except for limited areas of the Tablelands, these are all outside the current Myrtle Rust naturalisation zone.

NORTHERN TERRITORY: 'Top End' is here treated as north from about Katherine, 'Gulf' is the region from Limmen Bight to the Queensland border, and 'Victoria River District, VRD' is from roughly Wadeye (formerly Port Keats) to the WA border.

WESTERN AUSTRALIA: In the north, the generic term 'Kimberley' is used in its generally accepted sense, with occasional sub-regional qualifiers. For the south-west of WA, the IBRA bioregions (DSEWPaC 2013) become much more useful as delimiters of the climatic and vegetational zones likely to correspond to *A. psidii* establishment, should it get a foothold in the region. The IBRA bioregion codes applied to WA species in Table 4.3 follow those given on the map for Australia's 89 bioregions at http://www.environment.gov.au/land/nrs/science/ibra/australias-bioregions-maps.

OTHER STATES: For Victoria, Tasmania and South Australia, very general regional descriptors have been used.

The extent of actual overlap (Victoria, Tasmania, Northern Territory) and potential overlap (SA, WA, Lord Howe Island, Christmas Island) has been uniformly flagged as 'uncertain', although comments as to likelihood of overlap in the event of future full naturalisation are inserted in some cases.

Overlap characterisation – categories

Native host species distributions have been sourced from current Commonwealth and State plant censuses, State and Territory herbarium information systems (e.g. NSW *PlantNet* http://plantnet.rbgsyd.nsw.gov.au, Northern Territory *FloraNT* (eflora.nt.gov.au), WA *Florabase* https://florabase.dpaw.wa.gov.au), State and regional floras, the Australian Tropical Rainforest Plants edition 6 information system (https://www.anbg.gov.au/cpbr/cd-keys/rfk/), NSW BioNet (http://www.bionet.nsw.gov.au), Euclid Eucalypts of Australia edition 3 (https://www.anbg.gov.au/cpbr/cd-keys/euclid3/); MIH Brooker & DA Kleinig, *Field Guide to Eucalypts* vols 1-3, species-specific papers (mostly cited elsewhere in this Review and detailed in the References section), and – with caution – the Atlas of Living Australia (ALA, https://www.ala.org.au). Anomalous and outlying occurrence records in maps originating from databases have been checked to source, or against other information. The point accuracy of records that are unambiguously within the general naturalisation zone has not been checked.

A rough estimation has been made of the proportion of sites (assumed to represent populations) of each host species, that fall unambiguously or marginally within or outside of the Myrtle Rust zone as defined above. A great many host species are unambiguously within the zone and are assumed to be exposed to Myrtle Rust spore load on a constant or relatively frequent basis. Some of these are of spatially limited or habitat-specific distribution which makes categorisation straightforward. For example, any east coast host species fully within the zone, and which all information sources agree occurs only in subtropical or tropical rainforest vegetation types, or on their immediate margins, is assigned to the 'total' overlap category – as are wallum and near-coastal wetland species.

The 'overlap' – or perhaps more properly 'exposure' – categories used are:

- *Total and Near-total*: where the host species range lies totally within the Myrtle Rust zone, or with a very small proportion outside or doubtful;
- *Partial (most)*: where a large proportion of the host species occurrence sites, or inferred total individuals, are within the Myrtle Rust zone;
- *Partial (minor)*: where a relatively small proportion of the host species occurrence sites, or inferred total individuals, are within the Myrtle Rust zone;
- *Partial*: some in zone, some out, data insufficient for closer estimation; this category encompasses both the preceding ones;
- *Nil or marginal*: for areas lacking Myrtle Rust records from wild situations *and* where the various predictive maps indicate only a low or zero likelihood of Myrtle Rust establishment under current climate (e.g. NSW Southern Tablelands, Queensland semi-arid).
- *Uncertain*: data inadequate for categorisation of exposure/overlap risk.

The whole point of a non-quantitative categorisation of this sort is to avoid misleadingly precise percentages – clarity can only be improved by ground survey. 'Total' is clearly 100% exposure. If pressed, this reviewer would define 'near-total' as more than about 90% of sites or inferred total population (individuals) exposed, 'partial – most' as more than about 75-80%, and 'partial-minor' as less than about 30%.

The 'partial – most', and 'partial – minor' categories are clearly subjective, with a best -guess allowance being made for a lower degree of disease incidence for exposed host species that also occur in drier inland vegetation types close to, or beyond, the approximate western boundary of rust naturalisation, especially in Queensland, or for areas where disease occurrence data is particularly deficient. Population and sub-population size estimates are rarely available in the general literature, although inferences could be made, for some, from original survey and herbarium records and agency databases. This would greatly inform search strategies and conservation planning. For the purposes of this categorisation, accepted point occurrences from database-derived information sources (e.g. ALA, NSW BioNet) are taken as an indication of location number and distribution, and likely proportions of absolute plant numbers (total population size) within and outside the Myrtle Rust zone are inferred from the totality of information sources consulted, taking into account the number of sites falling into marginal or non-zone areas and their likely spatial extent. In some instances this is informed also by personal familiarity with regions and their vegetation. There is of course room for error here.

Susceptibility

The susceptibility ratings shown in brackets in Tables A4.1 and A4.2 below are those assigned to host species that occur in Queensland by Pegg et al. (2014), as added to or modified by Pegg et al. (2018). They are based on accumulated observational data on 'natural' infections (i.e. on wild or open-cultivated) host plants in that State.

The susceptibility categories are: *RT = relatively tolerant; MS, HS, ES = moderate, high, and extreme susceptibility*. Note that many known host species remain unrated. These ratings are provisional and subject to change as more observations emerge, especially on seedling and coppice growth. Low ratings are more likely go up than high ones to come down, unless populations in new areas of Myrtle Rust occurrence prove to have different levels of resistance. Absence of a susceptibility rating should not be assumed to mean that a species is relatively tolerant of *Puccinia psidii*; it is much more likely that it simply has not been observed to a level that allows any firm inference.

The Tasmanian eucalypt seedling ratings of Potts et al. (2016) are highly informative, and include some taxa that also fall within the geographical ambit of this categorisation, but being glasshouse-based are not included here; see Appendix 3 (complete Australian host list) for a summary of those ratings.

TABLE A4.1

Known host taxa for *Puccinia psidii* with natural distributions totally or near-totally within current zone of full Myrtle Rust naturalisation in eastern Australia. (n = 177). See Table A4.3 for detail.

The five native and endemic Lord Howe Island myrtaceous taxa are included on this list, as they would be totally exposed in the likely event that *Austropuccinia psidii* eventually invades and successfully establishes there.

- **Archirhodomyrtus** beckleri (southern chemotype) [unrated by Pegg et al. 2014 but subsequent observations suggest HS-ES, see Pegg et al. 2017, and Appendix 1; Pegg et al. (2018) rate the whole species (both chemotypes) as RT-HS].
- **Asteromyrtus** brassii (RT)
- **Austromyrtus** dulcis (RT-HS),
- A. tenuifolia (RT)
- **Backhousia** angustifolia (RT), B. bancroftii (RT), B. citriodora (MS-HS), B. enata, B. hughesii (MS), B. leptopetala (RT-HS), B. oligantha (MS-HS), B. sciadophora (RT), B. subargentea (RT), B. tetraptera,
- **Barongia** lophandra
- **Callistemon** formosus (RT), C. linearifolius, C. pachyphyllus (RT), C. polandii (HS),
- **Corymbia** citriodora subsp. variegata (RT), C. henryi (RT), C. intermedia, C. torelliana (RT),
- **Darwinia** glaucophylla, D. procera
- **Decaspermum** humile [Southern metapopulation] (ES), D. humile 'Northern metapopulation ' (RT),
- **Eucalyptus** baileyana, E. camfieldii, E. deanei, E. dunnii, E. grandis (RT-MS), E. haemastoma, E. microcorys, E. pellita, E. pilularis, E. planchoniana (RT-MS), E. resinifera subsp. resinifera, E. resinifera subsp. hemilampra, E. robusta, E. saligna, E. siderophloia, E. tindaliae (MS)
- **Eugenia** reinwardtiana (ES),
- **Gossia** acmenoides (HS), G. bamagensis (RT), G. bidwillii (RT), G. floribunda (RT), G. fragrantissima (MS), G. gonoclada (HS), G. hillii (HS-ES), G. inophloia (ES), G. lewisensis (MS-HS), G. macilwraithensis (MS), G. myrsinocarpa (MS-HS), G. pubiflora, G. punctata (MS),
- **Homoranthus** virgatus (MS),
- **Lenwebbia** lasioclada (RT), L. prominens (HS), L. sp. 'Blackall Range (PR Sharpe+ 5387)' (RT-ES, Pegg et al. 2018), Lenwebbia sp. 'Main Range (P.R. Sharpe+ 4877)' [no rating formally published but likely HS-ES based on pers. comms, see Appendix 1]
- **Leptospermum** barneyense (RT), L. juniperinum, L. liversidgei (MS), L. polygalifolium subsp. howense [Total if Myrtle Rust naturalises on Lord Howe Island], L. semibaccatum (RT-MS), L. spectabile, L. whitei, L. wooroonooran
- **Lindsayomyrtus** racemoides (RT),
- **Lithomyrtus** obtusa (RT),
- **Melaleuca** biconvexa, M. cheelii (RT), M. comboynensis (RT-MS), M. decora, M. howeana [Total exposure if *A. psidii* invades Lord Howe Island], M. linariifolia (RT), M. nodosa (HS-ES), M. quinquenervia (RT-ES), M. sieberi,
- **Metrosideros** nervulosa, M. sclerocarpa [both total if Myrtle Rust naturalises on Lord Howe Island],
- **Mitrantia** bilocularis (MS),

