Biosecurity New Zealand

Tiakitanga Pūtaiao Aotearoa

MPI 18607 Project Report (3.1- 2 & 3.1 -3)

Improved myrtle rust surveillance

Biosecurity New Zealand Technical Paper No: 2019/21

Prepared for the Ministry for Primary Industries
By Beccy Ganley[2], Julia Soewarto[1], Roanne Sutherland[1], Karyn Froud[3], Alby Marsh[2], Ellen-Mae Leonardo[1], Grant Pearse[1]

[1]Scion, New Zealand Forest Research Institute Limited
[2]New Zealand Institute for Plant and Food Research Limited
[3]Biosecurity Research Ltd.

ISBN No: 978-0-9951272-5-8
ISSN No: 2624-0203

July 2019

New Zealand Government

Ministry for Primary Industries
Manatū Ahu Matua

Disclaimer

While every effort has been made to ensure the information in this publication is accurate, the Ministry for Primary Industries does not accept any responsibility or liability for error of fact, omission, interpretation or opinion that may be present, nor for the consequences of any decisions based on this information.

Requests for further copies should be directed to:

Publications Logistics Officer
Ministry for Primary Industries
PO Box 2526
WELLINGTON 6140

Email: brand@mpi.govt.nz
Telephone: 0800 00 83 33
Facsimile: 04-894 0300

This publication is also available on the Ministry for Primary Industries website at http://www.mpi.govt.nz/news-and-resources/publications/

Executive summary

The problem

Austropuccinia psidii, the causal agent of myrtle rust disease, was first identified on mainland Aotearoa New Zealand in May 2017. This highly invasive fungal threatens the health and survival of native and exotic Myrtaceae in New Zealand. The impact of myrtle rust on susceptible hosts in New Zealand is unknown but overseas experiences have shown it can infect and kill seedlings through to large trees, and localised extinction of highly susceptible species has occurred.

This project

The objective of this project was to develop a framework for long-term surveillance and monitoring of myrtle rust in New Zealand. Collecting and analysing information on the impact of this disease on native and exotic Myrtaceae in New Zealand is essential to inform appropriate decision-making in the future.

The aims of this project were to (i) develop ground-based tools to assist with the long-term surveillance and monitoring of myrtle rust in New Zealand, (ii) use these ground-based tools to monitor the incidence and progression of myrtle rust on native species under natural conditions, and (iii) investigate the potential of remote sensing technologies to provide alternative methods to monitor difficult to access material or extensive forest areas.

Key results

A long-term monitoring form and a myrtle rust causal diagram were developed using a co-innovation approach to ensure both included factors identified by scientists, mana whenua, communities, industries and organisations that have a long-term interest in myrtle rust.

Monitoring of myrtle rust in a naturally occurring stand of Myrtaceae showed this disease severely impacted rōhutu/ramarama. Infection was also observed on mānuka and climbing rātā in the stand. The level of infection in rōhutu/ramarama was high, with up to 90-100% of new flush infected and subsequently dying. All seedlings monitored became infected and the majority died or are expected to die in the near future. Fruit in trees with infections also became infected and prematurely dropped.

Remote sensing methods using UAVs were able to provide useful data for both long-term site monitoring and as an adjunct to traditional ground-based assessments. This included high-resolution remotely sensed imagery that could be used to detect symptoms in canopy that is inaccessible from the ground, as well as the ability to take repeated captures to determine long-term impacts on tree health, species composition, and larger-scale ecosystem impacts across larger areas (~30 ha).

Implications of results for the client

The implication of myrtle rust on the survival of rōhutu/ramarama is highly concerning. In Australia, localised extinction of plant species has occurred when new flush, seedlings and flowers/seed are repeatedly infected. This level of infection is comparable to what is being observed in infected rōhutu/ramarama, hence localised extinction of this species is probable. How myrtle rust infection, dieback or death of host Myrtaceae plants will impact on invertebrates and their food web networks is unknown.

This study showed that remote sensing methods using UAVs can provide useful data for both long-term site monitoring and as an adjunct to traditional ground-based assessments. Long-term monitoring can benefit from repeated captures of RGB, multispectral, and 3D LiDAR data to derive information on tree health, species composition, and larger-scale ecosystem impacts across larger areas (~30 ha). Successful application of this approach would require regular data acquisitions (*e.g.* annual) for a long period of time (*e.g.* 5+ years). Coupled with ground validation, it is likely that these data would facilitate robust evaluation of the long-term ecosystem impacts of myrtle rust over larger areas.

For ground-based surveillance, the visual inspection of myrtle rust infected plants can be enhanced with the use of a camera with a zoom lens mounted on a UAV. The limitations of visual inspection such as limited observations of key structures such as shoots, flowers, and fruits in the upper canopy or lack of surveillance in inaccessible areas could be resolved by capturing high-resolution remotely sensed imagery and video for later analysis by plant pathology experts.

Further work

Recommendations for future research include:

- Continuing monitoring of the impact of myrtle rust on species of Myrtaceae within the sites reported this study need to be continued to determine the long-term consequences of this disease on individual plant and species survival. This includes determining if infected trees die, and the time between first infection and plant death for susceptible species.
- Extending ground-based long-term monitoring in different Myrtcaeae ecosystems across different climatic regions of New Zealand to assess the impacts of this disease to New Zealand's Myrtaceae. The surveillance form developed in this project should be used for any long-term monitoring initiatives to ensure relevant and consistent data is collected.
- The New Zealand Myrtle Rust Monitoring form needs to be made into an app format so it can be used on hand-held devices, and should be updated to include wider ecological impact factors when that work has been completed. An app format should also include a section where culture indicators can be added and recorded.
- In appropriate areas, ground-based surveillance should be accompanied by annual capture of remotely sensed data to support long-term change detection including larger-scale disease impacts, changes in species composition and compensatory growth.
- The ability for ground-based surveillance programmes to include integration of unmanned aerial vehicles (UAV) technology to provide remote views of inaccessible, upper canopy elements to improve monitoring of myrtle rust impacts should also be considered.
- Establish a shared database so data from nationwide monitoring can be deposited and used to assess impact, and be analysed to inform management decisions.
- Monitor the impact on invertebrates and their food web networks from infection, dieback or death of host Myrtaceae plants infected with myrtle rust in native ecosystems.
- Determine whether seeds from infected fruit are still viable and able to germinate.

The information collected from monitoring is critical to inform conservation priorities and assist in the development of long term management plans.

Appropriate permissions from hapū/iwi, private landowners, regional or district councils or the Department of Conservation need to be obtained to access land or capture images using UAV for monitoring myrtle rust.

Contents

1. Project background

To better understand myrtle rust and limit its impact in New Zealand, the Ministry for Primary Industries commissioned a comprehensive research programme in 2017 with more than 20 projects valued at over $3.7 million. Projects in this programme were completed by June 2019.

The projects covered research in the following themes:

- Theme 1 - Understanding the pathogen, hosts, and environmental influence.
- Theme 2 – Building engagement and social licence: Improved understanding of public perceptions and behaviours to allow better decisions about investment, improved design of pathway control strategies and maintain social license for use of management tools.
- Theme 3 – Te Ao Māori: Greater understanding of Te Ao Māori implications of myrtle rust in order to support more effective investments, and improved use of Mātauranga, specific Māori knowledge, and kaupapa Māori approaches in management regimes.
- Theme 4 – Improving management tools and approaches: Improved diagnostic and surveillance speed, accuracy and cost-effectiveness, supporting eradication efforts and enabling scaling up of surveillance efforts for a given resource. More effective treatment toolkits to avoid emergences of MR resistance to treatments and to enable disease control over increasingly large scales that will lead to reduced or avoided impacts.
- Theme 5 - Evaluating impacts and responses: Improved understanding of environmental, economic, social and cultural, impacts to inform risk assessment and management and to communicate implications to decision/makers and stakeholders.

This report is part of the MPI commissioned research under contract MPI18607 which addressed research questions within Theme 2, 4 and 5.

Text in the report may refer to other research programmes carried out under the respective theme titles.

2. Introduction

Austropuccinia psidii, the causal agent of myrtle rust disease, was first identified on mainland Aotearoa New Zealand in May 2017 (Ho et al. 2019; Guy and Barry 2017). This highly invasive fungal disease is originally native from South and Central America and infects exclusively plants belonging to the Myrtaceae plant family (Coutinho et al. 1998). Since the 2000s, myrtle rust has spread worldwide, causing devastating impacts upon forest ecosystems and severe economic hardship to some nursery industries (Doran et al. 2012; Pegg et al. 2017a). The global host range of myrtle rust comprises at least 450 species from 73 genera (Giblin and Carnegie 2014). Myrtle rust is considered as a global threat for every Myrtaceous-rich region because of its broad and continuous extension within new localities and host species, as well as its ability to adapt to different environmental conditions. *A. psidii* attacks new growing aerial plant tissues and, depending the host species, this can include leaves, stems, flowers and fruits (Glen et al. 2007). Symptoms of myrtle rust infection are characterized by the production of yellow lesions that contain urediniospores. In the most susceptible host species, the pathogen can cause severe defoliation, shoot-tip dieback and eventually plant death after repeating re-infection (Carnegie et al. 2016).

Since its first detection in New Zealand, myrtle rust has become established in several regions across the North Island, the top of the South Island, and recently the West Coast (Beresford et al. 2018). Subsequently, the pathogen has also been identified infecting 24 host species including several native and exotics Myrtaceae. Native host species include the iconic pōhutukawa (*Metrosideros excelsa*), ramarama (*Lophomyrtus bullata*), mānuka (*Leptospermum scoparium*), rātā (*Metrosideros* spp.) and swamp maire (*Syzygium maire*). Currently the impact of myrtle rust on susceptible hosts in New Zealand is unknown but overseas experiences paint a grim picture of what could be expected considering the wide host range of this pathogen and its ability to infect and kill seedlings through to large trees (Carnegie et al. 2016; Fernandez Winzer et al. 2017; Pegg et al. 2017b). Recent studies from Australia have shown that myrtle rust drove population decline and even localised extinction of highly susceptible species within four years of the pathogen being established in a native forest (Carnegie et al. 2016; Pegg et al. 2017b).

Acquiring knowledge and information from the natural field and over a long-time period is crucial to assist the decision making and apply a suitable strategy to mitigate the pathogen impacts. This can allow at-risk species to be targeted, and tools and strategies that can be used to combat the disease to be implemented appropriately. The purpose of this project was to (i) develop ground-based tools to assist with the long-term surveillance and monitoring of myrtle rust in New Zealand, (ii) use these ground-based tools to monitor the incidence and progression of myrtle rust on native species under natural conditions, and (iii) investigate the potential of remote sensing technologies to provide alternative methods to monitor difficult to access material or extensive forest areas.

3. Development of ground-based monitoring tools

The aim of this research was to develop tools that could be used for long-term monitoring of myrtle rust across New Zealand by mana whenua, communities, industries and organisations that have a long-term interest in myrtle rust. Although there is considerable international information available on surveillance and monitoring approaches to myrtle rust, it was acknowledge that simple transfer of this information into the New Zealand context would not be appropriate as it would not be broad enough to cater for the variety of end users in New Zealand who would be likely to undertake long-term monitoring, nor would it account for the unique relationship mana whenua and New Zealander's have with native trees and what this could add to any monitoring system established in New Zealand.

In this report, surveillance refers to one off inspections to determine absence or presence of myrtle rust whereas monitoring is repeat visits to the same tree or stands of trees to determine changes in disease severity and tree health over time.

3.1 A co-innovation approach to identify factors for long-term monitoring of myrtle rust

To engage with communities, industries and organisations that have a long-term interest in myrtle rust, a series of hui were held in three locations, Kerikeri, New Plymouth and Te Puke, in July 2018. These three regions represent the first incursion locations in New Zealand and all three were subject to incursion response measures, which included surveillance and tree removal. The hui were attended by a variety of stakeholders including hapu, iwi, community, industry, scientists, councils and governmental agencies. Factors that could contribute to disease spread or management in a New Zealand context were discussed and recorded (Figure 2.1.1), as well as those that were considered important or suitable for field measurement. This approach allowed us to identify factors that were New Zealand-specific and combine these with internationally available methods for myrtle rust surveillance.

Figure 2.1.1 Example of ideas recorded from hui participants

Following the hui, researchers categorised the responses recorded. Those identifying potential factors that may be associated with myrtle rust were used to develop a myrtle rust causal diagram, such as has been developed previously for Psa (Froud et al. 2017). The causal diagram, along with the raw data was shared with workshop participants for further feedback and transparency. Factors considered important or suitable for field measurement were used to develop a surveillance/monitoring form. Any other responses were feed through to the wider myrtle rust research team (other research themes) and the Ministry for Primary Industries (MPI) (Table 2.1.1).

Table 2.1.1. Individual statements contributed by hui participants at each location separated into categories they aligned most strongly with.

Output category	New Plymouth	Te Puke	Kerikeri	Total
1 Other Research Themes	27	30	53	110
2 Research Needs	31	41	26	98

3 Management of Disease	4	16	13	33
4 Surveillance Management	1	21	18	40
5 Survey Forms	79	57	51	187
6 Other Data Sources	17	22	19	58
7 Implementation/ MPI Communication	0	14	13	27
TOTAL per region	159	201	193	553

The hui were well attended across the three regions and had a wide range of participants representing a variety of different end users. A key message at all three hui was that future surveillance and monitoring data collected using the form developed in this project should be freely available to end users to evaluate and analyse, based on a policy that it would be freely given. Participants at the hui, in particular mana whenua, were clear that these hui should not be the only contact the researchers had with participants and that as part of developing an ongoing relationship, the organisers needed to return and share the results. In response to this request, a series of hui in all three locations were held in April 2019 and an interim summary of the research findings was presented.

