New Zealand's Biological Heritage National Science Challenge
Scoping Panel Report: Ngā Rākau Taketake

Section 1: Creating Impact

Vision and link to the Challenge mission

New Zealand's forests are the "lungs" or life of our country, filled with taonga that provide an immeasurable wealth of cultural, spiritual, ecological, aesthetic, recreational and economic benefits to all New Zealanders. Yet these forests are under threat from two invasive pathogens causing diseases known as kauri dieback and myrtle rust.

The mighty kauri and their dependent ecosystems are taonga to Māori and have significant spiritual and cultural importance with links to identity for northern New Zealand. These giants of our forests, including Tāne Mahuta, can live for over 1,500 years, but the magnificent trees are dying under our watch. They and the ecosystems they support are under dire threat from the invasive pathogen, *Phytophthora agathidicida*.

At the same time, our native Myrtaceae, including species such as pōhutukawa, mānuka, kānuka, ramarama and the many rātā species, are also under threat from the new invasive, *Austropuccinia psidii*, myrtle rust. It is unthinkable that pōhutukawa, another spiritually and culturally important species, could disappear from our northern coastlines, or other species of Myrtaceae and their ecosystems that span the length of New Zealand could be lost forever. These diseases are threatening the oranga (health, wellbeing and livelihood) of our kauri and Myrtaceae taonga. They are also impacting on te oranga o ngā tangata, the people and communities that rely on healthy forests.

The Challenge's mission is to save the precious taonga that make up the unique biological heritage of New Zealand. Our vision for success is that the mauri of kauri and our native myrtle species is safeguarded, sustained and enhanced for our tamariki and mokopuna. We will achieve this by drawing on the combined power of mātauranga Māori and Western science to treat and cure diseased trees, safeguard healthy trees and to protect next generations of trees. While our focus is on these two current threats, the work we do will help ensure our ecosystems thrive and are resilient to these and any future threats.

Kauri dieback and myrtle rust are two very different diseases but are similar in the impacts they cause and the threat they pose to native plants and their ecosystems. *Phytophthora agathidicida* is a soilborne oomycete pathogen that has infective propagules which can survive long-term in minute fragments of plant material. When present in soil, these infected plant fragments can easily be transported to new areas (where the pathogen is not present) by movement, in soil or plant matter attached to shoes, equipment, animals etc. If infective propagules in the contaminated soil encounter a susceptible kauri, they can ultimately infect and kill the tree.

Conversely, *Austropuccinia psidii* is an aerially spread rust fungus and the distinctive yellow spores produced can be spread by wind or on any surface that comes into proximity to the spores. This rust pathogen can infect over 480 species of Myrtaceae. In New Zealand at least 12 of the approximately 30 native species of Myrtaceae are known to be susceptible and there are numerous exotic species present that are also known to be susceptible.

Currently the pathogens that cause these diseases cannot be completely eradicated from New Zealand with the tools available. Although localised eradication is feasible, if an infection in an area is new or limited in size, the opportunities for this are limited and cannot prevent reinfection. These are diseases we will be living with for the foreseeable future which makes active management critical to save and preserve the mauri of the ngahere. Like human diseases, by limiting the spread and levels of inoculum of the pathogens we can reduce the number of trees infected and give those that are, an opportunity to fight the pathogens. Time allows us to develop effective new methods and tools to combat these diseases.

Much progress has already been made in addressing these two pathogen threats. Unfortunately, efforts to control and manage kauri dieback have faced criticism from the public and frustration from those involved. In particular, previous research funding has been criticised as piecemeal and uncoordinated, and management criticised for not involving or responding to mana whenua and communities. This has undermined trust and relationships among agencies, partners and stakeholders. The early myrtle rust response research has thus far avoided these issues, but risks falling into the same traps without strong leadership. Ngā Rākau Taketake represents an opportunity to take a different approach and to be an exemplar for how good, inclusive and collaborative research can be accomplished.