- **Pilidiostigma** glabrum (RT-MS), P. rhytispermum (RT-MS), P. tetramerum (MS), P. tropicum,
- **Rhodamnia** acuminata (RT), R. angustifolia (ES), R. arenaria (MS), R. argentea (MS-HS), R. australis (HS), R. blairiana (RT-MS), R. costata (RT-HS), R. dumicola (HS), R. glabrescens (MS), R. longisepala, R. maideniana (ES), R. pauciovulata (MS), R. rubescens (HS-ES), R. sessiliflora (MS-ES), R. spongiosa (HS), R. whiteana,
- **Rhodomyrtus** canescens (HS), R. effusa (MS), R. macrocarpa (MS), R. pervagata (MS-HS), R. psidioides (ES), R. sericea (MS), R. trineura subsp. capensis (MS),
- **Ristantia** pachysperma (MS-HS), R. waterhousei (RT),
- **Sphaerantia** discolor (MS),
- **Stockwellia** quadrifida (HS),
- **Syncarpia** glomulifera (both subspp.),
- **Syzygium** alatoramulum, S. alliiligneum, S. anisatum (RT-HS), S. apodophyllum (RT), S. aqueum (RT), S. argyropedicum (RT), S. australe (RT-MS), S. bamagense (MS), S. banksii (MS), S. boonjee (RT), S. buettnerianum, S. bungadinnia, S. canicortex (RT), S. claviflorum (MS), S. cormiflorum (RT), S. corynanthum (RT), S. cryptophlebium (MS), S. dansiei (RT), S. endophloium (RT), S. erythrocalyx (RT), S. erythrodoxum, S. floribundum (RT), S. francisii, S. fullargarii [Total if Myrtle Rust naturalises on Lord Howe island], S. glenum, S. graveolens, S. hedraiophyllum (RT), S. hemilamprum (both subspp.) (RT), S. hodgkinsoniae (RT-HS), S. ingens (RT), S. kuranda (MS), S. luehmannii (MS), S. macilwraithianum (RT-HS), S. maraca (RT), S. moorei (RT), S. mulgraveanum (RT), S. oleosum (RT-HS), S. paniculatum (RT), S. pseudofastigiatum (RT), S. puberulum (MS), S. resa, S. rubrimolle (RT), S. sayeri, S. tierneyanum (RT), S. trachyphloium, S. unipunctatum (RT-RT-MS), S. velarum, S. wilsonii (both subspp.) (RT), S. xerampelinum (MS),
- **Thaleropia** queenslandica
- **Tristania** neriifolia (MS),
- **Tristaniopsis** exiliflora (HS),
- **Uromyrtus** australis, U. lamingtonensis, U. metrosideros, U. tenella (RT),
- **Xanthostemon** chrysanthus (RT-MS), X. formosus, X. graniticus, X. oppositifolius (HS), X. youngii (MS).

TABLE A4.2

Known host species (n = 22) for *Puccinia psidii* with natural distributions having '<u>partial – most'</u> overlap with the current zone of full Myrtle Rust naturalisation in eastern Australia (i.e. overlap applies for most of reported sites/populations and/or an inferred preponderance of individuals). See Table A4.3 for detail. This category excludes 'partial minor' and 'total/near-total' overlap categories.

- **Angophora** costata (three subspp.), A. subvelutina,
- **Backhousia** myrtifolia (RT-MS),
- **Baeckea** linifolia,
- **Callistemon** salignus (RT),
- **Corymbia** citriodora subsp. citriodora, C. gummifera,
- **Eucalyptus** camaldulensis subsp. simulata, E. cloeziana (RT), E. curtisii (RT-HS),
- **Leptospermum** petersonii (RT), L. trinervium (MS)
- **Lophostemon** suaveolens (RT),
- **Melaleuca** alternifolia, M. decora, M. leucadendra (RT-HS), M. salicina (RT),
- **Neofabricia** myrtifolia (RT-MS),
- **Syzygium** smithii (RT-MS),
- **Tristaniopsis** laurina (RT).

Table A4.3
A categorisation of distributional overlap of Australian native host taxa (hybrids excluded), with myrtle rust naturalisation to April 2018.

- *Jursidictional abbreviations used*: Queensland (Qld), New South Wales (NSW), Australian Capital Territory (ACT - Canberra portion), Victoria (Vic), Tasmania (Tas), South Australia (SA), Western Australia (WA), Northern Territory (NTerr).
- Regional abbreviations: (For more detailed descriptions of these regions, see 'Regional Characterisation' section above.)

Queensland	
SEQ	South East Queensland
CQ	Central Queensland
NEQ	North East Queensland
CYP	Cape York Penninsula
NSW	
NC	North Coast
CC	Central Coast
SC	South Coast
NT	Northern Tablelands
CT	Central Tablelands
ST	Southern Tablelands
NWS	North Western Slopes
CWS	Central Western Slopes
SWS	South Western Slopes
NWP	North Western Plains
SWP	South Western Plains
NFWP	North Far Western Plains
SFWP	South Far Western Plains
Northern Territory	
VRD	Victoria River District
Western Australia (IBRA Bioregions)	
AVW	Avon Wheatbelt
COO	Coolgardie
ESP	Esperance Plains
GES	Geraldton Sandplains
GVD	Great Victoria Desert
JAF	Jarrah Forest
MAL	Mallee
MUR	Murchison
NUL	Nullarbor
SWA	Swan Coastal Plain
WAR	Warren
YAL	Yalgoo

- Endemic status is shown (in column 3) for single-jurisdiction taxa within Australia (for this category ACT is treated as part of NSW).

Table A4.3

A categorisation of distributional overlap of Australian native host taxa (hybrids excluded), with myrtle rust naturalisation to April 2018.

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Agonis flexuosa	WA	UNCERTAIN WA (IBRAs ESP, JAF, SWA, WAR)
Allosyncarpia ternata	NTerr (endemic)	UNCERTAIN, POTENTIALLY NEAR-TOTAL NTerr – (Top End especially eastern Arnhem Land creeks, gorges)
Angophora costata [subsp. uncertain] (A. costata *sens. lat*. includes subspecies recognised as A. euryphylla and A. leiophylla in NSW)	A. costata subsp. costata: Qld, NSW A. costata subsp. leiocarpa: Qld, NSW A. costata subsp. euryphylla: NSW	PARTIAL (MOST) Qld: - subsp. costata: probably minor or nil (only occurs in White Mtns), - subsp leiocarpa: total? SEQ, DD & N to Carnarvon-Mackay NSW: - subsp. costata: partial (most): NC CC SC CT. - subsp. leiophylla: partial (minor): NC NWS NWP - subsp. euryphylla: partial (most): NC CC CWS
Angophora floribunda	Qld, NSW, Vic	PARTIAL Qld partial (probably minor) – SEQ/Darling Downs, coastal CQ (probably not inland); Townsville area, Atherton (uncertain but likely); CYP east. NSW partial: NC CC SC NT CT NWS CWS NWP Vic – uncertain (Far E Gippsland, and scattered central Vic)
Angophora subvelutina	Qld, NSW	PARTIAL (MOST) Qld partial (most?) – SEQ N to c. Biloela (westernmost uncertain eg Wandoan) NSW partial (most?) -- NC CC SC NT CT
Archirhodomyrtus beckleri (Southern chemotype)	Qld, NSW	TOTAL Qld total: SEQ (southern chemotype) NSW total: NC (southern chemotype)
Asteromyrtus brassii	Qld, New Guinea	NEAR-TOTAL Qld: Cape York Peninsula (but usually in heath or open forest habitats)
Asteromyrtus magnifica	NTerr (endemic)	UNCERTAIN NTerr – uncertain (Top End, N of c. Katherine-Ngukurr)
Austromyrtus dulcis	Qld, NSW	TOTAL Qld total SEQ; NSW total NC