3.2 Development of a myrtle rust long-term monitoring form

A long-term monitoring form for myrtle rust was developed using the information obtained at the hui, reviewing current forms that were designed for surveillance during the incursion response and subsequent transition and combining this with international methods for determining disease symptoms and severity. The objective was the form should be useable by a wide variety of groups who have some level of knowledge of myrtle rust symptoms and who would be monitoring symptoms on specific host trees or stands of trees over time. It was not designed for general public to report myrtle rust, the Myrtle Rust Reporter app (https://inaturalist.nz/projects/myrtle-rust-reporter) serves this purpose. The form was developed with the intention that it would be developed into an app that could be used on a device, and that a centralised database for monitoring data would be established, both of which were out of scope for this project.

A draft form was developed, and field tested with researchers, mana whenua and DOC (Figure 2.1.2). Based on the feedback, the draft form was revised. These were particularly informative for understanding the level and type of pictures and descriptions of plant parts required. The final version (Appendix 1) of the monitoring form has seven sections. The need for a section on cultural indicators was identified at the hui but as these can be hapu-specific or may only apply to certain rōhe and thus, may not be applicable across New Zealand, the decision was not to include this in the form. This does not preclude hapu, iwi or other groups from developing their own cultural indicator sections to include when undertaking myrtle rust monitoring.

Figure 2.1.2 Testing the myrtle rust monitoring form

The data fields used by the Department of Conservation (DOC) and AsureQuality (AQ) / were mapped against developed data fields (Appendix 2) and allows future re-classification of response data to match the case definition.

The form is available electronically or in hard copy, along with a data entry spreadsheet, but could be developed into an app. A centralised database for receiving information from end users who are monitoring plants would allow great visability in the impacts this disease is having in native and urban environments. It is also recommended that wider ecological impact factors be included in a future update to the form when that work has been completed.

The myrtle rust case definition, unit of interest, monitoring form and associated datasheet gives the foundation that Iwi, hapū, community and governmental agencies and researchers can use to develop a consistent monitoring system across their managed lands, regions and nationally.

4. Long-term monitoring of myrtle rust in native forest

Pests and pathogens that can cause high mortality rates in their host species have a profound impact on forest structure and function (Liebhold et al. 1995; Roy et al. 2014). Myrtle rust is by definition an obligate biotrophic pathogen, i.e., it colonizes and extract nutrients only from living tissues and establishes long-term relationship with its host to complete its life cycle (Glen et al. 2007; Häffner et al. 2015). The long-term impacts on the host regeneration and ecosystems services, as well as the rate by which this pathogen can kill its host remain poorly understood. To date, only Australia investigated the long-term impacts of myrtle rust in their native environment. They reported gradual crown loss and tree mortality from the native ecosystem occurring less than four years after myrtle rust established in a forest (Carnegie et al. 2016). Changes of the plant community structure already started to occur in some areas where *A. psidii* had killed the most susceptible host species (Pegg et al. 2017a). The perceived threat to the New Zealand biodiversity is now being realised. Long-term monitoring of myrtle rust in the native environment is essential to (i) measure the impact on host survival and (ii) provide a framework for conservation and disease management including setting priorities to the most susceptible population species or environments. The objective of this study was to monitor the impacts of myrtle rust on native Myrtaceae species in native forest in New Zealand.

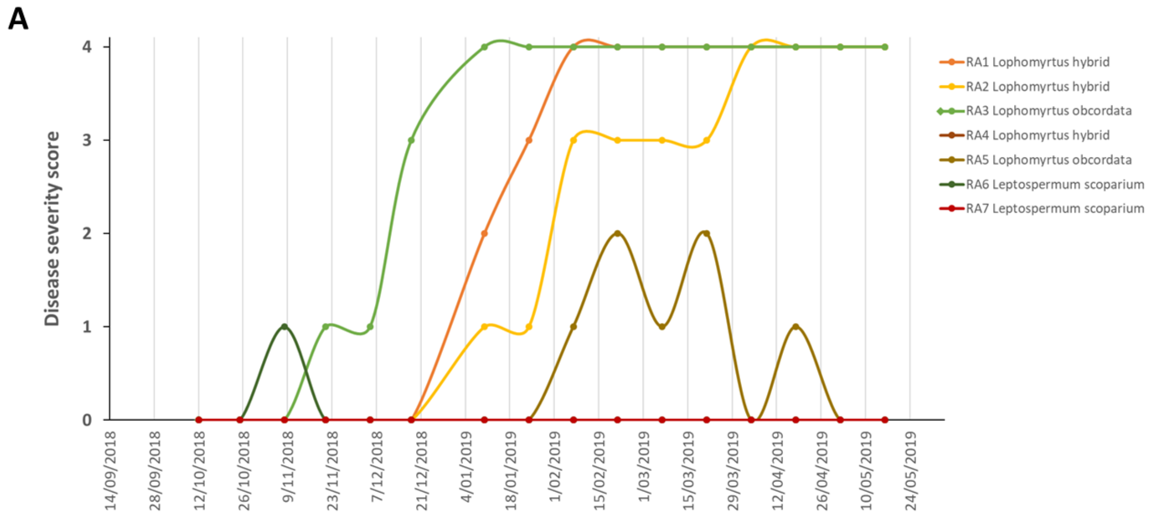
4.1 Disease progression in mature trees in an infected stand

Since October 2018 a site with infected rōhutu/ramarama hybrid trees in the Bay of Plenty has been monitored fortnightly to record the impact of myrtle rust on the host trees, seed and seedlings. Permission to monitor and sample from these sites was obtained from local hapū, private land owner and the Department of Conservation. The site includes a large stand comprising rōhutu/ramarama hybrids (*Lophomyrtus bullata x L. obcordata*), climbing rātā (*Metrosideros fulgans, M. diffusa* and *M. perforata)* and mānuka (*Leptospermum scoparium*). The first report of myrtle symptoms from this site was in April 2018 on rōhutu/ramarama hybrid trees (J. Bond, Pers. Comm).

Five rōhutu/ramarama hybrid trees (RA1-5) and two mānuka (RA6-7) were selected and tagged for long term monitoring. Two of the selected rōhutu/ramarama hybrids had myrtle rust symptoms in April 2018, but the other trees selected had no symptom of myrtle rust and were considered ‘myrtle rust-free’. In early October 2018, when intensive monitoring was started, there were no signs of new myrtle rust infection at the site.

The first sign of new myrtle rust infection (e.g. presence of fresh yellow pustules) was observed early November 2018 on one of the mānuka plants (Figure 3.1.1). The disease severity on the infected mānuka plant was low and the infection did not progress on this tree or any other surrounding mānuka trees or seedlings.

Figure 3.1.1 Time series plots for disease severity scores for five *Lophomyrtus* spp (rōhutu/ramarama) and two *Leptospermum scoparium* (mānuka) plants monitored in a myrtle rust infected site from 14 November 2018 – 24 May 2019.



Tree phenology on the rōhutu/ramarama hybrids were assessed every two weeks (Fig 3.1.2). The first flower bud was recorded in November 2018 and extended through January. Fruiting started in January and on the last monitoring in June 2019 developing and ripe fruit were still present on the trees. Production of new flush leaves and stems was not regular over the monitored period. By the end of November, myrtle rust infection was detected on one of the rōhutu/ramarama hybrids and progressively extend to the other monitored rōhutu/ramarama trees. By early February 2019, four of the monitored rōhutu/ramarama trees were infected by myrtle rust (Figure 3.1.1).

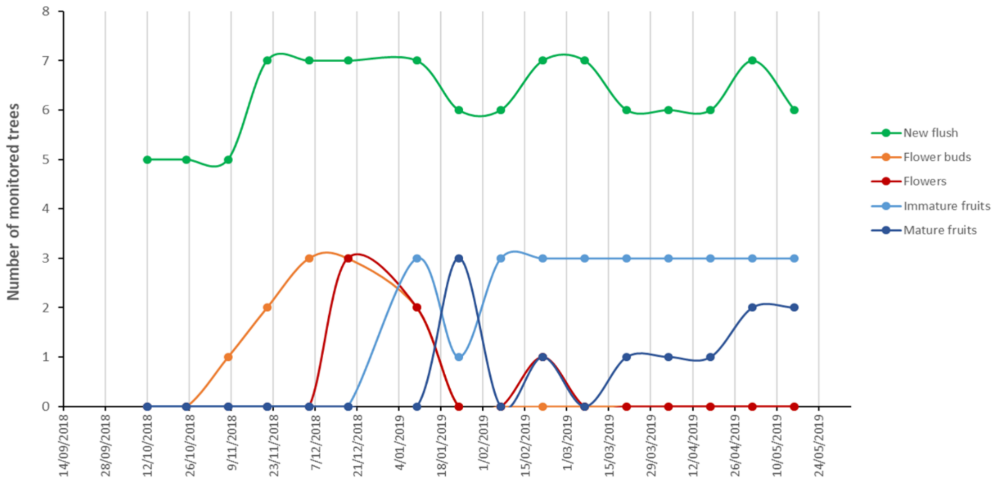


Figure 3.1.2 Time series plot from October 2018 to May 2019 for tree phenology of the presence of new flush, flower buds, flowers, immature fruits and mature fruits on *Lophomyrtus* spp (rōhutu/ramarama) in a myrtle rust infected site.

The disease progression and impacts varied within the rōhutu/ramarama hybrids intesively monitored. Three of the infected trees (RA1, RA2 and RA3) had the highest disease severity scores, with myrtle rust covering almost all the new flush (leaves and stem) and causing important dieback over time (Figures 3.1.1 and 3.1.3A). Repeated infection by myrtle rust of new emerging shoot over the monitoring period was also observed (Figure 3.1.3C). Conversely, one of the infected intensively monitored rōhutu/ramarama (RA5) had minor to moderate infection that only last for two months (Figure 3.1.1). Myrtle rust progressed across the stand of rōhutu/ramarama and extended up to 20 m into the forest. In March 2019, where the disease pressure was at its highest, myrtle rust symptoms were reported developing on new flush of climbing rātā (*Metrosideros diffusa*) in close proximity (within 3 m) to an infected rōhutu/ramarama hybrid.

Figure 3.1.3. Myrtle rust symptoms on *Lophomyrtus* spp (rōhutu/ramarama): (A) stem and leaves covered by yellow urediniospores and with dieback (B) young new leaf covered by urediniospores (C) new emerging shoot infected by urediniospores

Although rōhutu/ramarama flowers were present from November 2018 through to January 2019, no symptoms of myrtle rust were detected on any flowers. However, fruit were severely impacted (Figure 3.1.4). Myrtle rust infection on fruit have been reported in the literature (Pegg et al. 2013; Soewarto et al. 2018), however infection of fruit is not consistent across the host range of *A. psidii* and factors underpinning why some species are more susceptible are unknown. Emergence of immature fruits started in January 2019 and almost immediately all the fruits on two trees (RA2 and RA3) were already infected by rust. This resulted into a prematurely dropping of the fruits before complete ripening. Field observation of infection on fruits revealed the presence of fresh spores within the external surface of the fruit as well as inside the fruit capsule (Figure 3.1.5). Conversely, on RA5 myrtle rust infection only affected between 1-10% of the immature fruits and lasted for a month. This tree was the only infected, monitored rōhutu/ramarama that was able to produce mature and fully developed fruits. Although the myrtle rust disease did not infect the flowers buds or the flowers at this site, the impacts on fruit is concerning for natural regeneration.

In April 2019, the rust was detected for the first time on rātā that is in close proximity (within 3 m) to an infected rōhutu/ramarama hybrid.

Figure 3.1.4 *Lophomyrtus* spp (rōhutu/ramarama) fruit infected by myrtle rust

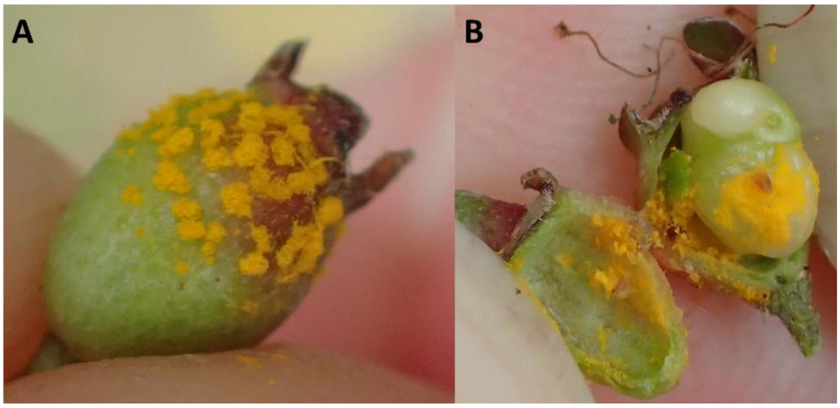


Figure 3.1.5 Infected *Lophomyrtus* spp. (rōhutu/ramarama) fruit, (A) infection on the outside of the fruit, and (B) infection inside the fruit.

5.1 Disease progression in seedlings in an infected stand

Two plots of seedlings (between 5–30 cm in height) under one of the infected rōhutu/ramarama hybrid trees that was monitored for myrtle rust (see section 3.1), were assessed fornightly for myrtle rust symptoms. Combined the plots had over 50 seedlings. In November 2018 there was no myrtle rust on any of the seedlings. The rust was first detected on the seedlings in December 2018 (Figure 3.2.1 and 3.2.2) and by February 2019, more than 90% of the seedlings were infected within the two plots. By March 2019 nearly all of the seedlings were infected and a large number were already dead (Figure 3.2.1). Although seedling mortality could be due to other environmental factors (e.g. hydric stress or other biotic/abiotic stress), evidence of shoot/tips dieback following myrtle rust infection was observed from December onwards (Figure 3.2.2). In May 2019 all of the seedlings still alive had tip dieback and some older leaves that were not infected were still present. There was emerging new flush on a small number of seedlings that was constantly re-infected, but whether these would allow the seedlings to survive over winter is needs to be determined.

