Fire and Rust – impact of myrtle rust on regeneration of fire damaged Myrtaceae and associated ecosystems

Final Report (PBSF029)

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1. Executive Summary

The impact *A. psidii* might have on regeneration following disturbance such as fire has long been considered a risk this pathogen posed prior to arrival in Australia, with detrimental consequences for forest structure and survival of dependent fauna and understory plants. Assessments in Australia since detection have identified significant detrimental impacts due to the fungus, including adverse effects on regeneration following disturbance events. Recent extreme fire events have resulted in significant impacts on a range of different ecosystems, with widespread epicormic and seedling regeneration now occurring or about to commence, creating ideal conditions for spread and impact of rust. This project aimed to determine the impact myrtle rust is having on species and ecosystem regeneration.

Monitoring plots were established in coastal heath and woodland ecosystems focused on species showing levels of susceptibility during initial surveys (see previous reports - Fire and Rust | Australian Network for Plant Conservation (anpc.asn.au). Plots were monitored monthly to determine impact of repeated *A. psidii* infection on fire affected reshooting trees of selected species. These species were *Melaleuca quinquenervia* and *M. nodosa*, *Eucalyptus pilularis* and *Leptospermum trinervium*. Monitoring plots were established in Yarringully Nature Reserve, Double Duke State Forest and Bundjalung National Park.

Impact from *A. psidii* infection was identified on all species monitored as part of this study. Impacts ranged from minor leaf spotting, periods of shoot and foliage dieback to reshoot and whole tree death. Flowering was also impacted, particularly the *Melaleuca* species, *M. nodosa* and *M. quinquenervia*. The level of impact and the duration of infection differed significantly between species assessed. Post fire recovery of *M. nodosa* was severely impacted by myrtle rust with repeated infection resulting in dieback, reduced flowering and death, particularly the small tree form. Only a few trees within the sites assessed produced multiple flowers/seed capsules. The influence of this reduced flowering rate on pollination processes is unknown as is the viability of seed produced on trees showing field tolerance.

While some site variation was observed when assessing the impact of *A. psidii* infection on fire affected *M. quinquenervia*, at all sites repeated infection resulted in dieback, reduced flowering and was associated with tree death. In some cases, *A. psidii* appeared to be the sole cause of tree death following repeated attack on the reshoots. The low numbers of trees producing flowers across the study sites appears alarming but in saying this, longer-term monitoring is required to see if this changes over time.

While the study identified many susceptible individuals within the species of *Melaleuca* assessed, it also identified individuals showing field resistance, producing flower and seed. Perhaps, this provides an opportunity to selectively collect germplasm for propagation and use in regeneration plantings and long-term conservation.

2. Introduction

While fire is considered an important selection agent in the development of Australia's native flora (Gill 1975), the development of new epicormic and young seedlings en-masse are ideal for the development and spread of *A. psidii*. The impact *A. psidii* might have on regeneration following disturbance such as fire has long been considered a risk this pathogen posed prior to arrival in Australia, due to infections by this fungus occurring exclusively on young tissue. Detrimental consequences for forest structure and survival of dependent fauna and understory plants were expected (Grgurinovic et al. 2006). Assessments in Australia since detection have identified significant impacts, including impacts on regeneration following disturbance events (Carnegie & Pegg 2018). Recent extreme fire events have resulted in significant impacts on a range of different ecosystems, with widespread epicormic and seedling regeneration now occurring or about to commence, creating ideal conditions for spread and impact of rust.

Fires

The 2019-20 bushfires in New South Wales (NSW) were unprecedented in their extent and intensity affecting native forest systems, burning large areas of bushland including World Heritage Listed National Parks. In New South Wales alone, 5.3 million hectares (6.7% of the State) were fire affected, including 2.7 million hectares in national parks (37% of the State's national park estate) (ABARES). More than 50% of the Gondwana Rainforests of Australia World Heritage property was affected by fire.

Individual fires burnt large areas of land with Myall Creek Road fire in the Richmond Valley burning more than 121,000 ha, impacting a range of ecosystems including coastal heath and woodland in Bundjalung National Park. Fires in Queensland affected similar ecosystems including the Border Ranges as well as wetlands and coastal ecosystems in the Sunshine Coast region impacting on 514,000 ha of forested area.

3. Aim

This project aimed to determine the impact myrtle rust has on species and ecosystems regenerating after wildfire. We aimed to study the impacts of repeated infection on reshoots of species identified as susceptible during initial surveys – *Eucalyptus pilularis*, *Leptospermum trinervium*, *Melaleuca quinquenervia* and *M. nodosa*.

4. Methods/Process

Sites were selected based on fire intensity mapping and surveys conducted to assess regenerating reshoots and seedlings of Myrtaceae across these sites. Walk through surveys and establishment of transects (50m x 1m) were used to determine species affected by *A. psidii* at the different sites. These results were included in previous reports (Fire and Rust | Australian Network for Plant Conservation (anpc.asn.au))

Monitoring plots were established to follow disease development on reshooting trees and impact on species over time. These consisted of 50 randomly selected trees of species of interest that were numbered and marked with flagging tape. Only trees that were producing visible reshoots were used in the study plots.

Assessments were conducted monthly where possible. However, Covid 19 lockdowns and border closures between NSW and Queensland (July 2021 to December 2021) prevented some assessments from occurring. Final assessments were done in January 2022 to record dieback levels and tree death.