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Austromyrtus tenuifolia	NSW (endemic)	TOTAL NSW **CC**
Backhousia angustifolia	Qld, NSW (NWS)	NEAR-TOTAL Qld: SEQ, CQ, NEQ, inland (e.g. Porcupine Gorge, Carnarvon NP) uncertain. NSW: uncertain (western edge of rust zone, nil so far at Gravesend)
Backhousia bancroftii	Qld (endemic)	TOTAL Qld NEQ (Cooktown to Innisfail)
Backhousia citriodora	Qld (endemic)	TOTAL Qld (coastal SEQ to c. Cairns)
Backhousia enata	Qld (endemic)	TOTAL Qld NQ (Tully R catchment)
Backhousia gundarara (syn. Backhousia sp. Prince Regent (W.O'Sullivan & D.Dureau WODD 42); B. 'bundara' in error.)	WA (endemic)	UNCERTAIN WA (Kimberley)
Backhousia hughesii	Qld (endemic)	TOTAL Qld (Rossville to Innisfail)
Backhousia leptopetala (syn. Choricarpia leptopetala)	Qld, NSW	TOTAL Qld: SEQ (S from Buderim) NSW: NC CC
Backhousia myrtifolia	Qld, NSW	PARTIAL (MOST) Qld total SEQ NSW partial (most): NC CC SC NT CT ST CWS
Backhousia oligantha	Qld (endemic)	TOTAL? Qld SEQ, CQ (Biggenden, Rockhampton? (Rockhampton rainshadow uncertain)
Backhousia sciadophora	Qld, NSW	TOTAL Qld SEQ NSW NC
Backhousia subargentea (syn. Choricarpia subargentea)	Qld, NSW	TOTAL Qld SEQ, CQ (Tweed Hds to Mackay) NSW NC
Backhousia tetraptera (syn. Backhousia 'Mt Stuart')	Qld (endemic)	TOTAL Qld (Townsville)
Baeckea gunniana	NSW, ACT, Vic, Tas	NIL OR MINOR NSW nil (western ST); ACT nil or occasional; Vic & Tas – uncertain (unlikely?)
Baeckea leptocaulis	Tas (endemic)	UNCERTAIN Tas

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Baeckea linifolia	Qld, NSW, Vic.	NEAR-TOTAL Qld: SEQ; NSW: NC CC SC; CT ST (eastern edges). Vic: uncertain (far East Gippsland)
Barongia lophandra	Qld (endemic)	TOTAL Qld: NEQ (lowland RF)
Beaufortia schaueri	WA (endemic)	UNCERTAIN WA (IBRAs AVW, COO, ESP, JAF, MAL)
Beaufortia sparsa	WA (endemic)	UNCERTAIN WA (IBRAs ESP, JAF, SWA, WAR)
Callistemon citrinus (syn. Melaleuca citrina)	Qld, NSW, Vic	PARTIAL Qld: probably most (Darling Downs) NSW partial (most) NC CC SC CT ST NWS CWS. Vic (E & W Gippsland) – uncertain
Callistemon formosus (syn. Melaleuca formosa, in Qld)	Qld (endemic)	TOTAL Qld: SEQ (N to c.Maryborough)
Callistemon linearifolius (syn. Melaleuca linearifolia)	NSW (endemic)	TOTAL NSW CC
Callistemon linearis (syn. Callistemon rigidus in some States, Brophy et al. 2013, Giblin & Carnegie 2014)	NSW	PARTIAL Qld: Partial SEQ; NSW NC CC ?SC NT NWS
Callistemon pachyphyllus (syn. Melaleuca pachyphylla)	Qld, NSW	TOTAL Qld total: SEQ (S from Hervey Bay); NSW total: NC
Callistemon pallidus (syn. Melaleuca pallida)	Qld, NSW, ACT, Vic, Tas	PARTIAL Qld: total SEQ (Border Ranges) NSW partial: NC SC NT CT ST CWS SWS ACT – nil or occasional; Vic, Tas – uncertain
Callistemon pinifolius (syn. Melaleuca linearis var. pinifolia, of Brophy et al. 2013)	Qld, NSW	PARTIAL NSW: CC ?NWS CWS
Callistemon polandii (syn. Melaleuca polandii)	Qld (endemic)	TOTAL Qld NEQ (Cooktown-Cape Flattery)

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Callistemon salignus (syn. Melaleuca salicina)	Qld, NSW (naturalised in Vic)	PARTIAL (MOST?) Qld: SEQ, S from Biloela. NSW: NC CC SC NT CWS ,
Callistemon sieberi (syn. Melaleuca paludicola)	Qld, NSW, ACT, Vic, SA	PARTIAL Qld total: SEQ (Warwick to NSW border) NSW partial: NC CC SC NT CT ST NWS CWS SWS NWP; Vic, SA – uncertain
Callistemon sp. 'Rock of Gibraltar (L.M. Copeland 3618)	NSW (endemic)	MARGINAL NSW: NT, marginal (altitude 700m, mostly dry sclerophyll)
Callistemon viminalis (syn. Melaleuca viminalis)	Subsp. viminalis: Qld, NSW, WA Subsp. rhododendron: Qld (Injune distr.)	PARTIAL - subsp. viminalis: Qld partial: most of E coast; central uplands and Boulia district uncertain. NSW partial: NC NT NWS NWP. WA – uncertain (Kimberley). - subsp. rhododendron: Qld – uncertain (restr. to Injune district).
Callistemon viridiflorus (syn. Melaleuca virens)	Tas (endemic)	UNCERTAIN Tas (widespread)
Calothamnus gilesii	WA (endemic)	UNCERTAIN WA (IBRAs AVW, COO, GES, GVD, MAL, MUR, NUL, YAL)
Calothamnus quadrifidus [subsp. uncertain, sensu WA Florabase]	WA (endemic)	UNCERTAIN WA (IBRAs AVW, COO, ESP, JAF, MAL, SWA)
Calothamnus quadrifidus subsp. asper (syn. C. asper)	WA (endemic)	UNCERTAIN WA (IBRA: AVW)
Calothamnus torulosus	WA (endemic)	UNCERTAIN WA (IBRAs GES JAF SWA)
Calytrix tetragona	Qld, NSW, ACT. Vic, Tas, SA, WA	PARTIAL (MINOR?) Qld partial: SEQ, unlikely in inland SQ/CQ; NSW partial: NC CC SC NT CT ST NWS CWS SWS NWP SWP NFWP SFWP. Vic, Tas, SA – all uncertain WA –uncertain (IBRAs: AVW, COO, ESP, JAF, MAL, NUL, SWA, WAR)

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Chamelaucium uncinatum	WA	UNCERTAIN WA (IBRAs: AVW, ESP, GES, JAF, SWA, WAR)
Corymbia citriodora [subsp. citriodora and subsp. uncertain]	Qld, NSW	PARTIAL (MOST?) Qld: Partial: SEQ to NQ, but many inland occurrences uncertain or unlikely NSW: Partial (most): **NC**
Corymbia citriodora subsp. variegata (syn. Corymbia variegata)	Qld, NSW	NEAR-TOTAL? Qld partial (most): SEQ (N to Maryborough); inland (Carnarvon, Chinchilla etc) uncertain; NSW total: NC
Corymbia ficifolia	WA	UNCERTAIN WA (IBRAs: ESP, JAF, WAR)
Corymbia gummifera	Qld, NSW, Vic	PARTIAL (MOST) Qld most: SEQ. NSW partial (most?): NC CC ST NT CT Vic – uncertain (far E Gippsland)
Corymbia henryi	Qld, NSW	TOTAL (but occurs mostly in Dry Sclerophyll Forest habitats) Qld total: SEQ and eastern Darling Downs NSW total: NC
Corymbia intermedia	Qld, NSW	NEAR-TOTAL Qld near-total: SEQ to FNQ (to Cooktown); upland occurrences uncertain NSW total: NC
Corymbia maculata	NSW, Vic	PARTIAL NSW: NC CC SC CT CWS; Vic – uncertain
Corymbia tessellaris	Qld, NSW, New Guinea	PARTIAL Qld partial: SEQ to NQ near coast (most populations?); inland sites unlikely; western CYP uncertain; NSW partial: NC NWP
Corymbia torelliana	Qld (endemic)	NEAR-TOTAL? Qld: SEQ, CQ (scattered), NEQ
Darwinia citriodora	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, ESP, JAF, SWA, WAR)
Darwinia glaucophylla	NSW (endemic)	TOTAL NSW CC
Darwinia procera	NSW (endemic)	TOTAL NSW CC

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Decaspermum humile (Southern metapopulation)	Qld, NSW	TOTAL Qld: SEQ; NSW: NC CC
Decaspermum humile (Northern metapopulation) (syn. D. humile 'North Queensland form')	Qld (also New Guinea)	TOTAL or NEAR-TOTAL Qld: Mackay-Eungella, Wet Tropics, eastern CYP; Carnarvon Gorge outlier is disjunct and uncertain, but microhabitat is likely suitable for Myrtle Rust.
Eucalyptus agglomerata	NSW, Vic	PARTIAL NSW partial: NC CC SC CT ST CWS; Vic – uncertain (E Gippsland)
Eucalyptus amygdalina	Tas (endemic)	UNCERTAIN Tas
Eucalyptus archeri	Tas (endemic)	UNCERTAIN Tas
Eucalyptus argophloia	Qld (endemic)	MARGINAL/UNCERTAIN Qld: western Darling Downs
Eucalyptus baileyana	Qld, NSW	TOTAL (nominally – but Dry Sclerophyll forest/woodland habitat) Qld partial (minority?): SEQ; inland ocurrences along GDR uncertain. NSW total: NC
Eucalyptus barberi	Tas (endemic)	UNCERTAIN Tas
Eucalyptus baueriana [subsp. uncertain]	NSW CC SC, Vic	PARTIAL NSW total: CC, SC; Vic – uncertain (EGipps).
Eucalyptus brookeriana	Vic, Tas	UNCERTAIN Vic and Tas
Eucalyptus burgessiana	NSW (endemic)	PARTIAL/MARGINAL NSW: CC CT (mallee shrubland, lower Blue Mtns)
Eucalyptus camaldulensis [subsp. uncertain]	Qld, NSW, Vic, SA	PARTIAL (MINOR) NSW: NC (marginal habitat for MR), NWS CWS SWS NWP SWP NFWP SFWP. ACT – nil or occasional Vic (statewide), SA (SE quarter) – both uncertain SEE NEXT
Eucalyptus camaldulensis subsp. simulata	Qld (endemic)	PARTIAL (MOST?) Qld: NEQ, CYP (but inland occurrences uncertain)
Eucalyptus camfieldii	NSW (endemic)	TOTAL NSW: NC CC