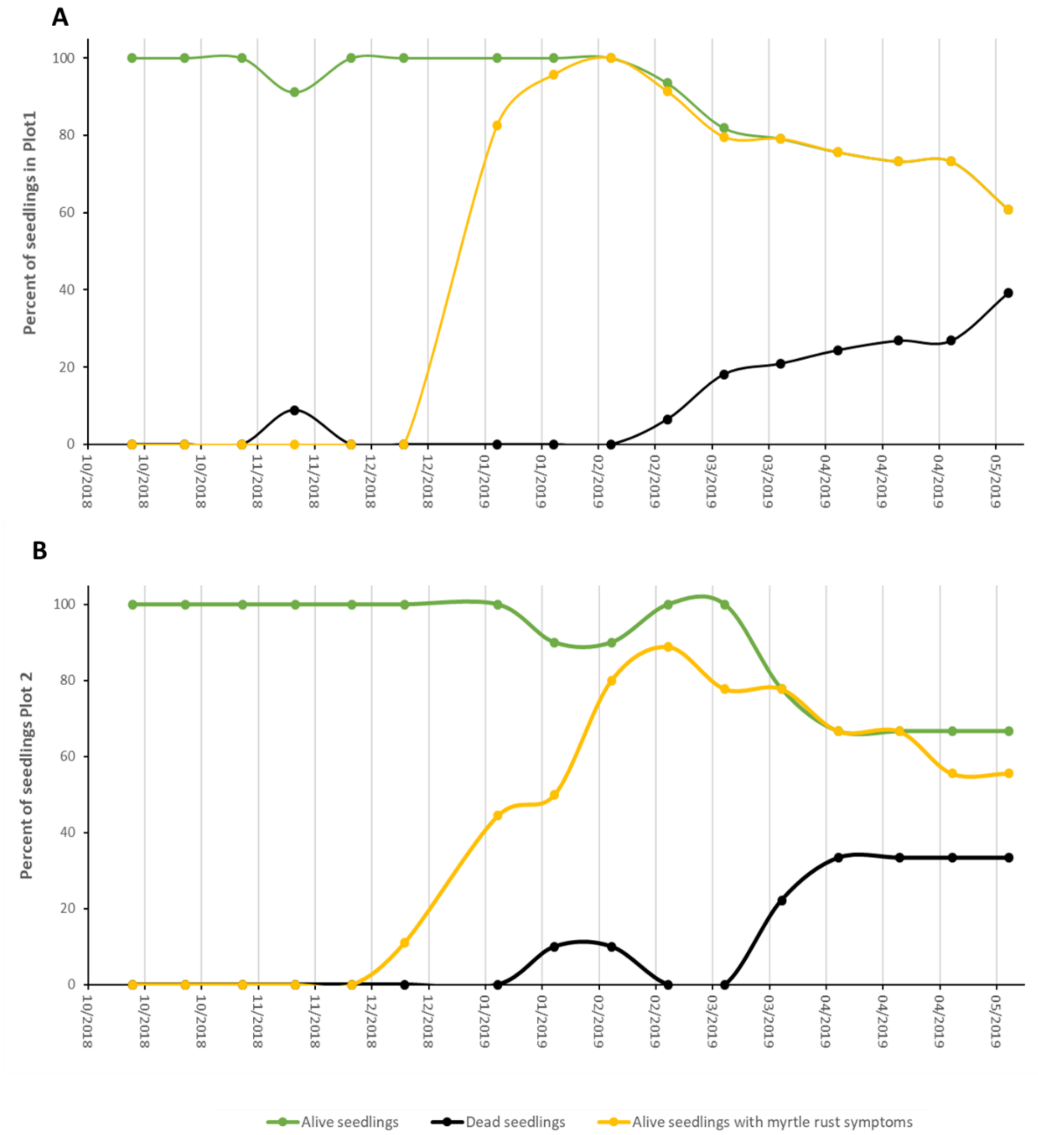


Figure 3.2.1 Time series plot from October 2018 to May 2019 of the percentage of alive, dead and myrtle rust infected *Lophomyrtus* spp (rōhutu/ramarama) seedlings within two plots (A and B) under an infected *Lophomyrtus* spp. (rōhutu/ramarama) tree.

Figure 3.2.2 Infected *Lophomyrtus* spp. (rōhutu/ramarama) seedlings with uredinospores and evidence of dieback caused by myrtle rust

3.2 Insect associations with myrtle rust in infected trees

Observations of invertebrates feeding and living on rōhutu/ramarama were made during myrtle rust monitoring (Figure 3.3.1). When new flush leaves were present and levels of myrtle rust on the trees were low, there were lots of invertebrates recorded. Once the new flush died on the monitored trees, the diversity of invertebrates decreased. During flowering of rōhutu/ramarama an abundance of native honey bees were seen collecting pollen; native bees play an import role of pollination in the native ecosystems (Hart 2016).

The impact of myrtle rust on invertebrate populations and subsequently bird populations is not known but is of concern considering the variation in diversity on these plants over a short period of time. In addition, these insects are likely assisting in the spread of this pathogen both within and between trees

Grazing of rust spores has been documented by invertebrate herbivores and molluscs (Ramsell and Paul 1990) but little is known about the grazing of myrtle rust. Ramsell and Paul (1990) also found that biotrophic pathogens can reduce the palatability of the tissue to vertebrate herbivores. It is currently unknown if insects in New Zealand will modify their feeding behaviour to graze on myrtle rust spores or whether pathogen infection will reduce the palatability of the plant material, and what effect this will have on invertebrate communities or wider food web networks.

Little is known about insect associations with *Lophomyrtus* spp. but if localised extinctions of rōhutu/ramarama should occur in the near future, this is likely to be correlated with loss of associated native invertebrates that are dependent on these species. The cascading effects of this loss to the native ecosystem is also unknown. The New Zealand giant stick insect (*Argosarchus hossidus*) requires a diet of ramarama to complete its life cycle, with newly hatched stick insects requiring essential food plant within 24-48 hours if they are to survive (Salmon 1955). Other species of New Zealand stick insects, such as the species observed on the trees monitored in this study (Figure 3.3.1 B), may have diets that are dependent on native Myrtaceae.

Figure 3.3.1 Invertebrates associated with myrtle rust on infected rōhutu/ramarama hybrids, (A) crab spider with yellow spores on its abdomen, (B) stick insect on infected fruit, (C) an inch worm, *Geometrid* sp. crawls over spores on an infected branch, and (D) moth egg batches laid on infected leaves and stem.

6.1 Monitoring for myrtle rust in an uninfected stand

A second site in the Bay of Plenty with a stand of rōhutu/ramarama hybrid trees was also monitored fortnightly from October 2018. This site is approximately 16 km from the infected site but had no evidence of myrtle rust infection. It was monitored monthly. Permission to monitor and sample from these site was obtained from local hapū and the Department of Conservation. The site included a stand of rōhutu, ramarama and hybrids (*Lophomyrtus bullata x L. obcordata*), climbing rātā (*Metrosideros fulgens* and *M. diffusa*) and *Metrosideros excelsa* (pōhutukawa).

Five rōhutu/ramarama trees (RO1-5) and one pōhutukawa (RO6) were selected and tagged for long term monitoring from early October 2018 to May 2019. During all this period, no sign of myrtle rust infection was detected. Monitored trees produced new flush leaves and stems during the entire time period (Figure 3.4.1). The first flower bud formation was reported in December 2018 on three different trees (RO1, RO5 and RO6) and flowering occurred over January 2019 (Figure 3.4.1). Fruiting started in January and extended until May 2019. Two seedlings plots were established and the survival of seedlings was recorded. Up to 5% and 10% of the seedlings were reported as dead in May 2019 in plot 1 and plot 2 respectively (Figure 3.4.2). As there was no myrtle rust in the site, any seedling death is likely due to natural attrition or environmental factors.

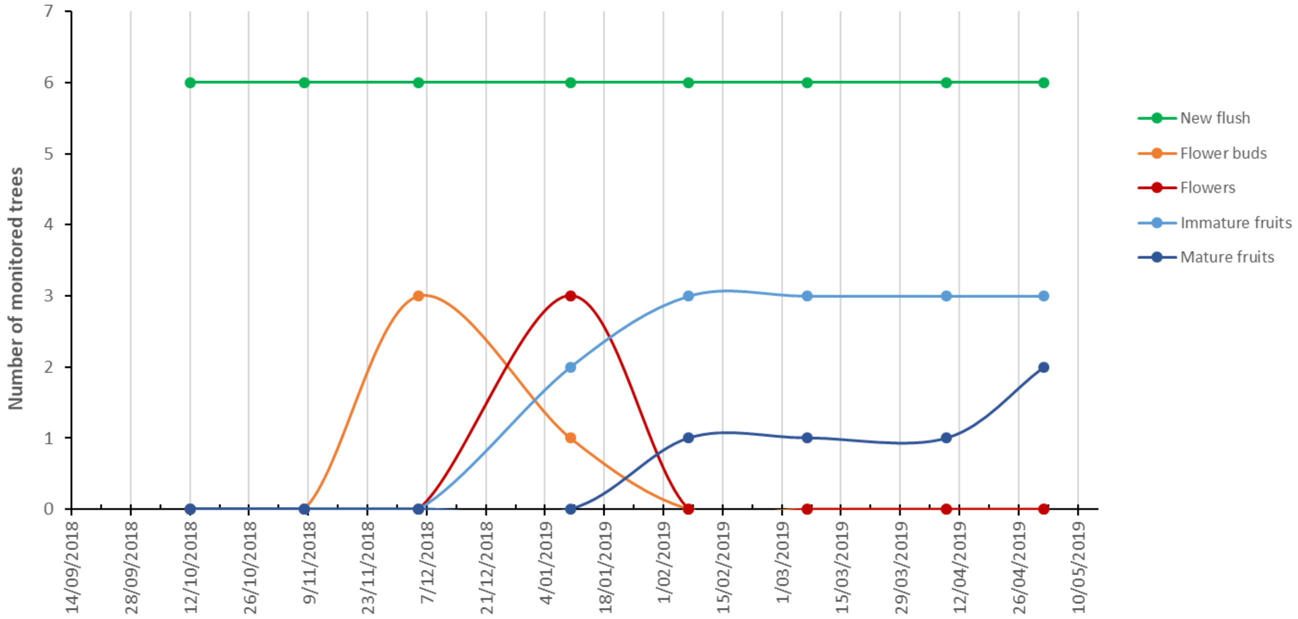


Figure 3.4.1 Time series plot from October 2018 to May 2019 for tree phenology of the presence of new flush, flower buds, flowers, immature fruits and mature fruits on *Lophomyrtus* spp (rōhutu/ramarama) in a site with no myrtle rust infection.

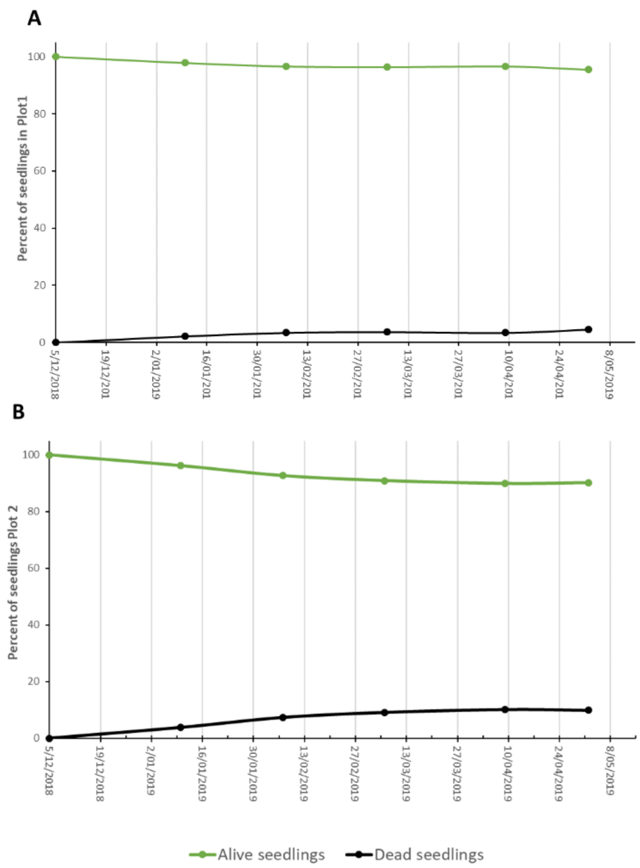


Figure 3.4.2 Time series plot from October 2018 to May 2019 of the percentage of alive and dead *Lophomyrtus* spp (rōhutu/ramarama) seedlings within two plots (A and B).

7.1 Conclusions and Recommendations

Monitoring of myrtle rust in a stand of Myrtaceae in natural conditions showed this disease severely impacted rōhutu/ramarama but infection was also observed on mānuka and climbing rātā in the stand.

Of particular concern was the level of infection in rōhutu/ramarama, with up to 90-100% of new flush infected and subsequently dying. All seedlings became infected and the majority died or are expected to die in the near future. On top of this the majority of fruit in trees with infections also became infected and prematurely dropped. The implication of this to the survival of this species is concerning. Based on what has been observed in Australia, where localised extinction has occurred for susceptible plant species that have repeated infection of new flush, seedlings and flowers/seed (Carnegie et al. 2016), localised extinction of rōhutu/ramarama is probable.