Data collected included:

- Fire intensity - low severity (burnt understory, unburnt canopy), moderate severity (partial canopy scorch), high severity (complete canopy scorch, partial canopy consumption), severe (full canopy consumption)
- Presence/absence of susceptible flush
- Disease incidence on foliage and stems -% of susceptible foliage and/or stems affected
- Disease severity on infected foliage and stems – low, low-moderate, moderate, moderate-high, high, high-severe, severe.
- Dieback caused by myrtle rust - % of reshoots affected
- Death caused by myrtle rust -% of reshoots killed
- Flowering – flower levels on trees assessed on a 0 to 4 scale, 4 being abundant flowers

Study sites

Three sites were selected:

Yarringully Nature Reserve, NSW

This site is a Melaleuca woodland with sections dominated by *Melaleuca quinquenervia* and others dominated by *Eucalyptus pilularis*. The small tree form of *Melaleuca nodosa* occurs in patches within the reserve. Fire impacts across the site were rated as severe with full canopy consumption.

Monitoring plots were established for:

- *Melaleuca quinquenervia*
- *Melaleuca nodosa* (small tree form)

Double Duke State Forest, NSW

Woodland dominated by *Eucalyptus pilularis* and *Eucalyptus pyrocarpa* overstory with a range of Myrtaceae in the understory including *Leptospermum* species, *Austromyrtus dulcis* and small patches of *Melaleuca nodosa*. *Melaleuca sieberi* is found closer to waterways within the State Forest. Fire severity was severe across the assessment area with full canopy consumption including large E. *pilularis* trees. Monitoring plots were established for:

- *Eucalyptus pilularis*
- *Leptospermum trinervium*

Bundjalung National Park, NSW

Bundjalung NP has a range of different ecosystems including coastal heath close to the coastline, melaleuca wetlands and coastal woodlands. All areas assessed were severely impacted by fire with full canopy consumption (Fig 1). Monitoring plots were established to assess species identified in broader surveys as being impacted by myrtle rust (Fig 2). Species monitored in Bundjalung NP were:

- *Melaleuca quinquenervia*
- *Melaleuca nodosa*
- *Leptospermum trinervium*
- *Eucalyptus pilularis*
- *Eucalyptus tindaliae*

Figure 1 Wildfire burnt large areas of coastal heath and woodland in Bundjalung NP with post fire regeneration sparked by rainfall in January 2020

Figure 2 Plots established in Myrtaceae rich environments and single species plots established for selected species

5. Results

Yarringully, NSW – Severe fire impact with full canopy consumption

Melaleuca nodosa

Monitoring of *M. nodosa*, a small tree form of the species, commenced in March 2020. The trees were affected by severe fire with full canopy consumption. Assessments were conducted monthly where possible but access to the site on some occasions was limited by flooding. After July 2021 assessments, Covid and the border closure prevented further assessments. A final measure to assess tree death was conducted in January 2022.

Table 1 Myrtle rust impact assessments on *Melaleuca nodosa* reshoots, Yarringully National Reserve, New South Wales

Assessment Date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree (1-4)
12/03/2020	96	60.42	41.03	1.59
2/04/2020	97.92	89.36	64.76	2.4
4/05/2020	91.67	90.91	69	2.25
1/06/2020	74.47	100	81.86	2.09
23/06/2020	42.55	85	72.06	1.94
3/08/2020	25.53	58.33	68.57	1.86
14/09/2020	97.83	62.22	6.61	1.39
2/11/2020	97.78	88.64	86.02	2.15
3/12/2020	80	25	5.56	1.11
20/01/2021	95.45	73.81	29.52	1.64
22/02/2021	71.79	75	56.43	1.76
19/04/2021	44.12	73.33	33.18	1.45
2/06/2021	20	66.67	100	1.75
7/07/2021	10	33.33	100	1

Tree flush levels peaked at the initial assessments from March to May 2020 as trees began to recover from the effects of the fire (Table 1). Trees with susceptible flush present declined after May 2020 with only 25% of trees with susceptible flush present in August 2020, before increasing again in September 2020. Leaf flush levels remained high from December 2020 through to February 2021, followed by a decline in April (44.2% of trees), June (20% of trees) and July (10% of trees) 2021. All trees assessed had some level of *A. psidii* infection recorded during the monitoring period.

The number of trees infected, and the average incidence and severity of infection, also fluctuated over time. The number of trees with *A. psidii* symptoms increased from 60% in March 2020 to 100% on the 1st of June 2020. The average disease incidence score per infected tree (81.86% of susceptible foliage infected) and severity of symptoms also peaked at this time. Disease levels, based on average disease incidence scores and average disease severity scores, were lowest in August and December 2020. This is despite there being a high proportion of trees with susceptible growth flush being present (97.83% and 80% respectively).

Infection of new growth resulted in dieback of reshoots on 91.49% of trees assessed with some level of dieback in June 2020 and 96.67% in July 2021. Tree deaths, because of repeated infection of reshoots, progressively increased over time (Fig 3). The first tree death was recorded in April 2020 and by February 2021 had increased to 17.32% of trees assessed. By the final assessment, 44.68 % of trees monitored had died with all having recorded disease incidence levels of >75% of the new, susceptible foliage at some or most of the assessment times. Of the remaining trees, 73.08% had high levels (>75% of reshoots affected) of dieback recorded with the likelihood of decline over time. This suggests that 85% of trees assessed will succumb to the effects of repeated *A. psidii* infection.