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Eucalyptus campanulata (syn. E. andrewsii subsp. campanulata)	Qld, NSW	Partial Qld: near-total?: coastal SEQ NSW: NC NT NWS? CWS?
Eucalyptus camphora [subsp.uncertain]	Qld, NSW, ACT, Vic	NIL OR MINOR Qld: Darling Downs (Granite Belt?). NSW: NT CT ST SWS. ACT: nil or occasional; Vic – uncertain (E half)
Eucalyptus carnea	Qld, NSW	PARTIAL NSW: NC (but dry sclerophyll habitat), NT.
Eucalyptus cephalocarpa	NSW, Vic	UNCERTAIN/PARTIAL NSW: far SC; Vic – uncertain (SE and South Central)
Eucalyptus cinerea	NSW, ACT	NIL/MARGINAL NSW: CT ST CWS SWS:; ACT
Eucalyptus cladocalyx	SA (endemic)	UNCERTAIN SA (Southern Flinders Ranges, northern KI, Eyre Peninsula)
Eucalyptus cloeziana	Qld (endemic)	PARTIAL (MOST?) Qld: coastal NSW border to c. Cairns; inland CQ unlikely
Eucalyptus coccifera	Tas (endemic)	UNCERTAIN Tas
Eucalyptus cordata subsp. cordata	Tas (endemic)	UNCERTAIN Tas
Eucalyptus cordata subsp. quadrangulata	Tas (endemic)	UNCERTAIN Tas
Eucalyptus cornuta	WA (endemic)	UNCERTAIN WA (IBRAs ESP, JAF, MAL, SWA, WAR)
Eucalyptus crebra	Qld, NSW	PARTIAL (but tends to drier habitats) Qld partial: (most of E coast); Qld inland unlikely. NSW partial: NC CC NT NWS CWS NWP
Eucalyptus curtisii	Qld (endemic)	PARTIAL (MOST) TO NEAR-TOTAL? Qld: SEQ; higher-alt inland populations uncertain
Eucalyptus dalrympleana subsp. dalrympleana	SA, NSW, ACT, Vic, Tas	PARTIAL (MINOR) Qld, NSW and Vic mostly at high elevations; possible exposure Vic, Tas, SA.
Eucalyptus deanei (syn. E. brunnea)	Qld, NSW	NEAR-TOTAL Qld total: far SEQ) NSW near-total: NC CC CT (but CT occurrences are at coastal altitudes)

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Eucalyptus delegatensis	NSW, ACT, Vic, Tas	UNCERTAIN/UNLIKELY? NSW ST; ACT; Vic (eastern half); Tas (widespread)
Eucalyptus diversicolor	WA (endemic)	UNCERTAIN WA (IBRAs ESP, JAF, SWA, WAR)
Eucalyptus dunnii	Qld, NSW	TOTAL Qld: SEQ; NSW: NC
Eucalyptus elata	NSW, Vic	PARTIAL NSW: CC SC CT ST; Vic – uncertain (eastern half)
Eucalyptus fastigata	NSW ACT, Vic	PARTIAL NSW partial: CC SC NT CT ST; ACT – nil/occasional; Vic – uncertain (EGippsland)
Eucalyptus forrestiana	WA (endemic)	UNCERTAIN WA (IBRAs: ESP, MAL)
Eucalyptus gillii	NSW, SA	NIL NSW NFWP; SA (northern Flinders Ranges)
Eucalyptus globoidea	NSW, Vic	PARTIAL NSW: NC CC SC (but dry sclerophyll habitat), CT ST CWS; Vic – uncertain
Eucalyptus globulus [subsp. uncertain]	NSW, ACT (naturalised), Vic, Tas, SA	PARTIAL (MINOR) (but note plantations) NSW: NC CC SC NT CT ST CWS SWS; ACT – nil or occasional Vic, Tas, SA – all uncertain, partial exposure possible
Eucalyptus globulus subsp. bicostata (syn. Eucalyptus bicostata)	NSW, ACT (naturalised), Vic, SA	NIL OR MINOR NSW: NC? (very marginal), CT, ST, CWS, SWS ACT – nil or occasional Vic (S & E), SA (small pop'n Burra district) – both uncertain
Eucalyptus globulus subsp. globulus (= Eucalyptus globulus sens. strict.)	Vic, Tas, SA (naturalised)	UNCERTAIN Vic, Tas – widespread in both, both uncertain
Eucalyptus gomphocephala	WA (endemic)	UNCERTAIN WA (IBRAs: GES, SWA)
Eucalyptus goniocalyx [subsp. uncertain]	NSW, ACT, Vic, SA	NIL OR MINOR NSW NT CT ST NWS CWS SWS; ACT – nil or occasional; Vic (widespread), SA (SE quarter) – both uncertain.
Eucalyptus grandis	Qld, NSW	TOTAL Qld total: SEQ, CQ, NQ (coastal S from c. Cairns; NSW total: NC

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Eucalyptus guilfoyleii	WA (endemic)	UNCERTAIN WA (IBRAs: JAF, WAR)
Eucalyptus gunnii subsp. gunni	Tas (endemic)	UNCERTAIN Tas
Eucalyptus gunnii subsp. divaricata	Tas (endemic)	UNCERTAIN Tas
Eucalyptus haemastoma	NSW (endemic)	TOTAL NSW: NC CC (but dry sclerophyll habitat)
Eucalyptus jacksonii	WA (endemic)	UNCERTAIN WA (IBRAs: JAF, WAR)
Eucalyptus johnstonii	Tas (endemic)	UNCERTAIN Tas
Eucalyptus laevopinea	Qld, NSW	PARTIAL (MINOR?) Qld partial: SEQ; Carnarvon uncertain. NSW partial?: NC (marginal) NT CT NWS CWS
Eucalyptus lehmannii	WA (endemic)	UNCERTAIN WA (IBRAs: ESP, MAL)
Eucalyptus longirostrata	Qld (endemic)	PARTIAL Qld: SEQ; southern CQ inland uncertain (e.g. Monto, Expedition Ra, Blackdown)
Eucalyptus marginata subsp. marginata	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, ESP, GES, JAF, MAL, SWA, WAR)
Eucalyptus megacarpa	WA (endemic)	UNCERTAIN WA (IBRAs: ESP, JAF, SWA, WAR)
Eucalyptus microcorys	Qld, NSW	TOTAL Qld Total: SEQ; NSW Total: NC CC
Eucalyptus moluccana	Qld, NSW	PARTIAL (but occurs in drier habitats) Qld partial: coast S from c. Cairns; contiguous uplands along GDR unlikely?. NSW partial: NC CC SC NT ?CT ST NWS CWS
Eucalyptus morrisbyi	Tas (endemic)	UNCERTAIN Tas
Eucalyptus nebulosa	Tas (endemic)	UNCERTAIN Tas
Eucalyptus nitens	NSW, Vic	NIL? NSW nil: NT ST; Vic uncertain but likely nil
Eucalyptus nitida (disputed synonym: E. ambigua)	Tas (endemic)	UNCERTAIN Tas

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Eucalyptus obliqua	Qld, NSW, Vic, Tas, SA	PARTIAL Qld: SEQ NSW: NC SC NT CT ST NWS CWS. Vic, Tas, (widespread in both) and SA (SE and KI) – all uncertain
Eucalyptus occidentalis	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, COO, ESP, JAF, MAL)
Eucalyptus olida	NSW (endemic)	PARTIAL / UNCERTAIN NSW: eastern NT, marginal for altitude: e.g. Timbarra, Gibraltar Ra.
Eucalyptus ovata [var. ovata]	NSW, Vic, Tas, SA	PARTIAL NSW: CC SC CT ST; Vic, Tas, SA – all uncertain.
Eucalyptus pauciflora subsp. pauciflora	Qld, NSW Vic, Tas, SA	NIL OR MINOR Qld: Darling Downs (Granite Belt) unlikely NSW: SC (possible near Bega) NT CT ST. ACT – nil likely. Vic, Tas, SA – all uncertain but unlikely, except near-coastal in Vic and SA.
Eucalyptus pellita	Qld (endemic)	TOTAL Qld: NEQ, eastern CYP
Eucalyptus perriniana	NSW, ACT, Vic,Tas	NIL OR MINOR NSW ST and ACT – both unlikely or occasional. Vic (eastern half, mostly at altitude) – uncertain Tas – uncertain/unlikely? (500-600m asl).
Eucalyptus pilularis	Qld, NSW	TOTAL Qld: SEQ incl. Fraser Is. WHA; NSW: NC CC SC.
Eucalyptus planchoniana	Qld, NSW	NEAR-TOTAL Qld total: SEQ; NSW partial: NC, *CC (naturalised), NT (extreme east possible)
Eucalyptus populnea [subsp.uncertain]	Qld, NSW	PARTIAL (MINOR) - subsp. populnea: Qld partial (coastal), inland unlikely. - subsp. bimbil: nil: Qld: S inland; NSW NWS CWS SWS NWP SWP NFWP SFWP

