Impacts of myrtle rust in New Zealand since its arrival in 2017

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Introduction

Myrtle rust, caused by *Austropuccinia psidii*, is an invasive fungal disease that affects plants in the myrtle family, the Myrtaceae. Of the almost 6,000 Myrtaceae species worldwide about 480 are currently recorded as hosts (Soewarto et al., 2019), but the host range is considered to be expanding (Carnegie and Lidbetter, 2012; Morin et al., 2012; Pegg et al., 2014). Myrtle rust originated in South America and has spread across the world at an increasing rate since the 1930s; it is now in more than 20 countries. Across the Pacific Ocean, it arrived in Hawaii in 2005, Australia in 2010, New Caledonia in 2013 and New Zealand in 2017. It is believed to have been carried to mainland New Zealand by wind from Australia across the Tasman Sea (Turner et al., 2017). The first New Zealand detections were on Raoul Island in the Kermadec Group in March 2017 and the first detection on the mainland was in Northland in May 2017 (Ho et al., 2019).

Myrtle rust epidemics are caused by the uredinial stage of *A. psidii* and the strain in New Zealand is the 'pandemic biotype' (Stewart et al., 2018), which is the same as that found in Australia and Hawaii. Signs of infection are pustules (uredinia) containing bright yellow, powdery urediniospores on infected leaves and stems, and dieback of young growing shoots (Fig. 1). In some species it also infects flowers and fruit (Fig. 2). Myrtle rust survives only on living plants and only infects new expanding shoots, buds, flowers and fruits. When warm moist conditions occur with a high spore load and a flush of new growth, myrtle rust can destroy all the growing shoots on highly susceptible plants. It has been reported in Australia that repeated infections over several years have killed mature trees, and species extinction in some natural habitats is reported to be occurring there (Carnegie et al., 2016; Pegg et al., 2017).

Fig. 1 Young, expanding shoots of *Lophomyrtus* with myrtle rust infection causing dieback, showing yellow urediniospores produced from uredinial pustules.

Fig. 2 *Lophomyrtus* with leaves and flower calyces and petals infected by myrtle rust.

When myrtle rust arrived in New Zealand, little was known about the impact it would have on the 27 native and more than 100 exotic Myrtaceae species but, from worst-case reports overseas, it was feared it could be devastating (MPI, 2017 a,b).

This article reviews information available since the pathogen was first found in New Zealand to summarise the impacts of the disease to date. It includes recent information presented at the Myrtle Rust Science Symposium, 'Ngā Taonga', held in Auckland on 9–10th September 2019, where research funded by the Ministry for Primary Industries (MPI) between October 2017 and June 2019 in the programmes MPI 18607 and MPI 18608, as well as the MBIE Catalyst Programme C11X1607, was summarised.

Surveillance of spread in New Zealand

From May 2017, MPI conducted an incursion response under the Biosecurity Act 1993 and in conjunction with the Department of Conservation (DOC) and AsureQuality, surveyed Myrtaceae across natural and urban areas of New Zealand. During the surveillance operation, public stakeholder updates by MPI summarised where and when myrtle rust was detected and the host species affected. Since arriving, *A. psidii* has been detected in 12 mainland regions (Table 1), which cover most of the North Island (except southern Gisborne, Hawke's Bay and Wairarapa) and, in the South Island, Tasman, Marlborough and West Coast (Fig. 3). In April 2018 the incursion response officially transitioned to long-term management and the frequency of surveillance updates then decreased. In August 2018, MPI surveillance ended and since that time new information about myrtle rust spread has been limited and has come from notifications by interested parties, including use of a smartphone app (Myrtle Rust Reporter), and the iNaturalist NZ – Mātaki Taiao website (https://inaturalist.nz).

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Table 1 The time course of first myrtle rust detections in 13 New Zealand regions since the first report on Raoul Island in the Kermadec Group in April 2017. Several months intervened between the detections in the fifth and sixth, the seventh and eighth, and the 12th and 13th regions (horizontal lines).