2024 Goals

The Challenge, in partnership with mana whenua, promote working with communities, agencies, and industry to identify and prioritise ecosystems at most risk, and to identify and employ the strategies and tools to protect them.

By 2024, our work ensures that:

1. Mātauranga Māori and kaupapa Māori research is embedded in the fight against plant pathogens, and kaitiaki are empowered to take action;
2. Communities and mana whenua are engaged and mobilised to participate in the battle against kauri dieback and myrtle rust - kō tātou;
3. Improved detection tools and an integrated surveillance system are in place, so monitoring the spread of the pathogens and diseases can inform management solutions;
4. Protocols and a prioritized action plan are established to preserve a representative collection of threatened germplasm, including both host plants and dependent species, and have preserved germplasm from priority species;
5. There is an understanding of which species and ecosystems are most at risk and what the impacts of the diseases are, so prioritisation of efforts inform better management decisions;
6. We understand the interactions between the hosts, pathogens and environment from genetic to landscape scales to help future-proof those species through resistance and resilience; and
7. New strategies and effective tools to prevent, treat, and cure the diseases that are co-designed, shared and agreed between mana whenua, communities, industry, regulatory organisations and researchers.

These goals will lead to integrated management of kauri and myrtle ecosystems based on the best science and mātauranga.

Beneficiaries

We are doing this for the mauri of our ngahere, focusing on kauri and myrtles, for all New Zealanders – current and future generations.

The ngahere

The ultimate beneficiaries of our work will be the kauri, the myrtle species and the ecosystems they are part of. The Challenge recognises the need to protect and grow these taonga as part of our biological heritage. Kauri and our native myrtle species represent integral parts of their ecosystems, without which the ecosystems could not survive, and many other dependent species would be lost. Kauri, for example, change the chemical composition of the surrounding soil and shape the local plant communities. Dozens of ferns, orchids and other epiphytes live in their canopies while kākā feed on their seeds.

Mana whenua

Mana whenua are key beneficiaries, as whānau, marae, hapū, iwi that are the kaitiaki of kauri and Myrtaceae species on their lands. They have duties and obligations as kaitiaki to protect, preserve and restore these taonga tuku iho. For many, their cultural identity and whakapapa is intrinsically linked to these species through, for example, taonga specimens, ecosystems and wāhi tapu sites such as Te Rerenga Wairua or the stand of pōhutukawa held by Ngāti Mutanga that was transported on the Tokomaru waka. Myrtaceae species are critical to cultural practices and understandings such as the maramataka (Māori Lunar Calendar) and associated tohu/seasonal indicators. Loss of taonga species leads to a loss of the practices and knowledge (mātauranga, rongoā) associated with these species, and an associated diminishing of the mauri of these ecosystems and the mana of kaitiaki tasked with their protection.

Communities

In addition to those values for mana whenua, these taonga species and ecosystems have social and cultural value for all New Zealanders. These species form essential parts of iconic landscapes that shape our national and local identities – from groves of ancient kauri to pōhutukawa-lined coasts and dense kānuka forests. Pōhutukawa have become symbols of the Christmas holiday, reproduced in art and holiday cards. Kauri wood and gum played key roles in the European settler economy, shaping history and helping to define Northern settler identity.

The tourism industry

Our taonga species contribute greatly to New Zealand's appeal as a tourist destination. Tāne Mahuta alone attracts over 150,000 visitors every year, and northern coastlines covered in pōhutukawa and landscapes defined by kauri and Myrtaceae contribute to our unique bioheritage visited by millions every year.

Primary industries

Kauri and myrtle species contribute to several primary industries. Of particular concern is the high value mānuka honey industry with over $350 million in annual export earnings, but the pathogens could also affect smaller industries based on mānuka and kānuka oils, rātā and pōhutukawa honey, feijoa or kauri plantations. Exotic species of Myrtaceae are often used in horticultural industries as shelter belts, loss of these could have indirect effects on other economically important crops to New Zealand. Many of the Myrtaceae, both native and exotic, are also important economic species for the nursery and plant propagation industry which provides the conservation, commercial and retail sectors with plants.

