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Tiakitanga Pūtaiao Aotearoa

NGĀ TAONGA

MPI 18607 Project Report

Evaluating impacts of and responses to myrtle rust in New Zealand

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Executive summary

The problem

In 2017 the Ministry for Primary Industries (MPI) commissioned research into myrtle rust (*Austropuccinia psidii*) to address critical knowledge gaps in social, cultural and scientific knowledge relating to the management of myrtle rust in NZ (MPI Project 18607). A priority research theme identified as part of this process was ‘evaluating impact and responses’ (Theme 4). The overall outcome of Theme 4 is an 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 project aims to develop monitoring approaches (including establishing baselines) for assessing the impacts of myrtle rust to environmental, economic, social and cultural values over time, and for understanding the impact of potential management interventions or responses.

Key results

This report documents: (i) a step-wise framework to establish robust baseline indicators that can help integrate evaluation of the environmental, economic, social and cultural impacts of myrtle rust; and (ii) use of modelling and impact assessment approaches to scope the potential environmental and economic consequences of myrtle rust based on the framework in (i).

The framework outlines an iterative process to evaluate the environmental, economic and socio-cultural impacts of, and developing responses to, new diseases that affect the natural environment. The framework allows for social learning to guide decision-making over the long term. There are five steps in the framework:

1) Define the desired outcome(s) and evaluation framework(s)
2) Identify indicators and data sources for achieving desired outcomes
3) Prioritise areas of impact
4) Assess potential impacts: Test indicators
5) Review framework and document lessons.

For step 1 we adopted a quadruple bottom line (QBL) perspective as outlined on the Biosecurity 2025 Strategy Direction Statement and used expert knowledge of system approaches for developing an evaluation framework. At the time of writing this report, the Myrtle Rust Strategy had just been made available. We have incorporated some of that strategy into our consideration and review process in step 5. Recommendations are made on how to re-enter a new cycle of impact and response evaluation under the framework with the desired outcomes expressed in the Myrtle Rust Strategy.

Some indicators are in place for measuring impacts; others require development based on data collected across the QBL impact areas (environmental, economic, social and cultural impacts); and still others require new research to develop methodologies.

Environmental indicators have been identified for biodiversity, air quality and climate regulation, water regulation, erosion control, natural hazard protection and pollination. Economic indicators have been identified for impacts on tourism, impact on nurseries and plant producers’ industries, productivity of mānuka honey and oil, additional control costs on producers and government, and non-tariff barriers to trade. Indicators are accompanied by available data for generating baselines and measuring impact over time.

Environmental baselines and an economic impact assessment are presented as worked examples of myrtle rust impact indicators, selected where information is available at a national level. The baselines include potential environmental consequences of myrtle rust on ecosystem services and biodiversity, as well as potential economic consequences on mānuka, including production, employment and erosion control losses. Economic analysis is accompanied by assumptions used for the generation of assessments to ensure comparability.

An initial set of socio-cultural indicators has been identified based on interactions with other themes and their data collection activities. Potential indicators have been identified at the national and regional level for cultural sites and mauri impacts, community and cultural health, recreation, and iconic landscape/ amenity value. Currently there is limited data available to assess these impacts.

Implications of results for the client

This framework needs to be applied with the input of key stakeholders in different contexts and at different scales as appropriate. The framework outlines an iterative cycle for developing indicators and designing interventions or responses to be further evaluated over time. Further work would be needed to test the reliability of the framework and indicators through localized cases and across impact areas with key stakeholders.

An initial focus has been on identifying indicators in areas of impact across the QBL for establishing national baselines for ongoing assessment and, with responses (including management options) still developing, some qualification of responses has been given based on data gathered from other themes. However, the processes outlined by the framework will need to be re-entered to ensure alignment with key strategic directions and investment plans.

Further development of social and cultural indicators is recommended with the Myrtle Rust Strategy in mind, including success factors and measures for achieving desired outcomes. Aligning the evaluation framework with the governments Myrtle Rust Strategy and Science Plan will help articulate the means for designing and developing long-term management activities and indications of their effectiveness.

Further work

Following on the first iteration of this step-wise framework, we have identified general areas of impact and identified existing data, data that needs modification and new possible sources of data. The client needs to develop these indicators and response plans along with strategic partners or stakeholders in long-term management of myrtle rust. The client needs to engage further with the myrtle rust Strategic Science Advisory Group to provide feedback and scope criteria for potential case study selection to validate the framework as a strategic planning and development tool and re-enter a new cycle of impact and response evaluation framework with the desired outcomes expressed in the Myrtle Rust Strategy.

Recommendations

This framework and our initial list of indicators provide the groundwork for impact assessment; however, the framework needs to be implemented by the response partners working with their stakeholders. This is important to ensure that the partners' and stakeholders' priorities and values are each reflected in monitoring and decision-making. Because Māori are partners in the myrtle rust response, it is essential they are empowered to direct and participate in that effort.

We recommend that MPI, in conjunction with the other myrtle rust response and management partners:

Process recommendations

- Build relationships to develop partnerships, co-invest in long-term monitoring and evaluation of impacts, and co-develop strategic responses to myrtle rust as an iterative process of plan, act, observe, and reflect.

- Build relationships with data owners and invest to facilitate information sharing and capability development for monitoring and evaluating impacts and responses, taking into account issues of data sovereignty.

- Develop a comprehensive stakeholder map, list of activities and data availability, and initiate discussions with these stakeholders to understand their impact evaluation needs and investment priorities. This project has created an initial list of stakeholders and their activities; and a list of indicators and their availability; however, these lists must be fully populated to complete step 3 of the framework (priority setting).

- Use the framework as a basis for ongoing strategic planning and investment conversations, supported by tools that enable evaluation, monitoring and learning, such as dynamic causal loop analysis, Drivers-Pressure-State-Impact-Response (DPSIR) tool, or logic or outcomes models.

- Use the framework iteratively to monitor, evaluate and learn about the effectiveness of actions to mitigate the impacts of myrtle rust, including engagement and communications, and to identify new indicators appropriate for evolving needs as new knowledge on impacts and responses becomes available.

- Scope criteria to select case studies with stakeholders and select case studies to test and apply the framework, e.g., a high-risk area, an urban and a rural area.

Recommendations related to environmental impacts & responses

- Co-invest in national infrastructure (LUCAS, DOC Tier 1 monitoring) to determine impacts of myrtle rust on the natural environment, and co-invest in reporting since some national reports already include evaluation of Myrtaceae species (i.e., southern rātā, Statistics New Zealand 2015). Co-investment might include determination of myrtle rust presence on individual species in plots to make a more defensible case for attribution of observed change to the pathogen.

- Co-invest in regional infrastructure (plot networks established by DOC and by some regional councils, e.g., Auckland Council, Bay of Plenty Regional Council, Greater Wellington Regional Council) to determine impacts of myrtle rust on the natural environment, especially for native Myrtaceae where national infrastructure has small samples (e.g. ramarama (*Lophomyrtus bullata*), rōhutu (*L. obcordata*), and northern rātā) or does not adequately sample species with narrow ranges or restricted ecosystems (e.g., pōhutukawa in coastal forest).

- Work with Māori, other agencies, and the research community to determine whether or how assessment of environmental indicators can be aligned with measures suited to evaluate impacts and responses from a Te Ao Māori perspective. Points of similarity and dissimilarity of assessments of plot-based measures were evaluated recently alongside those used by Tūhoe (Lyver et al. 2018), but not in the context of impacts of myrtle rust or other pathogens.

- Work with other agencies and the research community to:

  (i) determine sampling regimes suitable to assess species-specific effects. Some native Myrtaceae (e.g., mānuka, kānuka, southern rātā, pōhutukawa) depend on disturbance for recruitment and it would be wrong to expect regeneration to occur under canopies of these species; regeneration would be most likely to occur in disturbed sites away from current stands. Other Myrtaceae (e.g., ramarama, maire tawake) are probably shade-tolerant and therefore likely to regenerate under forest canopies.

  (ii) determine and implement methods suitable to assess impacts of myrtle rust on populations of *Metrosideros* liana species and northern rātā, a strangler, since current methods can only assess these coarsely and with high uncertainty and are unsuitable for reporting demographic changes..

- Co-invest with other agencies in remote sensing techniques suitable to distinguish Myrtaceae species where they are dominant and where they are minor components of indigenous forests and shrublands to allow scaling up of plot-based estimates.

- Co-invest with other agencies in scaling up modelled estimates of ecosystem services including erosion control, water regulation and pollination that are currently applied at local (catchment or regional scale), and for forests and shrublands where native Myrtaceae species are dominant and where they are minor components.

Recommendations related to economic impacts and responses

- Co-invest in capturing basic economic baseline data on the impacts of and responses to myrtle across key industries and investors, including:

  (i) Mānuka plantation and honey industries to track changes in myrtle rust spread, impacts on mānuka honey production and on projected returns on investments, to map changes from these projections and to map potential response strategies to minimise adverse impacts.

  (ii) Nursery industry to identify current investments required to manage myrtle rust and changes in operations such as species stocking and distribution, creating a case study of economic impacts and their potential effects on controlling the spread of myrtle rust and subsequent biodiversity impacts (for native revegetation activities associated with environmental restoration).

  (iii) Examine the potential for trade restrictions due to myrtle rust and initiate appropriate responses to avert impacts on the honey and feijoa export industries, including application of scenarios if specific markets were to be impacted.

  (iv) Examine economic impacts and responses on Māori land and Māori investments so that these are adequately identified, prioritised and documented as informed by Te Ao Māori.

- Further consider the economic impacts of erosion arising from loss of Myrtaceae in catchment areas and on coastlines, and the loss of carbon sequestration arising from areas impacted by myrtle rust to test and align the assumptions of impact modelling, including an understanding of:

(i) Dynamics of the impacts. If the simulated spread/impacts are to occur, the infestation rate could reach its maximum in year 4–7. As such investing in earlier intervention (year 1–3) is recommended.

(ii) Spatial distribution of the impact. Although we did not quantify total impacts at regional level, it might be helpful to identify vulnerable regions such as Gisborne, Hawke's Bay, and Manawatu-Wanganui. Gisborne has a highly erosion-prone landscape (26% of the land area in this region is susceptible to severe erosion compared to the national average of 8%), as such, the region doesn't have many large native tree areas, but these trees are holding a large amount of erosion back. Hawke's Bay and Manawatū–Whanganui, have large areas of mānuka/kānuka (which might indicate a higher mānuka honey production).

(iii) Budget of intervention. Cost of intervention should be placed against the figures we estimated for the impacts.

- Co-invest in national level modelling of potential economic impacts, including production losses and additional control costs.

Recommendations related to socio-cultural impacts & responses

- Support iwi and hapū to develop cultural indicators of myrtle rust impacts that are appropriate for each mana whenua group and to illustrate connections to wellbeing, knowledge transfer and Māori cultural values. This is necessary to ensure Māori values and aspirations are protected and to support mana whenua in their role as kaitiaki. To the extent possible and acceptable to the mana whenua groups involved, draw upon the established methodology used for Kauri Cultural Indicators and measures of mauri so that the measures produced may be comparable to other areas and other cultural value impacts. The value of this work extends far beyond myrtle rust management, so this should be pursued with support and co-investment from other Crown entities.

- Building on findings from the Theme 1 survey of impacted individuals (Allen et al. 2019), co-invest in the development and testing of methods for measuring those indicators for social and cultural impacts of myrtle rust and management options identified as lacking agreed-upon assessment methodologies.

- Commission research, or work with existing data collection programmes (e.g. the Lincoln University Public Perceptions of New Zealand's Environment survey or MBIE tourist survey) for opportunities to add or adapt questions, to collect key social indicators, including myrtle rust knowledge, perceived impacts on the recreation and amenity value, and perceived impacts from management actions to establish a baseline and system for ongoing monitoring of social impacts.

- Work with key stakeholders (e.g., DOC, tourism sector organisations, and regional councils) to establish baselines on current recreational activities at sites where Myrtacaea are a landscape feature and valued for cultural or aesthetic reasons, and develop management plans for protecting high value areas.

- Future research and implementation engagements should include thorough research discussions and prioritisations with stakeholders to ensure that the breadth and depth of current knowledge is considered in strategic planning and implementation.

Evaluating impacts of and responses to myrtle rust in New Zealand

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Introduction

Myrtle rust (*Austropuccinia psidii*) is a fungal disease that affects many myrtles, including some of New Zealand's iconic species such as mānuka and pōhutukawa. Myrtle rust has been recognised as a biosecurity threat to New Zealand for several years (Ramsfield et al, 2010; Teulon et al, 2015), with the potential for movement from Australia since it was discovered there in 2010 (Carnegie and Pegg, 2018). The disease was discovered on mainland New Zealand in mid-May 2017 and since then has spread across the North Island and the South Island.

Following the arrival of myrtle rust into New Zealand the Ministry for Primary Industries (MPI) and the Department of Conservation (DOC), with local iwi, the nursery industry, and local authorities, attempted to contain and control myrtle rust and determine the extent of its spread (MPI, 2018). At the end of 2017, MPI commissioned the 'Myrtle Rust Research Programme 2017/18' (MPI Project 18607) to addresses critical knowledge gaps and to deliver real-life management tools for myrtle rust. In April 2018 MPI announced that it was moving from incursion response and attempts to eradicate the disease into long-term management.

The MPI Project 18607 is a collaboration between Scion, Plant and Food Research and Manaaki Whenua Landcare and comprises four themes: 1) building engagement and social licence, 2) Te Ao Māori, 3) improving management tools and approaches, and 4) evaluating impacts and responses.

Theme 4 – evaluating impacts and responses is the subject of this report. The output of this theme is a framework for a consistent and continuous process to evaluate the environmental, social, cultural and economic impacts of new diseases that affect the natural environment. The framework developed enables iteration for monitoring and evaluating impacts and responses that will allow for social learning and guide good decision-making over the long term.

The framework provides scope for integration of quantitative and qualitative indicators of impact that respond to public interests, including iwi, hapū and whanau aspirations. We expect the framework to be useful for different contexts and to help guide decisions across environmental, economic, social and cultural values at different scales of impact.

While indicators can simplify and quantify complex phenomena, they are best used when aiding development and operation of monitoring and evaluation systems (Allen et al 2012). Developing indicators provides an opportunity to anticipate impacts where more responsive decision-making is needed, and when impacts are realised in unanticipated ways.

The goals of this theme are to: (i) build a step-wise framework to establish robust baseline indicators that can help integrate the environmental, economic, social and cultural impacts of myrtle rust; and (ii) use modelling and impact assessment approaches to scope the potential environmental and economic consequences of myrtle rust based on the framework in (i).

The outputs from this theme are:

(i) A framework that identifies key indicators for reporting on national-scale consequences of myrtle rust, including environmental, economic, social and cultural indicators;

(ii) Evaluation of environmental and economic impacts of myrtle rust based on the indicator framework, identifying key gaps for further research.

The overall outcome of the theme is improved understanding of environmental, economic, social and cultural impacts to inform risk assessment and management and to communicate implications to decision makers and stakeholders. In this report, socio-cultural indicators refer to those indicators related directly to people (social) and to what people do (culture) in a broad sense. We have not specifically taken a Te Ao Māori approach but invite MPI to further develop relationships to initiate strategic partnerships in evaluating impacts and responses through cultural health indicators (e.g. Chetham and Shortland, 2013).

Specific outcomes arising from this theme are:

(i) Establishment of an environmental baseline against which to evaluate the impacts of myrtle rust;

(ii) Intervention management can be prioritised based on likely environmental, social, cultural and economic outcomes;
(iii) Decision makers will have an information base from which to understand the environmental, economic, social and cultural impacts of myrtle rust.

The framework produced in this report is underpinned by the understanding of impacts across the quadruple bottom line and existing guidelines and criteria for choosing environmental indicators. These issues are explored in the literature review. The methods section presents the process of coming up with an initial framework for monitoring and evaluating impacts and responses and the results section presents and discusses examples from following the framework process, followed by conclusions and recommendations for MPI and agencies. …

Literature review

This section provides an overview of important information used as background material for this report, including understanding impacts across the quadruple bottom line, optimising the choice of indicators and defining them, xxx.

Understanding impacts across the quadruple bottom line

Social, cultural, economic and environmental values are known as the quadruple bottom line. Quadruple bottom line (QBL) theory has a history in non-economic forms of capital (Bourdieu, 1986) and in understanding the importance of networks and relationships (Putnam, 1993) for enabling development that is sustainable in social, economic, environmental and cultural terms (Dalziel et al, 2009). We must understand why we are doing things in addition to what and how we contribute to social, environmental and economic aspects of development.

The New Zealand government's biosecurity system is intended to 'contribute to the protection of four interlinked values' comprising the QBL:

- Environmental – including indigenous biodiversity, ecosystems and landscapes, taonga species and valued exotic species
- Economic – including primary industries, trade and tourism
- Cultural – including Māori cultural and spiritual values
- Social – including New Zealanders' lifestyles, health and wellbeing, our national identity, and recreational and historical values." (MPI, 2016, p.4).

For the purpose of protection and response, biosecurity is described as "the exclusion, eradication or management of pests and diseases that pose a risk to the economy, environment, cultural and social values, including human health." (MPI, 2018b, p.7).

In this report, response refers to the range of activities undertaken in response to the threat of myrtle rust, including short and long-term management. This is a broader definition of response than that used within MPI incursion response activities. It is not just the response of myrtle plants to disease but also the response of humans to the disease including observing, planning, acting and reflecting on the disease impacts and monitoring and evaluating the effectiveness of response efforts. Response includes management of the social and technical aspects of response such as communication and engagement as well as surveillance and monitoring.

To gain a better picture of real world effects, we need to consider the range of experiences and concerns that people have regarding myrtle rust impacts as these will shape how they value different areas of impact and, therefore, which indicators should be prioritised. This requires consideration of what knowledge currently exists, what concerns people have, what resources are available to generate new knowledge, and what capacities exist to act. These are not purely science research questions but embody a complete set of actors and actions that include governance arrangements and engagement practices that need to be appreciated and coordinated to deliver the best possible outcomes under conditions of uncertainty.

Optimising choice of indicators

The role of an indicator is to provide insight into the current state or condition of a system (including social, cultural, economic and environmental systems), enabling managers to monitor changes over time and assess the impacts from a stress or of management interventions. Ideally, several indicators should work together in an integrated framework to ensure the system as a whole is well represented across values, scales and time (Niemeijer & de Groot, 2008; van Oudenhoven, Petz, Alkemade, Hein, & de Groot, 2012).

The Ministry for Environment provide a guideline to support the application of the Environmental Reporting Act (1993) by focusing on the system that indicators will represent. "Under the Act, topics must fit into one of the following areas:

- State – the condition of the environment. State topics explain what the characteristics of each domain are, and how are they changing over time. An example from the atmosphere and climate domain might be the 'state of greenhouse gases'.

- Pressures – human activities and natural factors that influence the environment. Pressure topics help explain why the domains are in the state that they are in. For example, ‘pressures from pests, diseases and exotic species’ in the land domain.
- Impacts – explain the consequences of the state and changes in the state for New Zealanders. These topics will cover the impacts on ecological integrity, public health, the economy, Te Ao Māori (the Māori world view), and culture and recreation. For example, ‘impacts on biodiversity and ecosystem processes’.” (MfE, Topics for Environmental Reporting: Consultation Document p.7)

Because indicators are explicitly linked to specific impacts, purposes and contexts, it is imperative that management programmes define specific objectives and outcomes at each relevant spatial and temporal scale (Dale & Beyeler, 2001; Noss, 1999):

> “The purpose of measurement, the process of deciding what to measure, and determining who will benefit from the indicators are as critical as what to measure and how to define specific indicators and technical methods.” (Advisory Committee on Official Statistics, 2009, p. 7).

The primary challenge in selecting indicators, therefore, is in finding an acceptable balance of trade-offs (Dale & Beyeler, 2001). In the short-term, it is often necessary to start from the indicators which exist, rather than those which would be ideal, and then establish research to develop what is lacking over time (Layke et al., 2012).