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Eucalyptus pryoriana (syn. E. viminalis subsp. pryoriana)	Vic (endemic)	UNCERTAIN Vic (E from Melbourne)
Eucalyptus pulchella	Tas (endemic)	UNCERTAIN Tas
Eucalyptus punctata (syn. Eucalyptus biturbinata)	Qld, NSW	PARTIAL Qld (most or total): SEQ N to Coominglah SF; inland southern CQ uncertain. NSW NC CC SC CT ST CWS
Eucalyptus radiata subsp. radiata	NSW, ACT, Vic, Tas.	MARGINAL NSW CT ST; ACT; Vic (NE to Otways); Tas.
Eucalyptus regnans	Vic, Tas	UNCERTAIN Vic (eastern) and Tas – both unlikely, high/cool habitat
Eucalyptus resinifera [subsp. uncertain]	Qld, NSW	TOTAL OR NEAR-TOTAL - subsp.resinifera: NSW Near-total: NC, CC, SC - subsp. hemilampra: Qld total: SEQ to FNQ, near coast; NSW total: NC
Eucalyptus resinifera subsp. hemilampra	Qld, NSW	TOTAL Qld total: SEQ to FNQ, near coast; NSW total: NC
Eucalyptus risdonii	Tas (endemic)	UNCERTAIN Tas
Eucalyptus robusta	Qld, NSW	TOTAL Qld total: SEQ; NSW total: NC CC SC
Eucalyptus rodwayi	Tas (endemic)	UNCERTAIN Tas
Eucalyptus rubida [subsp. rubida]	NSW, Vic, Tas	NIL / MINOR / UNCERTAIN NSW: CT ST CWS SWS); Vic, Tas – both uncertain
Eucalyptus saligna	Qld, NSW	NEAR-TOTAL Qld (most): SEQ to CQ coast, occasional CQ inland uncertain. NSW (most): NC CC NT CWS
Eucalyptus siderophloia	Qld, NSW	NEAR-TOTAL Qld near-total: SEQ, CQ coast, occasional CQ inland uncertain. NSW total: NC CC
Eucalyptus sieberi	NSW, ACT, Vic, Tas	PARTIAL/UNCERTAIN NSW: NC, CC, SC, CT, ST, NC; ACT – nil/occasional. Vic (eastern half) and Tas (NE) – both uncertain.

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Eucalyptus smithii	NSW, Vic	PARTIAL NSW: SC CT ST; Vic (East and West Gippsland) – uncertain
Eucalyptus subcrenulata	Tas (endemic)	UNCERTAIN Tas
Eucalyptus tenuiramis	Tas (endemic)	UNCERTAIN Tas
Eucalyptus tereticornis [subsp. uncertain]	Qld, NSW, Vic, (also New Guinea)	PARTIAL Qld partial: coast S from Princess Charlotte Bay; tablelands & inland uncertain. NSW partial: NC CC SC NT CT ST NWS CWS. Vic – uncertain (Gippsland)
Eucalyptus tindaliae	Qld, NSW	NEAR-TOTAL OR TOTAL Qld near-total: SEQ; inland outliers uncertain. NSW near-total: NC, NT (Timbarra)
Eucalyptus torquata	WA (endemic)	UNCERTAIN WA (IBRAs: COO, MUR, Myrtle Rust unlikely)
Eucalyptus urnigera	Tas (endemic)	UNCERTAIN Tas
Eucalyptus vernicosa	Tas (endemic)	UNCERTAIN Tas
Eucalyptus viminalis [sens. strict., = subsp. viminalis]	NSW, ACT, Vic, Tas, SA	PARTIAL (MINOR) NSW: CC, SC, NT, CT, ST, NWS, CWS, SWS; ACT nil or occasional; Vic (partial?), Tas (partial?), SA (partial – Fleurieu Pen.)
Eucalyptus wandoo subsp. wandoo	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, ESP, GES, JAF, MAL, SWA)
Eucalyptus woodwardii	WA (endemic)	UNCERTAIN WA (IBRAs: COO, MAL, MUR, Myrtle Rust unlikely)
Eucalyptus xerothermica	WA (endemic)	UNCERTAIN WA (IBRAs: CAR, GAS, LSD, PIL; Myrtle Rust unlikely over most of range except maybe coast Exmouth to Karratha).
Eugenia reinwardtiana	Qld, WA	NEAR-TOTAL? Qld: E coast Maryborough to Cape York; western CY uncertain. WA: Kimberley coast – uncertain NTerr (not native): host in cultivation (Melville Is., Arnhem Land)
Gossia acmenoides	Qld, NSW	TOTAL Qld: SEQ & coast N to Mackay; NSW total: NC CC
Gossia bamagensis	Qld (endemic)	TOTAL Qld: FNQ (coastal)
Gossia bidwillii	Qld, NSW	TOTAL Qld: SEQ to FNQ (to Coen); NSW: NC

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Gossia floribunda	Qld, New Guinea and Papuasian islands	NEAR-TOTAL Qld: NEQ N from Ingham, CYP; west side of CYP uncertain)
Gossia fragrantissima	Qld, NSW	TOTAL Qld: SEQ; NSW: far NC
Gossia gonoclada	Qld (endemic)	TOTAL Qld: SEQ; old record Rockhampton area (extant?)
Gossia hillii	Qld, NSW	TOTAL Qld: coastal SEQ to FNQ; NSW: NC
Gossia inophloia (syn. Austromyrtus inophloia)	Qld (endemic)	TOTAL Qld: SEQ
Gossia lewisensis	Qld (endemic)	TOTAL Qld: NEQ
Gossia macilwraithensis	Qld (endemic)	TOTAL Qld: NEQ and CYP
Gossia myrsinocarpa	Qld (endemic)	TOTAL Qld: NEQ and CYP
Gossia pubiflora	Qld (endemic)	TOTAL Qld: Townsville region
Gossia punctata	Qld, NSW	TOTAL Qld: SEQ S of Hervey Bay; NSW: NC
Homoranthus croftianus	NSW (endemic)	MARGINAL NSW: NT
Homoranthus flavescens	NSW (endemic)	NIL OR MARGINAL NSW: NWS, CWS, NWP
Homoranthus melanostictus	Qld, NSW	NIL OR MARGINAL Qld: nil or marginal: Darling Downs, Inglewood N to Murphys Ra., W to Mitchell; easternmost localities possibly exposed. NSW: NWP.
Homoranthus montanus	Qld (endemic)	NIL LIKELY Qld: western Darling Downs, Leichhardt & Maranoa pastoral districts; NSW NWP.
Homoranthus papillatus	Qld (endemic)	MARGINAL Qld: Girraween; single ALA record N of Miles, uncertain.
Homoranthus prolixus	NSW (endemic)	NIL - overlap unlikely, NSW: NT NWS
Homoranthus virgatus	Qld, NSW	TOTAL Qld: SEQ coast, S from Bundaberg; NSW: NC.
Hypocalymma angustifolium [subsp. uncertain]	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, ESP, GES, JAF, MAL, SWA, WAR)
Kunzea ambigua	NSW, Vic, Tas	PARTIAL NSW: CC SC CT ST; Vic (coastal), Tas (E half) – both uncertain.
Kunzea baxteri	WA (endemic); Vic* (*naturalised)	UNCERTAIN WA (IBRAs: ESP, JAF, MAL, SWA)

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Kunzea ericoides	Qld, ACT, Vic, SA, Tas* (*naturalised)	PARTIAL Qld partial (most): SEQ N to Biggenden (except Granite Belt, where less likely) NSW partial: SC NT CT ST CWS SWS; ACT – nil or occasional. Vic (E half), Tas (E half), SA (Adelaide Hills) – all uncertain
Kunzea pomifera	Vic, SA	UNCERTAIN Vic (western), SA (south-eastern)
Lenwebbia lasioclada	Qld (endemic)	TOTAL Qld: NEQ, SEQ
Lenwebbia prominens	Qld, NSW	TOTAL Qld: SEQ; NSW: NC
Lenwebbia sp. Blackall Range (P.R. Sharpe+ 5387)	Qld (endemic)	TOTAL Qld: SEQ
Lenwebbia sp. Main Range (P.R. Sharpe+ 4877)	Qld, NSW	TOTAL Qld: SEQ; NSW: NC, NT (eastern edge)
Leptospermum barneyense	Qld (endemic)	TOTAL Qld: SEQ
Leptospermum brachyandrum	Qld, NSW	PARTIAL Qld partial (most?): Laura S to SEQ; GDR and western locales maybe unlikely. NSW partial: NC NT NWS
Leptospermum continentale [cv. 'horizontalis']	NSW, ACT, Vic, SA	PARTIAL NSW partial: CC SC CT ST CWS SWS. ACT – nil or occasional; Vic and SA (SE corner) – both uncertain.
Leptospermum deuense	NSW (endemic)	MARGINAL NSW SC (450 m alt., may be near altitude limit for rust)
Leptospermum glaucescens	Tas (endemic)	UNCERTAIN Tas
Leptospermum grandiflorum	Tas (endemic)	UNCERTAIN Tas
Leptospermum juniperinum	Qld, NSW	NEAR-TOTAL Qld total: SEQ coast S from Hervey Bay; nthn isolates Banana, Rockhampton. NSW partial (most?): NC CC SC CT ST
Leptospermum laevigatum	NSW, Vic, Tas. (naturalised in SA, WA, ?Qld)	PARTIAL NSW total: NC CC SC; Vic (whole coast), Tas – both uncertain.
Leptospermum lanigerum	NSW, Vic, Tas, SA	PARTIAL NSW: SC CT ST; ACT nil or occasional; Vic, Tas, SA – all uncertain