Sequence	Region	Date
1	Kermadecs	04-Apr-17
2	Northland	03-May-17
3	Taranaki	17-May-17
4	Waikato	21-May-17
5	Bay of Plenty	12-Jun-17
6	Auckland	21-Nov-17
7	Wellington	28-Nov-17
8	Manawatū	19-Mar-18
9	Tasman	04-Apr-18
10	Gisborne	13-Apr-18
11	Coromandel	20-Apr-18
12	Marlborough	30-May-18
13	West Coast	09-May-19

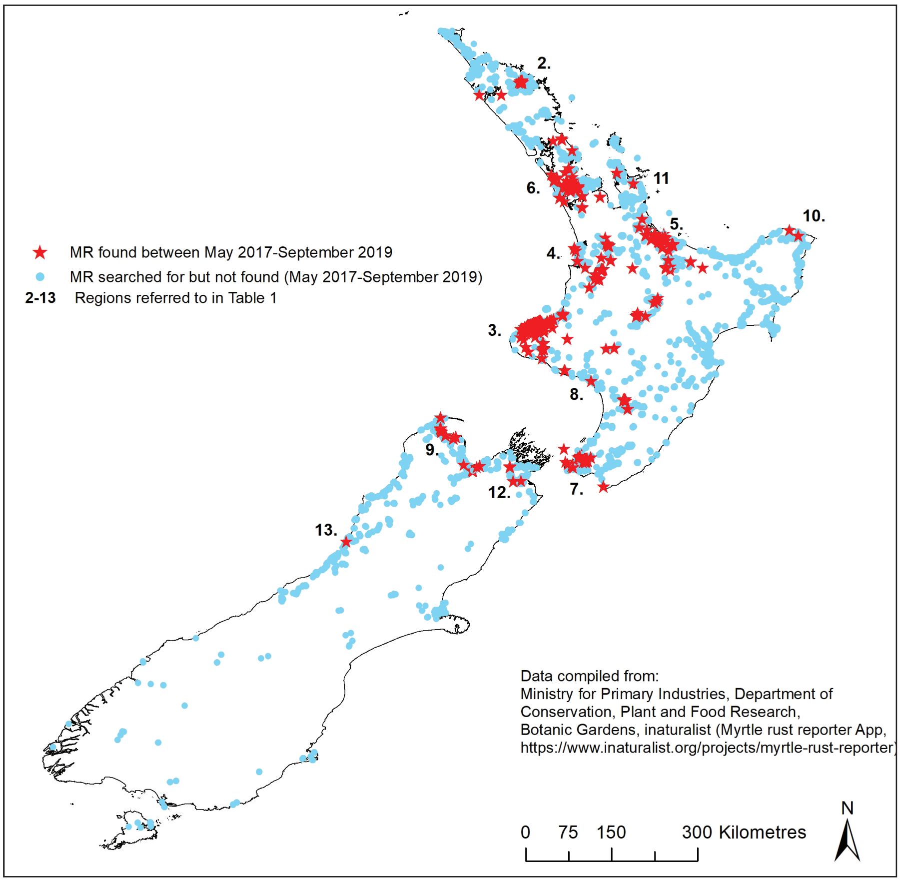

Fig. 3 Myrtle rust (MR) surveillance map, showing New Zealand locations where Myrtaceae plants have been found infected by *Austropuccinia psidii* since May 2017 (red stars) and where inspected plants were free of infection (blue dots). Most of this information came from Ministry for Primary Industries surveillance data collected prior to August 2018.