Delivery pathways

BioHeritage National Science Challenge (BHNSC) Innovation Pathway

Delivering on the challenge pathways requires a cohesive approach in collaboration with Māori, key partners, stakeholders, and communities. As with the wider Challenge, we envision an innovation pathway that weaves together each step of the process in integrated manner (Figure 1). However, the current situation does not yet reflect this aim. Our work will seek to reconnect and connect areas which have broken down or have been insufficiently supported.

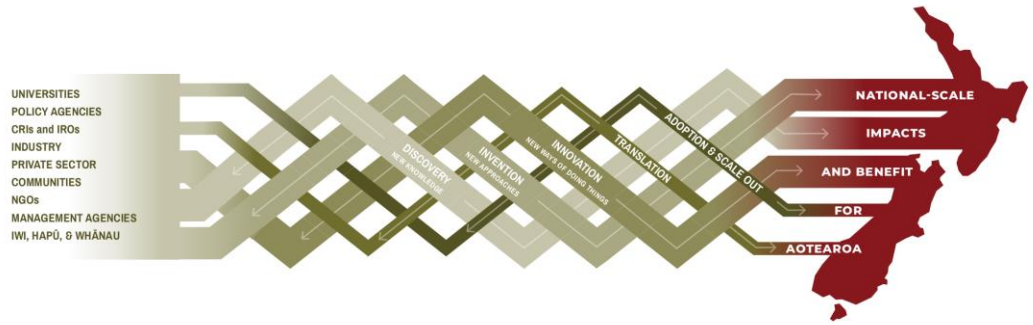
Figure 1. The innovation pathway

BHNSC Myrtle Rust Innovation Pathway.

The surge investment for myrtle rust will be directed at building on some of the key investments made to date, that are now either off contract or about to come off contract, with one or two notable exceptions (Catalyst funding to Plant and Food Research and the "Beyond Myrtle Rust" MBIE Endeavour programme). Working with the relevant stakeholders, the Scoping Group has identified key areas where investment should be continued, where new investment is required to make gains from previous work, and where research has been completed to a sufficient level for the investment to be deemed completed. In the course of scoping there have also been some key areas identified where further development is required, but perhaps at a scale beyond the current scope and size of the surge funding. A key example of this would be a New Zealand native germplasm collection or collections, which while important for the myrtle rust response and kauri dieback, would be a larger resource nationally, and would require funding well beyond the life of the surge investment. This may require a multi-lateral arrangement among interested parties, including some central government departments from a resourcing perspective.

It is clear in the context of myrtle rust that there is a current shortfall in investment for "Adoption and Scale Out" and "Translation" (Figure 2). For the former, if not the latter, there is a strong possibility of in-kind involvement of other parties, including mana whenua, community groups, local and regional councils, as well as the Department of Conservation (DOC). While this is potentially of strong benefit to the response, it will need to be coordinated effectively and with consideration of where it is appropriate these parties are funded for their involvement, especially where the work is beyond their day to day operations. Kaitiaki and mana whenua in particular need to be considered carefully in this regard to ensure the challenge principles are upheld. The risk of this issue is higher for the myrtle rust response than for kauri dieback due to the particular weakness of the implementation pathway being more at the "Adoption" than the "Development" end of the spectrum.

Figure 2. The current myrtle rust unbalanced innovation pathway



BHNSC Kauri Dieback Innovation Pathway.

Over ten years of effort has already been carried out on kauri dieback, involving a comprehensive range of mana whenua, central and local government, researchers, scientist, and communities. Unfortunately, this has been very fragmented and incohesive, resulting in research that is often not well translated into impact (Figure 3). A good example of this being the large number of diagnostic methods developed or under development, very much following a competitive model. This fragmentation has been institutionalised and created rifts among some parties involved, therefore, a significant shift is required. The Challenge will implement innovative change and re-calibrate collaborative partnerships under a values-based kaupapa, shifting mindsets for a step change approach. The following supports this step change for enabling the delivery of positive impacts for kauri dieback and myrtle rust.