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Leptospermum liversidgei	Qld, NSW	TOTAL NSW: NC
Leptospermum luehmannii	Qld, NSW	PARTIAL NSW: NC NT?
Leptospermum madidum [subsp. uncertain]	Qld, WA, NTerr	PARTIAL - subsp. madidum: Partial (degree uncertain): Qld partial (most?): CYP east (CYP west and interior uncertain); NTerr: uncertain but potentially total (east Arnhem Land & VRD). - subsp. sativum: SEE NEXT
Leptospermum madidum subsp. sativum	Qld, WA, NTerr	PARTIAL (DEGREE UNCERTAIN): Qld: CYP (likely partial, but not yet recorded as host in Qld). NTerr partial: Melville Is., Top End uncertain; WA – uncertain (W & S Kimberley)
Leptospermum morrisonii [cv. 'Burgundy']	NSW (endemic)	PARTIAL NSW: CC SC CT ST
Leptospermum myrsinoides	NSW, Vic, SA	UNCERTAIN / MARGINAL NSW: far SC; Vic, SA (SE) – both uncertain
Leptospermum nitidum	Tas (endemic)	UNCERTAIN Tas
Leptospermum petersonii	Qld, NSW; (naturalised in Vic.)	PARTIAL (MOST) Qld: SEQ; NSW: NC, CC (naturalised), NT (eastern, where may be vulnerable)

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Leptospermum polygalifolium [subsp. uncertain]	Qld, NSW (mainland &Lord Howe Is.)	PARTIAL overall - subsp. polygalifolium: Qld near-total: SEQ to NQ incl Atherton Tblds; NSW partial: NC CC SC NT CT ST; ACT – nil or occasional. - subsp. cismontanum: near-total?: Qld: SEQ; NSW total: NC CC. - subsp. howense: NSW - Lord Howe Island Group (endemic) – POTENTIALLY TOTAL if rust naturalises. - subsp. montanum: Qld: partial (most): SEQ (except Granite Belt, where unlikely); NSW partial: NC NT NWS. - subsp. transmontanum: Qld: partial (minor): near-coastal SEQ & CQ, but most are SEQ/CQ inland where less likely; northern outlier near Warang; NSW partial (minor): NC NT ?CT NWS CWS NWP. - subsp. tropicum: Qld (endemic): partial along coast: SEQ, CQ, NQ; inland CQ/WQ uncertain/unlikely
Leptospermum riparium	Tas (endemic)	UNCERTAIN Tas (widespread; Bass St islands at risk?)
Leptospermum rotundifolium	NSW, (naturalised Vic & WA)	PARTIAL NSW: CC SC CT ST,
Leptospermum rupestre	Tas (endemic)	UNCERTAIN Tas (mainly occurs at higher altitudes)
Leptospermum scoparium	NSW, Vic, Tas	UNCERTAIN NSW: marginal: SC (S from Mt Imlay); Vic (southern) and Tas – both uncertain.
Leptospermum semibaccatum	Qld, NSW	TOTAL Qld total: SEQ. (dubious record inland in NQ [Mt Emu]); NSW total: NC
Leptospermum spectabile	NSW (endemic)	TOTAL NSW: CC (but local habitat/climate may mitigate)

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Leptospermum trinervium	Qld, NSW, ACT, Vic	PARTIAL (MOST?) Qld partial (most): SEQ n to Rockhampton; inland populations incl. Granite Belt less unlikely; NSW partial: NC CC SC NT CT ST CWS; ACT – nil or occasional; Vic – uncertain (East Gippsland)
Leptospermum whitei	Qld, NSW	TOTAL QLD: SEQ; NSW: NC
Leptospermum wooroonooran	Qld (endemic)	TOTAL Qld: NEQ
Lindsayomyrtus racemoides	Qld (endemic)	TOTAL Qld: NEQ (Cooktown to Innisfail)
Lithomyrtus obtusa	Qld (endemic)	TOTAL Qld: CQ (Gladstone) N to Cape York, coastal
Lithomyrtus retusa	Qld. WA. NTerr	PARTIAL (potentially most) Qld [where not yet recorded as a host]: partial: NEQ, CYP, northern inland. WA – uncertain (northern Kimberley). NTerr (lpartial to most): Top End, Melville Is., Bathurst Is.; inland uncertain
Lophostemon suaveolens	Qld, NSW	PARTIAL (MOST) Qld partial (most): SEQ, CQ, NEQ, CYP; inland populations on and W of GDR uncertain to unlikely. NSW: total: NC
Melaleuca alternifolia	Qld, NSW	PARTIAL (MOST) Qld partial (most?): SEQ, but Granite Belt less likely. NSW partial (most?): NC NT
Melaleuca argentea	Qld, NTerr, WA	PARTIAL Qld partial: NEQ (coast and eastern tblds N from Cairns; eastern CYP); western CYP, Gulf, and monsoon inland, all uncertain WA – uncertain (Kimberley to Shark Bay); NTerr –uncertain (Top End & VRD)
Melaleuca armillaris [subsp. uncertain]	subsp armillaris: NSW, Vic, Tas;(naturalised ACT, SA, WA) subsp. akineta: SA (endemic)	PARTIAL - subsp. armillaris: NSW partial (most?): NC CC SC CT ST; ACT – nil or occasional; Vic, Tas – both uncertain - subsp. akineta: SA – uncertain (EP and YP)
Melaleuca biconvexa	NSW (endemic)	NEAR-TOTAL NSW: NC CC SC CT (eastern)
Melaleuca cardiophylla	WA (endemic)	UNCERTAIN WA (IBRAs: CAR, GAS, GES, SWA, YAL)

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Melaleuca cheelii	Qld (endemic)	TOTAL Qld: SEQ (Maryborough – Bundaberg region)
Melaleuca comboynensis	Qld, NSW	TOTAL OR NEAR-TOTAL Qld: SEQ (Border ranges) NSW: NC, NT (eastern edge - uncertain). [ALA records from SW NSW in error.]
Melaleuca decora	Qld, NSW	PARTIAL (MOST) Qld partial: (CQ, SEQ in part, Burnett to border; less likely in Granite Belt); NSW partial (most): NC CC SC CWS
Melaleuca ericifolia	NSW, Vic, Tas	PARTIAL NSW total: NC CC SC (except far SC). Vic (E Gippsland to Melbourne) and Tas (except far S) – both uncertain.
Melaleuca fluviatilis	Qld (endemic)	PARTIAL Qld: CQ coast, NEQ, Gulf and northern inland uncertain.
Melaleuca gibbosa	Vic, Tas, SA	UNCERTAIN Vic (Gippsland & far SW), Tas (except W coast), SA (YP, EP).
Melaleuca howeana	NSW (Lord Howe Is. Group, endemic)	POTENTIALLY TOTAL if rust naturalises NSW: Lord Howe Island Group incl. Balls Pyramid.
Melaleuca leucadendra	Qld, WA, NTerr	PARTIAL potentially most Qld partial: NQ, CQ (Cape York to Bundaberg), inland & Gulf uncertain. WA (Kimberley) and NTerr (Gulf and Top End/monsoon) – both uncertain.
Melaleuca linariifolia	Qld, NSW CT ST. (naturalised in Vic, WA).	NEAR-TOTAL Qld near-total: SEQ, Blackdown Tbld uncertain. NSW total: NC CC SC
Melaleuca lophocoracorum	Qld (endemic)	TOTAL Qld (Ravenshoe area) Note: This reliably reported host species is not yet fully (photographically) confirmed as a host, and is omitted from the host list at Appendix 3. It is nevertheless recommended for conservation actions – see Appendix 1 for rationale.
Melaleuca nervosa	Qld, WA, NTerr	PARTIAL Qld partial: NQ, CQ (Bundaberg to Cape York), western CYP/Gulf uncertain. NT (whole monsoon) and WA (Kimbereley and south) – both uncertain