The Ministry for Environment has developed a set of design principles to “ensure environmental reporting is: fit-for-purpose; meets the needs of audiences; and ensures high quality data, analysis and interpretation” (MfE, 2014. A Framework for Environmental Reporting in New Zealand, p. 6). To ensure reporting remains robust and transparent, MfE have based criteria on Statistics New Zealand principles and protocols. A summary (abridged) version of these principles is outlined by six criteria for selecting indicators in Table 1.

Table 1. Criteria and their description for selecting environmental indicators

Criteria	**Description**
Relevance	The degree to which the data meets user needs in coverage, content and detail.
Accuracy	The degree to which the information precisely describes the phenomena it was designed to measure.
Timeliness	The degree to which data produced are up-to-date, published frequently and delivered to schedule.
Accessibility	The ease with which users are able to access and understand the data and its supporting information.
Coherence/consistency	The degree to which data can be successfully brought together within a broad analytical framework and over time.
Interpretability	The availability of supplementary data and metadata necessary to interpret and use the indicator effectively.

Source: Abridged version from MfE 2014.

Defining optimal indicators

The role of an indicator is to provide insight into the current state or condition of a system, enabling managers to monitor changes over time and assess the impacts from a stress or of management interventions. They are individual variables, signals or signs that help to illustrate and characterise facets of complex systems in ways that are simple enough to be monitored, modelled and managed (Dale & Beyeler, 2001).

The selection of indicators necessarily depends on which impacts are valued and how the indicators will be used to determine whether that value is changing. For example, an indicator may be sufficient to show overall trends at a national scale over the long term but have too few data points or be too variable within a local area to help with local management decisions in the short term. Conversely, indicators specific to a time and place may be misleading when translated to the national scale. Ideally, several indicators should work together in an integrated framework to ensure the system as a whole is well represented across values, scales and time (Niemeijer & de Groot, 2008; van Oudenhoven, Petz, Alkemade, Hein, & de Groot, 2012).

Because indicators are explicitly linked to specific impacts, purposes and contexts, it is imperative that management programmes define specific objectives and outcomes at each relevant spatial and temporal scale (Dale & Beyeler, 2001; Noss, 1999). In its guidance on indicator development, Statistics New Zealand's Advisory Committee on Official Statistics (2009) cautions:

> "The purpose of measurement, the process of deciding what to measure, and determining who will benefit from the indicators are as critical as what to measure and how to define specific indicators and technical methods." (p. 7)

If objectives are unclear or overly broad when establishing a baseline and monitoring process, it increases the risk that the indicators selected will not meet future management needs (Dale & Beyeler, 2001). However, it is possible—or even ideal—for indicator development to occur as a part of an iterative adaptive management process where draft indicators are used as discussion points to help collaborative partnerships identify shared values and prioritise outcomes (Garrett, Ausseil, Williams, Dominati, & Dymond, 2016).

Several works have attempted to define the characteristics of an ideal indicator without clear consensus (e.g. Dale & Beyeler, 2001; Feld, Sousa, da Silva, & Dawson, 2010; Niemeijer & de Groot, 2008; Scholes, Biggs, Palm, & Duraiappah, 2010; van Oudenhoven et al., 2012); however, several themes are common throughout the assessment literature:

- **Relevance –** Indicators must serve the ultimate purpose of the assessment and monitoring programme (Feld et al., 2010; Niemeijer & de Groot, 2008; Noss, 1999; Scholes et al., 2010). These should be assessed iteratively to adapt as needed (Layke, Mapendembe, Brown, Walpole, & Winn, 2012), ideally in conjunction with stakeholders (Garrett et al., 2016).
- **Specificity** – Indicators must have a clearly defined relationship with the impact being assessed and be specific to that impact. They must respond in a predicable manner that reflects the particular stresses and/or management (Dale & Beyeler, 2001).
- **Reliability** – They must have a strong conceptual basis with a reasonably high level of reliability and validity—whether derived through western scientific methods, mātauranga Māori processes or other ways appropriate to the form of knowledge (Dale & Beyeler, 2001; Scholes et al., 2010). Indicators should be objective and quantifiable where possible (Dale & Beyeler, 2001; van Oudenhoven et al., 2012).
- **Ease of understanding** – In order for indicators to be meaningful for management discussions, they must be understandable to all, including scientists, stakeholders and policymakers (Dale & Beyeler, 2001; Scholes et al., 2010).
- **Sensitive across space and scale** – The spatial resolution must be appropriate to the impact being assessed and the purpose of the monitoring. Depending on the purpose of the indicator, it is often necessary to distinguish spatial differences (Scholes et al., 2010; van Oudenhoven et al., 2012). Indicators at a national scale may function adequately for overall impact assessment, but resolution at a local scale is typically necessary to be a meaningful guide for management decisions.
- **Sensitive across time** – There will typically be a delay between an impact and the ability to detect a change in the indicator for that impact. Particularly for some environmental indicators, the lag time before for impacts appear may stretch to decades or centuries. Good indicators change relatively quickly in response to changes in pressures or even before impacts occur (Dale & Beyeler, 2001; Scholes et al., 2010).

- **Practicality, ease of measurement and affordability** – Data collection for the indicators must be reasonably practical and cost-effective relatively to the impact being assessed (Scholes et al., 2010; van Oudenhoven et al., 2012). Conceptual indicators which are too impractical or costly to monitor cannot serve their purpose.
- **Data availability** – Data availability is a significant constraint, particularly for socio-cultural indicators which are often subjective and context-specific (Layke et al., 2012; van Oudenhoven et al., 2012). Existing data provides a baseline for comparison, allowing for immediate application of an indicator and comparison with other contexts. Without this data continuity, additional time will be needed before trends become apparent.

In practice, however, indicators are limited by realities including costs, the difficulty of measurement, lag-times between a pressure and its realised impacts, alternative explanations for change and the challenge of differentiating between normal variation and long-term trends. The primary challenge in selecting indicators, therefore, is in finding an acceptable balance of trade-offs (Dale & Beyeler, 2001). In the short term, it is often necessary to start from the indicators which exist, rather than those which would be ideal, and then establish research to develop what is lacking over time (Layke et al., 2012).

Indicator based reporting

Gabrielson and Bosch (2003) stated that a framework and presentation of indicators is not enough to develop a working list of indicators and an indicator-based report. A process involving the various partners needs to be set up and is equally important as capturing scientific and technical knowledge of an issue. Gabrielson and Bosch offer an initial description of requirements for an indicator-based reporting process, summarised in six steps:

1. Agree on a story: a description of the problem and its solutions;
2. List (most important) policy questions that arise from the problem description;
3. Select (ideal and actual) indicators that come close to answering these;
4. Data compilation;
5. Assessment;
6. Conclusion and communication of key messages (and modify, adapt, update and iterate) (Gabrielson and Bosch 2003, p. 17).

It is common for those coordinating an indicator reporting processes to jump immediately to Step 3 without having first considered the purpose for developing indicators. Steps 1 and 2 are critical parts for defining the problem and potential solutions, and then considering the policy questions that rise from this description. Indicators then become tools for helping answer these questions.

Steps 4 and 5 in Gabrielsen and Bosch recommendations also need to be undertaken by stakeholders and partners involved in defining a particular problem and testing of solutions (Indicator based reporting, Gabrielsen and Bosch, 2003, p. 17).

Prioritisation of taonga myrtle species by Māori

Alby Marsh and Hone Ropata conducted an extensive engagement process, gaining insight what's important to Māori in a myrtle rust response plan and prioritisation strategy for native New Zealand Myrtaceae (Biological Heritage, 2017). They propose three main themes for prioritisation of taonga as:

- Prioritisation of places;
- Prioritisation of species/ genera; and
- Prioritisation of special individuals and populations.

Effort ought to be focused on where myrtle rust is present and where favourable climate conditions apply, as a priority (Figure 1; Biological Heritage, 2017). Priority needs to be given to plant species that are most susceptible to myrtle rust and specific attention needs to be given to populations of native Myrtaceae species, especially those of cultural significance.

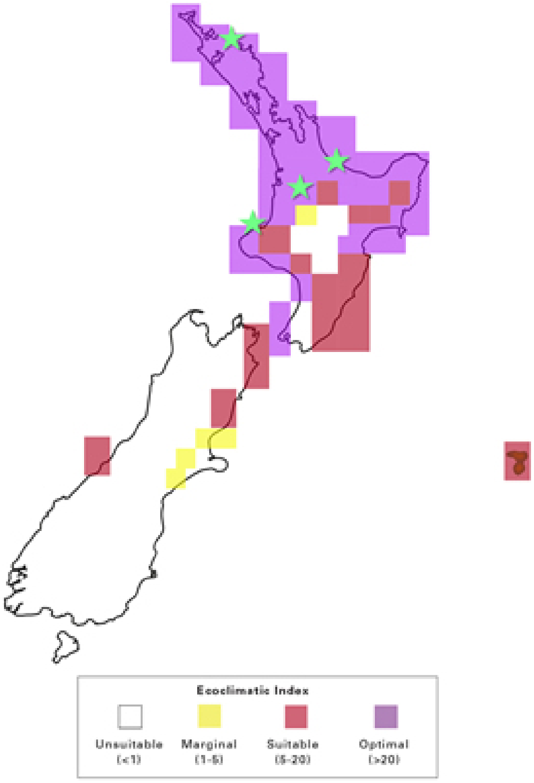


Figure 1. Map of New Zealand showing climate suitability for *Austropuccina psidii* under current (1971-1990) climate averages as indicated by the CLIMEX Ecoclimatic Index, published by Kriticos & Leriche (2008). Note: Green overlays indicate current hotspots for *Austropuccina psidii* as of September 2017, Kerikeri in Northland; Te Puke in the Bay of Plenty; Te Kuiti in Waikato; and New Plymouth in Taranaki.

Further concern regarded the official response to the incursion that has potential consequences for Māori communities, e.g., on moving plants between rohe and for those whose livelihood is dependent on healthy plant nurseries, as well as those who have invested time and resources into conservation efforts (Biological Heritage, 2017). As other questions about impacts are answered, prioritisations may change, especially if they impinge on cultural practices and uses of Myrtaceae.

Using multiple indicators: Conservation status of New Zealand's native Myrtaceae species

Key impacts may be represented by multiple indicators, as is the case for evaluating the conservation status of species. The conservation status of native Myrtaceae is an aggregate of other indicators brought together into an international assessment class. This provides an example of how indicators are brought together to serve a particular purpose. In this case, they are indicators from across various aspects of environment for establishing the conservation status of a species.

In the most recent (2017) assessment of the conservation status of New Zealand's indigenous vascular plants, de Lange et al. (2018) specifically reviewed the conservation status of the indigenous Myrtaceae because of the arrival of myrtle rust in the Kermadec Islands and the main islands of New Zealand. The assessment was informed in part by how closely related endemic New Zealand genera are to Australian genera that have been affected strongly by myrtle rust (the assessment of species in the endemic genera *Lophomyrtus* and *Neomyrtus* reflects their close relationship to Australian genera that are strongly affected). The threat status of New Zealand *Metrosideros* species was also made in the context of their probable vulnerability to another pathogen, *Ceratocystis lukuohia* and *C. huliohia* (rapid ʻōhiʻa dieback), which are present in Hawaiʻi (Barnes et al. 2018) but not in New Zealand.

Nine New Zealand species are assessed as nationally critical, including ramarama, rōhutu, and maire tawake (Table 15). To put this in context, this is the same status assigned to endemic birds that capture public attention such as kākāpō and black robin (Roberston et al. 2016).

Table 1. Conservation status of New Zealand's native Myrtaceae species.

Conservation status	Species
Nationally critical	*n* = 9; *Kunzea sinclairii, K*. *toelkenii*, *K*. *triregensis*, *Lophomyrtus bulllata*, *L*. *obcordata*, *Metrosideros bartlettii*, *M*. *kermadecensis*, *Neomyrtus pedunculata*, *Syzygium maire*
Nationally endangered	*n* = 2; *Kunzea salterae*, *K*. *tenuicaulis*
Nationally vulnerable	*n* = 15; *Kunzea amathicola*, *K*. *linearis*, *K*. *robusta*, *K*. *serotina*, *Leptospermum scoparium* var. *incanum*, *Metrosideros albiflora*, *M*. *carminea*, *M*. *colensoi*, *M*. *diffusa*, *M*. *excelsa*, *M*. *fulgens*, *M*. *parkinsonii*, *M*. *perforata*, *M*. *robusta*, *M*. *umbellate*
At risk	*n* = 1; *Leptospermum scoparium* var. *scoparium*

Part 1 – A framework that identifies key indicators for reporting impacts of myrtle rust

1.1 Methods

To evaluate the consequences of myrtle rust and its management, New Zealand requires robust indicators for environmental, social, cultural and economic systems and processes for prioritising them. We built a step-wise framework to identify indicators that can be implemented for evaluation as data become available. Where possible, we provide baseline values for measuring the long-term impacts of myrtle rust.

The original work plan for theme 4 (Appendix A) describes the process as it was planned; however, the formulation of the framework itself has resulted in the following order of steps (Figure 2):

1) Define the desired outcome(s) and evaluation framework(s)
2) Identify indicators and data sources
3) Prioritise areas of impact
4) Assess potential impacts: Test indicators
5) Review framework and document lessons.

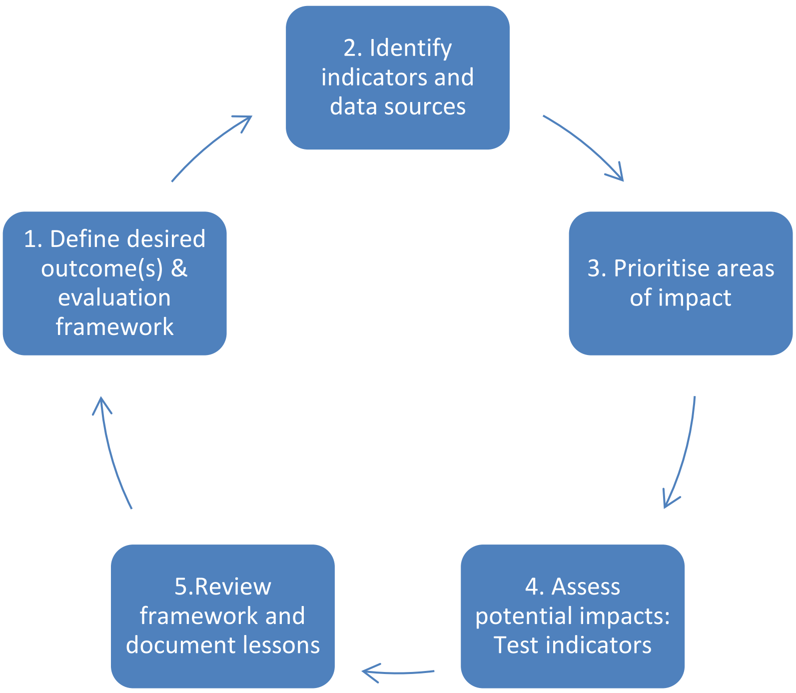


Figure 2. A step-wise framework to establish robust baselines and indicators

Step 1. Define desired outcome(s) & evaluation framework(s)

We used the overall theme outcome of '*improved understanding of environmental, economic, social and cultural impacts to inform risk assessment and management and to communicate implications to decision makers and stakeholders*' as proxy outcome for this research. While conducting this research, the Myrtle Rust Programme as a whole was undergoing a shift from eradication to long-term management.

In the absence of an officially agreed-upon strategy or clearly defined outcomes for myrtle rust at the time the framework was developed, we adopted the QBL perspective (environmental, economic, and socio-cultural[1]) that underpins the broader Biosecurity 2025 Direction for New Zealand's biosecurity system as the basis for assessment (MPI, 2016).

We first listed a group of issues and potential indicators related to myrtle rust short and long-term management and then explored three system thinking tools to support the development of the framework as part of step 1:

- Dynamic causal loop map
- Drivers, Pressures, States, Impacts, Responses (DPSIR)
- Logic or outcomes model

We considered these three tools useful based on our collective expertise and experience, bringing together social and technical aspects of impacts and response. We explored these tools as ways to conceptualise and communicate impacts and to help identify priority areas where indicators would be needed to measure the impacts of both the pathogen and its management.

Each of these tools can be considered as different parts in the analytical process, of i) exploring complex causal relationships; ii) understanding and designing effective points of intervention (to achieve desired outcomes); and iii) developing a logic model to assist in monitoring and evaluating impacts and responses (interventions).

Dynamic causal loop map

A dynamic causal loop map is a useful tool for decision makers looking at ways of analysing the interacting effects of different actions (nodes) in a complex system. A dynamic causal loop map can help make decisions around the mitigation of negative impacts and the design of response systems, appropriate actions and prioritisation in different contexts.

We mapped different myrtle rust issues to explore how they are related, indicating potential positive (the indicator increases) or negative (the indicator decreases) interactions. Mapping these relationships can help to identify early changes that are precursors to later impacts, possible feedback loops and key nodes which may cause multiple other cascading impacts (Niemeijer & de Groot, 2008). However, the complexity of the map and high degree of uncertainty regarding the strength of many relationships can make this approach impractical without facilitated support and investment potential to resolve uncertainties. Thinking with this model has underpinned the development of the indicator matrices across the four areas of impact (Appendix A).

Drivers, Pressure, States, Impacts and Responses (DPSIR) model

A DPSIR model is used in environmental decision-making to make explicit the set of dynamic elements impacting a system undergoing change and ways of intervening to give effect to desired outcomes. This tool is used for developing environmental indicators and especially for meeting sustainable development goals (OECD, 1991). Like the dynamic causal loop model, the DPSIR model is a way of mapping and simplifying complex interactions and its use may require facilitation to support management and decision-making.

The DPSIR model was introduced during the myrtle rust science workshop (13–14 September 2018) and discussed as a way of usefully linking across the social and natural sciences and policy/management for myrtle rust. This model is commonly used when developing environmental indicators because it helps to clarify the interactions within and between complex social, cultural, economic and environmental systems as well as the influence of management actions (e.g. Feld, Sousa, da Silva, & Dawson, 2010; Niemeijer & de Groot, 2008). This model was used to map the latest research in myrtle rust as part of MPI Project 18607 and joint research activities (see Appendix C).

[1] Socio-cultural are used here in hybrid form to make a distinction between Māori cultural indicators and those used more generally with respect to the whole New Zealand population.

Logic or outcomes model

A logic model is useful for management because it follows a step-wise process for working within a theory of change with focus on monitoring and evaluating the effects of management actions. Although it provides a less integrated view of the complex interactions between causes and impacts than the other models, the logic model provides simplicity and ease of use for management practitioners. We discussed the logic model as a pathway to relate specific outcomes to long-term impacts and to plan for interventions to facilitate desired outcomes.

We adapted a logic model (Scion and He Oranga mo Nga Uri Tuku Iho Trust, 2018; and AgResearch, 2016) by adding monitoring and evaluation components through all aspects of activities. We then took one example of the myrtle rust strategic outcomes to illustrate how the model would apply in practice.

We provide an illustrative example of using the logic model for one of the goals identified in the myrtle rust strategy draft made available in April 2019.

Step 2. Identify indicators and data sources

We discussed the problem of pest incursion and gathered high level information about myrtle rust focusing on potential impacts. A list of potential impacts from myrtle rust and myrtle rust management on the QBL values was formed based on a scan of literature, the model explorations in Step 1 and expert knowledge from diverse research backgrounds, including:

- Plant pathology;
- Kaupapa Māori;
- Ecology;
- Sociology;
- Environmental economics;
- Ecological economics
- Systems thinking; and
- Behavioural science.

We considered each potential impact from two perspectives to identify a set of initial indicators:

- the first perspective involved considering those indicators which would be ideal, even if the data were not currently available; and
- the second perspective involved identifying existing data sources which could be adapted to serve as possible indicators, even if they had limitations as indicators.