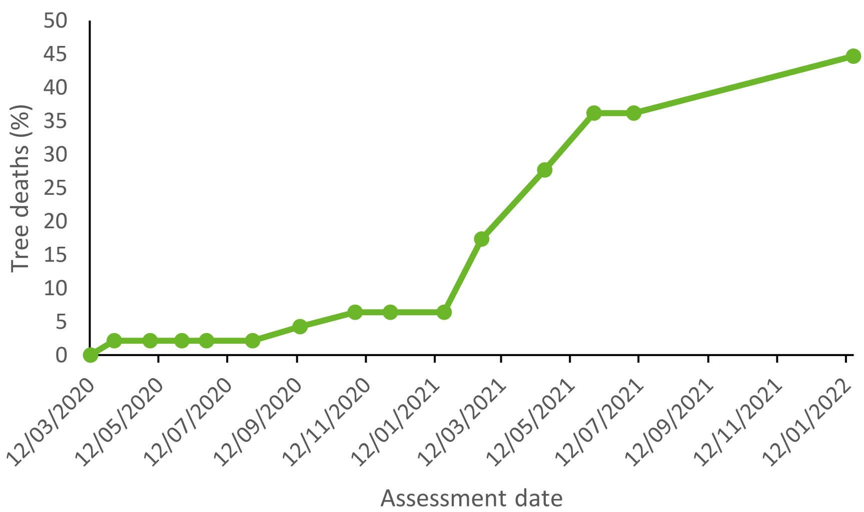

Figure 3 Progression of *Melaleuca nodosa* tree deaths caused by *Austropuccinia psidii* – Yarringully Nature Reserve, New South Wales.

Only three trees (6%) were identified to have any flower/fruit produced over the assessment period. Two of these trees had low levels of flowering.

Melaleuca quinquenervia

Fifty reshooting *Melaleuca quinquenervia* trees were randomly selected for monitoring within Yarringully Nature Reserve (Fig 4). All trees were considered large diameter, overstory trees and affected by severe fire with full canopy.

Figure 4 Large *Melaleuca quinquenervia* reshooting after severe fire damage in Yarringully Nature Reserve, NSW.

Table 2 Myrtle rust impact assessments on *Melaleuca quinquenervia* reshoots, Yarringully National Reserve, New South Wales

Assessment date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree
12/03/2020	100	0	0	0
2/04/2020	100	44	39.77	1.41
4/05/2020	100	64	37.81	2.12
1/06/2020	100	82	73.29	2.06
23/06/2020	80	82.5	50.76	1.52
3/08/2020	65.31	93	36.67	1.63
14/09/2020	95.83	71.74	20.61	2.09
2/11/2020	100	84.44	57.37	1.92
3/12/2020	100	43.18	12.63	1.37
20/01/2021	88.37	42.1	50	1.56
19/04/2021	65.91	44.83	23.08	1.31
2/06/2021	90.32	78.57	53.86	1.91
7/07/2021	89.65	76.92	37.63	1.95

Assessments commenced in March 2020 with all labelled trees producing new growth flush (Table 2). Susceptible flush was present on most trees at each assessment time. *Austropuccinia psidii* symptoms were first identified at the April 2020 assessment and identified on some trees at all assessment dates. Average disease incidence per tree peaked in June 2020, with the lowest disease levels recorded in December 2020 despite all trees having susceptible foliage present.

Tree deaths were first observed in August 2020 (2%) increasing to 42% by July 2021 and 66% at the final assessment in January 2022 (Fig 5). All dead trees had some level of *A. psidii* infection recorded during the assessment period. Six of these trees had only low disease levels recorded (<30% disease incidence) and other factors are likely to have contributed to tree death. Insect damage was observed on all trees, particularly during the spring months, with Mirids (*Eucerocoris suspectus*) causing damage to reshoots, often in combination with myrtle rust. All remaining living trees have had some level of infection recorded on susceptible foliage, primarily in the lower canopy reshoots.

Flowering was observed on eight trees (16%). No trees assessed were considered to have abundant (rating 4) levels of flowering. Four trees had moderate levels of flowering. All eight trees had some level of *A. psidii* infection recorded over the assessment period, two with high disease incidence levels (>50% of susceptible foliage). However, infection on these trees was limited to the lower canopy with no evidence of infection or dieback in the upper canopies.

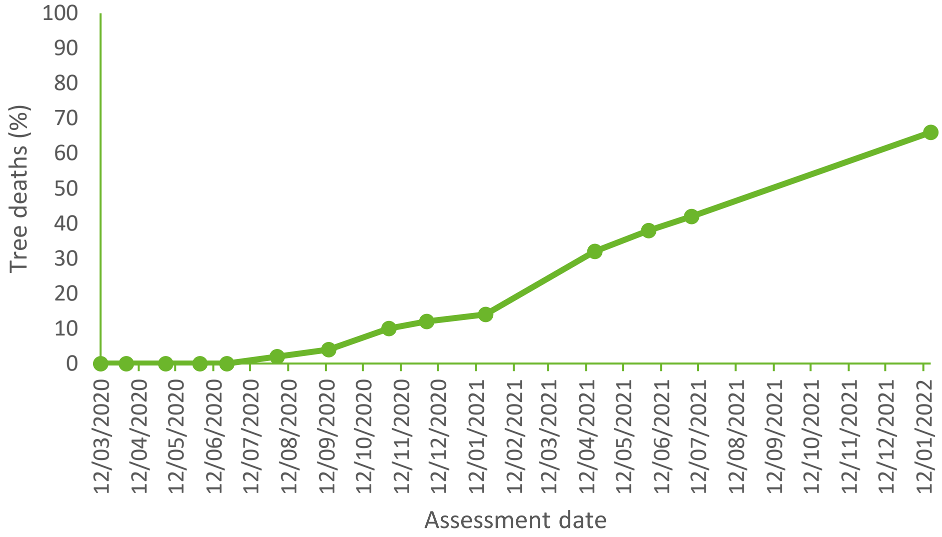

Figure 5 Progression of *Melaleuca quinquenervia* tree deaths caused by *Austropuccinia psidii* – Yarringully Nature Reserve, New South Wales.

Bundjalung National Park, NSW – Severe fire impact with full canopy consumption

Melaleuca nodosa

Monitoring the impact of myrtle rust on *M. nodosa* was focused on the "heath" form of the species that is common closer to the coast. This form is stunted in growth and often less than a meter in height and, in the absence of myrtle rust impact, produces masses of yellow flowers in early Spring months (Fig 6). Within the monitoring site there was some variability in height with some trees, based on the size of stems left after fires, reaching close to 2m in height. Assessments at the site commenced in May 2020 with a final assessment conducted in July 2021. A follow-up assessment to assess for flowering and dieback levels was conducted in January 2022 once covid restrictions were eased.