Like myrtle rust, a significant amount of kauri dieback work is either off contract or about to come off contract, limiting other current direct investment in the landscape that can be leveraged. Although there is potential, if a wider view is taken, for many organisations having work that could contribute even though they may not be wholly kauri focused. The Advanced Remote Sensing Aotearoa MBIE programme and investments in forest health research either by industry or CRIs being obvious examples.

Figure 3. The current broken kauri dieback innovation pathway

A priority is embedding a bicultural approach for responding to kauri dieback and myrtle rust. Māori are kaitiaki (guardians) of New Zealand's taonga and have statutory roles in the protection of natural resources. The Crown has obligations under the Te Tiriti o Waitangi to work in partnership with Māori. We have an absolute commitment to do this, not because we are obliged to, but because Māori are a critical part of the team that will deliver impact. Māori knowledge and resources can provide solutions and methods to combat kauri dieback and myrtle rust. Te Ao Māori will be embedded in our vision, values, and ways of working.

Implementation of this plan will increase the likelihood of science making an impact by encouraging and relying on:

- partnership with mana whenua;
- connection, alignment, and participation by those benefitting from the research;
- collaborative and multi-disciplinary research by a wide range of science providers;
- high quality science, peer review, and strong international linkages and domestic networks such as Ko Tātou This is Us, BioProtection Research Centre and Te Tira Whakamātaki (TTW);
- focus and passion to achieve the goals set over a robust investment and prioritisation process; and
- regular and investigative monitoring of research progress combined with flexibility to rapidly adapt and respond to research results to ensure the best management solutions are delivered.

Delivery pathways cover three main areas.

1. Working with mana whenua, communities, central and local government, industry and conservation organisations;
2. Collaborative science and mātauranga; and
3. Science and mātauranga prioritisation and adaptive response.

Working with communities

Working closely with mana whenua, central and local government, industry and conservation organisations, enables engagement with the public and communities using targeted methods developed to fit specific regions and contexts. Co-development of the programme will be part of all aspects of research. In particular, building relationships with mana whenua kaitiaki to form agreements around protection of indigenous rights, access to sites, and the use of taonga plant material. Best practice guides and material will be developed to increase community engagement and to deliver science outcomes. Co-design with mana whenua hapū/iwi to explore the relationship between this work and mātauranga, including in the design of surveillance programmes. Landowners (mana whenua hapū/iwi and others) and land managers will help develop protocols for collecting material, and data processing, handling and storage. A Waka Hourua model for co-governance, co-management, co-design treaty partnership, and facilitation and engagement will be developed. Mana whenua and community volunteer groups are informed and enabled through, for example, the Kauri Project, TTW, Kauri Rescue, Reconnecting Northland, and the Tangata Whenua Roopu.

Collaborative science

Through the BioHeritage scoping process the science landscape (what has been and is being done at present), key science priorities and strategies, and science providers have been identified. The large

amount of aligned research taking place has been considered, allowing research gaps to be identified. Engagement with wider kauri and myrtle research communities will inform other workstreams. Initiatives to increase collaboration include formation of multi-disciplinary, cross organisational research teams to deliver high quality science and mātauranga outcomes of benefit to New Zealand. Coordination of resources, materials and agreements through online databases and collections will be crucial within Ngā Rākau Taketake and can be coordinated across other workstreams to avoid duplication of effort. Key to our collaborative science approach will be co-design with mana whenua hapū/iwi.

Science prioritisation and adaptive response

Our intent is that the research programmes will be developed and executed in partnership with those who are responsible for implementation: mana whenua, communities, conservation groups, central and local government agencies, and relevant industries. This will help ensure that the investments deliver outputs that are fit for purpose and readily adoptable by the end users. It will also allow practical experience and local knowledge to continue shaping research as it progresses. In many areas of work, we hope to align our research with operational activities, allowing fast feedback to inform adaptative management and cost sharing. There are also opportunities to align research with other Challenge scoping groups, to existing research on myrtle rust and kauri dieback, and with research programmes across the wider ecology/bioprotection areas.