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Melaleuca nesophila	WA (endemic) (naturalised in Vic, SA)	UNCERTAIN WA (IBRAs: ESP, SWA)
Melaleuca nodosa	Qld, NSW	PARTIAL (MOST) Qld partial: SEQ (less likely in Granite Belt), WB, PC, DD, CQ tablelands. NSW partial: NC CC CWS
Melaleuca pustulata	Tas (endemic)	UNCERTAIN Tas
Melaleuca quinquenervia	Qld, NSW. (also Indonesia, New Guinea, New Caledonia).	NEAR-TOTAL Qld partial (most): entire E coast SEQ to FNQ; west side of CYP uncertain. NSW total: NC CC
Melaleuca saligna	Qld (endemic)	PARTIAL Qld: NEQ and E Cape York, W side of CYP uncertain.
Melaleuca sapientes	WA (endemic)	UNCERTAIN WA (IBRAs: COO, ESP, MAL)
Melaleuca sieberi	Qld, NSW	TOTAL Qld: SEQ (S from Maryborough); NSW: NC CC
Melaleuca squamea	NSW, Vic, Tas, SA	PARTIAL NSW partial (most): NC CC CT. Vic (SW), Tas (all), SA (lower Murray and YP) – all uncertain
Melaleuca squarrosa	NSW , Vic, Tas, SA	PARTIAL NSW total or near-total: CC SC. Vic (whole coast & hinterland), Tas (widespread), SA (far SE) – all uncertain
Melaleuca styphelioides	Qld, NSW; (naturalised in Vic)	PARTIAL Qld: probably total: (CQ and SEQ, S from Rockhampton) NSW partial (most): NC CC SC (to Nowra) NT CT CWS?
Melaleuca viridiflora	Qld, WA, NTerr	PARTIAL Qld partial: SEQ to Cape York, coastal); monsoon north, Gulf and western CYP all uncertain. NTerr (northern half) and WA (Kimberley) – both uncertain.
Metrosideros nervulosa	NSW (Lord Howe Is., endemic)	POTENTIALLY TOTAL NSW: Lord Howe Island
Metrosideros sclerocarpa	NSW (Lord Howe Is., endemic)	POTENTIALLY TOTAL NSW: Lord Howe Island
Mitrantia bilocularis	Qld (endemic)	TOTAL Qld: NEQ

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Neofabricia myrtifolia	Qld (endemic)	PARTIAL (MOST), potentially total Qld: NEQ (N from c. Ingham); CYP eastern; (CYP west and interior uncertain)
Osbornia octodonta	Qld, NTerr, WA	PARTIAL, potentially total Qld near-total: E coast, Cooloola to Cape York; W coast of CYP uncertain. NTerr (entire coast) and WA (coast S to Roebourne) – both uncertain
Pilidiostigma glabrum	Qld, NSW	TOTAL Qld: SEQ; NSW NC
Pilidiostigma rhytispermum	Qld (endemic)	TOTAL Qld: SEQ
Pilidiostigma tetramerum	Qld (endemic)	TOTAL Qld: NEQ
Pilidiostigma tropicum	Qld (endemic)	TOTAL Qld: NEQ
Regelia velutina	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, ESP)
Rhodamnia acuminata	Qld (endemic)	TOTAL Qld: SEQ & CQ N to Yeppoon
Rhodamnia angustifolia	Qld (endemic)	TOTAL Qld: Gladstone area
Rhodamnia arenaria	Qld (endemic)	TOTAL Qld: CYP (eastern)
Rhodamnia argentea	Qld, NSW	TOTAL Qld total: NSW border N to Bowen; NSW total: NC
Rhodamnia australis	Qld, NTerr	TOTAL OR NEAR-TOTAL Qld total: c. Townsville to Cape York NTerr – uncertain (coastal Top End – overlap uncertain but likely
Rhodamnia blairiana	Qld (endemic)	TOTAL Qld; NEQ
Rhodamnia costata	Qld (endemic)	TOTAL Qld: NEQ Mackay to c. Mossman
Rhodamnia dumicola	Qld (endemic)	TOTAL Qld: SEQ
Rhodamnia glabrescens	Qld (endemic)	TOTAL Qld: CQ Bundaberg to Bowen
Rhodamnia longisepala	Qld (endemic)	TOTAL Qld: NEQ Wet Tropics
Rhodamnia maideniana	Qld, NSW	TOTAL Qld: SEQ; NSW: NC
Rhodamnia pauciovulata	Qld (endemic)	TOTAL Qld: SEQ and CQ (Mackay region)
Rhodamnia rubescens	Qld, NSW	TOTAL Qld: SEQ; NSW: NC CC SC NT CT
Rhodamnia sessiliflora	Qld (endemic)	TOTAL Qld: NEQ (c. Townsville to c. Cape Tribulation)
Rhodamnia spongiosa	Qld (endemic)	TOTAL Qld: sporadic along most of e coast, Hervey Bay to Iron Range
Rhodamnia whiteana	Qld (endemic)	TOTAL Qld: Border Ranges, Main Range S from c. Cunninghams Gap

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Rhodomyrtus canescens	Qld (endemic)	TOTAL Qld: NEQ c. Ingham to c. Mossman
Rhodomyrtus effusa	Qld (endemic)	TOTAL Qld: NEQ (Julatten to Bloomfield)
Rhodomyrtus macrocarpa	Qld (endemic)	TOTAL Qld: CQ NEQ CYP (Mackay to Cape York)
Rhodomyrtus pervagata	Qld (endemic)	TOTAL Qld: NEQ, Townsville to Mossman [western CYP in ALA - geocode error]
Rhodomyrtus psidioides	Qld, NSW	TOTAL Qld: SEQ, NSW border N to c. Maryborough; NSW: NC CC
Rhodomyrtus sericea	Qld (endemic)	TOTAL Qld: CQ (Mackay area); NEQ (Ingham to Bloomfield)
Rhodomyrtus trineura subsp. capensis	Qld (endemic)	TOTAL Qld: NEQ (Malanda area), CYP east (Cooktown to Heathlands)
Ristantia pachysperma	Qld (endemic)	TOTAL Qld: NEQ (South Johnstone distr. to Cape Tribulation); CYP (isolated population Jardine R NP)
Ristantia waterhousei	Qld (endemic)	TOTAL Qld: NEQ (restricted, Airlie Beach area).
Sphaerantia discolor	Qld (endemic)	TOTAL Qld: NEQ (Mission Beach to Port Douglas)
Stockwellia quadrifida	Qld (endemic)	TOTAL Qld: NEQ (S edge of Atherton Tbld, Bellenden-Kerr Ra.)
Syncarpia glomulifera [subsp. uncertain]	Subsp. glabra: NSW Subsp. glomulifera: Qld, NSW	NEAR-TOTAL - subsp. glabra TOTAL: NSW NC (Buladelah to Kempsey) - subsp. glomulifera: partial (most): Qld, SEQ, CQ, NEQ (some inland CQ populations uncertain, e.g. Carnarvon); NSW: partial (most): NC CC SC CT
Syzygium alatoramulum	Qld (endemic)	TOTAL Qld: NEQ (Windsor Tableland to Mt Bartle Frere)
Syzygium alliligneum	Qld (endemic)	TOTAL Qld: NEQ (Cape Tribulation to Tully)
Syzygium angophoroides	Qld, WA, NTerr	PARTIAL (potentially near-total) Qld: near-total: NEQ/CYP (Paluma to Cape York); inland and western CYP uncertain. NTerr (Gulf, Top End, VRD) and WA (Kimb) – both uncertain.
Syzygium anisatum (syns. Anetholea anisata, Backhousia anisata)	NSW (endemic)	TOTAL NSW: NC
Syzygium apodophyllum	Qld (endemic)	TOTAL Qld: NEQ (Tully Gorge NP N to Rossville); disjunct CYP (Coen area)

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Syzygium aqueum	Qld (also Malesia, SE Asia, India)	TOTAL Qld: CYP (restricted to Claudie R/Lockhart area)
Syzygium argyropedicum	Qld (endemic)	TOTAL Qld: NEQ/CYP (N of Cooktown to Cape Grenville)
Syzygium armstrongii	NTerr (endemic)	UNCERTAIN, potentially total NTerr: Top End; known host in cult., Darwin 2015.
Syzygium australe	Qld, NSW	TOTAL Qld: near-total: Gold Coast to Daintree; a few inland CQ populations uncertain. NSW: NC CC SC NT(eastern edge)
Syzygium bamagense	Qld (endemic)	NEAR-TOTAL? Qld: CYP eastern; CYP inland and western, uncertain.
Syzygium banksii	Qld (endemic)	TOTAL Qld: NEQ, CYP
Syzygium boonjee	Qld (endemic)	TOTAL Qld: NEQ (Innisfail – Malanda – Deeral)
Syzygium buettnerianum	Qld, New Guinea, Solomon Is.	TOTAL Qld: NEQ, CYP
Syzygium bungadinnia	Qld (also New Guinea?)	TOTAL? Qld: CYP, TSI
Syzygium canicortex	Qld (endemic)	TOTAL OR NEAR-TOTAL Qld: NEQ (Townsville to nr Cooktown); Staaten River NP pop'n uncertain.
Syzygium claviflorum (syn. Acmenosperma claviflorum)	Qld, NTerr; (also Malesia incl. New Guinea & islands, SE Asia).	TOTAL Qld: CQ coast, NEQ, CYP; NTerr (Bathurst Is) – uncertain.
Syzygium cormiflorum	Qld (endemic)	TOTAL Qld: NEQ, CYP
Syzygium corynanthum	Qld, NSW	TOTAL Qld: SEQ; NSW NC
Syzygium cryptophlebium	Qld (endemic)	TOTAL (unless beyond Myrtle Rust altitudinal limit – grows to 1550 m asl) Qld: CQ, NEQ, CYP
Syzygium dansiei	Qld (endemic)	TOTAL Qld: NEQ (Windsor Tbld, Mt Spurgeon area)
Syzygium endophloium	Qld (endemic)	TOTAL Qld: CQ, NEQ (Mackay to near Cooktown)
Syzygium erythrocalyx	Qld (endemic)	TOTAL Qld: NEQ
Syzygium erythrodoxum	Qld (endemic)	TOTAL Qld: NEQ, southern CYP (Innisfail to Bloomfield area)