Figure 6 Coastal heath form of *Melaleuca nodosa* growing and flowering in Bundjalung National Park, NSW following the severe wildfires in 2019. Some evidence of field resistance to *Austropuccinia psidii* has been identified within studied populations.

The number of trees with active growth flush, considered susceptible to *A. psidii* infection, was variable with peaks and toughs in flush events coinciding with the percentage of trees infected. Factors, such as temperature and rainfall, influencing host and disease activity have not been compared at this time. However, no seasonal patterns were obvious when assessing the data (Table 3). Only three trees were assessed as being free from *A. psidii* symptoms throughout the assessment period. While no tree deaths were recorded, dieback of growing tips was identified on 63.83% of trees assessed and branch death/dieback on 52% of trees (Fig 7, 8).

Flowering was assessed in September 2020 and again in January 2022. The last assessment was based on presence of capsule/fruit as covid19 restrictions prevented site visits during the flowering period. In 2020, 60% of trees assessed had some flowers present. However, 46% had low levels of flowering, 32% with only one or two flowers per tree. Assessment of flowering in January 2022 identified capsule/fruit on only 17% of trees, a single tree with abundant amounts of capsule present.

Table 3 Myrtle rust impact assessments on *Melaleuca nodosa* reshoots, Bundjalung National Park, New South Wales

Assessment date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree	Trees with branch dieback caused by myrtle rust (%)
4/05/2020	100	72	88.61	3.19	0
1/06/2020	98	83.67	76.1	3.68	64
24/06/2020	36	72.22	57.31	2.77	76
4/08/2020	6	100	45	3.33	94
17/09/2020	42	0	0	0	88
3/11/2020	92	30.43	6.43	1.14	0
3/12/2020	0	0	0	0	0
20/01/2021	100	48	18.33	2	0
24/02/2021	64	78.12	56.4	3	0
29/03/2021	76	81.58	76.77	3.71	46
19/04/2021	58	82.76	69.37	3.33	58
3/06/2021	14	28.57	100	2	86
2/07/2021	60	33.33	5	1	82
18/01/2022	0	0			88.37

A "one-off" assessment of a different stand of *M. nodosa* was conducted in January 2022. This was a site bordering on a coastal woodland ecosystem and comprised of primarily the small tree form of *M. nodosa*. Ninety trees in total were assessed for dieback and presence of flower/fruit. 85.56% of trees assessed had some level of myrtle rust associated dieback. Of trees with dieback, 79.22% had dieback on all branches. Using a seven-point scoring scale, the average severity of the dieback was 4.39. Fourteen trees (15.56%) had fruit present, four with abundant numbers.

Figure 7 *Austropuccinia psidii* infection symptoms and impact on *Melaleuca nodosa* in Bundjalung National Park, NSW

Figure 8 *Austropuccinia psidii* infection symptoms on *Melaleuca nodosa*

Melaleuca quinquenervia

Three monitoring plots were established to assess the impact of *A. psidii* on *M. quinquenervia*. Disease symptoms were identified in the three plots assessed (Fig 9). Insect damage was also apparent at various times during the assessment period.

Figure 9 *Melaleuca quinquenervia* reshoot dieback caused by *Austropuccinia psidii*. Mirid damage also adds to the decline of new shoots (Top left)

Esk River plot

This site was situated along the bank of the Esk River and is predominantly small diameter trees. Fire through this site was considered severe with full canopy consumption. Myrtle rust symptoms were identified at all assessment times, with the number of trees infected increasing rapidly following the first assessment in April 2020. Peaks in disease levels, based on number of trees with symptoms, occurred in June 2020, November 2020 and May 2021 (Fig. 10, 11). Similarly, the level of disease incidence per tree and infection severity levels were highest at these assessment times (Table 4).

Table 4 Myrtle rust impact assessments on *Melaleuca quinquenervia* reshoots, Esk River Plot, Bundjalung National Park, New South Wales

Assessment date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree
3/04/2020	100	34	15	1.53
4/05/2020	100	80	64.25	2.45
1/06/2020	100	88	91.59	3.54
24/06/2020	68	91.18	93.55	3.13
4/08/2020	46	86.96	56.75	1.95
17/09/2020	86	62.79	24.07	2.15
3/11/2020	86	83.72	53.47	2.44
3/12/2020	64	71.87	39.56	1.78
20/01/2021	70	77.14	36.85	2.32
24/02/2021	78	71.79	69.64	2.39
29/03/2021	28	57.14	38.12	1.5
19/04/2021	70	60	60	2.29
11/05/2021	76	86.84	66.67	2.57
3/06/2021	76	76.32	76.9	3.48
2/07/2021	66	66.66	61.82	2.27

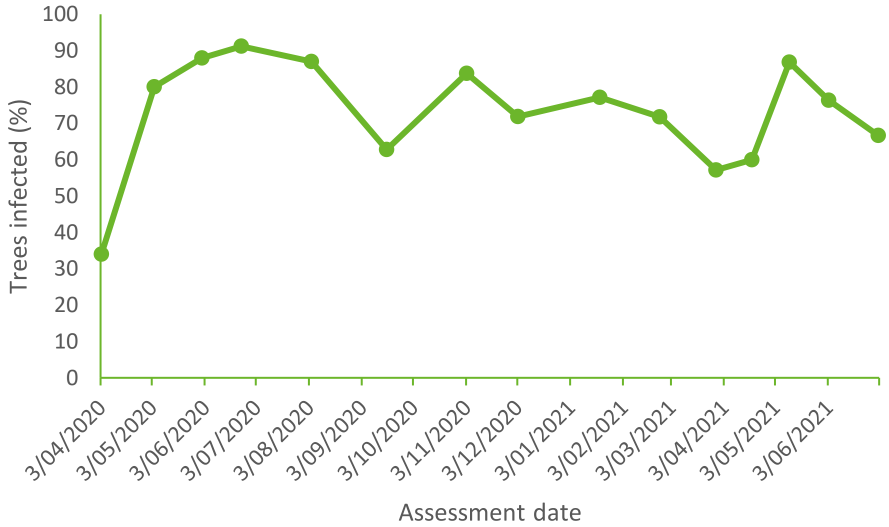

Figure 10 *Melaleuca quinquenervia* infection levels (trees infected) over the assessment period – Esk River Plot, Bundjalung NP, NSW.