Both types of indicators were included in the initial list. We then classified the indicators as environmental, economic and socio-cultural. These were compiled in a table format using Excel within a single spreadsheet for each impact area and described according to the following fields:

- Impact description:
    - Environmental e.g. Impact on biodiversity (supporting ecosystem services)
    - Economic, e.g. Impact on productivity of mānuka for oil
    - Socio-cultural, e.g. Impact on recreation
- Direction of impact: (+) or (-)
- Indicators (examples) per impact
- Data availability
- Data sources
- Data owners
- Existing data coverage
- Spatial resolution
- Impact lag time (latency)
- Specificity to myrtle rust
- Work required to address data gaps or make the data ready for use
- Known limitations and notes

These initial indicators were then presented to other project theme leaders and researchers for comment at the first Myrtle Rust science workshop on 13-14 September 2018.

Step 3. Prioritise areas of impact and develop baseline indicators

Prioritisation is part of the initial requirement for supporting engagement and planning processes. This step needs to be undertaken with the input of stakeholders. It is likely that priorities will vary across different types of stakeholder groupings and levels of concern across different or combinations of areas of impact.

Due to resource constraints we could only do a preliminary prioritisation, including:

- We reviewed the indicators from step 2 and prioritised them following a desktop review and alignment with the MfE guidelines for developing indicators. This resulted in an updated indicator matrix of national level indicators in Excel format (Appendix D).

- We shared the indicator matrix with participants of the Myrtle Rust science workshop held on 13-14 September 2018 and of the Strategic Science Advisory Group Science Symposium and Workshop held on 13-14 December 2018. Specifically, researchers and stakeholders attending these workshops were invited via email to review the indicators and the availability of current data, where existing data was insufficient, and what work could be necessary for additional data collection, modelling, methodological development.

- In parallel, we reviewed theme 1, 2 and 3 data to further identify areas of potential impact of myrtle rust. This included data from the Taranaki case study including interviews, and a national online survey of impacted individuals; and data from three hui (16-19 July 2019, New Plymouth, Te Puke and KeriKeri) conducted as part of the surveillance aspects of theme 3 and theme 2.

Step 4. Assess potential impacts: Test indicators

Step 4 was completed using two different national level assessment approaches: i) an environmental baseline using existing data and a protocol for calculating these indicators in the future; and ii) an application of the framework across the QBL for creating a baseline for assessing the impacts on mānuka honey industry in economic terms.

A preliminary test of national level indicators was initiated for the environmental indicators including: the number of plant species potentially affected, and the distribution of indigenous trees. The baseline includes occurrence of native Myrtaceae in plots on national 8-km grid through indigenous forests and shrublands.

National level indicators for economic impacts were tested using one element from each of the economic, environmental and social QBL areas as applied to the mānuka honey industry, where data was available.

Detailed methods for (i) and (ii) above are explained in Part 2 of this report.

Step 5. Review framework and document lessons

Step 5 involved reviewing the framework development process and documenting lessons for future application. To achieve this step, MPI provided feedback on a draft report and we reviewed the April 2019 Myrtle Rust Draft Strategy and the May 2019 Myrtle Rust Draft Science Plan to explore how the framework described in this report can inform these two documents and implementation plans. We also reflected on the inputs gathered and the process followed for any lessons in practice.

This step allowed for incorporating lessons as new knowledge became available (Figure 3). For example, potential users who reviewed the framework asked:

- What do we know about the impacts of myrtle rust at the moment?
- What challenges occurred when integrating qualitative and quantitative indicators (i.e. ‘mapping’ tangible and intangible impacts by capturing both narratives and numbers)?

Figure 3. Risk management actions changing across time informed by new knowledge.

In step 5 we also apply the logic model developed in step 1 to one area of outcome from the strategy as an illustration of how this framework can be used in conjunction with the Myrtle Rust Strategy.

1.2 Results and discussion

Step 1. Define desired outcome(s) & evaluation framework(s)

As explained in the methods section, we guided our research with the overall outcome of improved understanding of QBL impacts to inform risk assessment and management and to communicate implications to decision makers and stakeholders.

We explored three systems thinking tools as models for developing the evaluation framework. The dynamic loop map and the DPSIR tools helped us to develop the indicators matrix and potential points of intervention. Following the application of these tools, the logic model was proposed as a tool to support strategic planning and investment activities as well as a for ongoing monitoring and evaluation of implementation.

The dynamic causal loop map provided a model to explore the complexity of interacting QBL impacts and identify key areas of impact for which data was available or would need to be generated. The DPSIR tool was used to capture the breadth of myrtle rust research currently underway that could inform strategic decision makers on key areas of impact and identify potential responses (interventions). The logic model included drivers of long-term impact and problems or opportunities for intervention as important considerations for decision makers. It also included the need to reflect on assumptions and risks as time progresses to adapt response activities (e.g., from incursion response to long-term management) as new knowledge emerges.

Systems tool 1: Dynamic causal loop map
Following an initial meeting of the authors with other researchers from theme 1 and 2, we mapped complexity of cause and effect – through the online application Loopy v1.1 (Appendix B), a tool for modelling and observing effects of interacting systems through dynamic casual loop mapping. This helped to visualise and prioritise potential areas of impact and categorise them into QBL domains. Figure 4 shows the colour coded impact domains and key areas to consider for generating baseline indicators. The map is dynamic when accessed online at: https://bit.ly/2Nfj6D4

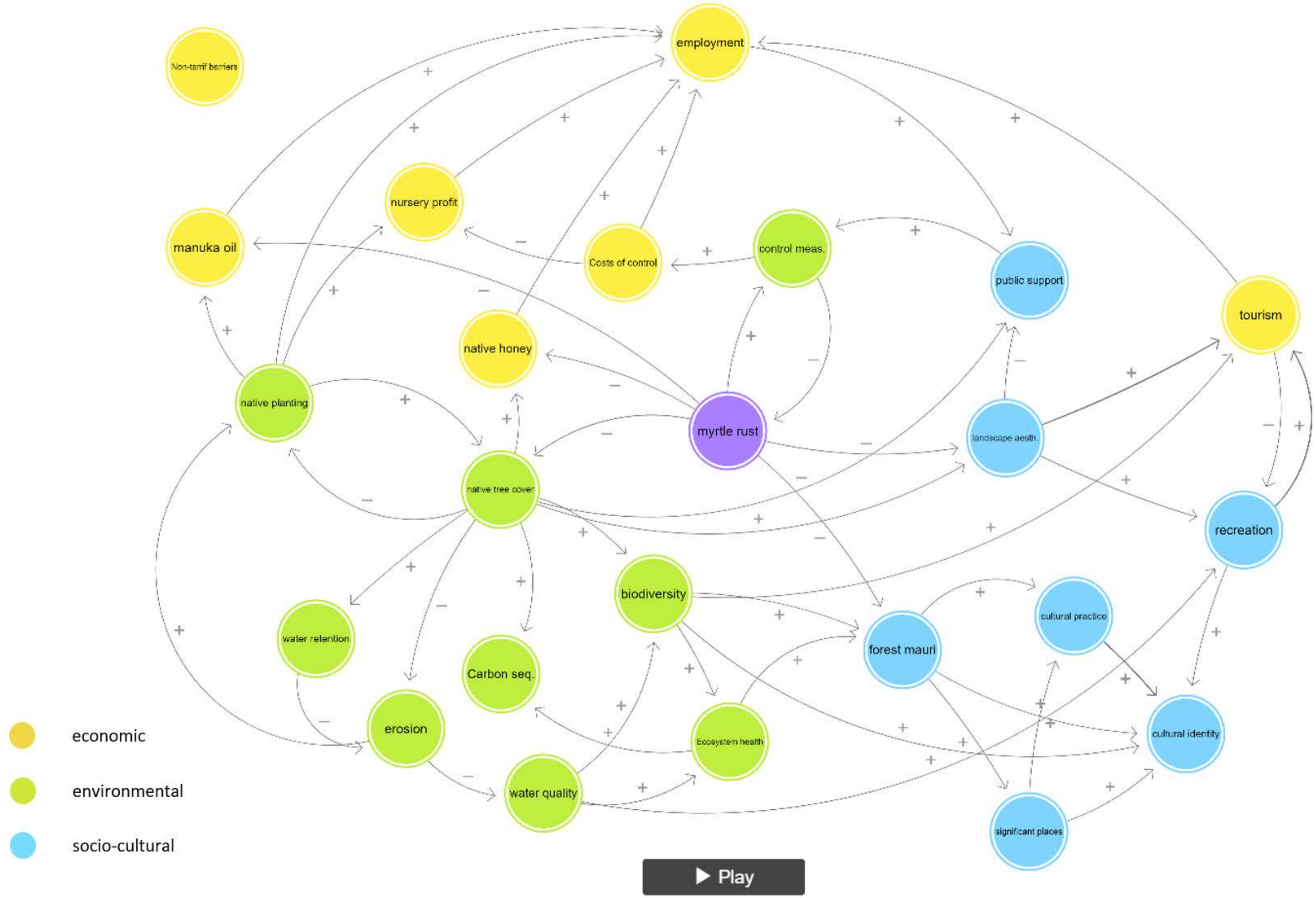


Figure 4. Systems tool 1: A dynamic causal loop map of myrtle rust impacts colour coded for economic, environmental and socio-cultural impacts

Systems tool 2: Drivers, Pressures, State, Impact, Responses (DPSIR) model
A Drivers, Pressures, State, Impact, Responses (DPSIR) model was drawn during the myrtle rust research workshop (Allen, 2018) held on 13-14th September 2018 to help visualise complexity of myrtle rust and knowledge needs (Figure 5). This provided a mechanism to capture a comprehensive map or rich picture of the current knowledge base and research activities (Appendix C). The DPSIR rich picture was simplified to support the development of thinking around known and unknown aspects of impact and potential areas of intervention (Figure 6).

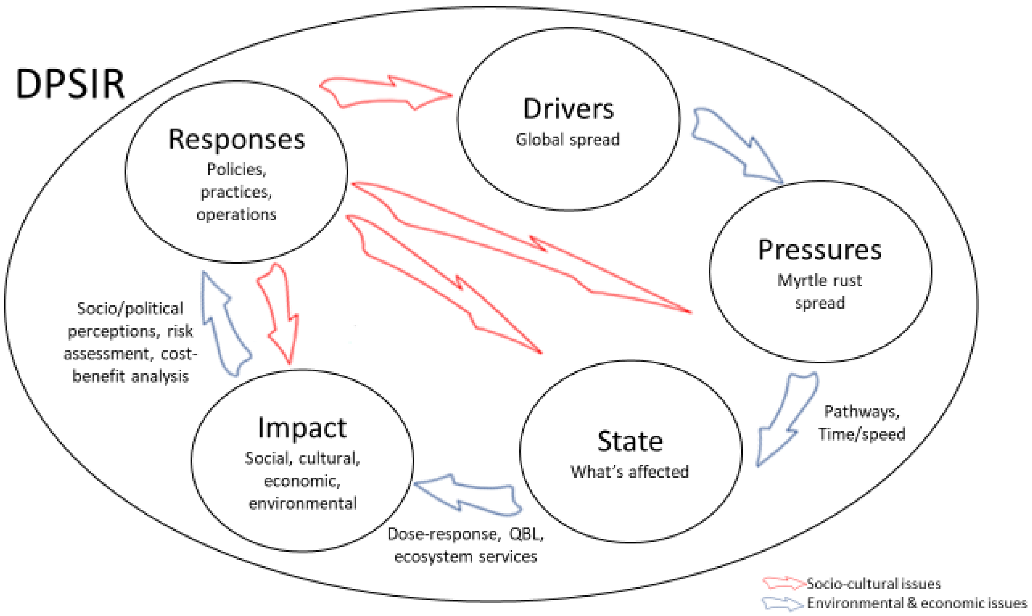


Figure 5. Systems tool 2: A graphic of the hand drawn DPSIR model shown at Myrtle Rust research workshop.

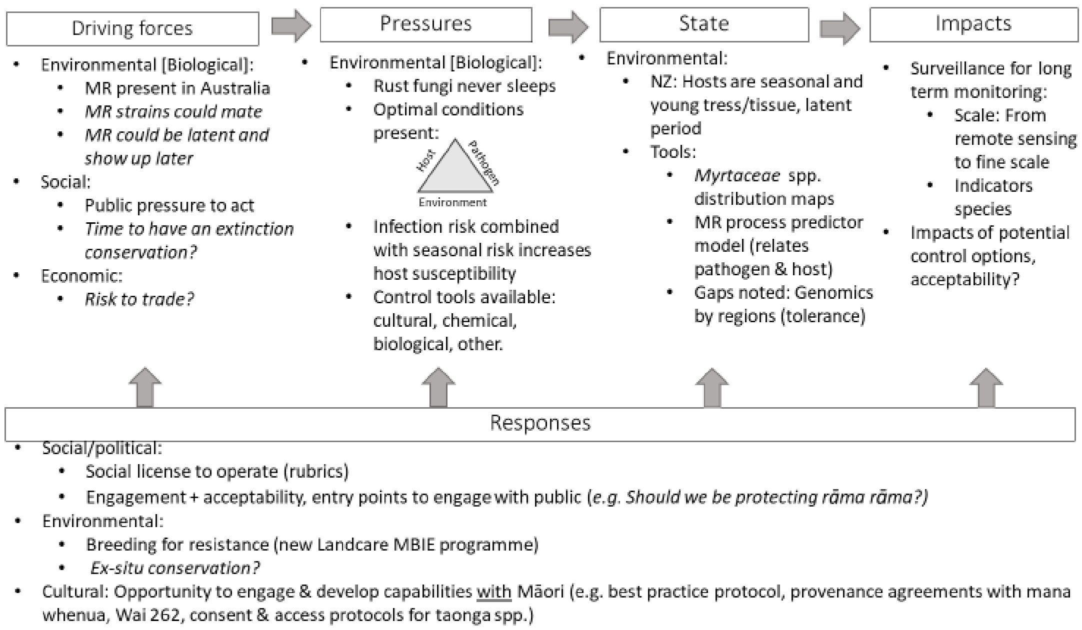


Figure 6. Simplified version of DPSIR rich picture used to develop thinking around potential areas of intervention (response actions).

Systems tool 3: Logic or outcomes model
A logic or outcomes model was developed based on previous work (Scion and He Oranga mo Nga Uri Tuku Iho Trust, 2018; AgResearch, 2016). Figure 7 shows the model to be applied by strategic decision makers and their partners for prioritisation of investment and implementation plans.

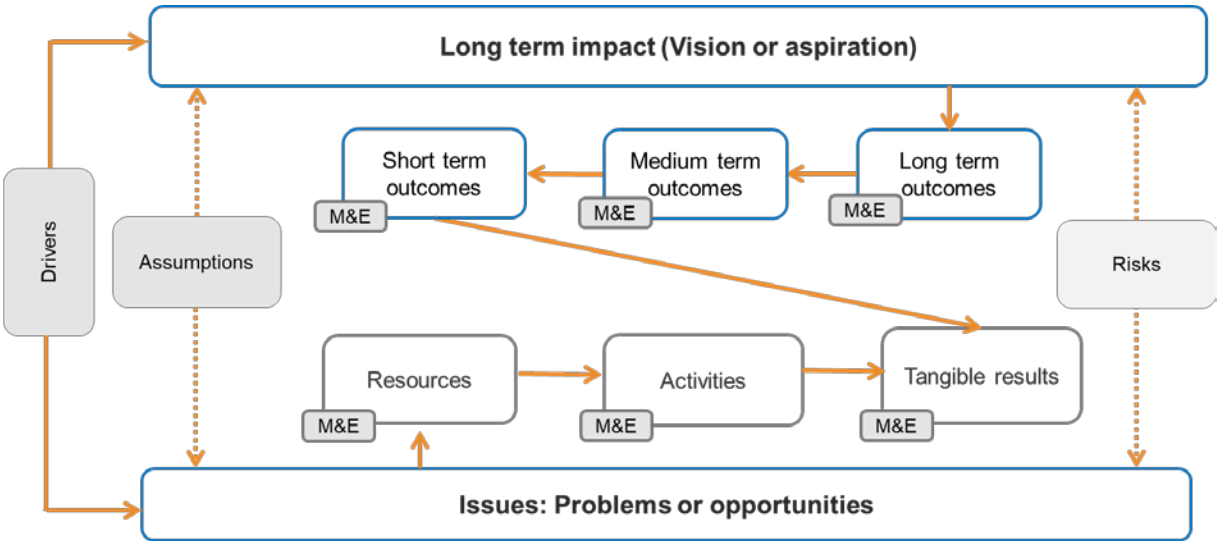


Figure 7. Systems tool 3: Logic and evaluation framework for myrtle rust (adapted from Scion and He Oranga mo Nga Uri Tuku Iho Trust, 2018; and AgResearch, 2016).
Note: M&E = monitoring and evaluation indicators.

This model includes evaluating assumptions, risks and drivers long-term impact of myrtle rust and problems or opportunities for intervention as important considerations for decision makers. The model allows for selecting indicators that are robust (consistent and continuous) over the short and long-term management of myrtle rust.

As the MfE guidelines for development of environmental indicators notes “consistency and continuity” is needed over time. MfE also notes that “It will take time to refine this system and get the reliable, well-structured and relevant statistics to support a cleaner environment.” (Topics for environmental reporting: Consultation document, 2015p. 5). The same would apply for managing myrtle rust.

Step 2. Identify indicators and data sources

A summary (abridged) version of the indicator matrix (Table 2) shows the type of impact and data availability on potential QBL impacts of myrtle rust at the national level.

Few of the indicators identified are considered ready for immediate use. Most would require at least some additional work to make the data specific to Myrtaceae species, to improve data coverage or to address other known gaps and limitations before reliable baseline data could be provided. In some cases, indicators will require the development of new processes, models, and research methods. This is particularly true of socio-cultural indicators, where some indicators will require significant engagement and co-development with mana whenua at the rohe scale, repeated across the affected areas.

While ongoing data collection for some indicators is already funded through existing programmes (e.g. economic statistics collected for regular reporting by MBIE), additional long-term funding will be required to repeat measurements and monitor changes for most of the indicators identified. Potential limitations for each indicator were noted under the field ‘known data gaps/notes’.

The indicators table also provides working space for practitioners to assess risk and response options for their given context, including fields for:

- initial risk evaluation;
- response: Potential response (e.g. education for prevention, management, etc.); and
- risk evaluation after response.

It is expected that Table 2 and Appendix D provide an overall guide to thinking about indicators but is not definitive for all types of impact settings. Much will be learnt from the experience of myrtle rust and its survival and control in different geographical and social settings. This requires flexibility in how the indicators 'tool' and evaluation framework is used, as is the case for the cultural indicators methodology developed for Kauri health (Chatham and Shortland, 2013).

The indicators developed could be applied to other pests and diseases in the broader context of biosecurity and ecosystems health. Further, a recently funded MBIE Programme "Beyond Myrtle Rust, towards ecosystem resilience" may be an ideal vehicle to continue the identification and refinement of indicators of myrtle rust impact from an ecosystems perspective.