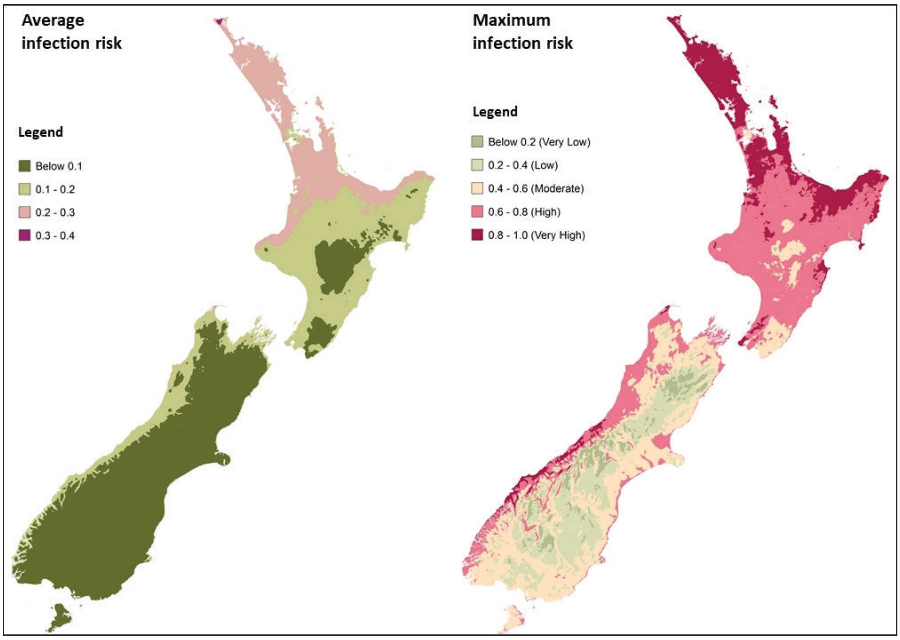

Fig. 4 Geographic distribution of *Austropuccinia psidii* infection risk predicted by the Myrtle Rust Process Model, showing average annual risk (left) and maximum risk (right), which occurs in summer or autumn. Maps were generated using virtual weather data supplied by the National Institute of Water and Atmospheric Research (reproduced from Beresford et al. 2018).

Climatic suitability and seasonal disease cycle

The origin of *A. psidii* is from tropical regions and little was known initially about how it would develop in New Zealand's temperate climate. A climatic risk model (the Myrtle Rust Process Model) was developed in 2017 and used to analyse patterns of regional myrtle rust infection risk (Beresford et al., 2018). The greatest risk occurs in the northern half of the North Island (excluding the Auckland isthmus) and in north-west Tasman (Fig. 4). Intermediate risk occurs in the Auckland isthmus, in North Island areas south of a line between Cape Egmont and East Cape, and in coastal Marlborough, Tasman and West Coast. Lowest risk occurs in eastern and southern parts of the South Island and at higher elevations. During summer and autumn, when *A. psidii* is most active, periods of high to very high infection risk (maximum risk in Fig. 4) can occur over a wide area. This suggests that the pathogen may eventually establish in most regions, although its impact in cooler areas may be restricted because of the limited seasonal period suitable for its development. The Myrtle Rust Process Model has also been used as a disease management tool to monitor short-term periods of myrtle rust activity and this information has been used by MPI, DOC and other stakeholders to plan surveillance and disease management activities.

Myrtle rust has an annual cycle of development in New Zealand. Seasonal epidemics start in late spring or early summer (November or December), with disease severity increasing rapidly during December and January. Depending on summer rainfall, infection may slow during dry hot weather, but increases again to a yearly maximum in early autumn (March to April). With cooling temperatures from mid-autumn to early winter (May to June), conditions suitable for infection become infrequent, although new disease symptoms from initially asymptomatic infections may still appear. The yearly minimum activity is from late winter to early spring (July to September), when temperatures are too cold for infection and few spores are available. There may be short periods during winter of warmer weather suitable for infection, particularly further north.

Recent research reported by Robert Beresford (Plant & Food Research, Auckland) at the 2019 Myrtle Rust Symposium provides new information on the overwintering of *A. psidii* in New Zealand's climate. The latent period (time from infection to new spores) becomes very long (>40 days) at average daily temperatures below 10°C. The fungus can survive symptomless inside the plant during the extended latent phase and can subsequently form uredinia and spores when temperatures rise again. This means that overwintering can occur as a latent infection and uredinial reinfection during winter is not necessary for survival between seasons. *A. psidii* is believed to be capable of completing a sexual cycle on single myrtaceous hosts, via teliospore production and basidiospore infection (McTaggart et al., 2018). However, the importance of the sexual cycle in seasonal epidemic development is not yet understood and teliospores have only infrequently been found in New Zealand. Other new information is that some hosts (e.g., *Lophomyrtus* spp., including ramarama) can continue to grow and produce new shoots at temperatures below 10°C, which is too cold for *A. psidii* infection and latent development. The ability to produce shoots when conditions are too cold for rust activity could help plants to survive myrtle rust attack.