Recommendations for future research include:

- The New Zealand Myrtle Rust Monitoring form needs to be made into an app format so it can be used on hand-held devices, and should be updated to include wider ecological impact factors when that work has been completed. An app format should also include a section where culture indicators can be added and recorded.
- Continuing monitoring of these sites and the impact of myrtle rust on species of Myrtaceae within to determine the long-term consequences on individual plant and species survival. Specifically, will infected trees die and how long will it take.
- Extending long-term monitoring in different Myrtaceae ecosystems across different climatic regions of New Zealand to assess the impacts of this disease to New Zealand's Myrtaceae. The surveillance form developed in this project should be used for any long-term monitoring initiatives to ensure relevant and consistent data is collected.

- Establish a shared database so data from nationwide monitoring can be deposited and used to assess impact and be analysed to inform decision-making in the future.
- Monitor the impact on invertebrates and their food web networks from infection, dieback or death of host Myrtaceae plants infected with myrtle rust in native ecosystems.
- Determine whether seeds from infected fruit are still viable and able to germinate.

This information is critical to determine conservation priorities and developing long term management plans.

5. Improved Myrtle Rust Surveillance through Remote Sensing

At present, the primary means of monitoring myrtle rust prevalence and impact in New Zealand is through visual inspection by trained plant pathology experts. Even though this method has disadvantages such as being time and cost-intensive, it is still the most accurate way of detecting and assessing presence and impact of myrtle rust. Visual inspection is subject to some limitations such as inaccessible locations on steep terrain or trees with tall canopies. These are instances where remote sensing methods can be utilized to aid visual inspections. In addition, data that can be gathered through remote sensing methods can cover large extents and can form a permanent record that, if repeated regularly, can provide the basis for long-term monitoring of myrtle rust impacts.

Remotely-sensed archived datasets have proven to be useful for long-term vegetation studies. National-scale monitoring programmes such as the National Ecological Observatory Network (NEON) aim to collect and process aerial remote sensing data across the United States over a 30-year time frame (Batelle, 2019). These data will be publicly available and will support long-term change detection and ecological studies. Remote sensing methods applied to data from sensors on aircraft and unmanned aerial vehicles (UAVs) have been widely used for biosecurity applications such as surveillance for biosecurity threats (Jurdak, et al., 2015), identification of plant pests and diseases (Mcfadyen, et al., 2014), and differentiation between healthy trees and trees affected by pathogens (Cui, et al., 2009; de Castro, et al., 2015; Devadas, et al., 2009; Heim, et al., 2018; Huang, et al., 2012; Huang, et al., 2007; Sandino, et al., 2018).

Earlier studies have focused on utilizing vegetation indices that are sensitive to tree health to determine the extent of disease outbreaks or to differentiate classes of healthy and infected trees. This type of work has often been done through laboratory-based experiments (Cui, et al., 2009; Devadas, et al., 2009) or through field measurements using data from airborne platforms (de Castro, et al., 2015; Huang, et al., 2012; Huang, et al., 2007). Recently, Heim, et al. (2018) attempted to evaluate the potential for remote sensing to detect and observe the impacts of myrtle rust. Using a portable field spectrometer, the authors provided a proof-of-concept for using spectral information to discriminate infection-free, fungicide-treated, and infected leaves on lemon myrtle (*Backhousia citriodora*) plants. The resulting classification, mainly based on the near-infrared (NIR) spectral region, yielded an overall accuracy of 95%. Furthermore, Sandino, et al. (2018) tested the performance of a hyperspectral camera onboard an unmanned aerial vehicle (UAV) for distinguishing paperbark trees infected with myrtle rust from uninfected trees in a farm in New South Wales, Australia. This study reported detection accuracies of between 94–97%.

In contrast to disease impact studies leveraging multi or hyperspectral data, this study aimed to (1) evaluate the capacity of high-resolution UAV imagery and LiDAR to inform long-term surveillance and monitoring; and (2) to trial the use of UAV-borne sensors to augment and assist visual inspections.

8.1 Materials and Methods

Two field assessments were carried out in a study site located in the Bay of Plenty. This location is one of the sites regularly monitored by Scion to understand the impacts of myrtle rust and is confirmed to have ramarama/rohutu plants (*Lophomyrtus* spp.) infected with myrtle rust. The site is located on flat terrain in a relatively open area near an access road which made it suitable for experimental UAV activities. The data capture and remote sensing inspections were carried out on the 18 December 2018 with a second capture completed on the 10 April 2019.

During the first flight, high-resolution multispectral images were captured using both the 5-band Sentera MS Double 4K sensor (Sentera LLC, Minneapolis, Minnesota, USA) and the 5-band Micasense Red Edge M3 sensor (MicaSense, Seattle, WA, USA) mounted on a DJI Matrice 600 hexacopter UAV. The average ground sampling distance (GSD) for the Sentera and Micasense cameras were 2.15 cm and 4.69 cm, respectively. The available bands for both sensors were blue (B), green (G), red (R), red-edge (RE), and near-infrared (NIR). During the second flight, LiDAR data was also captured using a LidarUSA Snoopy V-Series Lidar system incorporating a Riegl MiniVUX1-UAV laser scanner (Fagerman Technologies, Hartselle, Alabama, USA). Three-band (RGB) colour imagery was also captured using a DJI X3 camera with an average GSD of 5.27 cm. For all the flights, flight planning and mapping were carried out using a combination of UgCS (SPH Engineering, Riga, Latvia) and Map Pilot (Drones Made Easy, San Diego, CA, USA) flight control software. Further data processing included georectification and production of orthomosaic imagery using the Pix4Dmapper software application (Pix4D SA, Prilly, Switzerland). Multispectral data were further processed to compute vegetation indices such as the normalized difference vegetation index (NDVI) in ArcMap 10.6 (Eagle Technology, Auckland, New Zealand). LiDAR data were also processed in LAStools (RapidLasso, Gilching, Germany) to derive normalised heights and canopy height model (CHM).

In addition to this data capture, remote inspection methods were also trialled with one myrtle rust infected rohutu tree considered as the target. The remote inspection was carried out using a DJI Zenmuse Z30 camera (SZ DJI Technology Co., Ltd., Shenzhen, China) with an integrated 30 X optical zoom lens mounted on a DJI Matrice 600 UAV. During the first flight, the UAV and sensor were controlled by two operators. One operator controlled the craft and maintained a visual line of sight (VLOS) to the UAV while the other operator controlled the camera. A real-time video feed was established to a remote monitor that enabled trained myrtle rust experts to observe the video of the infected plant in real-time. The settings of both the drone and camera (*e.g.* flight altitude and camera focus) were adjusted accordingly to enable the experts to detect the signs of myrtle rust infection. During the second flight, this protocol was adjusted to have only one UAV pilot observing the site using a smaller craft, the DJI Matrice 210 quadcopter equipped with the same Z30 camera. This method simulated allowing a single operator to visually inspect trees and then switch to using the UAV to continue inspecting the out-of-reach sections of the canopy. The video feeds from both captures were recorded and saved for further post-capture analysis.

During both field campaigns, strict biosecurity protocols were followed to prevent myrtle rust contamination from UAV rotors while hovering, landing, and taking off over confined areas. A safe decontamination zone was set-up on site where all equipment was thoroughly wiped and cleaned with approved disinfectants.

9.1 Remote Sensing for Long Term Myrtle Rust Surveillance

Remotely-sensed spectral and 3D datasets captured during the fieldwork can serve as baseline datasets for long-term myrtle rust surveillance at the study site. The captured images of a subset of the study area using sensors of varied spatial resolutions: Sentera (2.15 cm), Micasense (4.69 cm), and DJI X3 (5.27 cm), show detailed views of the study site (Figure 4.2.1 a-c). The full capture areas ranged from 6.7 to 29.4 ha, demonstrating that this approach is suitable for analysis and monitoring of larger spatial extents that would not be practical using ground observations alone. At this site, the intensive field inspections carried out as part of Scion's broader surveillance programme allow overstory species to be delineated and positively identified in the imagery – providing a baseline map of species presence, canopy extent, and condition. Fine-scale detail such as leaf-level observation was not possible at this resolution; however, it is likely that larger-scale impacts such as significant dieback or decline could be visually identified if they were present (Figure 4.2.1 e-g). In addition, the capture of multispectral data adds value to these remotely sensed datasets. For example, vegetation indices such as NDVI are widely used as a measure of vegetation greenness and health. Healthy vegetation absorbs most visible red light but reflects a greater proportion of light in the NIR range, resulting in high NDVI values for healthy vegetation. The NDVI in the study area (Figure 4.2.1 d, h) shows high NDVI values for tree and plant canopies while bare, woody elements and other surfaces show lower NDVI values. Although no severe myrtle rust impacts were observed at this site, previous research has indicated that larger-scale impacts are likely to be detectable using this type of imagery (Sankaran, et al., 2010).

The maps produced from the UAV imagery (Figures 4.2.1 and 4.2.2) can serve as baseline datasets for further monitoring of the effects of myrtle rust in the area. With continued data collection at the site (*e.g.* annual re-captures), it would be possible to monitor and detect a range of substantial impacts on plant communities including changes in community structure, composition, and canopy dieback. With ongoing ground surveillance, these changes could be positively linked to the presence and impact of myrtle rust.

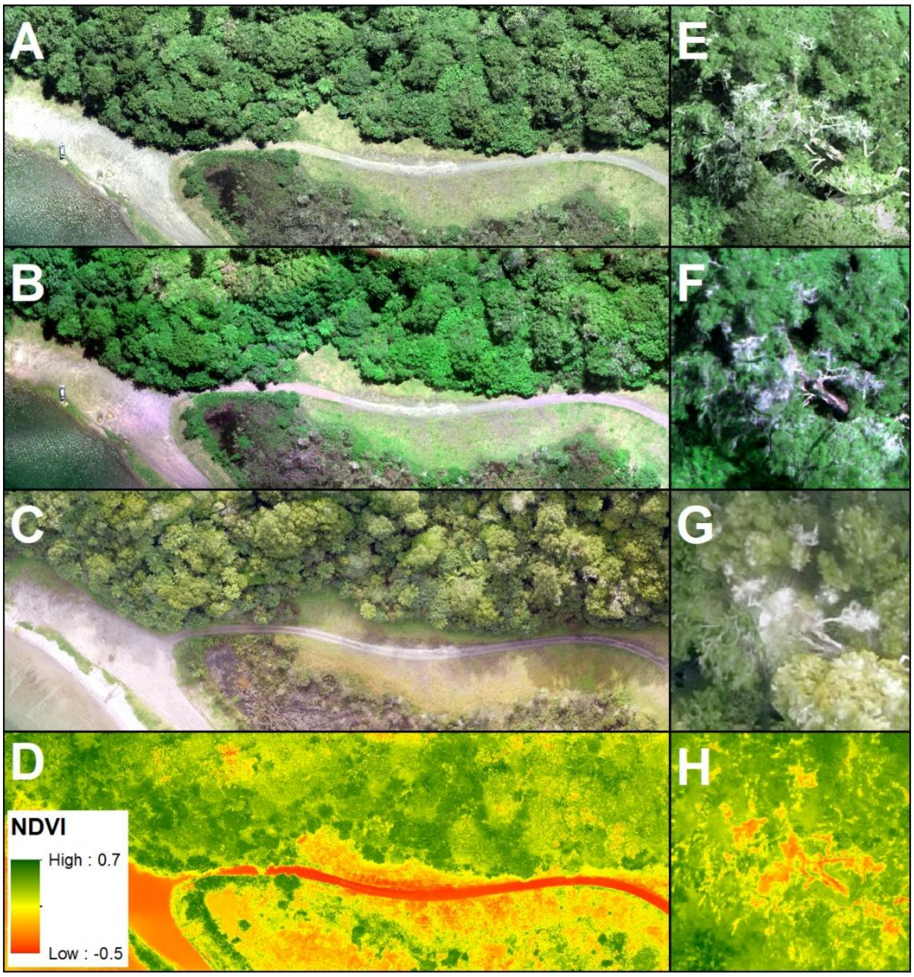


Figure 4.2.1 RGB imagery in decreasing spatial resolution captured by Sentera (a) and Micasense (b) cameras on the 18 December 2018 and captured by the DJI X3 (c) camera on the 10 April 2019. Magnified views of the Sentera (e), Micasense (f), and DJI X3 (g) imagery showing details from bare branches are shown alongside NDVI imagery of the same area (d and h) calculated using the Micasense red and NIR bands.

Three-dimensional information can be derived from LiDAR datasets (Figures 4.1.2 c-d). Further processing can lead to the derivation of different LiDAR metrics that have been shown to be related to horizontal and vertical vegetation structure as well as complexity (Lausch, et al., 2017). The resulting CHM in the study area can be used to delineate lower stature vegetations from taller trees and assist individual tree identification and characterisation (Figure 4.1.2 a). The CHM can also be related to various structural attributes (*e.g.* canopy height, volume, and biomass) and used to predict forest characteristics. Repeated monitoring of these attributes may reveal future impacts on forest structure and complexity that are not easily visible.