Table 2. Impacts, indicators and data availability (abridged; see full version in Appendix D)

Impacts	**Indicators**	**Data availability**
Indicators for environmental impacts of myrtle rust		
Biodiversity	Number of plant species potentially affected	Ready to use
Biodiversity	Status of widespread indigenous trees (recruitment vs mortality)	Existing data but work required to use
Biodiversity	Distribution of indigenous trees	Existing data but work required to use
Biodiversity	Land cover change	Existing data but work required to use
Air quality & climate regulation	Carbon sequestration (t/ha/year)	Existing data but work required to use
Water regulation	Water yield (mm/ha/year)	Existing data but work required to use
Erosion control	Sediment level (t/ha/year)	Existing data but work required to use
Water regulation	Flood control (Frequency?)	Existing data but work required to use
Natural Hazard Protection	Floods, storms, droughts (frequency?)	Not currently available
Pollination	Nectar or pollen production (kg/ha)	Limited data available

Impacts	Indicators	Data availability
Indicators for economic impacts of myrtle rust		
Impact on tourism industry	Number of tourism concessions on conservation land	Existing data but work required to use
Impact on tourism industry	Number of tourists citing 'spectacular landscapes and natural scenery' as reason for visiting or their subjective rating of NZ's natural environment	Ready to use
Impact on tourism industry	Number of tourism operators or people in tourism employment	Ready to use
Impact on tourism industry	Number of visitor nights	Ready to use
Impact on industry (nurseries, plant producers)	Numbers of nurseries raising and retailing native species	Existing data but work required to use
Impact on industry (nurseries, plant producers)	Revenue from retail of Myrtacea species	Not currently available
Productivity of mānuka for honey	Reduction in productivity ($/ha)	Not currently available
Productivity of mānuka for oil	Reduction in productivity ($/ha)	Not currently available (only sample budgets)
Additional control costs (by producers & government)	Additional costs to control the fungus ($/ha)	Not currently available
Non-tariff barriers for trade	Potential ban or restrictions, $/ha	Not currently available
Indicators for socio-cultural impacts of myrtle rust		
Impact on wahi-tapu sites	Number of wahi-tapu sites impacted	Not currently available
Impact on mauri	Subjective assessments of mauri / site quality (e.g. Mauri-ometer or Mauri Compass)	Not currently available
Community and cultural health	Ability to support Māori cultural practices and knowledge transfer	Not currently available
Community and cultural health	Ability to support wider cultural practices	Not currently available
Community and cultural health	Change in sense of place, place identity	Not currently available
Recreation	Number of people using/visiting all recreation spots (e.g. hiking tracks, camping sites)	Existing data but work required to use
Recreation	Number of people using/visiting specific recreation spots (e.g. hiking tracks, camping sites)	Limited data available

Impacts	Indicators	Data availability
Recreation	Subjective assessments of recreational site quality	Limited data available
Iconic landscapes / amenity value	Number of sites that are considered as iconic part of NZ landscape	Existing data but work required to use
Iconic landscapes / amenity value	Formal Visual Impact Assessments of landscape quality	Limited data available
Iconic landscapes / amenity value	Subjective assessments of state of native bush and forests overall; state of natural environments	Existing data but work required to use
Iconic landscapes / amenity value	Subjective assessments of state of specific native bush and forest areas	Not currently available
Community and cultural health	Change in population number/employment	Not currently available

Step 3. Prioritise areas of impact with stakeholders

A complete prioritisation requires actions and resources to be identified with stakeholders. Given the limitations noted in the methods section, the results of this step correspond to a preliminary prioritisation.

We received nine responses to our email request for feedback on the indicator matrix, which have added some detail, suggested additional indicators on biodiversity, provided some critique about whether it is comprehendible for practitioners and offered concerns about static nature rather than focused on activities such as engagement and development such as increased awareness. A couple have acknowledged the set of indicators as comprehensive (Appendix D).

We also assimilated and synthesised some of the key concerns gathered during stakeholder engagement through workshops and hui throughout other theme research activities. Table 3 shows impact areas gathered from the theme 3 surveillance hui (14–16 July 2018). Attendees included central and local government agencies, hapū, community, industry and research organisations. Table 4 shows impact areas of concern from participants attending the theme 1 engagement and social licence workshop held in Tāmaki, Auckland Landcare offices on 15 August 2018. These tables are a guide for considering areas of impact that did concern people, and showed that concern was across the QBL.

The impact areas gathered through research conducted as part of other themes (1–3) support the QBL approach taken and they also provide additional perspective on indicators and impact assessment. Some of what has been captured here formed part of our expanded view of indicators that we subsequently refined into a baseline set for use at a national level.

Stakeholders will need to further reflect on how the impact areas highlighted in Tables 3 and 4 could be used in the development of strategic and science plans for responding to myrtle rust, including addressing aspects of knowledge and awareness; as well as the costs of removing plants or the implications for policies like MPI's Billion Trees programme. Nursery protocols, cultural consents and communication of risk will become important elements of response management plans as well.

Table 3. Myrtle rust impact areas as reported as surveillance hui

Impact area	Different perspectives gathered
Ecosystem impacts	ecosystem collapse; ecosystems level impacts; stressed ecosystem at tipping points; pollution impacts
Assessing impacts	myrtle rust reduced, low impact; impact of myrtle rust on natural communities;
Industry impacts	cultural and commercial damage; quantify the loss of these plants to our ecosystem and related industries; commercial operators, bees taxing pollen, regulated where they are operating; tourism tax; stop cultivating Myrtaceae in nurseries
Cultural impacts	people; significant cultural impact from loss of taonga; hapū response team – differ from tribe to tribe; kotahitanga
Coastal impacts	pōhutukawa on [the] coast, education; impacts of coastal erosion, especially with rising seas
Forest impacts	informal and formal forest users
Psychological impact	arrogant [attitudes]; collateral damage
Economic impact	cost of removal impacts; replacement of dead Myrtaceae
Social impacts	peoples' indifference; public access; [awareness of] what are you planting?
Ecological impacts	end point extinction; myrtle rust an opportunity, pōhutukawa stress by possums, initiate people to kill some possums
Policy impacts	billion trees factor
Climate impacts	impacts of climate change

Table 4. Impact areas of concern noted by participants of engagement and social license workshop

Environmental	Economic	Socio-cultural
landscape	loss of revenue	lifestyle
amenity	replacement trees	sense of place
recreation	investments in mānuka	recreational opportunity
habitat	investments in nursery stock	spiritual connection
biodiversity	cost of erosion control	learning resources
water quality	cost of ecosystem collapse	knowledge development
erosion control	enforcement costs	alternative medicines
future knowledge	biosecurity consultancy	alternative materials
		cultural identity

Step 4. Test indicators through worked examples

The results for this step are in Part 2 of this report. Importantly, an environmental baseline was produced, as well as an economic baseline considering impacts across the QBL.

Step 5. Review framework and document lessons

The framework was designed as an iterative process involving a cycle of steps to structure the development of impact and response evaluation. A quadruple bottom line (QBL) approach provided the starting point for developing this impact evaluation framework – and looking at the national level to work with the data available or that could be adapted to develop baseline indicators prior to realising the effects of myrtle rust.

We also reviewed the strategy and provided an illustrative example of how this framework can be reapplied with the Myrtle Rust Strategy. In this step, lessons gained from the process of developing and testing the framework (Figure 2) are identified to assist in its future use.

Lesson 1. To be effective, the systems tools explored need to be applied with stakeholders and indicators prioritised as part of that process. Using the logic model to organise impact areas and prioritise indicators will help identify gaps in resources, activities and tangible results needed to achieve the outcomes. Such joint decision-making needs to be facilitated as there are many perspectives that need to be considered, and priorities and issues aligned in a way that can generate an agreed vision and plan of action (as suggested by Gabrielson and Bosch's (2003). Furthermore, any application of the framework would need to be developed with strategic decision makers and prioritised with mana whenua as required in different rohe.

Lesson 2. Indicators will have different meaning in different contexts. Additional indicators will have a pragmatic focus and vary from region to region, depending on different interests and values (including Māori cultural values). We did set a wider lens on indicators to tease out details and then returned to a simpler, more abstract set that could be useful for establishing baselines. We expect that this set will be expanded on and better defined to suit different contexts.

Lesson 3. Limitations exist for the indicators as a static set of categories and what they mean in a real-life setting of decision-making. Only then, can we highlight how any 'indicator' work needs to be tied to a set of actions, with goals and desired outcomes described and means of achieving them. Our logic or outcomes model provides an ideal method for structuring this discussion amongst strategic partners involved in short, mid and long-term response. The indicators then become a 'measure' of efficacy, etc and must be tied to that desired direction. Ideally indicator development needs to occur as a part of an iterative adaptive management process where draft indicators are used as discussion points to help collaborative partnerships identify shared values and prioritise outcomes.

Lesson 4. Socio-cultural indicators need to be developed and prioritised at the local level. While the initial focus of the framework was at the national level, it was expected that socio-cultural impact indicators will be more relevant at the local or regional level. Further, cultural indicators specifically related to Te Ao Māori also need to be reflected (e.g., Kauri cultural indicators methodology by Chatham and Shortland, 2013). It is likely that new areas of socio-cultural impact will relate directly to management actions, and therefore form a new set of indicator categories related to responses, including increased knowledge and awareness of myrtle rust. These will be essential to know how well management actions are performing in relation to the desired outcomes of the National Myrtle Rust Strategy and Science Plan.

Lesson 5. As specific outcomes for myrtle rust management are defined, strategic decision makers and their stakeholders will need to re-enter the step-wise framework at Step 1 (Figure 2) to ensure the indicators are appropriate and can be tailored for the newly defined outcomes as per the Draft Myrtle Rust Strategy (MPI, 2019). The framework and set of tools have been developed with the degree of flexibility required to be adapted for this purpose.

Lesson 6. As new knowledge becomes known about the impacts and effectiveness of responses, desired actions may change. The move from incursion response to long-term management has provided a test case for this. We can use this knowledge as a basis for understanding the change in activities and the different kinds of partnerships and resources required in moving from incursion response to long-term management.

Lesson 7. Step 4 (test indicators) has initially focused at the national level with economic and environmental indicator scenarios developed, noting that socio-cultural indicators are more localised and may require a different scale of assessment. To complete this step and ensure a range of priorities are addressed, assessment criteria for selecting sites needs to be formulated.

Lesson 8. The values for biodiversity are difficult to quantify. However, biodiversity impacts go beyond myrtle species themselves as forest floor, insect and ecological communities dependent on myrtle plants will also need to be accounted for as potential biodiversity losses.

We have also generated a set of research priorities based on the science workshops of September 2018 and science plan resulting from the December 2018 science symposium and looked at areas of priority for research identified during data collection and engagement activities of themes 1 to 3. We have looked at these in terms of the data gaps in the indicator matrix and how they align or otherwise (Table 5).

Priorities are likely to change over time as impacts are realised and desired outcomes of interventions are achieved or not. The Ministry for the Environment has recognised the need to have 'consistency and continuity' in indicators to enable data comparability over time. If objectives are unclear when establishing a baseline and monitoring process, it may increase the risk that the indicators selected will not meet future management needs. Decision makers need to be prepared to change indicators if they are not fit for purpose, as strategic direction unfolds from experiences with myrtle rust.

Table 5. Research priorities grouped by authors

Research priority group	Keywords from cards
Environmental aspects & short-term outcomes	
Environmental impacts of disease	e.g., weather impacts, tree location, climate impacts, ecosystem balance, environmental change
Contextual/ environmental relationships	e.g., genetic geography, soil relationships, symbiotic associations, host interactions, soil interactions, atmospheric protection
Disease behaviours/ life cycle	(locally in NZ environment): e.g., co-morbidity/ virulence, latency period, disease utility (?)
Species and other variations	e.g., species variations, other variation, hybrid plants, genetic variation
Human aspects & medium-term outcomes	
Impacts of management	e.g., fungicide impacts, bee management
Effectiveness of interventions	e.g., Efficacy, technologies, cultural practices, mapping efficacy/ efficiency, hygiene practices, fungicide testing, fungicide impacts, bee management
Cross-site learning	(e.g., lab/ field tests): e.g., site comparisons, genetic geography, field/ lab experiments, overseas lessons
Indigenous / local knowledge	e.g., cultural practices, genetic geography, indigenous knowledge, ecosystem balance, community intellectual property (IP), community engagement, plant histories, environmental change
Uncertainties & long-term outcomes	
Plant response and communication	e.g., soil relationships, plant communication, soil interactions
Visibility/ invisibility of disease	e.g., mapping efficacy/ efficiency, canopy surveillance, invisible presence, human error
Resistance knowledge	e.g., selective breeding, observed resistance, immune response
Vectors/ spread knowledge	e.g., vector risks, natural vectors, buffer plants, inoculum sources, pollinator types
Community knowledge/ engagement	e.g., community IP, community engagement

The areas identified above can help the process of re-entering the step-wise framework for Myrtle Rust evaluation of impacts and responses. Next, we provide an overview on how this process could be done.

Re-entering the step-wise framework with the Myrtle Rust strategy

Having established recommended baselines for developing impact indicators, there is a need to consider the Myrtle Rust Strategy and turn the focus to potential management actions. Most of the focus within the Strategy is on building partnerships and means for cooperation. Some attention is given to adopting knowledge, especially through Mātauranga Māori but most emphasis on is partnership, collaboration and empowerment of communities. Knowledge needs to be developed under the direction and framing of Mātauranga Māori as enabling science partnerships.

Some of the success factors in the Myrtle Rust Strategy are science or research management aspects such as:

- viable representative germplasm (however we note the need to also account for dependent species from our feedback and reflection); and
- strategic planning for research.

Otherwise success is seen in terms of social and cultural aspects such as:

- maintenance of culture and wellbeing;
- people actively safeguarding myrtles and ecosystems; and
- formation of collaborative relationships for effective delivery.

The success factors and measurement (desired outcomes) from the Myrtle Rust Strategy are documented below, to reflect on for the next iterative cycle of this evaluation framework. Impacts and indicators will need to be matched or modified to outcomes as required. The step-wise framework provides a set of systems tools and processes for MPI and its stakeholders / partners to consider in the development of impact assessment and potential responses to support the realisation of the Myrtle Rust Strategy.

An evaluation framework for impact assessment and response planning has been proposed, but its full implementation is out of the scope for this project. However, the Myrtle Rust strategy (Box 1) provides a starting point to transfer into a logic model. Here the long-term impact expressed as a vision or aspiration is: “The mauri of myrtle plants and dependent ecosystems is safeguarded and sustained”. The success factors are indicative of positive impacts derived through response activities. The measures are potential indicators of response activity capturing aspects of knowledge, relationships and programmes that can contribute to the generation of desired outcome/s.

The objectives can be expressed as short, medium and long-term outcomes from tangible activities. For example, science research and its dissemination, investments in protective activity, awareness of vulnerability and resilience, capacity of kaitiaki to exercise responsibilities, co-operation of interested parties in managing myrtle rust, and efficacy of response activities in minimising impacts.

The measures of success of the Myrtle Rust Strategy are all response oriented and do not reflect the impacts of the disease itself. These complement the framework and QBL indicator matrix and baseline indicators for measuring impact. With the strategy focused on developing responses to myrtle rust, the evaluation is now ready to shift focus, and re-enter a new cycle of the step-wise framework.

Strategic conversations at the national level are needed to articulate the impact assessment and evaluation with a new set of indicators around response. Ideally, this will open questions on how well the nation is performing in response efforts, and what needs to change to deliver on the overall desired outcome of the strategy of protecting the mauri of myrtles and the ecosystems that depend on them.

Any further development and application of this framework will need to go through a process of strategic planning and indicator prioritisation. MPI and the Strategic Science Advisory Group may be an appropriate planning body, but strategy needs to be developed with different partners and/or stakeholders in impact assessment and response planning, e.g., at the regional level. We provide some guidance on prioritisation of indicators based on a review of the literature and research from other themes.

Box 1. Myrtle Rust Strategy 2019-2023

Vision: "The mauri of myrtle plants and dependent ecosystems is safeguarded and sustained".

The Myrtle Rust strategy is based on principles of partnership, collaboration, transparency, Mātauranga Māori, collective responsibility, and empowered communities.

Objectives

- Understanding: The behaviour and impact of myrtle rust in Aotearoa New Zealand is understood and options for managing it are identified.
- Protection: Native myrtle and dependent species are safeguarded and sustained.
- Resilience: The resilience and integrity of ecosystems vulnerable to myrtle rust is enhanced
- Kaitaiakitanga: Whānau, hapū and iwi are supported to exercise their responsibilities as kaitiaki of their taonga, and natural and cultural resources that may be affected by myrtle rust.
- Collaboration: Those with an interest in myrtles and associated ecosystems work collaboratively to manage myrtle rust in Aotearoa New Zealand.

Success

We know what success looks like when:

- We have viable representative germplasm of priority species impacted by myrtle rust
- Myrtle rust research is strategically planned and aligned, and informs myrtle rust management
- Our culture and wellbeing experiences with myrtles do not decline
- Whānau, hapū, iwi, communities and industry are actively safeguarding their myrtle plants and ecosystem
- Collaboration between partners results in better relationships and more effective delivery.

Measures (of success)

- Knowledge and awareness of myrtle species and myrtle rust increases
- Awareness of myrtle rust, its impact and how to identify it increase
- Understanding of the spread of myrtle rust increases
- Trust and respect between all partners increases
- Partners are clear about everyone's roles and responsibilities
- A programme is in place that recognises kaitiakitanga and supports active participation by communities.

Source: New Zealand Myrtle Rust Strategy 2019-2023

An application of the logic model would be an appropriate means for developing an agreed vision for the strategy, and the required activities needed to help realise the vision. When doing this together with stakeholders as partners in the development of long-term management, the required buy-in and commitment to resourcing activities will be easier to achieve. Each element of the logic model and evaluation framework can be populated with specific indicators that reflect the objectives, successes and measurements of the Myrtle Rust Strategy.

A high-level example presented at the SSAG Science Symposium in December 2018 illustrates the use of the logic model (Figure 8).

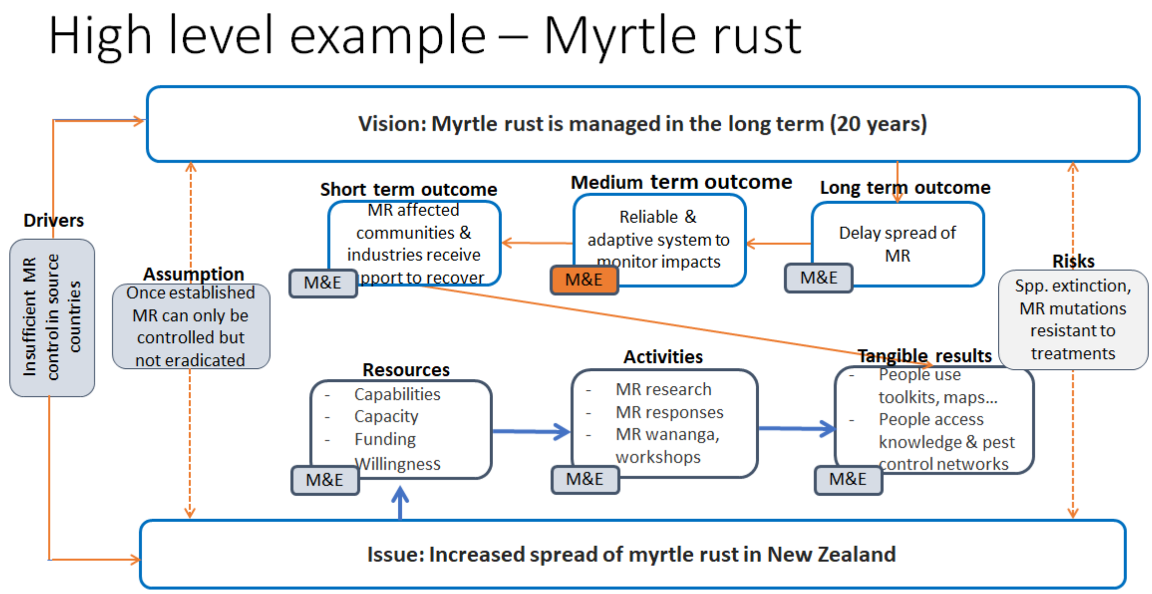


Figure 8. Systems tool 3: Logic model applied to myrtle rust

We have taken the first indicator of success 'representative viable germplasm for priority species impacted by myrtle rust' and applied it within our logic model to show how this can be done (including short, mid and long-term management) (Figure 9).