Susceptibility of native Myrtaceae

There was significant concern when *A. psidii* first arrived about the negative effect it may have on mānuka (*Leptospermum scoparium*) because of the high-value mānuka honey industry and because of the ecological importance of this widely distributed native species. There was also concern about impacts on pōhutukawa (*Metrosideros excelsa*), stemming from reports of the apparently high susceptibility of the closely related ōhi'a lehua (*Metrosideros polymorpha*) in Hawaii and the Kermadec pōhutukawa (*Metrosideros kermadecensis*) on Raoul Island (MPI, 2017c). It became clear early in the incursion that ramarama (*Lophomyrtus bullata*) and hybrids with rōhutu (*Lophomyrtus obcordata*) were very susceptible because of the relatively high number of ramarama and hybrid plants that were found to be infected during MPI surveillance (MPI, 2018a). The initial lack of objective information about the susceptibility of our native Myrtaceae made it impossible to predict the impacts that myrtle rust might have.

New research on the susceptibility of key New Zealand native myrtles was reported by Grant Smith (Plant & Food Research, Lincoln) at the 2019 Myrtle Rust Science Symposium. Seedlings grown from seed collected from mother plants of mānuka, kānuka (rawirinui; *Kunzea robusta*), rawiri mānuka (*Kunzea linearis*) pōhutukawa, ramarama and rōhutu from different locales in New Zealand were tested to determine whether resistance genes to *A. psidii* are present in these species. The seedlings were tested in Brisbane, Australia, by Geoff Pegg and Louise Shuey of the Queensland Department of Agriculture and Fisheries, by inoculating with the *A. psidii* pandemic biotype under controlled conditions and then recording the phenotypic host reaction. The results showed that there was myrtle rust resistance in some seedlings of mānuka, kānuka and rawiri mānuka. Interestingly, these species also showed significant stem infection. However, the resistance in these species was generally limited to only a few of the seedlings from a mother plant. For pōhutukawa, there was almost no resistance to *A. psidii* infection, with only one seedling classified as resistant. For the two *Lophomyrtus* spp., no resistant plants were found.

The resistance screening test used a controlled environment that maximises the opportunity for the pathogen to infect the plants and cause disease. The results to date suggest that the national mānuka, kānuka and rawiri mānuka populations are quite susceptible to myrtle rust and that pōhutukawa, ramarama and rōhutu are all very susceptible. However, these test results only provide information on the host's genetic resistance or susceptibility and need to be correlated with disease severity in the field because inoculum load, environmental conditions and host density can influence how myrtle rust develops in nature. It is possible, for example, that as the spore load of *A. psidii* increases in the New Zealand environment over time, plants that currently appear resistant in the field could become more severely affected. Furthermore, the definitions of resistance and susceptibility used in the inoculation tests may have classified some plants as susceptible when they actually have a small degree of resistance that, in the field, may limit disease development. The screening work is ongoing and host material tested so far may not represent the full range of genetic diversity of these species. It is possible that other resistant genotypes may exist in the host populations that were not represented in the samples screened to date.

MPI and DOC surveillance data collected during the incursion response, which indicated cumulative prevalence (the percentage of plants examined that were positive for *A. psidii* infection), may also give an indication of the relative field susceptibility of Myrtaceae species (Table 2). However, caution is needed when extrapolating surveillance data, as there may be sampling bias in the survey procedure and underestimation of prevalence because of the initially limited distribution of the pathogen. Mānuka showed only 0.02% prevalence on nearly 20,000 mānuka plants examined, which was the second-lowest prevalence out of the 11 taxa recorded with myrtle rust. This result is consistent with current information that mānuka is seldom observed with myrtle rust in the field. The reason why these field observations are different from the inoculation test results is uncertain and may include the points raised above. For pōhutukawa, myrtle rust is recorded from time to time in nurseries and on young trees, but there have been no alarming reports of it causing serious damage to the coastal pōhutukawa forests in the northern North Island. MPI surveillance data for *Metrosideros* spp. (predominantly pōhutukawa) during the first 15 months of the incursion response, showed 0.93% prevalence on more than 44,000 plants examined,

Table 2 Numbers of plants of various Myrtaceae species confirmed positive for *Austropuccinia psidii* infection during New Zealand myrtle rust surveillance from May 2017 to September 2018. Data from MPI (2018b).