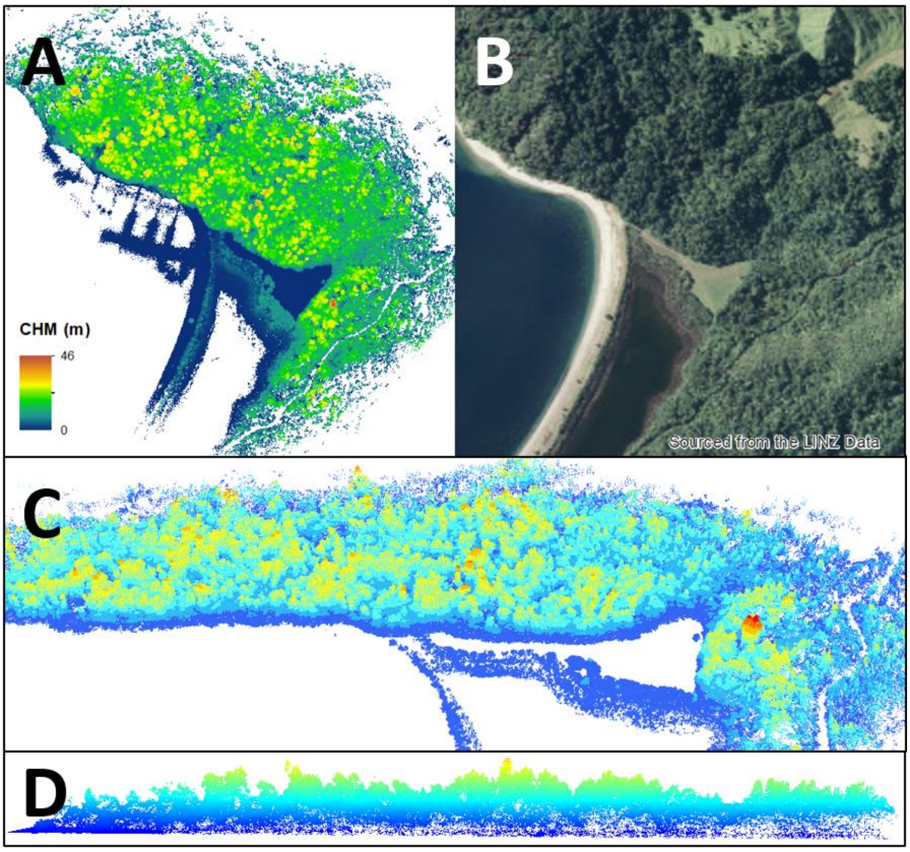


Figure 4.2.2 Canopy height model (a) of the study area (b) derived from LiDAR data. An oblique view of the ground-normalised LiDAR data is also shown (c) alongside a cross-section view of the point cloud (d).

10.1 UAV-assisted Myrtle Rust Inspection

The second objective of this research theme was to test the possibility for UAV-borne sensors to assist plant pathologists during field inspection activities. The intention was to test whether these sensors could afford better views of the upper canopy that could not be achieved from the ground.
During the first flight, the craft and sensor were controlled by two UAV pilots and a live video feed was remotely observed by plant pathology experts (first setup). The second flight involved a single pilot operating a smaller craft while walking along the forest edge (second setup) capturing video for post-flight analysis.

During the implementation of the first setup, the UAV was flown near the infected rohutu target plant at an initial altitude of 50 m. Based on comments from the plant pathogen experts, the flight altitude was reduced to 10 m to achieve a better close-up view of the small stems and leaves of the infected plant. During this flight, myrtle rust spores and dieback were difficult to visually detect (Figure 4.3.1 a-b) because of the stability of the craft and camera combined with the movement of the branches and leaves caused by ambient wind (~20 kph) and the movement of the craft in the wind, despite having a high-quality gimbal built into the camera system. Focusing on the potential infection was very difficult due to these slight movements. In addition, the target plant was in the understory layer and was overshadowed by larger trees which further complicated camera focus and control. With the learnings gained from the 1st setup, the remote inspection during the 2nd setup focused on the upper canopy layers in addition to capturing shots of an infected plant within the understory layer. The inspection was also carried out in the early morning with lower ambient wind and more even lighting conditions across the study area. Due to extended delays in obtaining UAV operation permits for the study site, the inspection could only be done after the peak of disease expression. However, the data captured using this approach showed that it was possible to detect myrtle rust related dieback and lesions (Figure 4.3.1 c-d). This footage could be effectively reviewed to assess impacts in the upper portion of the canopy and the photographs and video could provide archival data for long-term monitoring and re-inspection. However, the inspection was sensitive to weather conditions and inspection work needed to coincide with ideal field conditions. Considerations included sky conditions (*i.e.* either fully overcast or cloud-free), solar illumination, shadow, and wind levels that could affect the craft stability or cause movement of branches.

Instead of replacing the traditional inspection methods of detecting and monitoring myrtle rust, remote sensing methods, particularly using UAVs, can be used concurrently to overcome the limitations of both methods. For instance, UAV remote inspection could be used to extend surveillance activities to leaves, shoots, fruits, and flowers in the upper canopies of host species in inaccessible areas. Visual inspection would remain the preferred method for assessing understory plants or to detect myrtle rust disease symptoms especially at the very early stage of the infection (*e.g.* symptoms development commonly starting on the abaxial surface of the leaves). The use of the two inspection methods in conjunction is more practical and feasible than attempting to automate fine-scale myrtle rust surveillance using UAVs alone.

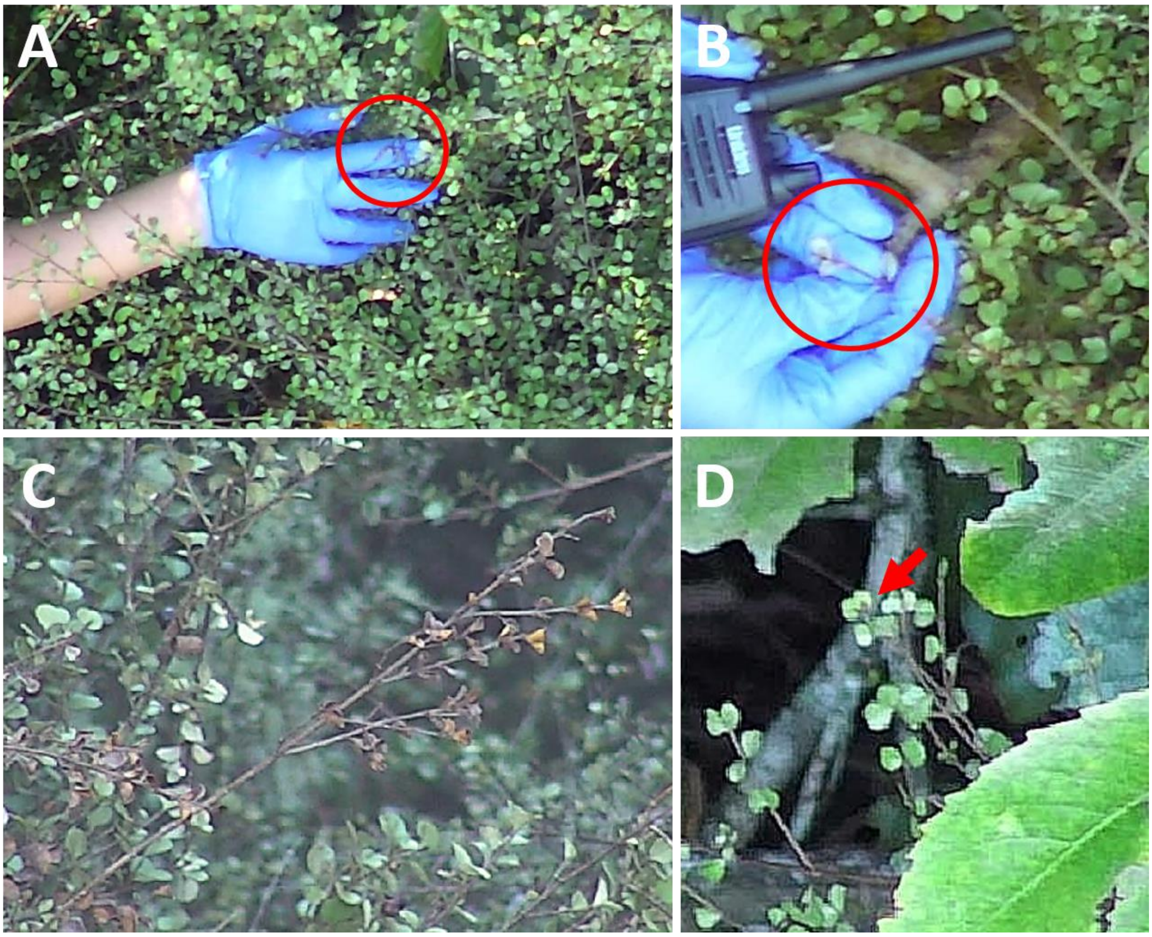


Figure 4.3.1 Imagery extracted from the video feeds collected during the first (a, b) and second (c, d) UAV flight campaigns. The first flight produced images with barely visible dieback (a) and yellow spores (b) while the improved imagery from the second data capture made symptoms of myrtle rust such as dieback (c) and lesions (d) more apparent.

11.1 Conclusions and Recommendations

This study showed that remote sensing methods using UAVs can provide useful data for both long-term site monitoring and as an adjunct to traditional ground-based assessments. Long-term monitoring can benefit from repeated captures of RGB, multispectral, and 3D LiDAR data to derive information on tree health, species composition, and larger-scale ecosystem impacts across larger areas (~30 ha). Successful application of this approach would require regular data acquisitions (*e.g.* annual) for a long period of time (*e.g.* 5+ years). Coupled with ground validation, it is likely that these data would facilitate robust evaluation of the long-term ecosystem impacts of myrtle rust over larger areas.

For ground-based surveillance, the visual inspection of myrtle rust infected plants can be enhanced with the use of a camera with a zoom lens mounted on a UAV. The limitations of visual inspection such as limited observations of key structures such as shoots, flowers, and fruits in the upper canopy or lack of surveillance in inaccessible areas could be resolved by capturing high-resolution remotely sensed imagery and video for later analysis by plant pathology experts.

Based on these findings, we recommend:

1. That long-term monitoring sites be established in appropriate areas and that ground-based surveillance is accompanied by annual capture of remotely sensed data to support long-term change detection including larger-scale disease impacts, changes in species composition and compensatory growth.

2. That ground-based surveillance programmes should consider integration of UAV technology to provide remote views of inaccessible, upper canopy elements to inspectors to improve monitoring of myrtle rust impacts.

6. Acknowledgements

This work has been undertaken under contract MPI 18607 led by Scion, Plant and Food Research and Manaaki Whenua Landcare Research and the following collaborators: AsureQuality, Biosecurity Research Ltd., Learning for Sustainability and Te Tira Whakamātaki.

The information and opinions provided in the Report have been prepared for the Client and its specified purposes. Accordingly, any person other than the Client uses the information and opinions in this report entirely at its own risk. The Report has been provided in good faith and on the basis that reasonable endeavours have been made to be accurate and not misleading and to exercise reasonable care, skill and judgment in providing such information and opinions.

Neither Scion as the lead contractor, nor any of its employees, officers, contractors, agents or other persons acting on its behalf or under its control accepts any responsibility or liability in respect of any information or opinions provided in this Report

We would like to acknowledge and thank mana whenua who have offered their time and expertise in the initial stages of this research, and for kindly allowing scientists to access their lands, receive plant samples and undertake other activities critical for this research.

We would like to acknowledge the contributions of all the organisations who have assisted the research team including the Ministry for Primary Industries, the Department of Conservation, regional and district councils, industry representatives, private land owners and the public.

We would also like to thank Waitangi Wood from Te Tira Whakamataki and staff from Plant and Food Research and Scion who have contributed to or assisted in delivering this research.

7. References

Beresford R, Turner R, Tait A, Paul V, Macara G, Yu Z, Lima L, Martin R (2018) Predicting the climatic risk of Myrtle Rust during its first year in New Zealand. New Zealand Plant Protection 71 (Rust Patho):332-347. doi:https://doi.org/https://doi.org/10.30843/nzpp.2018.71.176

Carnegie A, Lidbetter J (2012) Rapidly expanding host range of *Puccinia psidii* sensu lato in Australia, vol 41. doi:10.1007/s13313-011-0082-6

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 (1):127-144. doi:10.1007/s10530-015-0996-y

Coutinho TA, Wingfield MJ, Alfenas AC, Crous PW (1998) Eucalyptus rust: A disease with the potential for serious international implications. Plant Disease 82 (7):819-825. doi:10.1094/PDIS.1998.82.7.819

Doran J, Lea D, Bush D (2012) Assessing Myrtle Rust in a Lemon Myrtle provenance trial. Canberra, Rural Industries Research and Development Corporation,

Eriksson O, Ehrlén J (2008) Seedling recruitment and population ecology. In. pp 239-254. doi:10.1017/CBO9780511815133.013

Fernandez Winzer L, Carnegie AJ, Pegg GS, Leishman MR (2017) Impacts of the invasive fungus Austropuccinia psidii (myrtle rust) on three Australian Myrtaceae species of coastal swamp woodland. Austral Ecology 43 (1):56-68. doi:10.1111/aec.12534

Froud KJ, Beresford RM, Cogger N (2017) Risk factors for kiwifruit bacterial canker disease development in 'Hayward' kiwifruit blocks. Australasian Plant Pathology 46 (5):421-431. doi:10.1007/s13313-017-0504-1

Giblin F, Carnegie A (2014) Puccinia psidii (Myrtle Rust) - Australian host list. Version current at 24 Sept. 2014. http://www.anpc.asn.au/resources/Myrtle_Rust.html.

Glen M, Alfenas AC, Zauza EAV, Wingfield MJ, Mohammed C (2007) Puccinia psidii: a threat to the Australian environment and economy —a review. Australasian Plant Pathology 36 (1):1-16. doi:10.1071/ap06088

Guy N, Barry M (2017) Response underway following myrtle rust find. https://www.beehive.govt.nz/release/response-underway-following-myrtle-rust-find.