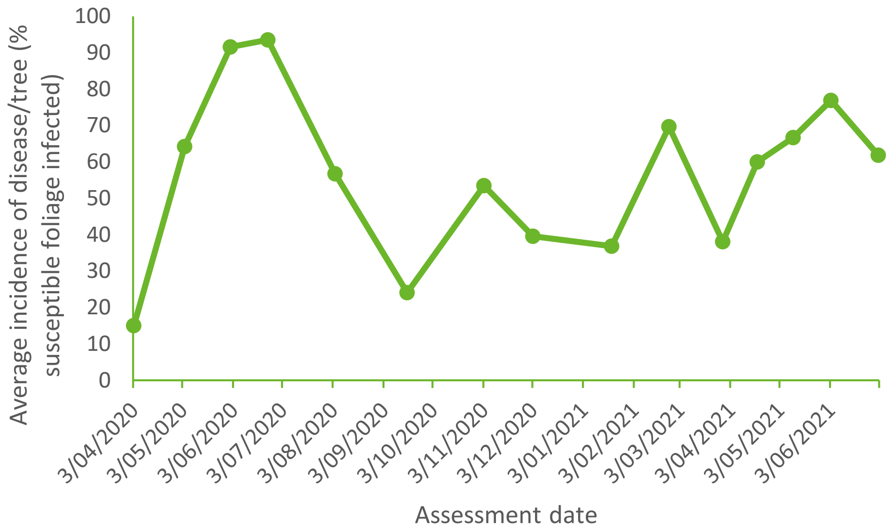

Figure 11 *Austropuccinia psidii* disease incidence levels on *Melaleuca quinquenervia* trees over the assessment period – Esk River Plot, Bundjalung NP, NSW.

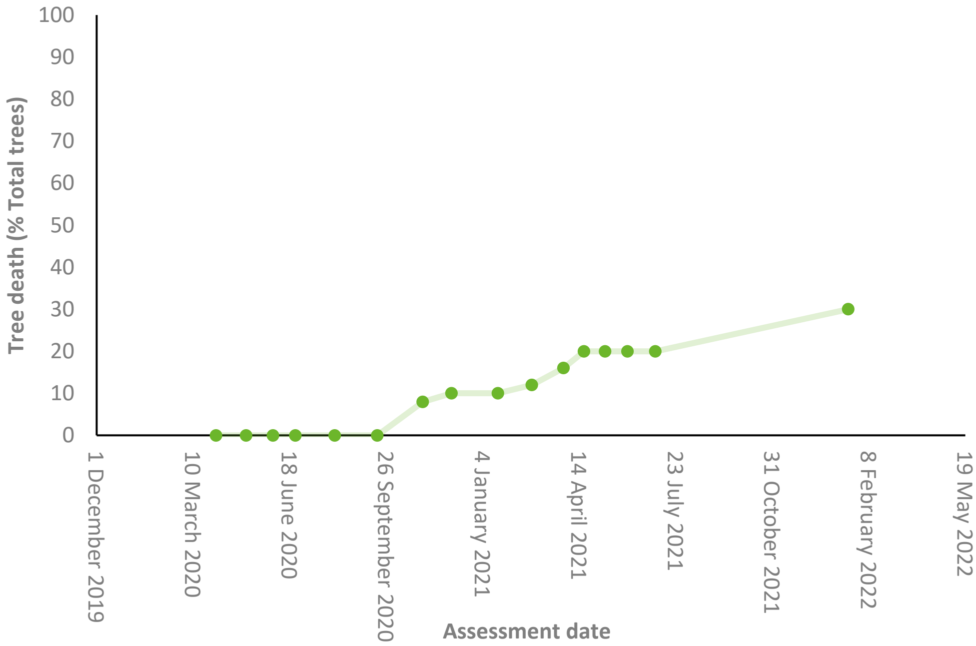

Figure 12 Myrtle rust associated tree deaths in *Melaleuca quinquenervia* plots monitored over time – Esk River Plot, Bundjalung NP, NSW.

Tree deaths because of repeated *A. psidii* infection on reshoots on fire affected *M. quinquenervia* were first identified in November 2020, seven months after symptoms were first observed (Fig. 12, 13, 14, 15). At this time, 8% of trees were recorded as dead, increasing to 20% by April 2020 and 30% at the final assessment in January 2022.

Flowering was observed on three trees only (6% of total trees assessed). Only a single tree had moderate levels of flowering, with the other two having low levels recorded. While all trees had some level of *A. psidii* infection symptoms recorded, all had low disease incidence levels (>10%).

Figure 13 Rapid decline of *Melaleuca quinquenervia* reshoots caused by *Austropuccinia psidii* – left to right May, June, August 2020

Figure 14 Impact of *Austropuccinia psidii* infection on reshoots of *Melaleuca quinquenervia* – Esk River, Bundjalung National Park, NSW.

Figure 15 Decline and death of reshoots following repeated *Austropuccinia psidii* infection of reshoots on fire affected *Melaleuca quinquenervia*, Esk River, Bundjalung National Park, NSW.