Host common name (MPI database)	Botanical name (MPI database)	No. confirmed positives	No. plants examined	Percentage prevalence
Ramarama	*Lophomyrtus* spp.	658	14,220	4.63
Monkey apple	*Syzygium* spp.	160	10,183	1.57
Willow myrtle	*Agonis flexuosa*	7	504	1.39
Australian tea tree	*Thryptomene* spp.	1	82	1.22
Pōhutukawa, northern rātā, southern rātā	*Metrosideros* spp.	418	44,718	0.93
Australian water gum	*Tristaniopsis* spp.	1	340	0.29
Bottle brush	*Callistemon* spp.	21	12,232	0.17
Chilean guava	*Ugni molinae*	2	1,236	0.16
Feijoa	*Acca sellowiana*	5	18,216	0.03
Mānuka	*Leptospermum scoparium*	3	19,808	0.02
Gum	*Eucalyptus* spp.	1	6,961	0.01
Other		0	16,047	0.00
	Overall	1,277	144,547	0.87

suggesting that there is some degree of field susceptibility, whilst again the inoculation test results suggested high susceptibility. For ramarama, field observations have indicated a high degree of susceptibility. In the MPI surveillance statistics, myrtle rust prevalence on ramarama and hybrids was 4.63% on about 14,000 plants examined, the highest percentage of all species, and five times the prevalence on pōhutukawa. For ramarama, both the surveillance information and field observations agree with the inoculation test results that ramarama is highly susceptible to myrtle rust.

Impact of myrtle rust on *Lophomyrtus* spp.

The only results from structured field monitoring of myrtle rust impacts on native Myrtaceae to date have been collected in the Rotorua Lakes District by Roanne Sutherland and Julia Soewarto of Scion, Rotorua, and Beccy Ganley of Plant & Food Research, Te Puke; these results were presented at the 2019 Myrtle Rust Science Symposium (Fig. 5). The Myrtaceae monitored at the site included ramarama, rōhutu, natural hybrids between these two species, climbing rātā (*Metrosideros* spp.) and mānuka. The ramarama, rōhutu and hybrids have been severely affected by *A. psidii*, with the majority of new flush stems and leaves becoming infected, leading to shoot death. Developing fruits were also infected, causing them to drop prematurely, and all the seedlings monitored at the site have become infected, with the majority dying in the first season of infection. Trees and seedlings that are repeatedly and heavily infected are expected to die eventually and this, combined with loss of viable seed because of fruit infection, means natural regeneration of *Lophomyrtus* spp. will be severely affected and localised extinction is probable. Rātā and mānuka were also infected but at a very low severity compared with the *Lophomyrtus* spp. Monitoring also showed that severely infected plants had decreased insect activity and diversity, highlighting the multi-trophic ecosystem risk that this invasive disease poses.

Fig. 5 Roanne Sutherland and Julia Soewarto of Scion monitoring *Lophomyrtus* seedlings for *Austropuccinia psidii* in December 2018.

Discussion of myrtle rust impacts to date

The threat that myrtle rust could cause economic, ecological or social harm through damage to native and exotic Myrtaceae in New Zealand led to early government investment. This included preparedness prior to its arrival, the incursion response subsequent to its arrival, and scientific research to understand, predict and manage the threat. Such costs are to be expected for any harmful invasive organism and it would be a good outcome for New Zealand if this was the extent of the impact from myrtle rust. However, indications are that there will be ongoing and possibly increasing effects.

In 2017 MPI commissioned a report by the New Zealand Institute of Economic Research (Ballingall and Pambudi, 2017), which predicted myrtle rust would have short term national economic impacts that were "very small on an economywide basis, though could inflict more significant financial pain on individual nurseries, feijoa and guava growers, and Mānuka honey producers." Long term impacts on GDP were identified based on assumptions about a drop in mānuka honey production coupled with strong growth in the size of that industry. Feijoa and guava industry impacts were not expected to affect the macroeconomy, but nursery production was expected to suffer ongoing effects. Indications so far suggest that severe impacts on the mānuka honey industry have not materialised, although there is still concern about an increasing effect as the pathogen becomes more established and prevalent in the New Zealand environment.

For susceptible Myrtaceae species worldwide, the most severe direct impacts of myrtle rust are on young plants in nurseries, on newly transplanted trees, and where rapid regrowth is occurring (Tommerup et al., 2003; Makinson, 2018). The high vulnerability of young plants may be due to the high proportion of young, susceptible shoots in the leaf canopy combined with sheltered conditions close to the ground that favour long wet periods suitable for infection. The limited carbohydrate reserves in young trees means that shoot death from myrtle rust infection will cause poor thrift and possibly tree death.