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Syzygium eucalyptoides [subsp. uncertain]	Qld, NTerr, WA	PARTIAL - subsp. eucalyptoides: Qld partial: NEQ; CYP/Gulf monsoon uncertain); WA, NTerr – both uncertain. - subsp. bleeseri: Qld partial?: CYP; NTerr (Top End, VRD), WA (Kimberley) – both uncertain.
Syzygium eucalyptoides subsp. eucalyptoides	Qld, NTerr, WA	PARTIAL Qld: eastern CYP; central and western CYP and Gulf both uncertain. NTerr (Gulf, Top End, VRD) and WA (Kimberley) – both uncertain.
Syzygium fibrosum	Qld, NTerr	PARTIAL Qld: NEQ, CYP eastern; NTerr – uncertain (Top End).
Syzygium floribundum (syn. Waterhousea floribunda)	Qld, NSW	TOTAL Qld: SEQ, CQ coastal; NSW: NC
Syzygium forte subsp. forte	Qld, NTerr	PARTIAL Qld: NEQ, CYP east; CYP west uncertain; NTerr (Top End, uncertain).
Syzygium forte subsp. potamophilum	Qld, WA, NTerr	PARTIAL Qld: CYP east; CYP west uncertain NTerr (Top End), WA (Kimberley coast) – both uncertain.
Syzygium francisii	Qld, NSW	TOTAL Qld: SEQ; NSW: NC CC
Syzygium fullargarii	NSW: (Lord Howe is., endemic)	POTENTIALLY TOTAL. NSW: Lord Howe Island
Syzygium glenum	Qld (endemic)	TOTAL Qld: NEQ
Syzygium graveolens (syn. Acmena graveolens)	Qld (endemic)	TOTAL Qld: NEQ
Syzygium hedraiophyllum (syn. Waterhousea hedraiophylla)	Qld (endemic)	TOTAL Qld: NEQ (Innisfail to Mossman)
Syzygium hemilamprum) (subsp. uncertain) (syn. Acmena hemilampra)	subsp. hemilampra: Qld, NSW, NTerr. (also New Guinea) subsp. orophilum: Qld (endemic)	- subsp. hemilampra: NEAR-TOTAL Qld: entire east coast; W tip of CYP uncertain; NSW: NC NTerr (Bathurst Is. Croker Is. Uncertain) - subsp. orophilum: Qld TOTAL: NEQ, CYP

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Syzygium hodgkinsoniae	Qld, NSW	TOTAL Qld: SEQ; NSW NC
Syzygium ingens (syn. Acmena ingens)	Qld, NSW	TOTAL Qld: SEQ; NSW NC
Syzygium kuranda	Qld (endemic)	TOTAL Qld: NEQ
Syzygium luehmannii	Qld, NSW	TOTAL Qld: SEQ, NQ; NSW NC
Syzygium macilwraithianum	Qld (endemic)	TOTAL Qld: NEQ?, CYP east
Syzygium maraca	Qld (endemic)	TOTAL Qld: NEQ
Syzygium minutuliflorum	NTerr (endemic)	UNCERTAIN NTerr
Syzygium moorei	Qld, NSW	TOTAL Qld: SEQ; NSW NC
Syzygium mulgraveanum (syn. Waterhousea mulgraveana)	Qld (endemic)	TOTAL Qld: NEQ
Syzygium nervosum	WA, NTerr, Chr Is	UNCERTAIN WA (Kimb.), NTerr (Top End), Christmas Island
Syzygium oleosum	Qld, NSW	TOTAL Qld: (most of E coast, NSW border to c. Mossman); NSW: NC CC
Syzygium paniculatum	NSW (endemic)	TOTAL NSW: NC CC SC
Syzygium pseudofastigiatum	Qld (endemic)	TOTAL Qld: NEQ?, CYP east
Syzygium puberulum	Qld (also Malesia)	TOTAL (in Australia) Qld: NEQ, CYP east
Syzygium resa (syn. Acmena resa)	Qld (endemic)	TOTAL Qld: coastal CQ and NEQ (inland Qld record in ALA, *Hyland 8005*, is a geocoding error)
Syzygium rubrimolle	Qld (endemic)	TOTAL Qld: NEQ
Syzygium sayeri	Qld (endemic)	TOTAL Qld: NEQ
Syzygium smithii (syn. Acmena smithii)	Qld, NSW, Vic	PARTIAL (MOST) Qld near-total: SEQ, CQ coast, NEQ; NSW partial (most): NC CC SC NT CT NWS CWS; Vic – uncertain.
Syzygium suborbiculare	Qld, WA, NTerr	PARTIAL Qld: NEQ & CYP east; CYP inland & west uncertain. NTerr (Top End) and WA (Kimb) – both uncertain

Known host taxon (and synonyms)	Natural occurrence	Range overlap with Myrtle Rust in Australia OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Syzygium tierneyanum	Qld, New Guinea and Malesian islands	NEAR-TOTAL (in Australia) Qld: NEQ & CYP east; CYP inland & west uncertain.
Syzygium trachyphloium	Qld (endemic)	TOTAL Qld: NEQ
Syzygium unipunctatum (syn. Waterhousea unipunctata)	Qld (endemic)	TOTAL Qld: NEQ
Syzygium velarum	Qld (endemic)	TOTAL Qld: NEQ?, CYP
Syzygium wilsonii [subsp. uncertain]	subsp. wilsonii: Qld (endemic) subsp. cryptophlebia: Qld (endemic)	TOTAL - subsp. wilsonii: Qld: NEQ Subsp. cryptophlebia: Qld: CQ, NEQ, CYP
Syzygium xerampelinum	Qld (endemic)	TOTAL Qld: NEQ
Thaleropia queenslandica	Qld (endemic)	TOTAL Qld: NEQ (in rainforest)
Thryptomene calycina	Vic, SA	UNCERTAIN Vic (mainly Grampians); SA (Mt Gambier, ?Mt Lofty Ra.)
Thryptomene saxicola	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, ESP, JAF, WAR)
Tristania neriifolia	NSW (endemic)	TOTAL NSW: CC CT
Tristaniopsis collina	NSW (endemic)	PARTIAL NSW: NC CC SC NT CT ST
Tristaniopsis exiliflora	Qld (endemic)	TOTAL Qld: coastal CQ to Cape York; (ALA map point N of Croydon appears to be geocode error – relates to Jardine R.)
Tristaniopsis laurina	Qld, NSW, Vic	PARTIAL (MOST) Qld: total: SEQ; NSW: NC CC SC CT CWS; Vic (E Gippsland) uncertain.
Uromyrtus australis	NSW (endemic)	TOTAL NSW: NC
Uromyrtus lamingtonensis	Qld, NSW	TOTAL Qld: SEQ (Border Ra/Lamington); NSW: NC (Border Ra).
Uromyrtus metrosideros	Qld (endemic)	TOTAL Qld: NEQ (Innisfail to Cape Tribulation)
Uromyrtus tenella (syn. 'Austromyrtus sp. Lockerbie scrub')	Qld (endemic)	TOTAL Qld: NEQ
Verticordia chrysantha	WA (endemic)	UNCERTAIN WA (IBRAs: AVW, COO, ESP, GES, MAL, MUR, SWA, YAL)

Known host taxon (and synonyms)	**Natural occurrence**	**Range overlap with Myrtle Rust in Australia** OVERLAP OVERALL ESTIMATE IN CAPS; - overlap regional estimate (highlighted) - remaining host distribution (not highlighted)
Verticordia plumosa [var. uncertain]	WA (endemic)	UNCERTAIN WA - var. plumosa: IBRAs AVW, ESP, JAF, SWA, WAR. - var. ananeotes: IBRA: SWA - var. brachyphylla: IBRAs: AVW, COO, ESP, GES, JAF, MAL, SWA, WAR. - var. grandiflora: IBRAs: ESP, JAF, MAL - var. incrassata: IBRAs: AVW, COO, ESP, MAL - var. vassensis: IBRAs: SWA, WAR.
Xanthostemon chrysanthus	Qld (endemic)	TOTAL Qld: NEQ, southern CYP; inland ALA records (Croydon, Banana) uncertain
Xanthostemon formosus	Qld (endemic)	TOTAL Qld: NEQ (Daintree-Cape Trib.)
Xanthostemon graniticus	Qld (endemic)	TOTAL Qld: NEQ (restricted, ranges inland from Cape Trib.)
Xanthostemon oppositifolius	Qld (endemic)	TOTAL Qld: SEQ
Xanthostemon youngii	Qld (endemic)	TOTAL Qld: CYP (eastern)