Water hole plot

This site was located on a lagoon system draining from a swamp, inland from the coast (Fig. 16). The site is likely nutrient deficient and quite acidic, supporting only narrow stemmed *M. quinquenervia* trees. *Melaleuca sieberi* was also common at this site and found to be infected with *A. psidii* at times. In addition to the restrictions on travel from covid19, some assessments were not possible due to flooding restricting access to this site.

Figure 16 Narrow stemmed *Melaleuca quinquenervia*, Water Hole Plot

Table 5 Myrtle rust impact assessments on *Melaleuca quinquenervia* reshoots, Water hole plot, Bundjalung National Park, New South Wales

Assessment Date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree
3/04/2020	100	0	0	0
4/05/2020	56	21.43	25.83	1.83
1/06/2020	78	64.1	49.8	1.96
24/06/2020	86	72.09	55	1.84
4/08/2020	94	74.47	53	2.11
17/09/2020	100	79.17	37.89	2.42
3/11/2020	97.92	76.6	35.17	1.64
3/12/2020	72.92	48.57	14.7	1.82
20/01/2021	60.42	68.97	36.5	1.7
19/04/2021	62.5	56.67	72.94	2.65
3/06/2021	72.92	65.71	71.74	3.39
2/07/2021	89.36	45.24	41.03	2.16

The levels of infected trees increased from May 2020, peaking in September with 79.17% of trees having some symptoms evident. Disease incidence and severity levels per tree peaked in September 2020 and again in June 2021 (Table 5).

Only three trees within this plot died due to myrtle rust. Ten trees (21.27% of living trees) were observed to have flowers present, three with moderate or abundant levels of flowering.

Swamp plot

The swamp plot is a site that was inundated for much of the assessment period and comprised of large diameter, tall *M. quinquenervia* trees close to the Esk River. The fire damage through the area was severe with full canopy consumption (Fig 17).

Figure 17 Large diameter fire affected *Melaleuca quinquenervia* (Swamp Plot) showing canopy consumption in 2020 (LHS) and lack of recovery in 2022 (RHS). Increased light levels as a result of a lack of canopy increased algal and reed growth.

Table 6 Myrtle rust impact assessments on *Melaleuca quinquenervia* reshoots, Swamp plot, Bundjalung National Park, New South Wales

Assessment Date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree
4/08/2020	88	45.45	50.5	1.65
17/09/2020	91.84	68.89	38.87	2.6
3/11/2020	89.8	75	39.45	1.87
3/12/2020	100	20.41	8.93	1.22
20/01/2021	91.49	25.58	15.27	0.86
24/02/2021	78.38	27.59	32.78	0.71
19/04/2021	96.67	27.59	45.17	1.39
3/06/2021	93.33	50	55.53	2.78

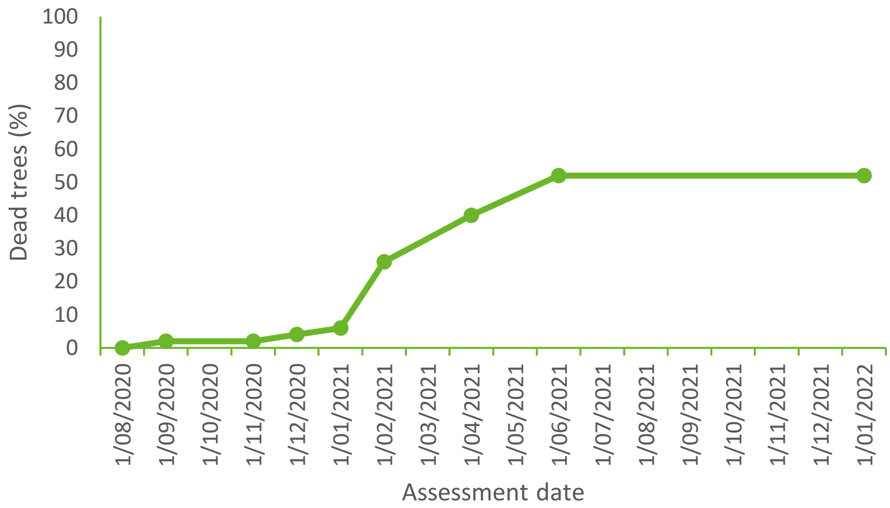

Figure 18 Myrtle rust associated tree deaths in *Melaleuca quinquenervia* plots monitored over time – Swamp plot, Bundjalung NP, NSW.

Reshooting occurred at various heights on the tree trunks, including the top of 20m+ tall trees, making assessment for myrtle rust symptoms difficult at times. Eighty-eight percent of trees had symptoms of *A. psidii* infection at some stage over the assessment period (Table 6). Assessments for disease incidence and severity were compared at different canopy heights – lower, middle and upper. While a complete analysis has not been completed for this report, the data suggests that canopy height does not influence disease incidence levels for *M. quinquenervia*.

Of the 26 trees that died (52% total trees assessed – Fig. 18), only three didn't have any evidence of myrtle rust symptoms over the assessment period. Of the trees that remain alive, myrtle rust symptoms were observed on all but four of the 24 trees. Approximately 45% of these living trees had moderate to severe disease incidence levels (≥50% foliage with symptoms) at some time over the assessment period.

Flowering was observed on six trees (20%) only. Two trees were considered to have moderate to abundant flowering levels. Those trees that did produce flowers had either no evidence of *A. psidii* infection or only low levels (<10% disease incidence).

Eucalyptus pilularis

Plots to monitor the impact of *A. psidii* on reshooting *E. pilularis* (Black Butt) were established in Bundjalung National Park (two plots) and Double Duke State Forest (one plot). All plots were monitored monthly for disease incidence and severity and impact on reshoots.