Häffner E, Konietzki S, Diederichsen E (2015) Keeping Control: The Role of Senescence and Development in Plant Pathogenesis and Defense, vol 4. doi:10.3390/plants4030449

Hart N (2016) Monitoring New Zealand's native bees: a collaborative approach using image analysis. Auckland University of Technology,

Ho WWH, Baskarathevan J, Griffin RL, Quinn B, Alexander BJR, Havell D, Ward N, Pathan A (2019) First Report of Myrtle Rust Caused by Austropuccinia psidii on Metrosideros kermadecensis on Raoul Island and on M. excelsa in Kerikeri, New Zealand. Plant Disease. doi:10.1094/PDIS-12-18-2243-PDN

Junghans DT, Alfenas AC, Brommonschenkel SH, Oda S, Mello EJ, Grattapaglia D (2003) Resistance to rust (Puccinia psidii Winter) in Eucalyptus: mode of inheritance and mapping of a major gene with RAPD markers. Theoretical and Applied Genetics 108 (1):175-180. doi:10.1007/s00122-003-1415-9

Liebhold A, MacDonald WLD, Bergdahl D, Mastro V (1995) Invasion by Exotic Forest Pests: A Threat to Forest Ecosystems, vol 30. doi:10.1093/forestscience/41.s1.a0001

Pegg G, Taylor T, Entwistle P, Guymer G, Giblin F, Carnegie A (2017a) Impact of Austropuccinia psidii (myrtle rust) on Myrtaceae-rich wet sclerophyll forests in south east Queensland, vol 12. doi:10.1371/journal.pone.0188058

Pegg G, Taylor T, Entwistle P, Guymer G, Giblin F, Carnegie A (2017b) Impact of Austropuccinia psidii (myrtle rust) on Myrtaceae-rich wet sclerophyll forests in south east Queensland. PLOS ONE 12 (11):e0188058. doi:10.1371/journal.pone.0188058

Pegg GS, Brawner JT, Lee DJ (2014) Screening Corymbia populations for resistance to Puccinia psidii. Plant Pathology 63 (2):425-436. doi:10.1111/ppa.12097

Pegg GS, Giblin FR, McTaggart AR, Guymer GP, Taylor H, Ireland KB, Shivas RG, Perry S (2013) Puccinia psidii in Queensland, Australia: disease symptoms, distribution and impact. Plant Pathology 63 (5):1005-1021. doi:10.1111/ppa.12173

Pegg GS, Perry S, Carnegie Angus J, Ireland K, Giblin FR (2012) Understanding Myrtle Rust epidemiology and host specificity to determine disease impact in Australia. Cooperative Research Centre for National Plant Biosecurity, Ramsell J, Paul N (1990) Preferential Grazing by Molluscs of Plants Infected by Rust Fungi, vol 58, 145-150. doi:10.2307/3545421

Roy BA, Alexander HM, Davidson J, Campbell FT, Burdon JJ, Sniezko R, Brasier C (2014) Increasing forest loss worldwide from invasive pests requires new trade regulations. Frontiers in Ecology and the Environment 12 (8):457-465. doi:10.1890/130240

Salmon JT (1955) Stick insects. Tuatara: Journal of the Biological Society 5 (3):78-81

Soewarto J, Carriconde F, Hugot N, Bocs S, Hamelin C, Maggia L (2018) Impact of Austropuccinia psidii in New Caledonia, a biodiversity hotspot. Forest Pathology 48 (2). doi:10.1111/efp.12402

Tommerup IC, Alfenas A (2003) Guava rust in Brazil—a threat to Eucalyptus and other Myrtaceae, vol 33.

8. Appendix 1. New Zealand Myrtle Rust Monitoring form

The Monitoring form is a ‘living document’. The version in this report is dated as 30 June 2019. For an up to date form, please contact MPI on MyrtlerustNZ@mpi.govt.nz

New Zealand Myrtle Rust Monitoring form

This form has been designed for use by trained myrtle rust observers and can be completed on paper or digitally using a tablet (or another electronic device).

The unit of interest is an individual plant or stand of small trees/shrubs or a hedge of the same species in a specific location. Any seedlings of these plants should be included in the unit of interest and recorded on the same form as the adult plant or stand.

It is extremely valuable to know where, and on which hosts, myrtle rust is present. It is also extremely valuable to know where, and on which hosts, myrtle rust IS NOT PRESENT. Please complete all relevant fields each time you monitor, regardless of myrtle rust presence or absence.

What we define a Myrtle Rust positive site:

Confirm host identification by a trained observer, OR expert confirmation of a submitted photo of the host,

AND,

Confirmed observation of myrtle rust symptoms by a trained observer, OR expert confirmation of a submitted photo of suspect myrtle rust symptoms on a host.

How to fill the form

The first time you visit a site complete the site description on page two. You will only need to do this once.

Fill page 3 at least once a year for an annual monitoring.

Fill the rest of the form each you come back to a site to monitor the same plant.

Use separate forms to record results for different host species in the same stand or hedge.

How to submit photos to confirm the plant species identity and/or myrtle rust infection

Photos can be submitted through the Myrtle Rust Reporter App available from iTunes: https://itunes.apple.com/nz/app/myrtle-rust-reporter/id1283825389?mt=8

and Android: https://play.google.com/store/apps/details?id=com.intranel.myrtlerustreporter&hl=en

How to submit the completed forms

Scanned copies of the form can be sent to the following email addresses:

An excel spreadsheet is also available which can be filled in and submitted
Karyn.froud@biosecurityresearch.co.nz or Julia.Soewarto@scionresearch.com or Roanne.Sutherland@scionresearch.com

SITE DESCRIPTION

Date (dd/mm/yyyy):______/_____/______ **Observer name(s):**

____

Contact phone: _________________________________ And/or email: ________________________________

Individual plant identifier number: ________________________

(This can be created by using the first 2 letters of the location and plant number e.g. Whakatane plant 2 would be WH02)

GPS coordinates: North: _____________________ **East:** _____________________ **(NZTM 2000 recommended)**

Or Lat: ______________________ **Long:** _______________________

Or address: ____

____

Describe the area where the plant is located and how to find the plant:

Habitat: tick all that apply

Native forest	☐	Riparian	☐
Commercial plantation	☐	Scrubland	☐
Urban	☐	Reserve (park or fields)	☐
Rural	☐	Urban street planting	☐
Wetland	☐	Garden (home, school, business)	☐
Coastal	☐	Farmland	☐
Botanic garden	☐	Lake side	☐
Orchard	☐	natural	☐
Nursery	☐	planted	☐
Roadside	☐	**other____________________________**	☐

Site owner has given permission to add data to the National MR database:

No ☐ Yes ☐

Land ownership (*if known*)

Maori title land	☐
DOC managed	☐
Territorial authority managed/owned	☐
Private owner	☐
Other	☐

PLANT DESCRIPTION

Monitored plant identification (See Appendix 1):

Common/Maori name: ____

Genus: ____

Latin species name (if known): ____

Confidence level of host species identification: very confident ☐ confident ☐ not confident ☐

Marking the Plant

If this plant will be regularly monitored, ensure that you are able to locate it easily. One way is the use of flagging tape with the individual plant identification number on, or another method that can be removed without damaging the plant.

Monitored plant height (in metres): 0-1 m ☐ 1-5 m ☐ 5-10 m ☐ >10 m ☐

Location of the monitored plant within the forest structure:

Not in a forest	☐
Seedling	☐
Understory	☐
Canopy	☐
Emergent tree	☐

Population size:

Number of mature plants (*i.e.* greater than 30 cm in height) of the same plant species present (within 3 m radius):		Number of seedlings (*i.e.* under 30 cm in height) of the same plant species present (within 3 m radius)	
0	☐	0	☐
1-10	☐	1-10	☐
10-25	☐	10-25	☐
More than 25	☐	More than 25	☐

Other myrtle species present within 3 m radius: No ☐ Yes ☐ (See Appendix 1):

If yes what species____

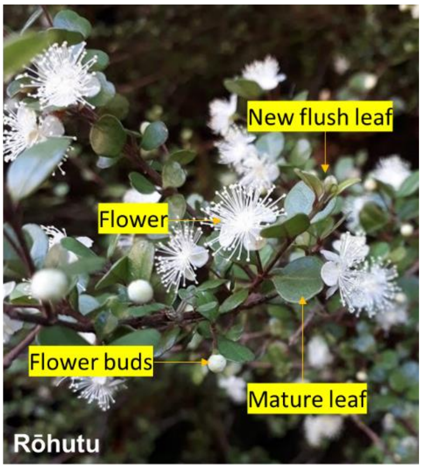
General comments on the plant

REGULAR PLANT DESCRIPTION

Monitored plant growth (see Appendix 2)

Which plant parts can you observe?

New flush leaves	**No** ☐	**Yes** ☐
New flush stems	**No** ☐	**Yes** ☐
Flower buds	**No** ☐	**Yes** ☐
Flower	**No** ☐	**Yes** ☐
Immature fruits	**No** ☐	**Yes** ☐
Mature fruits	**No** ☐	**Yes** ☐
Mature leaves	**No** ☐	**Yes** ☐



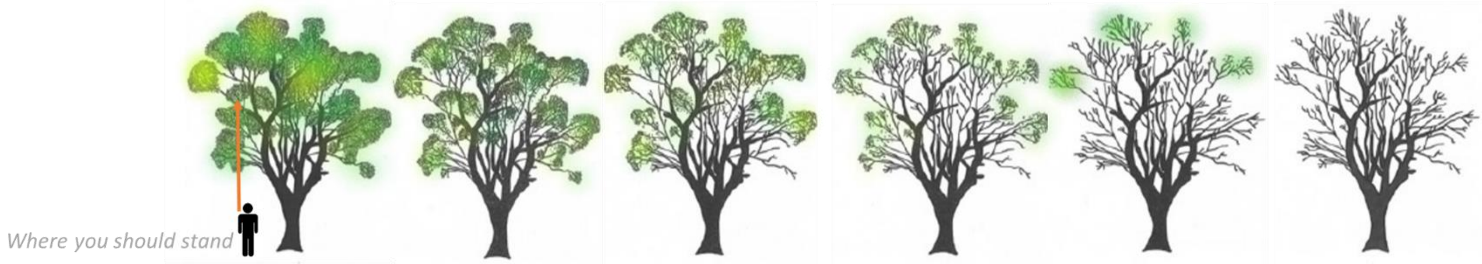
Foliage light exposure of the monitored plant:

Full light in the open (100% light) ☐

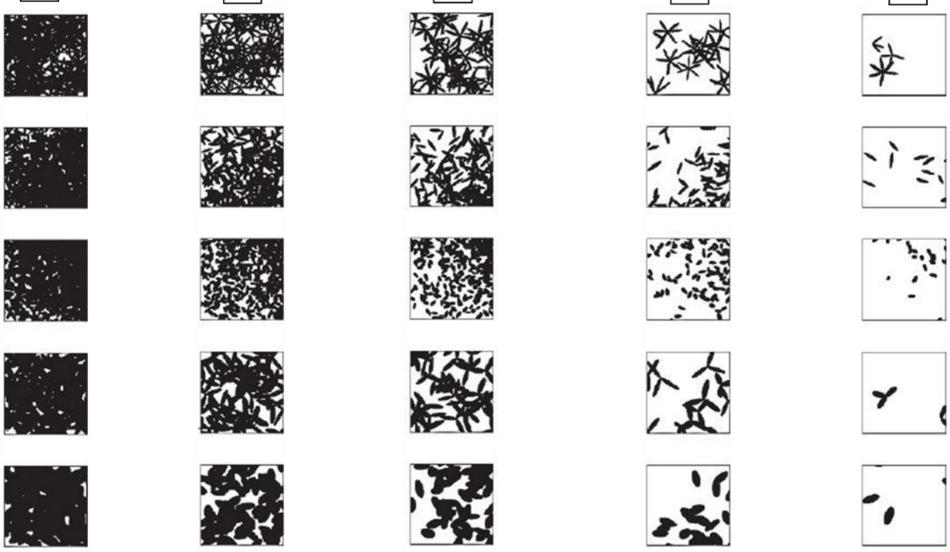
Partial shade (50% light) ***e.g. forest margin*** ☐

LLow light under canopy (less than 10% light) ☐

Canopy density of the monitored plant **from standing directly underneath the tree.** **This does not include other plant species that are part of the forest canopy or small trees.**



Canopy density:	95%	75%	55%	25%	5%	No leaves
Thick the one that applies	☐	☐	☐	☐	☐	☐



Modified from Souter et al. 2010 and The Foliar Browse Index Field manual from DoC

Photo:

A photo of the plant has been taken. Yes ☐

what is the photo file name: ______________________________

Have you taken a close-up photo of the leaves: No ☐ Yes ☐

if Yes, what is the photo file name: ______________________________

OTHER ENVIRONMENTAL DISTURBANCES

From the monitored plant, do you see:

Evidence of mammalian browsing	No	☐	Yes	☐
Insect browsing	No	☐	Yes	☐
Other leaf spots	No	☐	Yes	☐
Poor drainage / wet feet	No	☐	Yes	☐

Other ill-health: ____

If you are in a natural ecosystem, describe the general health around the monitored plant:

Cultural health indicators and maramataka – under development

Evidence of recent site disturbance (i.e new since the last time that you monitored the plant):

No new evidence of disturbance	**No**	☐	**Yes**	☐
Fire	**No**	☐	**Yes**	☐
Windfall	**No**	☐	**Yes**	☐
Slips/land slide	**No**	☐	**Yes**	☐
Track maintenance	**No**	☐	**Yes**	☐
Pruning of hosts	**No**	☐	**Yes**	☐
Animal disturbance	**No**	☐	**Yes**	☐
Evidence of animal pest control	**No**	☐	**Yes**	☐
Evidence of weed spray	**No**	☐	**Yes**	☐
Mowing	**No**	☐	**Yes**	☐

Other disturbances: ____

MYRTLE RUST DISEASE SEVERITY ASSESSMENT

Myrtle rust observer training type: CRI ☐ Territorial authority ☐ DOC ☐ TTW ☐ Iwi ☐ Forest and Bird ☐

AsureQuality ☐ MPI ☐ Not trained ☐ Self-trained ☐ Other, specify: ________________________

Weather condition during the observation: Sunny ☐ Overcast ☐ Rainy ☐

Plant infection status: infected ☐ **not detected** ☐ suspect myrtle rust to be present ☐

STOP HERE IF NO MYRTLE RUST –

CONTINUE IF MYRTLE RUST IS PRESENT OR SUSPECTED TO BE PRESENT

Which plant parts are showing Myrtle rust symptoms?