The New Zealand nursery industry, which produces young and potentially vulnerable plants has been impacted by myrtle rust. This has been less from direct damage caused by the pathogen and more from the procedures and actions required under the Biosecurity Act to limit the spread of myrtle rust. The first myrtle rust detections in Northland, Taranaki and Te Kuiti during May 2017 were all in plant nurseries. In total, 13 nurseries were confirmed with myrtle rust up to the time the MPI surveillance operation ended in August 2018 (MPI, 2018b). The Biosecurity Act required infected plants to be destroyed and prevented the movement of plants from controlled areas, although the impact of these procedures on nursery businesses was subsequently buffered through a compensation process.

Myrtle rust is now under long-term biosecurity management and because it is classified as an unwanted organism it is an offence to spread infectious material deliberately. For nursery managers, the dread of *A. psidii* detection on any myrtles they may stock has led them to avoid myrtaceous plants. Auckland Council (2019) also currently recommends replacing myrtle species with non-myrtaceous species in restorative plantings. However, long-term continuation of this approach could alter the biodiversity balance in large plantings with unknown ecological consequences. Biosecurity New Zealand (a business unit of MPI) points out that, for restoration plantings, “Some species may have high levels of natural resistance or tolerance to myrtle rust” and “It is generally considered that prohibiting or avoiding the planting of all native myrtle species to try and avoid myrtle rust infection is not the best approach” (Biosecurity New Zealand, 2018).

The greatest pending ecological impact of myrtle rust on native Myrtaceae currently appears to be the threat to *Lophomyrtus* spp. It may be that these species are able to produce new shoots during winter when temperatures are too cold for rust development, allowing plants a period of growth free from pathogen attack. However, during the summer flowering and fruiting season conditions are often highly suitable for rust development, so reproduction by these species could be severely compromised. There are still many unknowns about the risk to other New Zealand Myrtaceae species, including the rarer ones, although so far there appears to be no evidence indicating that swamp maire (*Syzygium maire*) and Bartlett’s rātā (*Metrosideros bartlettii*) have been affected by myrtle rust.

Little research effort has been expended on the impacts of myrtle rust on exotic myrtles in New Zealand. Fortunately, feijoa (*Acca sellowiana*) and gum trees (*Eucalyptus* spp.) appear to be resistant, but for another Australian native, the lilly pillys (*Syzygium australe*, *S. floribundum*, *S. paniculatum*, and *S. smithii*) some horticultural selections are highly susceptible, while others are resistant. Lilly pilly is a popular garden and hedge plant in northern New Zealand and is used for shelter around rural dwellings and horticultural crops. However, *Syzygium australe* and *S. smithii* are regarded as pest plants because of their spread via bird-carried seeds and their ability to out-grow New Zealand native plants. Where susceptible lilly pillys are used for hedges, shoot death from myrtle rust attack degrades the tree canopy, making them unfit-for-purpose. The use of alternative hedging species would be desirable, to avoid both myrtle rust attack and the use of invasive plant species.

Myrtle rust is likely to have ongoing economic, ecological and social impacts in New Zealand, as it has in Australia, and the extent of the impacts on New Zealand’s flora is likely to take some years to become fully apparent. It is important to accurately predict impacts in advance, and the most important pieces of information needed for this in New Zealand are: 1) relative field susceptibility of individual Myrtaceae species, 2) surveillance data on where *A. psidii* has spread to, and 3) effects of regional differences in climate on seasonal myrtle rust epidemics. By quantifying these components and modelling their interactions it should be possible to predict whether myrtle rust will cause particular host species in specific areas to go into decline or whether it will have only a minor impact.

Further research funding for myrtle rust in New Zealand is being made available by the government. The Myrtle Rust Strategic Science Advisory Group is encouraging scientists, research teams and research organisations to collaborate and co-design research proposals and programmes based on the Myrtle Rust Science Plan priorities. Ongoing research includes the ‘Beyond Myrtle Rust’ programme managed by Manaaki Whenua – Landcare Research. The Ngā Rākau Taketake – Saving our Iconic Trees programme, administered by New Zealand’s Biological Heritage Ngā Koiora Tuku Iko, is also allocating funding to accelerate myrtle rust research by government agencies, councils, research providers, Māori and interest groups.

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