Science prioritisation has already been partially addressed by the BHNSC rapid implementation group in alignment with prioritisation for kauri dieback and myrtle rust identified by the respective Strategic Science Advisory Group (SSAG) science strategies and stocktakes of science undertaken or currently underway. Based on these priorities, four research projects were identified and are currently being funded by the BHNSC (https://bioheritage.nz/surge-funding-investment/). The first three commenced in July 2019, including urgent research into surveillance, mātauranga Māori projects and tools for improved detection and control. In addition, research on myrtle rust that needed to continue over summer and autumn to ensure valuable information on pathogen establishment and impacts was captured, was identified through discussions with the wider myrtle rust research community. This research project commenced in November 2019.

We acknowledge that all the goals outlined in this scoping panel report and the research required to meet these goals are necessary and urgent, but due to funding and resource constraints needs to be prioritised. This prioritisation will build on the research stocktakes and SAGG science strategies that have already engaged with mana whenua and the wider research and end user communities. However, the most critical component identified that needs to be prioritised for both diseases are tikanga-based protocols and frameworks to ensure all research undertaken respects mana whenua kaitiakitanga. Detailed plans for research prioritisation are in development.

Data and outcomes from research on kauri dieback and myrtle rust will be shared openly (subject to IP considerations) to enhance collaboration and expedite delivery of outcomes. At least one 'kauriland summit' and one myrtle rust hui with mana whenua hapū/iwi partners, government, industries and other relevant community stakeholders will be conducted annually to give an overview of progress, research updates, and garner feedback on ways forward for the coming year. These summits and other engagement can further provide opportunities to identify new people and capabilities which can contribute to the work.

Risks

The area of plant pathogens is complex, especially when dealing with the issues of kauri dieback and myrtle rust. Both of these pathogens are inherently difficult to manage, sometimes for different reasons. Since these issues are already present and research underway, many of these could be more accurately considered as known challenges than risks. Our work aims to be more integrated, inclusive and transparent so as to address many of these identified challenges.

Science risk

Phytophthora cause some of the most intractable plant diseases we know. Microscopic, they are difficult to detect and often it is not until expression of disease occurs that their presence is realized. They are also extremely difficult to control, and do not respond well to common pesticides, which is unsurprising as they are not related to fungi, which is what these tools are predominantly developed for. *Phytophthora* (name means plant destroyer) are often devastating in plant populations, and ultimately host resistance seems to be the solution in many situations. Given kauri are taonga, and there are cultural concerns around how this is managed, this places an extra layer of complexity on the situation. Similar to *Phytophthora*, rusts are also notoriously difficult to manage plant pathogens. Whilst easy to detect, as they produce bright yellow/orange spores, control of these pathogens is difficult. Fungicide options are limited, and many are not overly effective or suitable for treating large areas where there is constant dispersal of spores for reinfection or in ecosystems where they may have detrimental impacts on non-target species. *Austropuccinia psidii* is a particularly challenging rust pathogen as it has a very large host range, unlike most rust fungi, and also has the largest fungal genome that has ever been sequenced – giving it the ability to recombine and evolve rapidly. Both pathogens and the diseases they cause require innovative solutions to their management, this means that work undertaken will have inherent risk in that much of it will be pioneering (microbial interactions/biocontrol is an obvious example).

Our inclusive approach will ensure that we are exploring innovative ideas from across the spectrum of science, mātauranga Māori and practical local knowledge. This has already proven successful at identifying possible rongoā inspired treatments for kauri dieback, and we know that we have not yet fully tapped the potential of these knowledge resources.

We can also help mitigate this risk by actively working with researchers around the globe who are tackling myrtle rust, other rusts or *Phytophthora*. Many of these connections have already been made through existing projects and our work intends to build these relationships into an international biosecurity community that shares knowledge about progress, failures and future risks.