	Myrtle rust symptoms		
New flush leaves	**No ☐**	**Yes ☐**	**suspect ☐**
New flush stems	**No ☐**	**Yes ☐**	**suspect ☐**
Flower buds	**No ☐**	**Yes ☐**	**suspect ☐**
Flowers	**No ☐**	**Yes ☐**	**suspect ☐**
Immature fruits	**No ☐**	**Yes ☐**	**suspect ☐**
Mature fruits	**No ☐**	**Yes ☐**	**suspect ☐**
Mature leaves	**No ☐**	**Yes ☐**	**suspect ☐**

Are the same host species within 3 m radius infected: No ☐ Yes ☐ Suspect ☐

Are there other myrtle species within 3 m radius infected: No ☐ Yes ☐ Suspect ☐

If yes, what species? (See Appendix 1):

MYRTLE RUST DISEASE SEVERITY ASSESSMENT

Percent of plant visually observed: **1-25% ☐ 25-50% ☐ 50-75% ☐ 75-100% ☐**

Percent of plant part with symptoms (see Appendix 2):

Plant parts	0 **None are infected** (0%)	1 **1-10 are infected** (1-10%)	2 **Up to half are infected** (10-50%)	3 **More than half are infected** (50-80%)	4 **Almost all are infected** (80-100%)
New flush leaves	☐	☐	☐	☐	☐
New flush stems	☐	☐	☐	☐	☐
Flowers buds	☐	☐	☐	☐	☐
Flowers	☐	☐	☐	☐	☐
Immature Fruits	☐	☐	☐	☐	☐
Mature fruits	☐	☐	☐	☐	☐
Mature leaves	☐	☐	☐	☐	☐

Lesions and spores:

Red spots	No	☐	Yes	☐
Yellow spores (Urediniospores)	No	☐	Yes	☐
Grey (Old spores)	No	☐	Yes	☐
*Dark brown spores (Teliospores)	No	☐	Yes	☐

**can only be seen/confirmed under microscope*

Other Myrtle rust related symptoms:

Browning and curling leaves or shoots	No	☐	Yes	☐
Defoliation/Leaf loss	No	☐	Yes	☐

Myrtle rust related dieback:

0%	1-10%	10-50%	50-80%	80-100%	Entire plant dead
☐	☐	☐	☐	☐	☐

Photo

A photo of the myrtle rust infection on the plant has been taken: Yes ☐

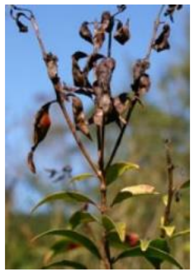
What is the photo file name: ______________________________

General comments on the infection

MYRTLE RUST DISEASE SEVERITY ASSESSMENT

1) Severity score modified from Pegg *et al.*, 2012:

Pick a score for assessing the disease severity according to your previous observations in the form.
Plant parts refers to stem, leaf, flowers, buds and fruits.

	Score	Symptom Description	
☐	0	no evidence of Myrtle rust symptoms	
☐	1	minor leaf spots with myrtle rust pustules on <10% of plant parts, only a few pustules per infected plant parts.	 
☐	2	Myrtle rust pustules present on 10-50% of plant parts, moderate number of pustules per infected plant part.	 
☐	3	Myrtle rust pustules present on 50-80% of plant parts, multiple pustules per plant part, blighting and distortion (curly).	 
☐	4	Myrtle rust present on the majority of plant parts, multiple pustules per infected plant part, foliage dieback, evidence of stem and shoot dieback.	 

MYRTLE RUST MANAGEMENT

Have you managed the infected plant (*e.g.* pruning, spray or plant removal)?

No ☐ Yes ☐

<u>If Yes,</u> please specify: ____

Are you intending to actively manage the infected plant? No ☐ Yes ☐

<u>If Yes,</u> what do you intend to do: ____

Appendix 1: List of myrtle rust hosts and potential hosts in New Zealand

Scientific name	Common name	Native /non-native
Acca sellowiana	feijoa	Non-native
Agonis flexuosa		Non-native
Callistemon sp.		Non-native
Corymbia sp.		Non-native
Eucalyptus globoidea		Non-native
Eucalyptus sp.		Non-native
Kunzea aff. *robusta*	Weeping kānuka	Native
Kunzea amanthicola	sand kānuka; rauwiritoa	Native
Kunzea ericoides	manuoea, titira, atitira, kanuka	Native
Kunzea linearis	northern kānuka; rauwiri	Native
Kunzea robusta	lowland kānuka; rauwirinui	Native
Kunzea salterae	Moutohorā kānuka	Native
Kunsea serotina	upland kānuka ; mākahikātoa	Native
Kunzea sinclairii	Barrier kānuka	Native
Kunzea tenuicaulis	geothermal kānuka	Native
Kunzea toelkenii	Bay of Plenty kānuka	Native
Kunzea triregensis	Three Kings kānuka	Native
Leptospermum aff. *scoparium* "Auckland"		Native
Leptospermum aff. *scoparium* "coastal silver prostate"		Native
Leptospermum aff. *scoparium* "East Cape"		Native
Leptospermum aff. *scoparium* "North Cape"		Native
Leptospermum aff. *scoparium* "Surville Cliffs"		Native
Leptospermum aff. *scoparium* "Three Kings"		Native
Leptospermum aff. *scoparium* "Waikato peat bog"		Native
Leptospermum aff. *scoparium* var. *incanum* "North Cape"		Native
Leptospermum scoparium var. *incanum*	northern mānuka	Native
Leptospermum scoparium var. *scoparium*	mānuka ; kahikatoa	Native
Lophomyrtus bullata	ramarama, bubble leaf	Native
Lophomyrtus obcordata	rōhutu	Native
Melaleuca sp.		Non-native
Metrosideros albiflora	kauri rātā vine; akatea	Native
Metrosideros bartlettii	Bartlett's rātā; rātā moehau	Native
Metrosideros carminea	carmine rātā vine	Native
Metrosideros colensoi	pendant rātā vine	Native
Metrosideros diffusa	white rātā vine	Native
Metrosideros excelsa	pōhutukawa	Native
Metrosideros fulgens	scarlet rātā vine	Native
Metrosideros kermadecensis	Kermadec pōhutukawa	Native
Metrosideros parkinsonii	crimson rātā	Native
Metrosideros perforata	small white rātā vine	Native
Metrosideros robusta	northern rātā	Native
Metrosideros umbellata	southern rātā	Native
Myrtus communis		Non-native
Neomyrtus pedunculata	rohutu	Native
Syzygium australe		Non-native
Syzygium maire	swamp maire; maire tawake	Native
Thryptomene calycina		Non-native
Ugni molinae	chilian guava	Non-native

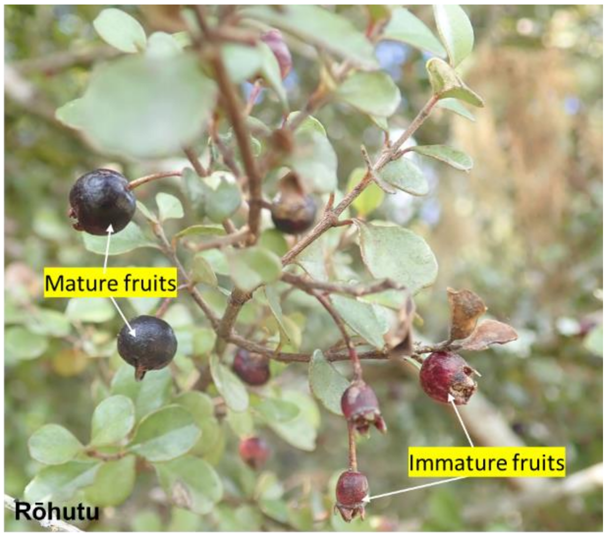
Appendix 2Plant development stage and myrtle rust symptoms

Plant development stages

New flush leaves or stem: new young growth, soft to touch, lighter in color, leaf size ranges from small to same size as fully

Mature leaves. Fully developed leaves that are darker in colour and firmer to touch than the new flush leaves.

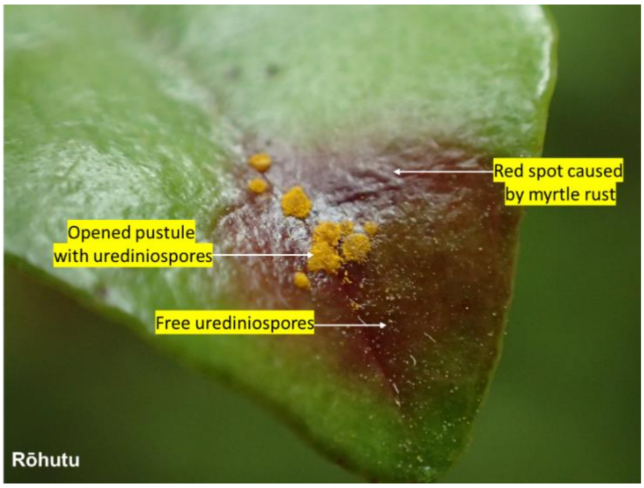
Flower buds: developing flowers surrounded by sepals.



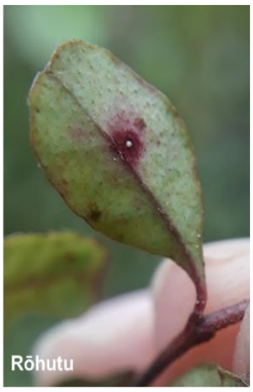
Immature fruit: early stage development of fruits, when the flowers part is no longer present (stamen, petals, pistil).

Mature fruit: fully developed fruit or mature seeds capsules.

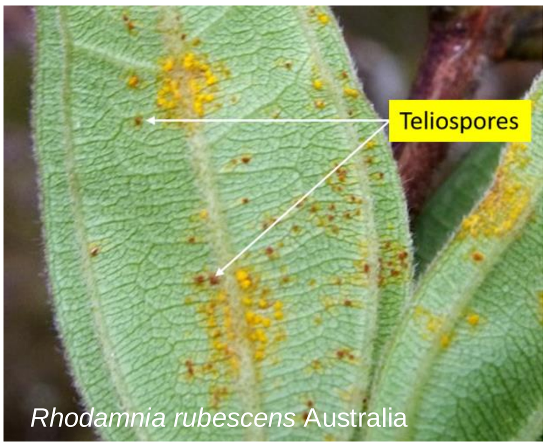
Myrtle rust symptoms



Red spot: red-purple lesion, general plant reaction to biotic stress (*e.g.* insect, pathogen), it can be the first signs of myrtle rust infection. Yellow spores (Urediniospores): yellow myrtle rust spores present inside a pustule. Spores disperse widely when the pustule erupts.



Grey (Old spores): old yellow myrtle rust spores that lost their



Dark brown spores (Teliospores): next stage of myrtle rust spore cycle, brown coloured, may also occur with yellow myrtle rust spores.

CREDITS

This form was designed as part of the MPI commissioned research project MPI18607. The content of the form was developed by Roanne Sutherland, Julia Soewarto, Karyn Froud and Rebecca Ganley with the contribution of Mana Whenua, Department of Conservation, Regional and District Councils, industry representatives, private land owners, public and staff from research organizations who have assisted in the development and testing of the form.

Biosecurity New Zealand
Ministry for Primary Industries
Manatū Ahu Matua

Ko Tātou
This Is Us Biosecurity 2025

scion
FORESTS · PRODUCTS · INNOVATION

Plant & Food
RESEARCH
RANGAHAU AHUMĀRA KAI

TE TIRA WHAKAMĀTAKI
Māori Biosecurity Network

Biosecurity Research

9. Appendix 2. Mapping data fields

Datasheet field descriptors and mapping of response data from the Department of Conservation and AsureQuality/Ministry for Primary Industries against the National Surveillance Form developed as part of this study.