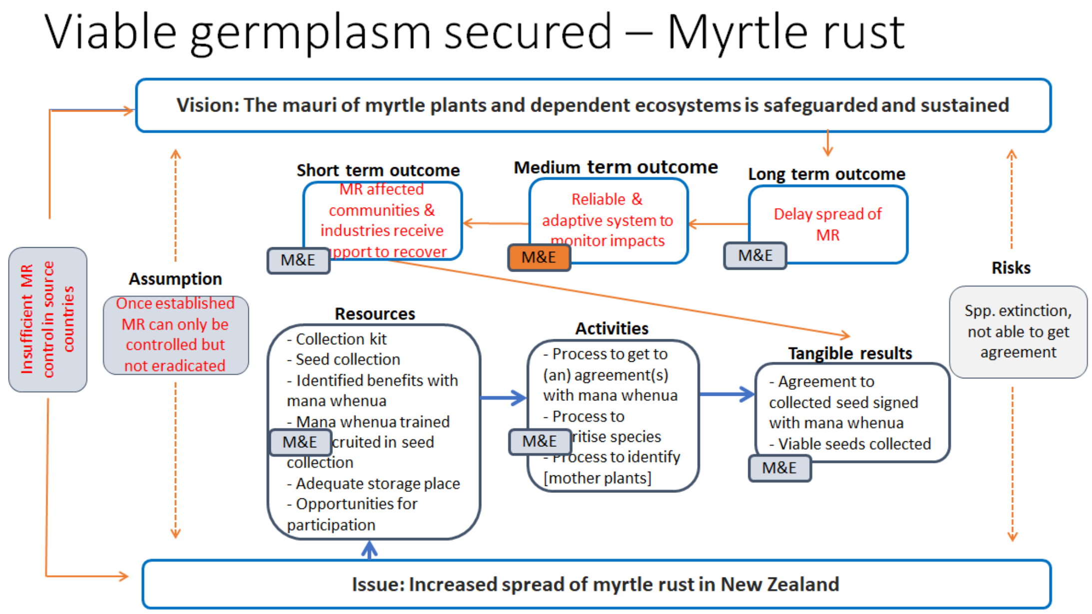


Figure 9. Systems tool 3 applied to the desired outcome of having a representative viable germplasm as stated in the Draft Myrtle Rust Strategy.

An initial list of stakeholders and their activities was compiled to support future processes of strategic planning and implementation (Appendix F). Inputs from all themes were drawn on to complete this list of current activities related to myrtle rust, including i) interacting with other stakeholders, ii) gathering information and knowledge, and iii) any actions being undertaken on the ground. These could help decision makers engage stakeholders and prioritise action areas as long-term management plans are developed.

Part 2 – Evaluation of environmental and economic impacts of myrtle rust

2.1 Methods

2.1.1 Environmental indicators methodology

Some environmental indicators that are candidates to evaluate impacts of myrtle rust were assessed using >1200 nationally representative permanent vegetation plots that sample indigenous forests and shrublands and form part of the Land Use Carbon Accounting System (LUCAS; Ministry for the Environment 2015) and which are used, on public conservation land, as the Department of Conservation's Tier 1 monitoring programme (DOC 2019). We identify physical parameters for indicators of Myrtaceae distribution (e.g. number of plots where each species is present), abundance (e.g. basal area, aboveground biomass), and population structure (e.g. number of stems in size classes). We provide baseline values for these indicators (our baseline periods will be 2002–2007 and 2009–2014) and a protocol for calculating these indicators in the future so that change against baseline values can be reported.

2.1.2 Economic baseline methodology

While the potential economic impacts of myrtle rust are many, our analysis was limited to understand the magnitude and range of impacts that myrtle rust could have on mānuka/kānuka forests (including native and planted forests) given the uncertainty around many biological and economic parameters. Analysis focused on specific indicators to represent the economic, environmental, and social impacts of myrtle rust. In our analysis, reduction in honey profits represents the economic impacts, value of lost sequestered carbon and avoided erosion represents environmental impacts, and lost jobs represent social impacts.

We limited the assessment of impacts of myrtle rust to national level measurable indicators. While we recognise that the assessment is narrow in its scope, the impacts considered are the only ones for which data is currently available or could be derived from available sources. The economic assessment of impacts can be expanded to include other indicators if data becomes available, such as indicators of impacts on tourism and the nursery industry.

To estimate the potential impacts of myrtle rust in New Zealand, we developed a bio-economic model that assesses how far the pest could reach within a time frame and the subsequent economic, environmental, and social impacts within that range. As such, we first assessed the economic and environmental assets at risk from myrtle rust infestation. Then we developed a pest spread model, and estimated the value of potential damage, over space and time, on several impact indicators including mānuka/kānuka honey profits, ecosystem services (carbon sequestration and avoided erosion), and lost employment related to mānuka/kānuka honey production.

Assumptions for assets at risk

To estimate the values of assets at risk we assumed the following:

- Honey production is estimated at 40 kg per hectare, assuming one hive per hectare (Daigneault et al., 2015).
- Earnings before interest and taxes (EBIT) for honey production are estimated at $98 per hectare (Daigneault et al., 2015).
- Carbon sequestration from mānuka/kānuka is estimated at 0.6 tonne per hectare (Daigneault et al., 2018).

- Only ~45% of the mānuka/kānuka area are used for mānuka honey production and the distribution of honey production is the same as the distribution of mānuka/kanuka trees (Ballingall and Pambudi, 2017)
- One tonne of CO_2e is valuated at $25 (New Zealand Productivity Commission, 2018).
- One tonne of sediment is valuated at $3 (Daigneault et al., 2017).
- Three beekeeping jobs will be lost if 1,000 hectares of mānuka is completely infested (Daigneault et al., 2015).

Technically, the model integrates a spatial map of mānuka/kānuka distribution in New Zealand which was sourced from the Land Cover Database (LCDB v.4), and soil erosion map generated from the New Zealand Empirical Erosion (NZeem) model (Dymond et al., 2010). In addition, given the above-mentioned assumptions, spatial information on honey production and, net revenues, carbon sequestration and lost jobs from mānuka/kānuka forests and plantations were estimated.

Myrtle rust spread modelling

Myrtle rust spread is dependent on several key parameters. In our analysis we limit our model to only two key parameters: population growth rate/dispersal rate and the scale of current infestation. We developed an implicit spatio-temporal pest spread model for myrtle rust based on a logistic growth dispersal curve. This curve represents the percentage of hectares of mānuka/kānuka forests (including some small plantations) invaded over time, which was estimated as follows (Robinet et al., 2012):

$$N_t = \frac{N_0 \exp(r\,t)}{1 + N_0(\exp(r\,t) - 1)/100} \qquad (1)$$

where, N_0 is the initial percentage of the mānuka/kānuka forests invaded at time t = 0; N_t is percentage of the mānuka/kānuka forests invaded at time t; r is the relative rate of spatial increase per year.

To capture the scale of potential impacts, we constructed a mean spread/impact scenario and potential boundaries around this mean. To set the boundaries around the estimated mean, we developed a maximum scenario which combine the maximum values of both uncertain parameters of the model and a minimum scenario which combine the min values of both uncertain parameters of the model. Sensitivity analysis (in which we change the value of one parameter and fix the other parameters) could be more useful in situations where much lower uncertainty is present as the objective is to know the effect of uncertainty in specific parameter on the model output. In our situation, we are trying to capture the scale of the impacts by presenting minimum, mean, and maximum potential impacts rather than the effect of one parameter on model output.

It is clear that myrtle rust can spread over large distance by wind (e.g., across the Tasman Sea), however, no studies quantify how many km -on average- the fungus could travel per year (CABI, 2019). Based on reviewing dispersal rates of other invasive species that spread with similar mechanisms (i.e. wind, cold fronts, and thunderstorms), we assumed that the rate of dispersal (r) of myrtle rust in New Zealand has a mean value of 0.5, a minimum value of 0.3, and maximum value of 0.7. Previous modelling studies showed that a dispersal rate of 0.3 could reflect, on average, a spreading distance of ~80 km per year (Robinet et al., 2012; Soliman and Inglis, 2018; Grant and Seevers, 1989; Onstad et al., 1999).

Moreover, given that myrtle rust is already present in several regions but not widespread yet, we assumed that 6 percent of mānuka/kānuka forests are already infested by the myrtle rust for the mean infestation scenario, while 4 and 8 percent are assumed for the minimum and maximum infestation scenario (Biosecurity New Zealand, 2018; CABI, 2019). In addition, the minimum, mean, and maximum damage rate (e.g. honey production loss rate) is assumed to be 5, 10, and 15 percent (Ballingall and Pambudi, 2017). Overall, the minimum scenario assumes a min rate of dispersal (r=0.3), 4 percent of all mānuka/kānuka forests and forests is already infested, and a minimum damage rate of 5 percent. Similarly, the mean scenario assumes a mean dispersal rate (r=0.5), 6 percent of all mānuka/kānuka forests and forests is already infested, and a mean damage rate of 10 percent. Finally, the maximum scenario assumes that the dispersal rate is at maximum potential (r=0.7), 8 percent is already infested, and a maximum damage rate of 15 percent.

Economic impacts of Myrtle rust

Given the information on pest spread and damage rate mentioned above, we calculated the impacts on profits from mānuka honey, value of avoided erosion, and value of lost sequestrated carbon due to partial tree mortality or damage. To estimate the present value of future damages, we used a discount rate of 6 percent (Treasury New Zealand, 2008).

2.2 Results & discussion

2.2.1 Environmental indicators

Some environmental indicators that are already reported at national level are suitable for assessing and reporting some of the impacts of myrtle rust. The infrastructure developed for reporting change in carbon stocks in New Zealand (Land Use Carbon Accounting System, LUCAS; Ministry for the Environment 2015) provides a representative sample of indigenous forests and shrublands throughout the main islands of New Zealand (Holdaway et al. 2017). Indigenous forests and shrublands are by far the main habitat for native Myrtaceae species, with most species restricted to them (Wardle 1991), and some indigenous forests and shrublands are dominated by them (e.g., Stewart & Veblen 1982, Wiser et al. 2011). The representative sample that LUCAS provides is also the basis of reporting trends in the ecological integrity of New Zealand's public conservation land (DOC's Tier 1 monitoring; Department of Conservation 2019). This infrastructure does not extend to outlying islands (Kermadec and Auckland Islands) where indigenous forests are dominated by Myrtaceae species. The infrastructure of LUCAS and DOC's Tier 1 monitoring is used not only to report national trends in carbon but also in biodiversity and has been used for national State of Environment reporting, including native Myrtacaeae species (i.e., southern rātā, *Metrosideros umbellata*, Ministry for the Environment 2018).

Importantly, with the infrastructure established in 2002 and, with two full measurements of sample points completed before 2017 (the first known incursion of myrtle rust), there is already a baseline of trends in environmental indicators across indigenous forests and shrublands against which to assess change in native Myrtaceae which were taking place before the arrival of myrtle rust. For example, changes in successional native shrublands are likely for both composition and carbon are likely as stands age (Carswell et al. 2012, Holdaway et al. 2017). Within indigenous forests, regeneration of some Myrtaceae trees is likely to be dependent on periodic disturbance (e.g., Stewart & Veblen 1982), and changes in populations of others may be influenced by combined influences of natural disturbances and browsing by non-native mammals (Bellingham & Lee 2006). These influences on native Myrtaceae are ongoing, as well as effects of climate change, and all potentially interact with effects of myrtle rust.

Below, we give examples to demonstrate that the national infrastructure provided by LUCAS and DOC's Tier 1 monitoring is fit for purpose for reporting some changes, but note that for rare or restricted species new investment will be required to determine changes, and that the capacity to report changes in some life forms (stranglers and lianas) will require development and implementation of new methods. In all cases, capacity to report change requires a commitment to ongoing repeated measurements.

We also report changes in the conservation status of New Zealand's native Myrtaceae species, which is informed by multiple data sources, including national plot networks.

Distribution of indigenous trees

Number of plots where native Myrtaceae species are present

This indicator summarises the occurrence (or frequency or occupancy) of each species across the permanent plot network. The indicator is expressed as a proportion of the total number of plots in the sample. The values quantify which species are most common, and changes in those values over time can be used as an 'early warning signal' for deeper investigation into population-level processes.

Effects of myrtle rust on individual species needs to be evaluated against background drivers of change for individual species. Even if the presence of myrtle rust is assessed with confidence at each plot measurement for all co-occurring Myrtaceae, there are other influences on the populations of these species. Population processes can be influenced by natural disturbances (e.g., extra-tropical cyclones, earthquakes), disturbances caused by people (e.g., logging, removal of Myrtaceae trees at local scales perceived to be at risk, and fires, most of which are set by people), climate change (e.g., increased temperature or diminishing rainfall), and biological invasions (e.g., regeneration failure caused by abundant deer or goats). Disentangling multiple drivers of change and attribution of change is problematic, especially when multiple drivers are coincident (Peltzer et al. 2014). For example, models of likelihood of myrtle rust occurrence follow a latitudinal gradient (from greatest at low latitude to lowest at high latitude) and simultaneously tree dynamism (the average of tree mortality and recruitment rates) follows the same latitudinal gradient (greatest dynamism at low latitude and lowest at high latitude) (Bellingham et al. 1999). This has often been ignored in the past – for example, some authors have attributed all tree mortality of *Metrosideros* species to possums (e.g., Rose et al. 1992) and ignored other drivers of change (e.g., signals of past disturbance; Bellingham & Lee 2006). Experimental approaches offer some prospects of disentangling drivers of change – for example, it would be possible to investigate whether plots in areas subject to possum control and also potentially affected by myrtle rust differ from those that have not been subject to possum control.

Nonetheless, if myrtle rust caused widespread mortality in a species, it is very likely it could be detected against the backdrop of other drivers of change. A major advantage of the Tier 1/LUCAS plot network (and many local networks of plots scattered through New Zealand) is that the plots provide time-series data from before the arrival of myrtle rust, which present background rates of change. If the equivalent of a Tier 1/LUCAS network existed in the eastern United States from the 1880s, it could have been used to document the natural dynamics of the widespread and often dominant American chestnut (*Castanea dentata*) in forests, including local mortality (e.g., to hurricanes; Xi et al. 2008). However, plots would have then shown the rapid mortality of chestnuts, at first locally, and then widely as the main driver of change took place – this tree became extinct as adults throughout almost all its natural range between 1904 and 1950 as it succumbed to the virulent, non-native chestnut blight (*Cryphonectria parasitica*; Woods & Shanks 1959). Conversely, if, for example, a widespread species in New Zealand such as mānuka were to show widespread death throughout the country, including beyond the range of any occurrence of myrtle rust, then one could have some confidence that myrtle rust was not the primary driver of observed change and that some other agent was likely.

This indicator uses methods that provide data on the complete vascular plant composition of each sample point (a permanent 20 m × 20 m plot established on a national 8 km × 8 km grid; Holdaway et al. 2017). Compositional data on each plot is collected using a relevé (a method whereby each plant species is recorded within fixed height tiers, including epiphytes (plants established on tree crowns or trunks); Hurst & Allen 2007). Data from relevés is therefore suitable for reporting native Myrtaceae because the method includes all species, including lianes that cannot (easily) be tagged and counted in the way that trees are. Data were drawn from 860 permanent plots that had been measured twice. We tested for a difference in the proportion of plots where each species was found using a simple two-sample proportion test (resulting in a z and P statistic for each species). Note that we removed 8 instances of *Metrosideros* not identified to species (code = METROS) from the two measures as these cannot be used for this analysis.

There were no significant changes in occurrence (or frequency or occupancy) by any species of Myrtaceae between the first and second measurements of plots (Table 6). These values provide valuable baseline values against which future change can be assessed.

Table 6. Summary of occurrence (or frequency or occupancy) for each Myrtaceae species in two measurements of a national-scale survey of indigenous forests and shrublands. *z* statistic values tabulated calculated compare the proportion of plots between the two census periods for each species. P values tabulated list the statistical significance of the *z* statistic for each species (no P value is <0.05, hence none is significant).

Species	**Proportion of plots in measurement 1 (2002–2007)**	**Proportion of plots in measurement 2 (2009–2013)**	***z***	***P***
Metrosideros diffusa	0.278	0.278	0.072	0.789
Metrosideros umbellata	0.173	0.173	0.016	0.899
Leptospermum scoparium	0.164	0.164	0.017	0.897
Metrosideros perforata	0.159	0.159	1.970	0.160
*Kunzea ericoides**	0.152	0.152	0.071	0.790
Metrosideros fulgens	0.152	0.152	0.623	0.430
Metrosideros robusta	0.037	0.037	0.017	0.897
Lophomyrtus bullata	0.008	0.008	0.084	0.772
Lophomyrtus obcordata	0.008	0.008	0.000	1.000
Metrosideros colensoi	0.006	0.006	0.310	0.578
Metrosideros parkinsonii	0.006	0.006	0.084	0.772
Metrosideros excelsa	0.003	0.003	0.126	0.723
Metrosideros albiflora	0.002	0.002	0.000	1.000
Metrosideros species	0.002	0.002	1.130	0.288
Syzygium maire	0.002	0.002	0.167	0.683
Metrosideros carminea	0.000	0.000§	0.000	1.000

* Note that this combines all species of *Kunzea* recognised by de Lange (2014), because during most of the period reported above, only two species were recognised.

§ Present in 1 plot at the second measure.

Status of widespread indigenous trees

Basal area, stem density and size class distributions

This analysis uses permanent plots in New Zealand's natural indigenous forests (n = 775) with tagged stem data from both measurement periods. Not all forest plots have taggable stems because, for example, they may be early successional or tall shrublands that lack taggable trees. This accounts for the difference in number of plots between this analysis and the previous one.

Lianas are not consistently tagged as trees on LUCAS plots so we removed all liana species with one important exception – northern rātā (*Metrosideros robusta*) – that establishes as an epiphyte and then develops as a liana that eventually engulfs a host tree to form a tall forest tree as an adult (Knightbridge & Ogden 1998). Measuring this species as a stem is problematic because stems first appear as roots, descending from the host tree. From the MfE (2015) manual:

"When establishing plots, lianas (woody, climbing plants) and descending aerial roots of hemiepiphytes or stranglers (e.g., *Griselinia lucida*, some *Metrosideros robusta*) do not need to be tagged or measured but are recorded on the recce description (Section 3.4). The only exception is when a clearly defined *Metrosideros robusta* stem can be tagged and measured in a repeatable manner for estimating carbon".

While we include northern rātā in this analysis we acknowledge that changes might reflect complications with measurement in the early life history phase as much as other factors.

Lastly, we could only assess change statistically in species that were found in 3 or more plots in at least one period. Maire tawake (*Syzigium maire)* was only tagged as a stem once, in one plot, in the second measurement and is not reported here. It is clear that the national representative sample is inadequate to report changes in this tree species, as well as others that have local distributions (e.g., pohutukawa, *Metrosideros excelsa*). Sample sizes for two species in which wild populations are infected by myrtle rust (ramarama, *Lophomyrtus bullata* and rōhutu, *L. obcordata* and assessed to be "nationally critical" in conservation status, see 4.1.4) are also low. For all of these species, as well as for northern rātā, remeasurement of extant regional networks of plots or establishment of new plots will be needed to determine changes in their populations.

There were no significant differences in either basal area (Table 7) or stem densities (Table 8) in any of six tree species across the national plot network between the two sample periods.

Table 7. Basal area (m^2 per ha, with 1SE) of Myrtaceae found on at least 3 plots across either measurement period. Statistical power for inference for the two *Lophomyrtus* species is very low.

Species	**N plots**	**Mean BA (± 1SE) first measure (2002–2007)**	**Mean BA (± 1SE) second measure (2009–2013)**	***t***	***P***
Leptospermum scoparium	114	4.28 (0.61)	3.89 (0.57)	0.476	0.635
Kunzea ericoides	111	8.59 (0.97)	9.42 (1.02)	-0.586	0.558
Metrosideros umbellata	110	11.28 (1.61)	10.57 (1.50)	0.324	0.746
Metrosideros robusta	26	12.69 (4.23)	8.07 (3.44)	0.848	0.401
Lophomyrtus bullata	4	0.41 (0.26)	0.37 (0.26)	0.100	0.924
Lophomyrtus obcordata	4	0.03 (0.02)	0.05 (0.02)	-0.808	0.452

Table 8. Stem density (n stems per ha, 1SE) of Myrtaceae found on at least 3 plots across either measurement. Statistical power for inference for the two *Lophomytus* species is very low.