Funding risk

The budget for myrtle rust is considerably lower than for kauri dieback, yet the number of hosts and geographical range of this species is much greater. This clearly constrains the amount of research into myrtle rust, despite it arguably being as large, if not a larger, concern. The timeframe for committed funding is also very short, limiting what can be carried out especially as some host species can be very long lived and disease effects can often be measured in years rather than months. For both kauri dieback and myrtle rust, the amount of funding allocated to the Challenge is substantially less than that estimated to be required by the respective science plans developed by the SSAGs. For both, there will need to be strong prioritization of research ideas.

While the Challenge cannot tackle this work alone, the funding allocated can provide a core around which we can build a complete programme. We believe we can help close some of the gaps by

identifying synergies between workstreams in Ngā Rākau Taketake and across the Challenge. In some cases, our work aligns closely with research needs in other areas, outside plant pathogens among industries and government, providing opportunities for combined efforts and support. For example, work on kauri and myrtle ecosystem restoration can help inform wider conservation efforts. Similarly, developing measures of biodiversity and social or cultural health can help inform decisions from resource management to community health. We also have opportunities to work together with operational management groups to support each other and share costs.

Respectful process for mātauranga and kaupapa Māori

There is a risk that, if not handled appropriately, mātauranga could be misused or shared beyond where practitioners are comfortable. This could rapidly erode buy-in with Māori, and result in losing the opportunity to apply mātauranga to kauri dieback and myrtle rust. There is also a risk that mātauranga contribution could be tokenism, if not implemented effectively across Ngā Rākau Taketake. Some previous projects in myrtle rust and kauri dieback have demonstrated how mātauranga Māori and Western science can support each other respectfully and productively. We will build on these existing relationships, with leadership and oversight from Mana Rangatira, to ensure Ngā Rākau Taketake is an exemplar for respectful process.

Disengagement – communities and researchers

It will not be possible for the Challenge to fund every research idea, nor engage with every researcher. This can result in ill feeling within the research community that they have been overlooked. It is also possible that not all research has been effectively scanned in the scoping process. Likewise, engagement with community will not reach everyone, so will need to be carefully managed to ensure that the effort best connects with those who have an interest. This has been a particular challenge with the response to both diseases to date. We have endeavoured to be transparent at every stage of this process thus far and sought wide input into our work. Ngā Rākau Taketake has established monthly open online meetings for those with interest in myrtle rust to share and learn what research is happening. An equivalent monthly meeting is in the process of being established for kauri dieback. Annual symposia will provide additional opportunities for people to become involved.

Conflict and competition

Many organizations have been involved in the myrtle rust and kauri dieback responses to date, and many feel that they are key players in this area. Introduction of new capacity and capability is needed, but needs to be done respectfully, not only for the researchers and organizations themselves, but also recognizing their key relationships with mana whenua and stakeholders. There are also research areas where there are different possible approaches that may interact in a competing manner (i.e. different methods and techniques for surveillance and detection). It will be inevitable that the Challenge will not be able to fund all areas and methods, and thus will need to prioritize approaches funded. We will make explicit that we expect research to prioritise collaboration and cooperation across organisations and perspectives.

Operational support

Despite the impact both diseases are having, and the long-term threats they pose to our ecosystems are recognized, there is very little financial operational support for mana whenua and stakeholders. This is a risk not only to researchers' ability to engage appropriately with relevant individuals and organizations, but it also means there are potentially financial constraints for implementation of research outcomes. There is also risk with groups that currently have operational funding but could lose it in the future, compromising their ability to contribute over the duration of the research. Whilst

there are initiatives to obtain more operational funding, the extent of this is limited. We hope that our research and the outputs we produce will help provide evidence for the need and value of further investment.