National Surveillance Form Database Rec fields	National Surveillance Form title	Field restrictions (scale, presence/absence, free form text, number)	Doc fields	AQ/MPI
UniqueObservationID	NA	Number (sequential, generated when data is added)	**NA**	OBJECTID
Date	Date	Date field dd/mm//yyyy format	**Creator**	NA
ObserverName	Observer name(s):	free form text	**NA**	NA
ContactPhone	Contact Phone	free form text	**CreationDate**	Date Surveyed
ContactEmail	And/or email	free form text	**Plot_ID**	NA
IndividualPlantIdentifierNumber	Individual plant identifier number	numbers	**Tree_NVS_Code**	Tree ID
GPSNorth	GPS coordinates: North	numbers (NZTM 2000 projection)		
GPSEast	GPS coordinates: East	numbers		
GPSLat	Or GPS coordinates: Lat	numbers	**POINT_X**	
GPSLong	Or GPS coordinates: Long	numbers	**POINT_Y**	
SiteAddress	Or address	free form text		SpatialEngine_ObID
SiteDiagram	Describe the area where the plant is located and how to find the plant:	NA - Hard copy only		
HabitNatForest	Native forest	Code to 1 if selected, code to 0 if not selected		
HabitCommPlantation	Commercial plantation	Code to 1 if selected, code to 0 if not selected		
HabitUrban	Urban	Code to 1 if selected, code to 0 if not selected		
HabitRural	Rural	Code to 1 if selected, code to 0 if not selected		
HabitWetland	Wetland	Code to 1 if selected, code to 0 if not selected		
HabitCoastal	Coastal	Code to 1 if selected, code to 0 if not selected		

HabitBotanicGard	Botanic garden	Code to 1 if selected, code to 0 if not selected		
HabitOrchard	Orchard	Code to 1 if selected, code to 0 if not selected		
HabitNursery	Nursery	Code to 1 if selected, code to 0 if not selected		
HabitRoadside	Roadside	Code to 1 if selected, code to 0 if not selected		
HabitRiparian	Riparian	Code to 1 if selected, code to 0 if not selected		
HabitScrub	Scrubland	Code to 1 if selected, code to 0 if not selected		
HabitReserve	Reserve (park of fields)	Code to 1 if selected, code to 0 if not selected		
HabitStreet	Urban street planting	Code to 1 if selected, code to 0 if not selected		
HabitGarden	Garden (home/school/business)	Code to 1 if selected, code to 0 if not selected		
HabitFarmland	Farmland	Code to 1 if selected, code to 0 if not selected		
HabitLakeside	Lakeside	Code to 1 if selected, code to 0 if not selected		
HabitNatural	Natural	Code to 1 if selected, code to 0 if not selected		
HabitPlanted	Planted	Code to 1 if selected, code to 0 if not selected		
HabitOtherList	Other (please state)	free form text		
DBPermission	Site owner has given permission to add data to the National MR database	Text YES/NO		
LandOwnership	Land ownership Maori title land, DOC managed, Territorial authority managed/owned/ private owner/ other	Dropdown menu data validation of: MAORI/DOC/TA-COUNCIL/PRIVATE/OTHER		
CommonMaoriName	Common/Maori name	Dropdown menu data validation from Appendix 1 of form		
Genus	Genus	Dropdown menu data validation from Appendix 1 of form - forms the case definition	**Tree_Genus**	Tree Genus

Species	Latin species name (if known)	Dropdown menu data validation from Appendix 1 of form		
ConfLevelHostID	Confidence level of host species identification	Dropdown menu data validation of: VERY CONFIDENT, CONFIDENT, NOT CONFIDENT	**Species_Confidence**	
PlantHeight	Monitored Plant Height 0-1m	Dropdown menu data validation of: 0-1M/ 1-5M/5-10M/>10M	**Tree_Height_m**	Tree Height (m)
NotForest	Location in forest - Not in a forest	Code to 1 if selected, code to 0 if not selected		
ForestSeedling	Location in forest - Seedling	Code to 1 if selected, code to 0 if not selected		
ForestUnderstory	Location in forest - Understory	Code to 1 if selected, code to 0 if not selected		
ForestCanopy	Location in forest - Canopy	Code to 1 if selected, code to 0 if not selected		
ForestEmergentTree	Location in forest - Emergent Tree	Code to 1 if selected, code to 0 if not selected		
PopnMature	Population Size mature plants 0, 1-10, 10-25, >25	Dropdown menu data validation of: 0, 1-10, 10-25, >25		
PopnSeedling	Population Size seedling plants 0, 1-10, 10-25, >26	Dropdown menu data validation of: 0, 1-10, 10-25, >25		
OtherMyrtaceaePresent	Other Myrtaceae species present within 3m radius	Text YES/NO		
OtherMyrtaceaeList	If other Myrtaceae present, what species?	free form text		
PlantComments	General comments on the plant	free form text		
NewFlushLeaves	New flush leaves	Text YES/NO		
NewFlushStems	New flush stem	Text YES/NO		
FlowerBuds	Flower buds	Text YES/NO	**Flowering_Fruit_Act (Not flowering or fruiting/Flowering)**	**Flowering_Fruit_Act (Not flowering or fruiting/Flowering)**
Flowers	Flowers	Text YES/NO	**Flowering_Fruit_Act (Not flowering or fruiting/Flowerin**	**Flowering_Fruit_Act (Not flowering or fruiting/Flowering/ Flowering and unripe fruit)**

			g/Flowering and unripe fruit)	
ImmatureFruits	Immature fruits	Text YES/NO	**Flowering_Fruit_Act(Flowering and unripe fruit/unripe fruit/unripe fruit and ripe fruit)**	**Flowering_Fruit_Act(Flowering and unripe fruit/unripe fruit/unripe fruit and ripe fruit)**
MatureFruits	Mature fruits	Text YES/NO	**Flowering_Fruit_Act (unripe fruit and ripe fruit/ripe fruit)**	**Flowering_Fruit_Act (unripe fruit and ripe fruit/ripe fruit)**
MatureLeaves	Mature leaves	Text YES/NO		
FoliageLight	Foliage light exposure - full light in open 100%, partial shade 50%, low light under canopy <10%	Dropdown menu data validation of: FULL/PARTIAL/LOW		
CanopyDens%	Canopy density of monitored plant	Dropdown menu data validation of: 95%/ 75%/ 55%/ 25% / 5% / No leaves		
PhotoTakenPlant	Have you taken a photo of the plant	Text YES/NO		
PlantPhotoFileName	What is the plant photo file name	free form text		
PhotoTakenLeaves	Have you taken a close-up photo of the leaves	Text YES/NO		
LeavesPhotoFileName	What is the leaves photo file name	free form text		
AnimalBrowsing	Evidence of animal browsing	Text YES/NO		
InsectBrowsing	Insect browsing	Text YES/NO		
OtherLeafSpots	Other leaf spots	Text YES/NO		
PoorDrainage	Poor drainage/ wet feet	Text YES/NO		
IllHealthOtherList	Other ill-health	free form text		
ForestHealthState	If you are in a natural ecosystem, describe the general health around the monitored plant	free form text		
NoDistrub	No new evidence of disturbance	Text YES/NO		
FireDisturb	Fire	Text YES/NO		
Windfall	Windfall	Text YES/NO		

SlipLandslide	Slips, land slide	Text YES/NO		
TrackMaint	Track maintenance	Text YES/NO		
HostPruning	Pruning of hosts	Text YES/NO		
AnimalDisturb	Animal disturbance	Text YES/NO		
AnimalControl	Evidence of animal pest control	Text YES/NO		
WeedSpray	Evidence of weed spray	Text YES/NO		
Mowing	Mowing	Text YES/NO		
DisturbOtherList	Other disturbances	free form text		
MRObservTrainingCRI	Myrtle rust observer training type	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingTA	Myrtle rust observer training type	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingDOC	Myrtle rust observer training type	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingTTW	Myrtle rust observer training type	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingIwi	Myrtle rust observer training type	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingFAB	Myrtle rust observer training type	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingAQ	Myrtle rust observer training type, AsureQuality	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingMPI	Myrtle rust observer training type, MPI	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingNone	Myrtle rust observer training type, not trained	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingSelf	Myrtle rust observer training type, self-trained	Code to 1 if selected, code to 0 if not selected		
MRObservTrainingOther	Myrtle rust observer training type, other specify	free form text		
WeatherConds	Weather condition during the observation, sunny, overcast, rainy	Dropdown menu data validation of: SUNNY/OVERCAST/RAINY		
MRStatus	Plant infection status: Infected, not detected, suspect myrtle rust to be present	Dropdown menu data validation of: INFECTED/NOT DETECTED/SUSPECT	**Canopy_Imp_Score (Confirmed positive or negative by lab results)**	Survey Completed

MRNewFlushLeaves	Plant parts showing Myrtle Rust symptoms - New flush leaves	Dropdown menu data validation of: NO/YES/SUSPECT	**Canopy_Imp_Score (Old growth without obvious rust/Old and new leaf without any obvious rust/Old and new leaf with some rust)**	**Canopy_Imp_Score (Old growth without obvious rust/Old and new leaf without any obvious rust/Old and new leaf with some rust)**
MRNewFlushStems	Plant parts showing Myrtle Rust symptoms - New flush stem	Dropdown menu data validation of: NO/YES/SUSPECT	**Canopy_Imp_Score (Obvious leaf rust dead stems or branches/Obvious leaf rust but no dead stems or branches)**	**Canopy_Imp_Score (Obvious leaf rust dead stems or branches/Obvious leaf rust but no dead stems or branches)**
MRFlowerBuds	Plant parts showing Myrtle Rust symptoms - Flower buds	Dropdown menu data validation of: NO/YES/SUSPECT	**Bud_Fruit_Score**	**Bud_Fruit_Score**
MRFlowers	Plant parts showing Myrtle Rust symptoms - Flowers	Dropdown menu data validation of: NO/YES/SUSPECT	**Bud_Fruit_Score**	**Bud_Fruit_Score**
MRImmatFruits	Plant parts showing Myrtle Rust symptoms - immature fruits	Dropdown menu data validation of: NO/YES/SUSPECT	**Bud_Fruit_Score**	**Bud_Fruit_Score**
MRMatureFruits	Plant parts showing Myrtle Rust symptoms - Fruits	Dropdown menu data validation of: NO/YES/SUSPECT	**Bud_Fruit_Score**	**Bud_Fruit_Score**
MRMatureLeaves	Plant parts showing Myrtle Rust symptoms - Older leaves	Dropdown menu data validation of: NO/YES/SUSPECT	**Canopy_Imp_Score (Old growth without obvious rust/Old and new leaf without any obvious rust/Old and new leaf with some rust)**	**Canopy_Imp_Score (Old growth without obvious rust/Old and new leaf without any obvious rust/Old and new leaf with some rust)**
MRSameSp3m	Are the same host species within 3 m radius infected	Dropdown menu data validation of: NO/YES/SUSPECT		
MROtherMyrtSp3m	Are there other Myrtaceae species within 3 m radius infected	Dropdown menu data validation of: NO/YES/SUSPECT		

MROtherMyrtSpList	Other Myrtaceae species within 3m are infected, if YES, what species	free form text		
PercentPlantObs	Percentage of plant visually observed	Dropdown menu data validation of: 1-25%, 25-50%, 50-75%, 75-100%	**Perc_Tree_Surveyed**	
MRSevereNewFlushLeaves	Percent of plant part with symptoms - New flush leaves	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%		
MRSevereNewFlushStems	Percent of plant part with symptoms - New flush stems	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%		
MRSevereFlowerBuds	Percent of plant part with symptoms - Flower buds	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%		
MRSevereFlowers	Percent of plant part with symptoms - Flowers	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%		
MRSevereImmatFruits	Percent of plant part with symptoms - Immature fruits	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%		
MRSevereMatureFruits	Percent of plant part with symptoms - Mature fruits	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%		
MRSevereMatureLeaves	Percent of plant part with symptoms - Mature leaves	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%		
LesionRedSpores	Lesions and spores - Red spots	Dropdown menu data validation of: NO/YES		
LesionYellowSpores	Lesions and spores - Yellow spores (urediniospores)	Dropdown menu data validation of: NO/YES		
LesionGreySpores	Lesions and spores - Grey (old spores)	Dropdown menu data validation of: NO/YES		
LesionBrownSpores	Lesions and spores - Dark brown spores (teliospores)	Dropdown menu data validation of: NO/YES		
CurlingLeavesShoots	Brown and curling leaves and shoots	Dropdown menu data validation of: NO/YES	**Tree_Branch_Score**	**Tree_Branch_Score**
Defoliation	Defoliation leaf loss	Dropdown menu data validation of: NO/YES	**Canopy_Imp_Score (Dead canopy coppice activity)**	**Canopy_Imp_Score (Dead canopy coppice activity)**

MRHostDieback	Myrtle rust related dieback	Dropdown menu data validation of: 0%, 1-10%, 10-50%, 50-80%, 80-100%, Entire plant dead	**Canopy_Imp_Score (Obvious leaf rust dead stems or branches/Obvious leaf rust but no dead stems or branches/ Dead tree)**	**Canopy_Imp_Score (Obvious leaf rust dead stems or branches/Obvious leaf rust but no dead stems or branches/ Dead tree)**
PhotoTakenMR	Have you taken a photo of the myrtle rust on the plant	Text YES/NO		
MRPhotoFileName	What is the myrtle rust photo file name	free form text		
MRComments	General comments on the infection	free form text	**Comment**	Comment relating to sample
MRDiseaseSeverity	Myrtle rust disease severity - severity score 0=no evidence of MR symptoms, 1= minor leaf spots pustultes<10% few per plant, 2= MR pustules 10-50% plant parts moderate amount of plant, 3= MR pustules 50-80% plant parts multiple per plant blightling and distortion, 4= MR on most plant parts and most of plant with foliage stem and shoot dieback.	Dropdown menu data validation of: 0, 1,2,3,4	**Canopy_Imp_Score (match to Pegg scores)**	**Canopy_Imp_Score (match to Pegg scores)**
MRMngt	Have you managed the infected plant	Text YES/NO		
MRMngtSpecify	Specify how you have managed an infected plant	free form text		
MRMngtIntend	Are you intending to actively manage the infected plant	Text YES/NO	**Canopy_Imp_Score (Tree Removed)**	**Canopy_Imp_Score (Tree Removed)**
MRMngtIntendSpecify	Specify how you intend to manage the infected plant	free form text		
CaseDefnHostConfirmed	NA - post field visit, indicate how Myrtaceae host ID was confirmed, either by trained observer, by photo	Dropdown menu data validation of:Trained observer/Photo confirmation/Not confirmed		

	confirmation by an expert or not confirmed			
CaseDefnMRConfirmed	NA - post field visit, indicate how Myrtle rust symptoms were confirmed, either by trained observer, by photo confirmation of an expert, or not confirmed	Dropdown menu data validation of:Trained observer/Photo confirmation/Not confirmed		
No match				UNQ
No match				REL_OBID
No match				Sample Taken
No match				Likelyhood sample may be positive
No match				Date sample reported Negative
Additional observation				Canopy Impact Score on Revisit
Additional observation				Flowering Activity Score on Revisit
Additional observation				Trees Branch Score on Revisit
Additional observation				Bud and Fruit Score on Revisit
No match				Status calculation
Additional observation				Revisit Date
No match			**Seed_Collected**	
No match			**EditDate**	
No match			**Editor**	
No match			**Specimen_Collected**	
No match			**Other_Spec_Collected**	