Species	**N plots**	**Mean stem density (± 1SE) first measure (2002–2007)**	**Mean stem density (± 1SE) second measure (2009–2013)**	***t***	***P***
Leptospermum scoparium	114	1666.4 (277.1)	1486.6 (244.4)	0.487	0.627
Kunzea ericoides	111	1435.8 (207.3)	1461.3 (213.2)	-0.086	0.932
Metrosideros umbellata	110	241.3 (33.8)	230.3 (33.6)	0.231	0.818
Metrosideros robusta	26	56.0 (8.8)	29.0 (10.2)	2.006	0.051
Lophomyrtus bullata	4	256.5 (149.4)	225.0 (160.1)	0.143	0.891
Lophomyrtus obcordata	4	18.8 (12.0)	43.8 (6.2)	-1.852	0.129

There were changes in the size structures of two widespread species, kānuka, *Kunzea ericoides* (highly significant, Table 9) and mānuka, *Leptospermum scoparium*, both towards slightly greater mean diameter size, and there was a 28% increase in mean size of northern rātā.

Table 9. Mean diameters and Kolmogorov-Smirnov tests (*D* and *P*) for differences in size class distributions within species, between the two measurement periods. Mean diameter (and 1SE) provided for context but note that the KS statistic tests for differences in the distribution of values, not the mean value.

Species	**N plots**	**Mean DBH (± 1SE) first measure (2002–2007)**	**Mean DBH (± 1SE) second measure (2009–2013)**	***D***	***P***
Leptospermum scoparium	114	4.95 (0.03)	5.01 (0.03)	0.023	0.048
Kunzea ericoides	111	7.10 (0.06)	7.36 (0.07)	0.030	0.007
Metrosideros umbellata	110	15.95 (0.57)	15.79 (0.58)	0.016	0.999
Metrosideros robusta	26	29.63 (6.04)	37.87 (8.68)	0.345	0.021
Lophomyrtus bullata	4	4.27 (0.23)	4.35 (0.24)	0.117	0.957
Lophomyrtus obcordata	4	3.97 (0.99)	3.44 (0.60)	0.524	0.612

For all of these analyses, results for northern rātā should be interpreted cautiously because of issues related to when and how this species is recorded (see text above from the MfE field manual). A shift towards a larger mean diameter could reflect uncertainty among teams in whether or not to tag small roots (which develop in to stems). This could be re-investigated or a higher minimum diameter (currently 2.5 cm diameter at 1.35 m; DBH) could be used. Running the analysis using only stems 10cm DBH or greater showed no difference between the two periods. Further work will be required to address this limitation.

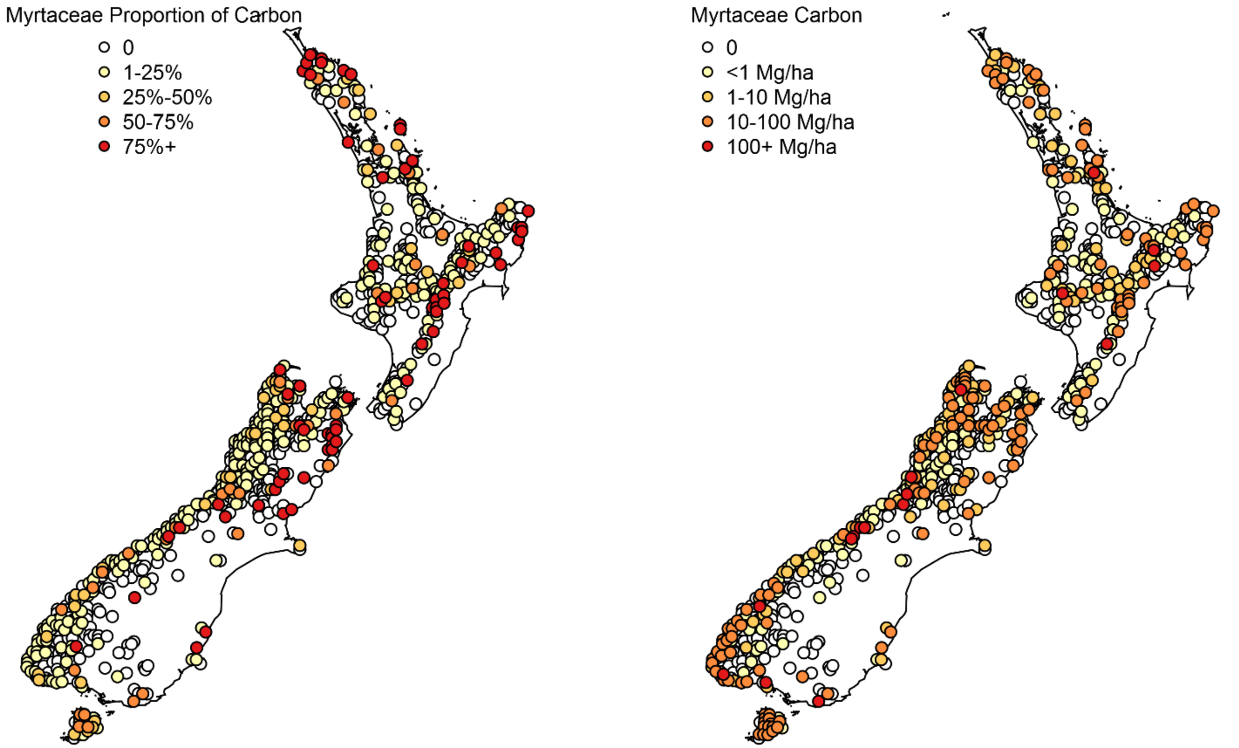
Carbon sequestration

We calculated the total carbon stored on each plot across all species and for Myrtaceae species only from the second (most recent) period (n = 916 plots). Methods follow Holdaway et al. (2016) but do not included propagated uncertainty.

The greatest net amount of carbon stored by Myrtaceae species in indigenous forests and shrublands (>100 Mg/ha) were concentrated mostly in plots in central Westland (Figure 4), most probably in forests dominated by southern rātā, which has a very high wood density (800 kg/m^3; Coomes et al. 2002).

The proportion of the total carbon stored on a plot by Myrtaceae species showed a different geographic pattern, with many plots in the northern North Island and the east of both North and South Islands with >75% of the carbon comprised by Myrtaceae species (Figure 10). The total carbon stored on these plots was typically low (<10 Mg/ha), and many of these are likely to be secondary forests and successional communities, often comprised of mānuka and kānuka. Although the absolute amounts of carbon stored is low, these developing forests are critical in national initiatives to store forest on land formerly used for extensive agriculture (e.g., Emissions Trading Scheme) and the amount of carbon stored in mānuka- and kānuka-dominated communities is many sites, especially at low elevation on better soils, is likely to increase with time. Loss of either or both species to myrtle rust could thwart initiatives to store carbon, with mānuka and kānuka potentially replaced by successional species with lower wood densities (e.g., gorse, *Ulex europaeus*).

Figure 10. Proportion of carbon stored on plots by Myrtaceae species on a representative plot network that samples indigenous forests and shrublands, and the amount of carbon stored on these plots by Myrtaceae species.



2.2.2 Economic indicators impact assessment – applying a QBL baseline

An economic impact assessment on mānuka honey production was conducted by combing four areas of indication across the QBL- environmental (avoided erosion, carbon sequestration), social (loss of employment) and economic (reduction in profits). Our results show that value of avoided erosion is the highest impact followed by honey profits, and value of lost sequestrated carbon. This could be due to the fact that most of the native trees are present on marginal land which are often characterised by high erosion rates.

Assets at risk

The results show that the annual value of assets at risk is estimated at $123.7 million, in which 38.7 million are net revenues from honey production, 13.4 million from carbon sequestration (estimated value of 0.5 million tonne of CO_2e), and $71.6 million from avoided erosion (estimated value of 23 million tonne of sediment) (Tables 10 and 11).

Table 10. The economic (honey production) and environmental (sequestered carbon and avoided erosion) assets at risk, distributed by region.

Region	Area (Ha)	Honey Prod (tonne/year)	EBIT Honey ($/year)	Carbon Seq (tonne/year)	Erosion (tonne/year)
Bay of Plenty	28,844	509	1,246,984	17,306	327,871
Canterbury	140,748	2,484	6,084,843	84,449	519,803
Gisborne	33,644	594	1,454,521	20,187	11,384,343
Hawke's Bay	127,287	2,246	5,502,882	76,372	1,867,685
Manawatu-Wanganui	110,626	1,952	4,782,580	66,375	1,883,809
Marlborough	102,557	1,810	4,433,778	61,534	288,318
Nelson	3,541	62	153,092	2,125	9,244
Northland	13,500	238	583,629	8,100	848,940
Otago	55,087	972	2,381,528	33,052	214,514
Southland	33,791	596	1,460,875	20,275	83,756
Taranaki	36,045	636	1,558,322	21,627	853,521
Tasman	48,365	853	2,090,907	29,019	559,190
Waikato	55,781	984	2,411,544	33,469	317,242
Wellington	64,719	1,142	2,797,953	38,832	3,814,130
West Coast	41,372	730	1,788,611	24,823	906,991
Total	895,908	15,809	38,732,050	537,545	23,879,356

Note: EBIT = Earnings Before Interest and Taxes.

Table 11. Valuation (in dollar terms) of sequestered carbon and avoided sediment by mānuka/kānuka trees, assuming $25 per tonne of carbon and $3 per tonne of sediment.

Region	Carbon value ($/tonne)	Sediment value ($/tonne)
Bay of Plenty	432,658	983,612
Canterbury	2,111,221	1,559,410
Gisborne	504,666	34,153,028
Hawke's Bay	1,909,302	5,603,054
Manawatu-Wanganui	1,659,383	5,651,427
Marlborough	1,538,361	864,953
Nelson	53,117	27,731
Northland	202,498	2,546,819

Otago	826,304	643,543
Southland	506,871	251,268
Taranaki	540,682	2,560,564
Tasman	725,469	1,677,571
Waikato	836,719	951,726
Wellington	970,789	11,442,391
West Coast	620,583	2,720,972
Total	13,438,623	71,638,069

Myrtle rust spread modelling

The results show that in the mean scenario, 90% of the host mānuka area could be infested in 10 years' time, while it could take 18 years in the minimum infestation scenario and 7 years in the maximum infestation scenario. Figure 11 shows the modelled infested area over time for the three scenarios. The minimum scenario assumes a min rate of dispersal (r=0.3) and 4 percent of all mānuka/kānuka forests and plantations is already infested. The mean scenario assumes a mean dispersal rate (r=0.5) and 6 percent of all mānuka/kānuka forests and plantations is already infested. The maximum scenario is assuming that the dispersal rate is at maximum potential (r=0.7) and 8 percent is already infested.

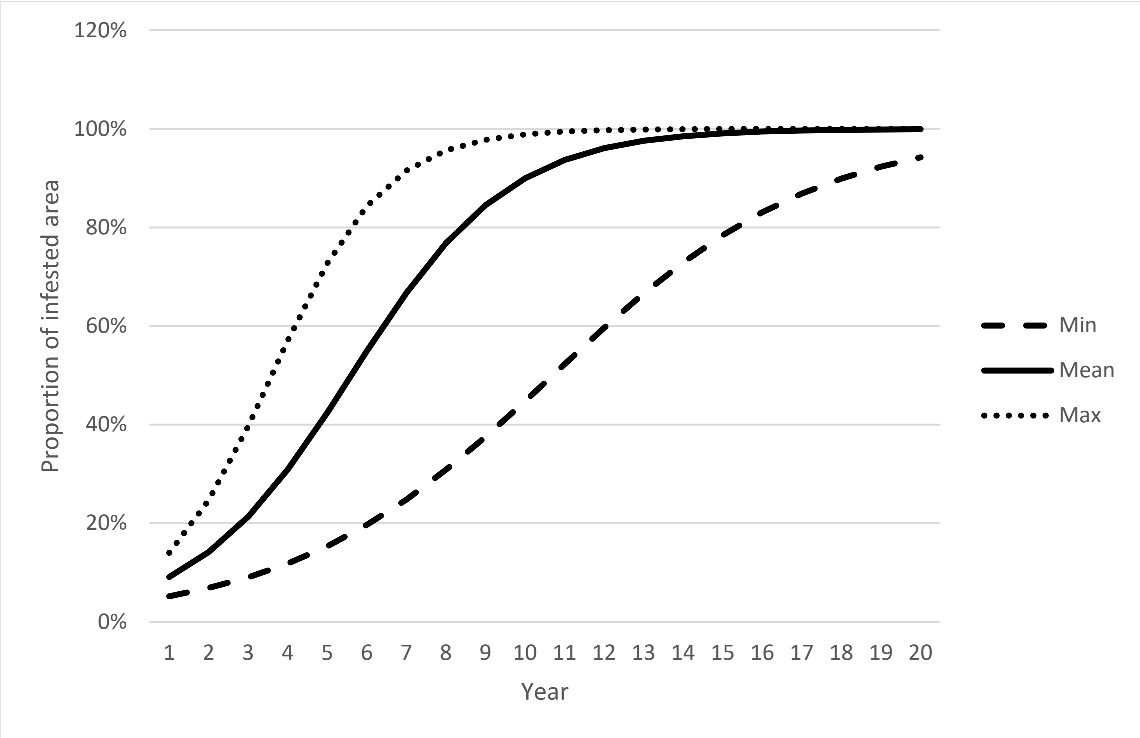


Figure 11. Proportion of infested area over 20 years.

Economic impacts of Myrtle rust

The results show that the indicative impact over 20 years is estimated between \$52 and \$397 million with a mean value of \$157 million. The estimated damage of the mean scenario (i.e. \$157 million) is the sum of \$49 million of lost profits from honey production, \$17 million representing the value of lost sequestrated carbon, and \$91 million representing the value of avoided erosion (Table 12 and Figure 12). These values represent the damage over 20 years which was discounted to the present value using a discount rate of 6 percent. Table 12 shows that the maximum impact will be realized between year 15–18, depending on the scenario, which will then decrease with a marginal amount. In addition, 1,748 jobs were estimated to be lost. However, at the same time, additional jobs may be created to control and manage the pest but these were not considered in this assessment due to unavailability of data.

Table 12. Indicative economic impact of myrtle rust over 20 years in million New Zealand dollars, assuming a 6% discount rate.

	Value (million dollars)		
Year	**Min**	**Mean**	**Max**
1	0.32	1.12	3.82
2	0.41	1.68	6.46
3	0.52	2.48	10.16
4	0.67	3.52	14.33
5	0.86	4.77	18.04
6	1.09	6.10	20.68
7	1.37	7.35	22.24
8	1.68	8.39	23.04
9	2.04	9.17	23.40
10	2.42	9.70	23.51
11	2.80	10.04	23.51
12	3.18	10.25	23.45
13	3.54	10.36	23.37
14	3.85	10.41	23.29
15	4.13	10.43	23.20
16	4.35	10.43	23.11
17	4.54	10.41	23.03
18	4.68	10.39	22.95
19	4.79	10.36	22.88
20	4.87	10.34	22.81
Total	**52.12**	**157.72**	**397.32**

Note: The impact represents the sum of lost net revenues, the value of additional erosion, the value of emitted carbon. The minimum scenario assumes a min rate of dispersal (r=0.3), 4 percent of all mānuka/kānuka forests and plantations is already infested, and a minimum damage rate of 5 percent. The mean scenario assumes a mean dispersal rate (r=0.5), 6 percent of all mānuka/kānuka forests and plantations is already infested, and a mean damage rate of 10 percent. The maximum scenario is assuming that the dispersal rate is at maximum potential (r=0.7), 8 percent is already infested, and a maximum damage rate of 15 percent.

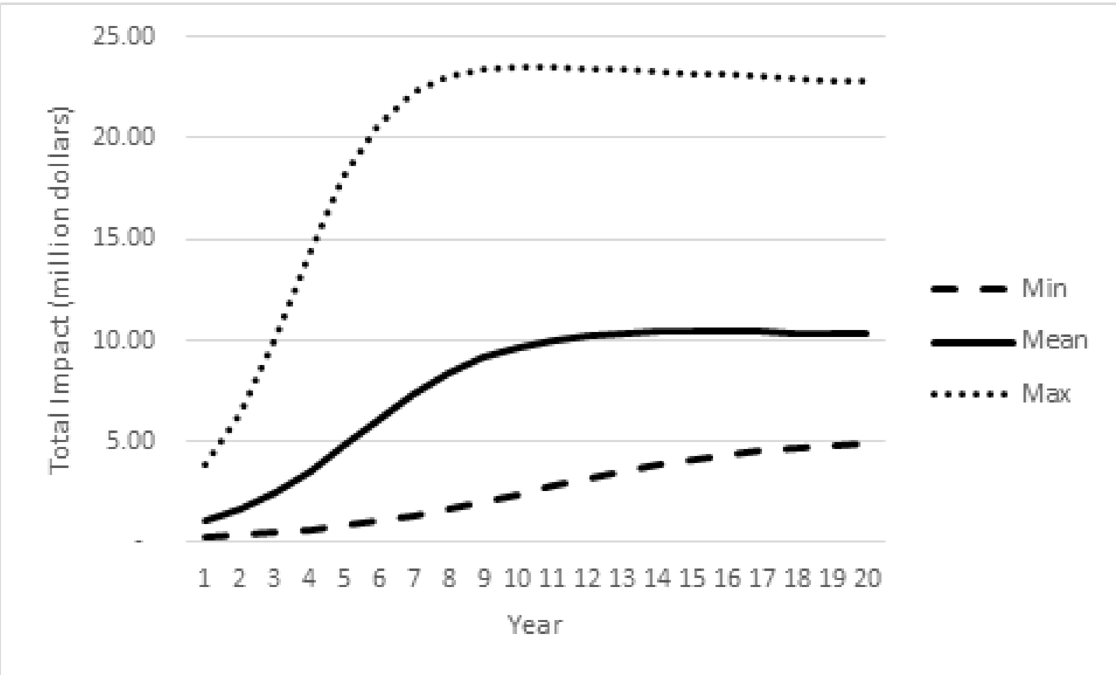


Figure 12. Indicative impacts over 20 years for the minimum, mean, and maximum scenarios, assuming a discount rate of 6 percent

This assessment is comparable with the NZIER assessment commissioned by MPI prior to the commencement of this research. Our estimate includes carbon and erosion impacts expressed as dollar values, however the estimates are more conservative than NZIER (Table 13).

Table 13. Comparison between our analysis and NZIER - myrtle rust estimated impacts

Parameter	Our analysis (million dollars)	NZIER (million dollars)
Min	$52	$150
Mean	$158	$304
Max	$397	$465

It is not clear what has created the difference between NZIER results and our assessment, there could be a few reasons for that.

1. They said: “In addition to the mānuka honey productivity decreases that we assume, the sector also loses labour, land (especially) and capital to competing uses in the primary sector as profitability drops. It therefore suffers a double whammy: it loses resources, and the resources it retains are less productive after myrtle rust starts to take hold”.
2. Probably we also assumed a slower infestation dynamic (which takes longer time to build up).
3. In addition, we might have more accurate spatial distribution of mānuka trees as our area is based on satellite images (Land Cover Database, LCDB).

Conclusions

This report has contributed to the following outcomes:

(i) Establishment of an environmental baseline against which to evaluate the impacts of myrtle rust; we have presented in Part 1 an indicator matrix and in Part 2 the application of of environmental and economic baseline with clear assumptions and methods;

(ii) Intervention management can be prioritised based on likely environmental, social, cultural and economic outcomes; we have set the groundwork for setting priorities through different impact and research areas identified across MPI 18607 project;

(iii) Decision makers will have an information base from which to understand the environmental, economic, social and cultural impacts of myrtle rust; the indicators matrix and the step-wise framework have been presented and discussed with some stakeholders. Further work will be required using the Myrtle Rust Strategy as a guiding document.