Figure 19 *Austropuccinia psidii* impact on *Eucalyptus pilularis* epicormic reshoot

Figure 20 *Austropuccinia psidii* symptoms on new shoots and young foliage of *Eucalyptus pilularis* epicormic reshoots

Bundjalung plot 1

Fifty-eight percent of trees assessed were found with some level of *A. psidii* infection at the first assessment in June 2020 (Fig. 19, 20). Of those infected, only 6.9% had infection occurring on reshoots in the upper canopy and 62% with symptoms in the mid canopy. At the second assessment, completed a month later (July 2020), disease levels had declined significantly with only 38% of trees showing new infection and of these, 10% had symptoms in the mid-canopy and no evidence of new infection in the upper canopy reshoots. By August 2020, only 3 trees (6%) had infection occurring on new shoots, all identified in the lower canopy reshoots. No further disease was identified in subsequent assessments. During the time disease was observed, impacts did include defoliation and dieback of reshoots, primarily in the lower canopy.

Bundjalung plot 2

The second plot followed similar patterns with infection levels declining three months after assessments commenced in May 2020. Twenty-eight percent of assessed trees had some level of *A. psidii* symptoms. Similarly, disease incidence levels were highest in the lower canopy compared to reshoots in the mid and upper canopy.

Double Duke State Forest

A single monitoring plot was established in Double Duke State Forest where, like Bundjalung NP, the fire impact was severe with full canopy consumption. Assessments were first conducted in March 2020 with a single tree found to be infected. This increased to 14 trees (23.33%) in June 2020, followed by a decline in July (16.95%) and again in August (1.7%). No disease was found during subsequent assessments.

Leptospermum trinervium

Two monitoring plots were established to study the impact of *A. psidii* on *L. trinervium* regeneration after fire, a site in Double Duke State Forest and one in Bundjalung National Park.

Double Duke State Forest

Sixty trees were labelled and monitored monthly (were possible) from March 2020 until November 2020.

Table 7 Myrtle rust impact assessments on *Leptospermum trinervium* reshoots, Double Duke State Forest, New South Wales

Assessment Date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree
12/3/2020	100	3.33	5	1
2/4/2020	100	65	13.59	1.61
4/5/2020	100	89.65	63.75	2.88
1/6/2020	94.83	80	48.07	2.75
23/6/2020	94.83	71.87	26.30	2.43
3/8/2020	55.17	30.77	10	2.25
14/9/2020	22.41	35.29	9.16	1.67
2/11/2020	84.48	8.16	9.17	1.17

The number of trees with *A. psidii* symptoms increased following the establishment of plots, peaking in May 2020 (89.65) in trees with susceptible flush (Table 7). Disease levels then declined, which seemed to coincide with a slowdown in growth rates with the number of trees producing active flush declining over time. However, as growth levels increased in November 2020, disease levels remained low. This is more likely to be related to climatic conditions at the time. Unfortunately, due to site access issues, no further assessments were done on this plot. However, at the September 2020 assessment, 81.03% of trees were found to have some level of myrtle rust associated dieback. Assessments of flowering identified that 86.21% of trees had some level of flowering, 66% of these considered to have abundant levels.

Bundjalung National Park

Table 8 Myrtle rust impact assessments on *Leptospermum trinervium* reshoots, Bundjalung National Park, New South Wales

Assessment Date	Trees with susceptible flush (%)	Trees infected (%)	Average incidence of disease/tree (% susceptible foliage infected)	Average severity of disease/tree
12/3/2020	100	1.67	25	2
3/4/2020	100	55	26.06	1.7
4/5/2020	96.67	56.9	49.7	2.85
1/6/2020	71.67	48.84	28.33	2.09
24/6/2020	43.33	38.46	7.5	1.6
4/8/2020	21.67	15.38	5	2.5
3/11/2020	45	0	0	0

Approximately 60% of trees assessed had some level of *A. psidii* infection on reshoots of *L. trinervium* after fire in the Bundjalung National Park (Table 8). Disease incidence (number of trees infected and average incidence and severity per tree) peaked in May 2020 and declined in subsequent assessments. Dieback of branch tips because of repeated *A. psidii* infection was found on 53% of all trees assessed. All trees had some level of flowering recorded with the majority having moderate or abundant levels.

Other species

Only low levels of rust have been identified on spotted gum (*Corymbia henryi*). However, in all sites where spotted gum has been assessed both seedlings and epicormic reshoots have been heavily infected and severely damaged by the endemic leaf and shoot pathogen *Quambalaria pitereka* (Fig 21). It is unknown if infection by *Q. pitereka* will prevent *A. psidii* infection and disease development. However, *Q. pitereka*, like *A. psidii*, affects new growth and requires similar climatic conditions for infection and disease development.

Figure 21 *Quambalaria pitereka* infection and damage on spotted gum, *Corymbia henryi* and *Corymbia henryi* seedling with *Austropuccinia psidii* infection on the growing tip (top right)

Austropuccinia psidii has also been reported on a range of other eucalypts but only causing minor damage including *C. intermedia* and *E. amplifolia* subs. *amplifolia* (Fig 22). This is a first record for field infection in Australia. Reshoots of *Eucalyptus tindaliae* were also commonly found infected with *A. psidii*. Symptoms were primarily found on juvenile foliage, with only small lesions on newly emerging adult foliage. A monitoring plot was established on a stand of regenerating *E. tindaliae* in Bundjalung National Park, but disease levels declined rapidly, and any infection recorded only resulted in minor foliage damage (Fig 23).

Figure 22 *Austropuccinia psidii* infection on *Eucalyptus amplifolia* subsp. *amplifolia*

Infection on *Eucalyptus planchoniana* was found on both seedlings and reshoots of fire affected trees (Fig 24). No plots were established to monitor impacts on reshoots as insufficient tree numbers were identified at each site. The greatest impact caused by *A. psidii* was on seedlings with infection resulting in death where infection levels were high.