We have developed a set of indicators across the quadruple bottom line (QBL) for generating baselines prior to the impact of myrtle rust. This matrix of QBL is captured in three spreadsheets as environmental, economic and socio-cultural impact areas that will be useful for MPI and its stakeholders to develop monitoring and evaluation programmes (related to investment and research prioritisation and implementation). However, it is essential that MPI do this in partnership with Māori through mana whenua to enable investment that supports Te Ao Māori cultural values and aspirations.

We have also developed a framework involving five steps for developing indicators that can be applied to new contexts of myrtle rust response, as new knowledge becomes available. Step 5 of that framework has provided an opportunity to reflect on the current status of myrtle rust long-term management response planning, investment and prioritisation. This step has been completed after receiving feedback on the March 2019 report from MPI. Further information from the myrtle rust strategy and draft science plan have supported the development of lessons for future iterations of the step wise framework. We also note the importance of agreeing on a common goal that describes the problem and its potential solutions, as a shared vision; and listing the most important policy questions arising from the problem description.

Step 3 has shown how myrtle rust impacts can be determined working across the QBL for a selected example, combining assumptions with available data to evaluate future social, environmental and economic impacts for key indicators of impact (employment, erosion control, carbon sequestration, and profitability) on the mānuka honey industry. The costs of worst case scenario impacts are significant with the costs of erosion control yielding the highest impact.

Furthermore Step 3 has also drawn on existing data to show how environmental impacts on Myrtaceae distributions and population dynamics can be measured against baseline data. However further data collection will be needed to have sufficient power to determine change in locally distributed and naturally rare species, and to interpret dynamics of *Metrosideros* lianas and the strangler, northern rātā. Existing regional and local plot networks and potentially new plots would be needed, beyond those currently being measured for environmental reporting. However, biodiversity impacts such as functional aspects of Myrtaceae in the landscape, e.g., supporting other species, will need further research.

The importance of using a range of indicators to help support the purposes of reporting, e.g., on conservation status, illustrates how different indicators are used together to understand impact such as conservation status.

The tools and processes used to develop this framework have been instructive and useful to systemic analysis and processes around the social, cultural, ecological and technical complexities of myrtle rust impacts and responses.

Limitations

For this project we did not have the resources to run workshops with stakeholders and so used other workshops and hui from other themes as proxies for gathering information to develop this framework, for example input from the participants of the science workshop and symposium.

Further work is needed to co-develop indicators that capture narrative and numbers to support a description of the problem and its solutions (at different scales and in different decision-making contexts), and to reconcile some of the tensions around quantitative assessment, including assumptions used against the experiences and perceptions of stakeholders.

We cannot assume to be able to speak for stakeholders regarding priorities and the allocation of resources. However, the following guidance is provided as to what might be important to consider when making priority and investment decisions.

Although we envisioned and started engaging with Te Ao Māori theme at the start of the project and discussed with Theme 2 how their input can be included (i.e. through a technical meeting of Maori indicators experts), this engagement could not materialise within the time frame required.

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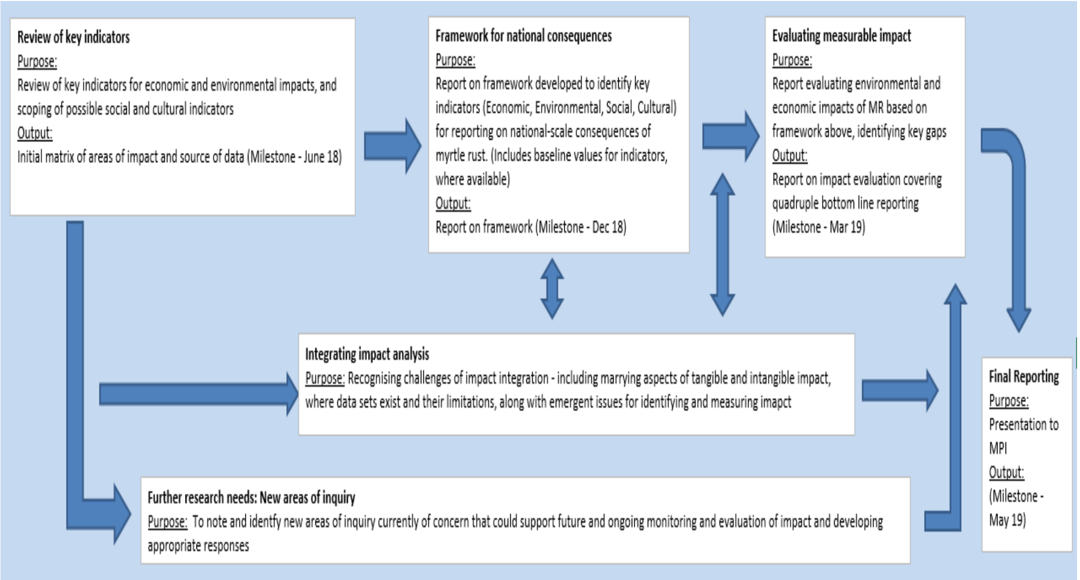
Appendix A

Project plan and milestones



Appendix B

Figure B1. Dynamic causal loop / Myrtle rust issues map.
Screenshot of the draft dynamic causal loop. Available at https://bit.ly/2wlvIrQ

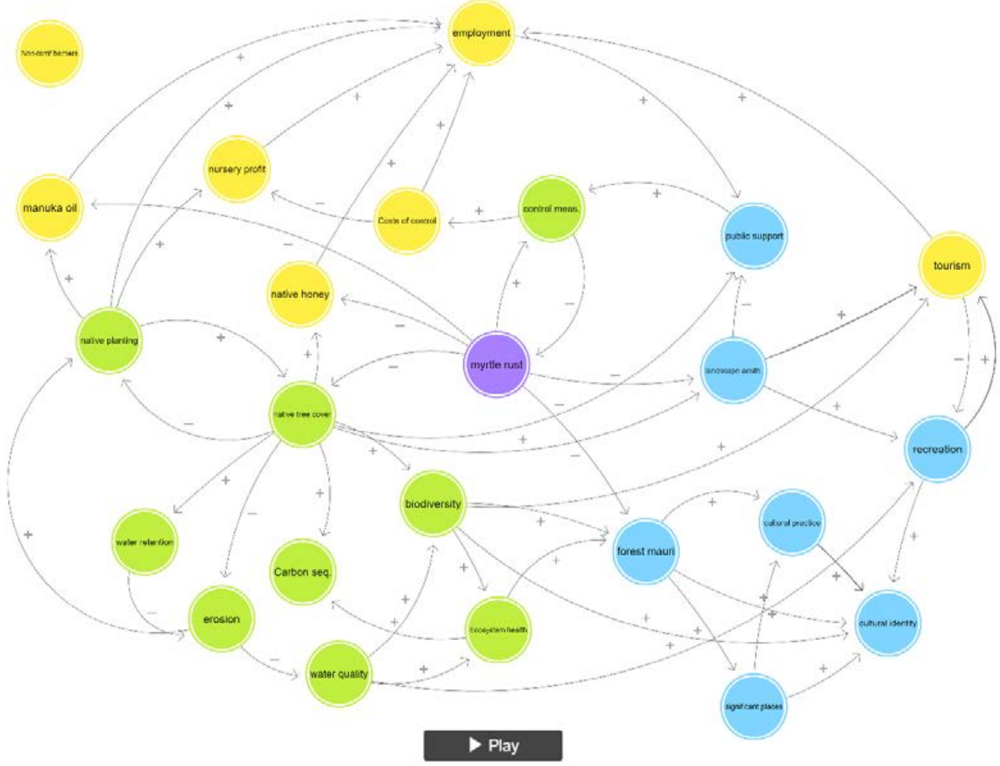
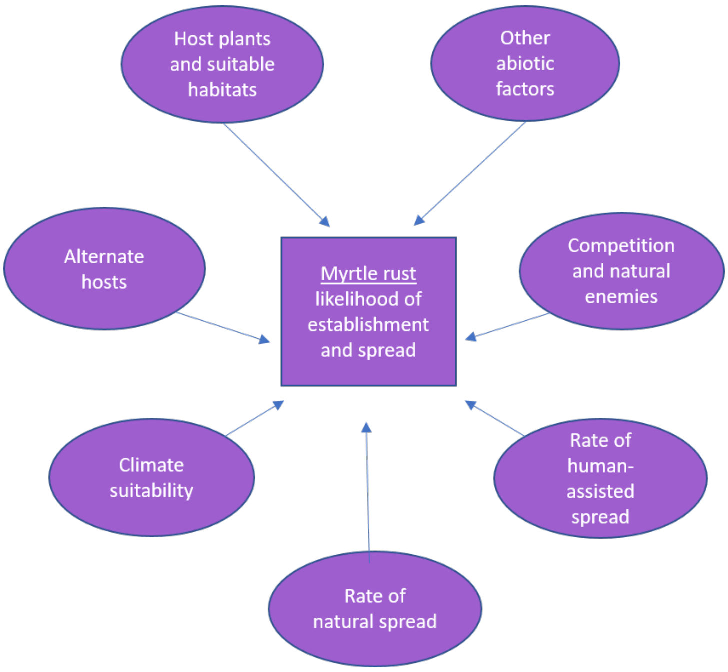
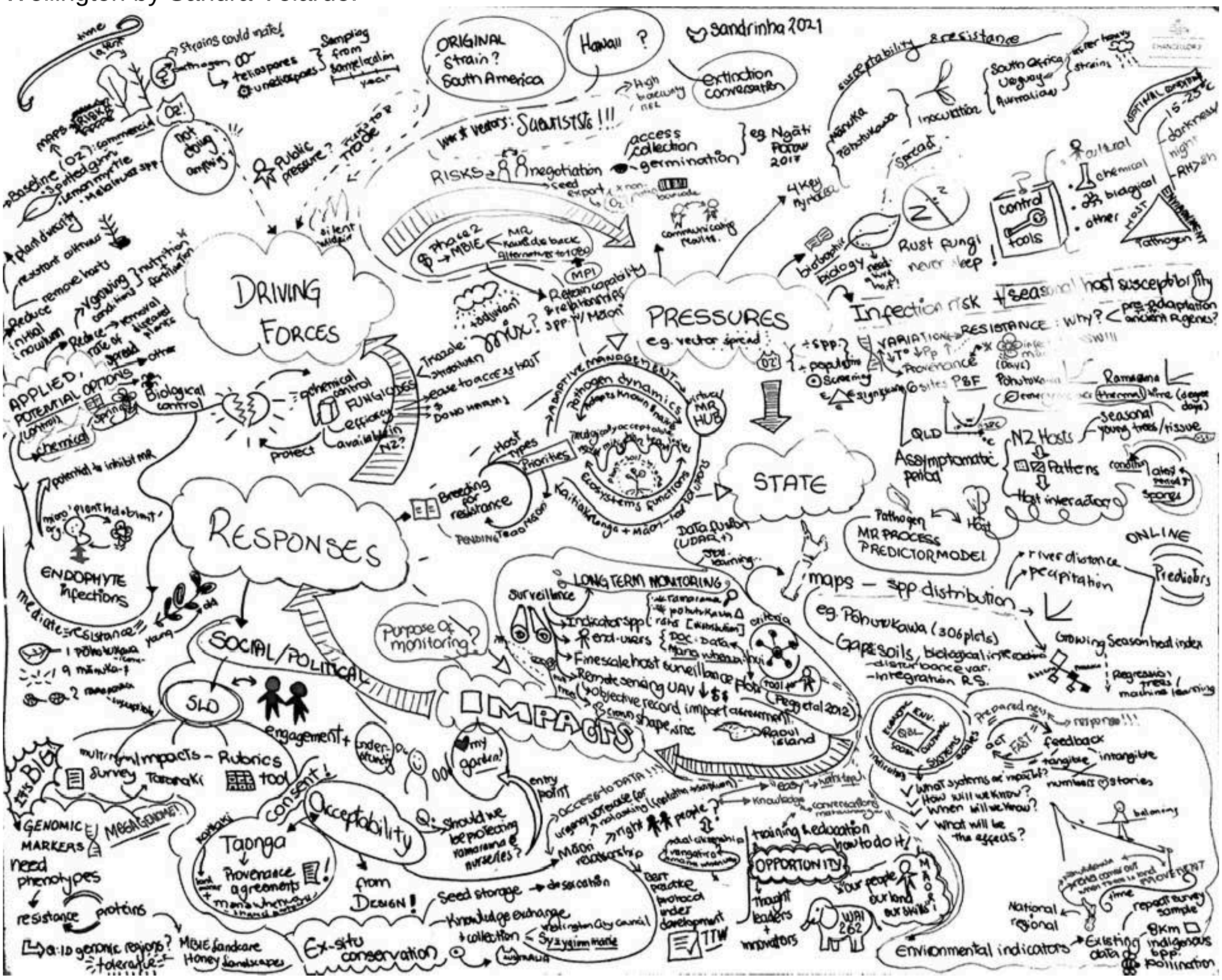


Figure B2. Biophysical aspects of myrtles rust for modelling impact assessment.
This figure was generated as a complementary tool to locate biophysical aspects of myrtle rust impact areas that could be modelled for developing a quantitative QBL impact assessment (discussed in step 4).



Appendix C

DPSIR map. Live graphic record captured at Myrtle rust science meeting 13–14 September 2018, Wellington by Sandra Velarde.



Appendix D

Indicators for environmental impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Biodiversity (S)	Number of plant species potentially affected	Ready to use	Ngā Tipu o Aotearoa, New Zealand Organisms Register	Manaaki Whenua - Landcare Research (MWLR), NZ Virtual Herbarium	Nationwide	Not applicable	Short term	Moderate	None	Focus on species level (rather than genotype) has limitations. For example, there is considerable genotypic and phenotypic variation within mānuka, yet currently only one "species" would be regarded as potentially affected. There is much less known about genotypic variation in other native Myrtaceae species, and nothing about others, including those that are infected in wild populations (Lophomyrtus spp.)
Biodiversity	Innoculum loads	No data existing	N/A	N/A	N/A	N/A	Short term	High	Significant work needed to develop a standardised method of recording innoculum loads or infection rating at sites across NZ	No data existing. This is needed to inform management and understand thresholds of disease i.e. if there is a disease tipping point for species or ecosystems. It also would help link actual impacts or MR with indicators. Maps to DOC outcome 1.1.5 Disturbance. Measure. 1.1.5.6 Disease and invertebrate pest outbreaks (ie spread of MR)

Indicators for environmental impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Biodiversity	Banked germplasm of significant myrtles (exotic, native and significant populations)	DOC and NZIFSB	DOC and NZIFSB hold data. Other possible sources are P&F, Agresearch, Botanic Gardens, local Iwi	DOC, NZIFSB	Nationwide	NA	Short term	High	Some - to align all data sources	This is a required output for the long-term management strategy recently developed. Maps to 1.4.3 Loss of genetic Diversity. Measure 1.4.3.2 Genetics of taxa under management (ie of genotypic variation for some myrtaceae)
Biodiversity (S)	Status of widespread indigenous trees (recruitment vs mortality)	Existing data but work required to use	Environmental domain reporting data	StatsNZ/MfE; DoC; MWLR (NVS databank)	Nationwide	Plot-scale (mostly 400 m2)	Medium term	Moderate	Requires additional work to calculate demographic rates for individual Myrtaceae tree species. Requires insititution or reinstatement of local plot networks for species of restricted geographic distribution (e.g., Lophomyrtus spp., Syzygium maire, pōhutukawa). Requires repeated measurements	Data from LUCAS/DOC Tier 1 are suitable for widespread common species (mānuka and southern rātā, and kānuka, aggregating all Kunzea spp.). No demographic data are available for liana species; methods are required to do so. Suitable means of evaluating the demography of northern rātā (a strangler) requires investigation.

Indicators for environmental impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Biodiversity (S)	Distribution of indigenous trees	Existing data but work required to use	Environmental domain reporting data	StatsNZ/MfE; DoC; MWLR (NVS databank), NZ Virtual Herbarium	Nationwide	Plot-scale (mostly 400 m2), point scale (herbarium records), used construct national-scale models	Medium term	Moderate	Requires additional work to produce species distribution models for individual Myrtaceae species (in part addressed by Theme 2). Can be augmented by citizen science records (e.g., iNaturalist records). Requires 5-yearly updates to include new distribution records, and to take account of any new taxonomic treatments.	Current distributions require uncertainty estimates for different life forms on plots. Distinguishing trees from tagged individuals can determine misidentifications in the field, but uncertainty of other life stages (seedlings, saplings) is unknown, as is uncertainty of detection of northern rātā (a strangler; begins life mostly in tree canopies) and of liana species. Herbarium records, iNaturalist records, and some plot-based data are biased spatially.
Biodiversity	Status of indigenous vines/shrubs (recruitment vs mortality)	Possible existing data but new monitoring required	NVS data	MWLR (NVS databank)	Nationwide	Plot-scale	Medium term	Moderate	Monitoring of species which are not covered well represented on standard monitoring plots. This would include all climbing rata species.	Currently poorly measured, but could serve as good indicator of ecosystem health. Maps to DOC outcome 1.4 Preventing declines and extinctions.
Biodiversity	Loss of habitat / food for myrtaceae dependent species	Not currently available	N/A	N/A	Nationwide	Plot-scale	Medium term	Moderate	N/A	

Indicators for environmental impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Biodiveristy	Change in ecosystem function, as a result of species extinction with change in forest nursery species impacting forest development or weed establishmen t	Not currently available	N/A	N/A	N/A	N/A	N/A	N/A	N/A	
Biodiversity (S)	Land cover change	Existing data but work required to use	Environment al domain reporting data	StatsNZ/Mf E; DoC	Nationwide	10-m raster	Long term	Moderate	Would require additional work to make data specific to Myrtaceae species (i.e., to combine with "Distribution of indigenous Myrtaceae trees", above), probably using new remote imagery techniques. Requires repeated measurements	The only LCDB class that can report Myrtaceae is mānuka/kānuka (and that class currently does not distinguish between those two species). There are only two current native forest classes resolved for national reporting, both unsutiable for reporting trends in Myrtaceae..

Indicators for environmental impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Biodiversity (S)	Conservation status of indigenous land species	Ready to use	Environmental domain reporting data	StatsNZ/MfE; DoC	Nationwide	Various	Long term	High	None. Status assessments reviewed every five years for all indigenous taxa. Requires 5-yearly updates, including taking account of any new taxonomic treatments.	All Myrtaceae species now considered (at least) threatened because of myrtle rust. If new taxonomic evaluations of current concepts of species (e.g., within mānuka) result in more species within genera, then this will have implications for reporting change in status within taxa. Focus on species (as far as variety) level (rather than genotype) has limitations (as above).
Air quality & climate regulation (R)	Carbon sequestration (t/ha/year)	Existing data but work required to use	Carbon inventory data	LUCAS MfE, Scion, MWLR	Nationwide	Plot-scale (mostly 400 m2), modelled nationally	Long term	Low	Requires time to model specific Myrtaceae impacts using existing models. Requires repeated measurements.	Overlay with Myrtaceae distribution. Marginal carbon sequestration rate change over time (e.g. 30 years). We could make an average estimate per year. Primary data are needed for allometries of several Myrtaceae trees (Metrosideros spp., Syzygium maire, Lophomyrtus spp.) to reduce uncertainty of species-specific estimates. Decay rates of coarse woody debris of native Myrtaceae species is unknown and required for total C budgets.