Figure 23 *Austropuccinia psidii* symptoms on *Eucalyptus tindaliae* reshoots

Figure 24 *Austropuccinia psidii* on *Eucalyptus planchoniana* seedlings

6. Discussion and conclusion

Impact from *A. psidii* infection was identified on all species monitored as part of this study. Impacts ranged from minor leaf spotting, periods of shoot and foliage dieback to reshoot and whole tree death. Flowering was also impacted, particularly the *Melaleuca* species, *M. nodosa* and *M. quinquenervia*. The level of impact and the duration of infection differed significantly between species assessed.

While infection on *Eucalyptus* species caused some significant levels of shoot and foliage dieback, active disease symptoms were only observed for six months, declining rapidly after an initial disease peak soon after reshooting commenced on fire affected trees. Interestingly, infection and subsequent impact was primarily limited to the lower canopy, particularly for *E. pilularis*. This has been reported previously for eucalypts grown in plantation in Brazil (Zauza *et al*. 2010). It is unknown exactly what factors limit disease susceptibility over time and if leaf maturity or changes in host physiology might play a role. In the case of *E. tindaliae*, there was an obvious change in foliage type, juvenile to adult, over the assessment period with the adult foliage appearing to be more resistant or tolerant to *A. psidii* infection. Our observations would suggest that long term impact on reshooting trees is limited. However, as reported by Pegg *et al*. (2021a,b), impacts were significant on seedling regeneration post fire with infection resulting in death for more susceptible individuals.

The incidence of disease within populations of *L. trinervium* monitored in this study was high with >89% of trees with symptoms in Double Duke State Forest and >56% in Bundjalung National Park. However, disease levels declined rapidly as growth rates slowed and frequency of new growth flush declined. There was little impact on flowering rates observed, even on the more susceptible individuals with most trees producing moderate to abundant levels of flower. The long-term impacts of *A. psidii* on this species post fire appear to be limited.

Post fire recovery of *M. nodosa* was severely impacted by myrtle rust with repeated infection resulting in dieback, reduced flowering and death, particularly the small tree form. Unlike the species mentioned above, *A. psidii* infection continued throughout the assessment period with any new flush produced becoming infected if the conditions were favourable for disease development. While not dead, many of the trees in the coastal heath site were in severe decline and unable to compete with non-Myrtaceae or more tolerant species – e.g. *Leptospermum polygalifolium*. Only a few trees within the sites assessed produced multiple flowers/seed capsules. The influence of this reduced flowering rate on pollination processes is unknown as is the viability of seed produced on trees showing field tolerance.

While some site variation was observed when assessing the impact of *A. psidii* infection on fire affected *M. quinquenervia*, at all sites repeated infection resulted in dieback, reduced flowering and was associated with tree death. In some cases, *A. psidii* appeared to be the sole cause of tree death following repeated attack on the reshoots. However, in other cases (e.g. large diameter trees in Yarringully and Bundjalung Swamp plot) other factors appeared to contribute. Insect attack, particularly mirid bugs, appeared to adversely affect regrowth but levels were not quantified in this study. Some trees died without any evidence of myrtle rust on reshoots, suggesting the damage from the fire was also a factor in tree survival. However, the low numbers of trees producing flowers at this site appears alarming but in saying this, longer-term monitoring is required to see if this changes over time. Additional monitoring on these sites would also be valuable to examine seedling regeneration at each site. Previously, we reported significant levels of *A. psidii* infection within seedling populations (Pegg *et al.* 2021 a,b) but within these populations we also rated resistant and tolerant seedlings.

While this study provided evidence of the impacts of *A. psidii* on post fire regeneration of certain Myrtaceae, it does not provide evidence of the effect of fire intensity on disease incidence and severity for these species. Identifying sites where fire intensity was lower but with a similar plant community structure was difficult. Similarly, the use of fungicide to quantify impacts was not possible due to the height of many of the trees and the proximity to waterways in National Parks and Reserves. However, results reported previously (Pegg et al. 2021 b) would suggest that a low fire severity on *M. quinquenervia* will reduce the frequency of epicormic reshoots and as such reduce the incidence and severity of myrtle rust impact. However, fire intensity in lower growing coastal heath areas may not be as significant a factor – e.g. *M. nodosa*. It must be remembered that *A. psidii* has caused significant impact on a range of species where disturbance is not a factor.

A better understanding of the consequences of multiple disturbance factors on tree and forest health are required to fully understand impact and management strategies required. Halofsky *et al*. (2020), highlighted interactions between fire and other disturbances, such as drought and insect outbreaks, as potentially primary drivers of ecosystem change. While we observed insect impacts on all species assessed, we did not study the interactions between this damage and that caused by *A. psidii*. He *et al*. (2021), when studying the interaction between fire and sudden oak death (*Phytophthora ramorum*), state that while individual forest disturbances are well studied, interactions between multiple disturbances and changes of spatial patterns of forested landscapes are rarely quantified. When looking at different landscape patterns, their study suggested that wildfire had a significant role in the re-emergence of *P. ramorum*. They concluded that wildfire together with sudden oak death had a long-term detrimental effect on forest recovery. Our studies would suggest that this is the case with fire and myrtle rust, but longer-term studies are required along with more extensive ecological impact including the consequences of changes in plant population structure to the ecosystem.

While the study identified many susceptible individuals within the species of *Melaleuca* assessed, it also identified individuals showing field resistance, producing flower and seed. Perhaps, this provides an opportunity to selectively collect germplasm for propagation and use in regeneration plantings and long-term conservation. Ideally, a subset of seedlings would be screened for susceptibility under controlled conditions to enhance disease resistance selection.

7. References

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