Indicators for environmental impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Water regulation (R)	Water yield (mm/ha/year)	Existing data but work required to use	WaterYield model (spatial output)	MWLR (Anne-Gaelle Ausseil)	N/A	10-m resolution	Long term	Low	Requires time to model specific Myrtaceae impacts using existing models.	Tree mortality will likely increase water yield in the area as runoff from erosion-prone and pastoral areas is increased. Attribution to Myrtaceae species is currently only possible for mānuka/kānuka LCDB category. Attribution to other locally dominant Myrtaceae canopy trees (southern rātā, pōhutukawa) and distinguishing mānuka from kānuka requires additional investment.
Erosion control (R)	Sediment level (t/ha/year)	Existing data but work required to use	SedNetNZ and NZEEM model (spatial output)	MWLR (John Dymond)	N/A	10-m resolution	Long term	Low	Requires time to model specific Myrtaceae impacts using existing models.	Attribution to Myrtaceae species is currently only possible for mānuka/kānuka LCDB category. Attribution to other locally dominant Myrtaceae canopy trees (southern rātā, pōhutukawa) and distinguishing mānuka from kānuka requires additional investment.
Water regulation (R)	Flood control (Frequency?)	Existing data but work required to use	N/A	N/A	N/A	?	Long term	Low	N/A	Attribution to Myrtaceae species is currently only possible for mānuka/kānuka LCDB category. Attribution to other locally dominant Myrtaceae canopy trees (southern rātā, pōhutukawa) and distinguishing mānuka from kānuka requires additional investment. Some data may exist in regional council monitoring.

Indicators for environmental impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Natural Hazard Protection (R)	Floods, storms, droughts (frequency?)	Not currently available	N/A	N/A	N/A	N/A	Long term	Low	N/A	Related to the water regulation service, there are likely natural hazards such as floods, storms, and droughts due to reduced forest areas.
Pollination (R)	Nectar or pollen production (kg/ha)	Limited data available	Floral resources model	MWLR (Anne-Gaelle Ausseil)	Catchment only	10-m resolution	Long term	Low	Requires time to model specific Myrtaceae impacts using existing models. Primary data required for necatr/pollen yeilds for most native Myrtaceae. Scaling up from catchment to national scale is underway for mānuka (MBIE programme) but more resources are required for other species.	Attribution to Myrtaceae species is currently only possible for mānuka/kānuka LCDB category. Attribution to other locally dominant Myrtaceae canopy trees (southern rātā, pōhutukawa) and distinguishing mānuka from kānuka requires additional investment.

Indicators for economic impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Impact on tourism industry	Number of tourism concessions on conservation land	Existing data but work required to use	DoC data	DoC	Nationwide	Associated with specific conservati on lands	Long term	Low	Minimal; would require permission from data owners and compilation	May be difficult or impossible to quantify the impact related to Myrtacea species unless for specific Myrtaceae dominated landscapes.
Impact on tourism industry	Number of tourists citing 'spectacular landscapes and natural scenery' as reason for visiting or their subjective rating of NZ's natural environment	Ready to use	MBIE quarterly International Visitor Survey	MBIE	Nationwide	National	Long term	Low	None; data is already public	May be difficult or impossible to quantify the impact related to Myrtacea species
Impact on tourism industry	Number of tourism operators or people in tourism employment	Ready to use	MBIE monthly Tourism Satellite Account; Monthly Regional Tourism Estimates	MBIE	Nationwide	Regional	Long term	Low	None; data is already public	May be difficult or impossible to quantify the impact related to Myrtacea species
Impact on tourism industry	Number of visitor nights	Ready to use	Statistics NZ Accommodat ion Survey	Statistics NZ	Nationwide	Regional	Long term	Low	None; data is already public	May be difficult or impossible to quantify the impact related to Myrtacea species
Impact on industry (nurseries, plant producers)	Numbers of nurseries producing and retailing native Myrtaceae species	Existing data but work required to use	Register of plant nurseries	NZPPI	Nationwide	National	Short term	Moderate	Minimal; would require permission from data owners and compilation	May be better to focus on specific Myrtaceae species

Indicators for economic impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Impact on industry (nurseries, plant producers)	Revenue from retail of Myrtacea species	Not currently available	NZIER report - Expert estimation by industry	N/A	N/A	N/A	Short term	High	Moderate; Currently only rough estimation by industry experts of total national production and potential loss. Would require data collection; surveys of nurseries	Sensitive commercial data requiring special consideration and handling.
Productivity of Manuka for honey	Reduction in productivity ($/ha)	Not currently available	Enterprise budgets are available; Apiculture NZ honey production data; MPI data; Manuka/Kanuka national distribution available at LCDB (Landcare Research)	Apiculture NZ and Comvita; MPI, Landcare Research	N/A	N/A	Short term	High	Moderate. Currently only sample budgets and expert estimation by industry available for production loss. Would require data collection.	Potential for quantity and quality loss. Quality will be probably moving from high to low UMF but can also be measured in $/ha. Both can be integrated and measured as loss in profitability. Sensitive commercial data requiring special consideration and handling
Productivity of Manuka for oil	Reduction in productivity ($/ha)	Not currently available (only sample budgets)	N/A	N/A	N/A	N/A	Short term	High	Unknown; if it already exists, would require permission from data owners; if it does not exist, would require data collection	Sensitive commercial data requiring special consideration and handling
Additional control costs (by producers & government)	Additional costs to control the fungus ($/ha)	Not currently available	NZIER report - Expert estimation by industry	N/A	N/A	N/A	Short term	High	Moderate; Currently only expert estimation by industry for nursery additional control/production cost. Would require central and local government agencies and producers to track and report resources expended on myrtle rust specifically	

Indicators for economic impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required**	**Known limitations / comments**
Non-tariff barriers for trade	Potential ban or restrictions, $	N/A	Past kiwi case (2011), apples?. Data on exported honey volumes (& destination) are available	MPI (Michael Ormsby)	N/A	N/A	N/A	Variable	Moderate; would need to design and model potential scenarios (e.g., if specific markets were to impose a ban or if products were to lose market value)	

Indicators for socio-cultural impacts of myrtle rust

Impacts	Indicators	Data availability	Data source(s)	Data owner(s)	Existing data coverage	Spatial resolution	Impact lag time	Specificity to myrtle rust	Work required to obtain	Known limitations / comments
Impact on wahi-tapu sites	Number of wahi-tapu sites impacted	Limited data available	Impacted sites inventory; Mapping Māori Priorities project	Mana whenua	N/A	Local	Long term	High	Major; work underway on "Impact on wahi-tapu sites" with the Beyond Myrtle Rust Project: Mapping Māori Priorities; would require ongoing engagement and monitoring on a wide scale with mana whenua in each affected rohe depending on degree of information requested (i.e. whether simply the number of sites affected or locations of and details about those sites).	Potentially sensitive cultural data that would require special consideration and handling.
Impact on mauri	Assessment of mauri / site quality by mana whenua	Limited data available	N/A	Mana whenua	N/A	Local	Long term	Moderate	Major; work to develop methodologies well underway, but would still require significant work for each local iwi/hapu to adapt existing tools and conduct individual assessments for their rohe.	Necessarily subjective and specific to each mana whenua group; difficult to assess/compare nationally but could show direction of change over time within each rohe and this could be loosely mapped. May be difficult to isolate impact of myrtle rust.
Community and cultural health	Ability to support Māori cultural practices and knowledge transfer	Not currently available	N/A	Mana whenua	N/A	Local	Long term	Moderate	Major; would require significant work to develop assessment tools/measures and then for each local iwi/hapu to adapt these general tools to their specific needs and conduct assessments for their rohe	Necessarily subjective and specific to each mana whenua group; difficult or impossible to assess/compare nationally but could show change over time within each rohe; some data may already be captured in tools measuring mauri. May be difficult to isolate impact of myrtle rust.
Community and cultural health	Ability to support wider cultural practices	Not currently available	N/A	N/A	N/A	N/A	Long term	Variable	Major; would require baseline research followed by repeated monitoring	e.g. loss of pohutukawa at Christmas, etc.

Indicators for socio-cultural impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required to obtain**	**Known limitations / comments**
Community and cultural health	Change in sense of place, place identity	Not currently available	N/A	N/A	N/A	N/A	Long term	High	Major; would require baseline research followed by repeated monitoring	Difficult to measure but a fantastic indicator if done
Recreation	Number of people using/visiting all recreation spots (e.g. hiking tracks, camping sites)	Existing data but work required to use	DoC's annual Survey of New Zealanders (?); MBIE's quarterly International Visitor Survey; Lincoln University's Public Perceptions of New Zealand's Environment survey***	MBIE; AA Travel, Tourism Industry Aotearoa	Nationwide	National	Long term	Low	Minimal; would require permission from data owners	DOC survey may have been discontinued after 2016 and has methodological limitations.
Recreation	Number of people using/visiting specific recreation spots (e.g. hiking tracks, camping sites)	Limited data available	DOC and regional council park visitor data	DOC; regional councils	N/A	Local	Long term	Moderate	Moderate; would require access from councils where data is collected and additional visitor monitoring where not currently collected	Councils do not necessarily collect this data or use consistent methods; may be difficult to associate impacts with myrtle rust specifically.
Recreation	Subjective assessments of recreational site quality	Limited data available	Varies	Various	Some baseline assessmen ts exist for specific sites	Local	Medium term	Moderate	Major; would require baseline surveys followed by repeated monitoring	Existing case studies are limited in scale and typically associated with a single type of recreation

Indicators for socio-cultural impacts of myrtle rust

Impacts	Indicators	Data availability	Data source(s)	Data owner(s)	Existing data coverage	Spatial resolution	Impact lag time	Specificity to myrtle rust	Work required to obtain	Known limitations / comments
Iconic landscapes / amenity value	Number of sites that are considered as iconic part of NZ landscape	Existing data but work required to use	Varies	AA Travel and Tourism Industry Aotearoa	Nationwide	National	Long term	Low	Moderate; would require compilation of iconic site inventory data [1) Location, 2) Site name, 3) Ranking (minor/major), 4) Qualitative description, 5) Source],	Unsure about using the number of sites as a metric. It would be better to aggregate assessments of site quality instead
Iconic landscapes / amenity value	Formal Visual Impact Assessments of landscape quality	Limited data available	Various	Various	Some baseline assessments exist for specific sites	Local	Long term	Moderate	Major; would require development of a nationally applicable and consistent landscape assessment methodology and then assessment of iconic landscapes	Currently inconsistent landscape assessment methodologies; assessments generally limited to areas designated as outstanding natural landscapes; may be difficult to quantify importance of Myrtacea species
Iconic landscapes / amenity value	Subjective assessment of state of native bush and forests overall; state of natural environments	Existing data but work required to use	Lincoln University's annual Public Perceptions of New Zealand's Environment survey; Quality of Life survey	Lincoln University (Ken Hughey et al.);	Nationwide	National	Medium term	Low	Minimal; would require permission from data owners and compilation	May be difficult or impossible to quantify the impact related to Myrtacea species
Iconic landscapes / amenity value	Subjective assessment of state of specific native bush and forest areas	Not currently available	N/A	N/A	N/A	Local	Medium term	Moderate	Major; would require baseline surveys followed by repeated monitoring; methodologies exist but not standardised or agreed-upon	May be difficult or impossible to quantify the impact related to Myrtacea species

Indicators for socio-cultural impacts of myrtle rust										
Impacts	**Indicators**	**Data availability**	**Data source(s)**	**Data owner(s)**	**Existing data coverage**	**Spatial resolution**	**Impact lag time**	**Specificity to myrtle rust**	**Work required to obtain**	**Known limitations / comments**
Knowledge and awareness	Assessment of levels of knowledge about the disease, the hosts, the vectors, rate of spread, etc	Not currently available	Biosecuirty survey is a general instrument that could be more specific, e.g., for myrtle rust or kauri dieback	BNZ	N/A	Local	N/A	High	Moderate: would require additional questions inserted to annual survey, on levels of awareness and permission of MPI to make that publically available	Such data collection rarely idenfies whether awareness changes anything that people are doing, may require additional questions and analysis
Social licence to operate	Assessment of management actions, whether acceptable to publics and on what grounds could be made acceptable	Limited data available	MPI current programme of urgent myrtle rust research - Theme 1 enaggement and social licence	MPI/Scion	Nationwide	Regional	N/A	High	Moderate; methodologies exist and some baseline data has been collected but would require more widespread surveying and ongoing monitoring.	Based on known or assumed management options at the time, can be changes in knowledge and approaches over time and need to update as dynamic condition
Community and cultural health	Change in population number/ employment	Not currently available	N/A	N/A	N/A	Local	Long term	Low	Major; would require development of a nationally applicable and consistent assessment methodology and then assessment of on a large scale	Refers to likelihood that a change in the rural population/ employment could happen with significant tree infestation, e.g. farm labour, honey industry, etc.; may be difficult or impossible to quantify the impact related to Myrtacea species

Appendix E

Questions posed to indicator matrix reviewers

Email sent on Thursday 28th March 2019

"Thank you for helping to review our list of myrtle rust impacts indicators. We appreciate your time and feedback even if you can only spare a few minutes.

This spreadsheet lists potential indicators for myrtle rust impacts. Our list was compiled based on a literature review, on expert knowledge from researchers in the myrtle rust programme and on input from participants in the science and stakeholder workshops. Though we recognise that some indicators may cross domains, we have roughly grouped these by environmental, economic and socio-cultural impacts. Note that the lists include both those indicators which would be ideal and those for which we have data available but which may not be as accurate or specific to myrtle rust.

We ask that you please look at the sheet(s) relevant to your expertise and comment on our draft indicators. The list below includes some overall questions to consider, and specific questions are listed next to the relevant indicator. Please pay particular attention to those cells highlighted in orange."

Questions for reviewers
1. Are any key indicators or available data sets missing from our draft list?
2. Should any of the listed indicators be removed?
3. Are there any better indicators which would capture the impacts of myrtle rust more directly?
4. Are our estimates of the work required to develop missing indicators accurate?
5. Do you agree with our rough assessments of specificity, resolution and coverage?
6. Are we providing the correct type and level of detail about these indicators in the table columns?"

Responses to the request (N=9)

Stuart Fraser, plant pathologist, Scion
- Most red dragon ramarama I've inspected in Rotorua is infected.
- Roanne and Julia's monitoring is showing dieback on species of *Lophomyrtus* plus impacts on the ability of these species to regenerate.
- This is despite this summer being suboptimal for the rust, based on Rob Beresford's data.
- This is worrying for the future of these species.
- Individual trees of susceptible species, such as *Syzygium jambos*, remain uninfected in Auckland suggesting that the present lack of infection on other species (with unknown susceptibility) cannot be taken as a sign of possible resistance – rather they may be "escaping" infection due to low inoculum levels.
- Early observations suggest *Austropuccinia psidii* is able to sexually reproduce in New Zealand. A mixed mating strategy (both clonal and sexual reproduction) increases the evolutionary potential of the pathogen and threatens the long-term effectiveness of certain management strategies, such as resistance breeding or chemical control.

Additional indicator
- Environmental:
    - o Impacts on species dependent on and associated with threatened species of Myrtaceae. E.g. impact on associated fungi, bacteria, other microbia, insects, plants, birds, bats (?), etc

Rebekah Fuller, Post-doctoral researcher, Lincoln AgriTech (Maori)
Great job, the indicators are looking good. I am sure that Maj has replied already but we will be looking at completing some of the work mentioned in the socio-cultural impacts of myrtle rust. For example "Impact on wahi-tapu sites" with the "Beyond Myrtle Rust Project" called Mapping Māori priorities. My only comment is that I disagree with the general statement below. I would suggest that there will be some elements of Māuri that would be comparable if the data is available.

- IMPACT ON MAURI: Necessarily subjective and specific to each mana whenua group; difficult or impossible to assess/compare nationally but could show direction of change over time within each rohe and this could be loosely mapped. May be difficult to isolate impact of myrtle rust.

Tui Shortland, Repo Consultancy Ltd (Maori)
I am currently working with Ngati Rehia who will be developing their own indicators. It would be advisable for you to support them in their work too

Grant Smith, Plant pathologist, Plant & Food
Sent response to another expert elicitation process from OEH NSW on key threatening processes on species reestablishment. Impacts on threatened species and KTP impact on threatened species recovery.

Bill Dyck, Science and technology broker
Has looked but not seen any impacts

Karyn Froud, Biosecurity Scientist, Consultant and Epidemiologist
A quick look at the environmental indicators, and says it looks quite comprehensive

Tony Beauchamp, Technical Support Officer Ecology, DOC

- Environmental
  Under water regulation (R), flood control frequency, What data exists currently and how much additional work or data would be required to use this as an indicator?
  "Unknown but maybe there is data in annual reports to councils on the costs of slip removal in annual reports. If pohutukawa is impacted then this may well increase?"
- Economic
  Impact on tourism industry, Number of tourism concessions on conservation land, Would it be possible to relate this data to landscape/amenity site data? Are there better indicators for tourism industry impacts?
  "maybe at some sites like Rangitoto and Te Paki which are myrtaceae landscapes you could do it."
- Impact on industry (nurseries, plant producers), Numbers of nurseries raising and retaining native species, Is this assessment of the work required accurate?
  "You really want to concentrate on what nurseries are producing or stocking in terms of mytraceae as in Australia they moved out of them. Could be the number of nurseries selling ramarama. MPI will have some indication of this via their Taranaki response"

Fiona Thomson, Myrtle Rust Project Manager, DOC
Not easy to understand what is being asked for. It's unclear whether she respond as a reviewer, stakeholder or practitioner.

DOC is currently working on seed collection and erecting signage. They work mostly with iwi and less with the general public.

They have been developing indicators with Kate McNutt and extending that though developing an outcomes monitoring framework. Mapping spread would be a valuable tool for them. They do have additional indicators, it would be useful to do a cross check with DOC's framework development. Now with the MR Strategy available there were aspects of performance in that with corresponding development and resources. They would like an understanding of the spread of myrtle rust, where it is, how long it has been in a local area, and better knowledge of the science of spread. Currently they are still sending their detections to MPI and telling the public to tell MPI if they find it.

Rob Beresford, Principal Scientist, Plant & Food
May be difficult to detect in the natural estate but the natural range of lophomytrus was at its limit in Auckland. Red Dragon grows better in Christchurch than Auckland, its more compact in Christchurch and lankier in Auckland. Compared to pohutakawa, lophomyrtus had adapted to cooler conditions. Pohutakawa bud terminate below 8 dgerees and lophomyrtus sruviev down to almost 0 degrees.

Environmental pressures depend on where its established, there are high to low environments of pressure. Crop management practices such as disease hygiene can help to reduce inoculum loads. Locating sources of inoculum like lily pily hedges could be a way of prioritising where to look via modelling the environmental range.

Will Allen, Independent systems scientist, action researcher and evaluator, Will Allen & Associates
Had a look but could not find how to include anything of importance. It read like an externalised view of impact and indicators and was difficult to add into the socio-cultural space. It's all about where the dust settles rather than how people engage or learn, and subsequently respond. There are changes in levels of awareness or changes in levels of concern that could be captured, that may or may not result in action.

Appendix F

Building relationships between key stakeholders and their activities

Table G1 outlines key stakeholders and areas of activity that we could ascertain based on our research interactions. Six main activity areas are identified:

1) surveillance and monitoring
2) information provision
3) knowledge gathering
4) management/ strategic plans – including biosecurity response and protection plans
5) engagement and awareness – including awareness raising
6) seed collection – including baking, resistance testing, and genetic analysis

Table G1: Sample stakeholders and activities currently being undertaken (in black) (synthesis from Theme 1 and Theme 3) and possible activities (red and blank)

Stakeholders	Activity
Government	
Botanical Gardens	Surveillance and monitoring, information provision, knowledge gathering
DOC	Seed collection, awareness raising
Auckland Council	Management/ strategic planning, knowledge gathering, surveillance and monitoring
Industry	
Plantation Forests	Surveillance and monitoring
Nurseries	Biosecurity response plans (in development)
NZPPI	Nursery management protocols
Community	
1 e.g., Native plantings	
2 e.g., Species conservation councils	
3 e.g., School groups	
Mana whenua/ hapū/ iwi	
Te Tira Whakamataaki	Seed collection
hapū/ iwi	Surveillance and monitoring
Mana whenua	Protection plans
Non profit	
Project Crimson	Surveillance and monitoring, engagement and awareness
Forest and bird	Engagement and awareness
Services	
Environmental monitoring	Information provision, knowledge gathering Surveillance and monitoring
Research	
MPI Project 18607	Information provision, knowledge gathering Surveillance and monitoring, seed collection
Catalyst ????	Resistance testing, genetic analysis

Report information sheet

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