Political risk

Both diseases are high profile and pose major threats to ecosystems. With the investment that the surge funding represents, there will be high expectations of delivery of tangible outcomes. Given the science and operational support risks outline above, this exposes organisations and the Challenge to reputational risk if delivery is not significant. We must be careful to balance optimism against pragmatism so as to manage expectations for what we can achieve within the time frame. However, we must also remain positive. While it is unlikely that any technologies within this century could nationally eradicate these diseases, we have shown great progress towards managing their impacts and growing the resilience of the affected host species and ecosystems. Our work can provide a strong foundation for building a long-term future for our taonga.

Communications and relationship management

Because efforts to understand and combat these two pathogens are already underway, the Ngā Rākau Taketake programme is working in the context of existing relationships and past action. While many strong relationships have been built through this previous work, relationships among some key partners and stakeholders have become contentious. This makes the need to build — or re-build — relationships even more important for the programme.

Part of our work itself about how best to engage with all parties and to build effective collaborative partnerships. We will not simply tell our message — we intend to communicate through action. Our work will demonstrate the values we hold and our commitment to working together with all partners and stakeholders in these pathogen threats.

Mana whenua kaitiaki

Mana whenua relationships are central to the Challenge overall and to Ngā Rākau Taketake in particular. We will build upon existing relationships, including the Tangata Whenua Roopu (who are part of the Kauri Dieback Programme), Te Tira Whakamātaki, and mana whenua hapū/iwi which have been involved in previous research, to connect with others and build new relationships with mana whenua groups which have yet to be involved. It will be necessary to be pro-active in growing these relationships by reaching out and supporting mana whenua to participate. Part of this effort will include annual hui on each disease to maintain relationships, to share knowledge in all directions, to discuss paths forward and to encourage and nurture young kaitiaki to participate actively in the work.

Central and local government

A significant portion of our native forests and urban estate are managed by central and local government agencies, including Biosecurity NZ (Ministry of Primary Industries), DOC and councils. These agencies are responsible for much of the operational management of both pathogens and will be crucial partners for development and implementation of research outcomes. They also have extensive networks with local mana whenua and communities. We are including people from these key organisations in developing and carrying out our work programmes to ensure that we maintain strong connections throughout the process.

Communities

Community support and participation will be essential as members of the public are often involved in surveillance, implementing management tools and undertaking restoration projects, and are also directly impacted by complying with controls. Part of the research programme will involve identifying how best to engage with and support communities and individuals to become more involved. A critical starting point is working with non-government organisations, DOC, and regional councils that have been leading the fights against the diseases at an operational level and which have already developed extensive communication networks and education campaigns. We will align with these organisations' existing websites for each disease to communicate ongoing work openly and transparently.

Conservation groups

Conservation groups hold considerable experience in restoration and other operational activities. Moreover, they will be key partners for mobilising communities and individuals to participate in managing these diseases. Several such groups have already participated in previous work addressing these pathogens or have expressed interest at the myrtle rust and kauri dieback science symposiums. We will build on these relationships and leverage them to work with their partners. This too will be a part of our research programme identifying opportunities and means to improve the involvement of environmental and community organisations.

Industry

Industries will be key partners. In particular, the nursery industry, plant trade, arborist and landscaping sectors will be essential for carrying out controls and for supplying material for restoration planting. The tourist industry will be essential for helping to educate visitors and ensure compliance with control measures. Primary industries will also play an important role in disease management. These industries will be engaged through their existing industry networks and organisations, such as the New Zealand Plant Producers Inc., the New Zealand Plant Protection Society, Apiculture New Zealand, New Zealand Biosecurity Institute, New Zealand Arboricultural Association and the Tourism Industry Aotearoa.

Section 2: Incentivising Investment

Essential activities

This programme sets out to achieve impact by saving our kauri and myrtle forests from the threat of dieback and disease. In theory disease management is simple. One needs to disrupt the conditions that allow pathogens to cause disease and the vectors that allow it to spread. The pathogen may be targeted, or the host or environment can be changed to make conditions less favourable for the pathogen or to allow the host to better defend itself from attack. In practice, disease control is incredibly complex because of scale, difficulty in implementation and need to avoid collateral damage. Broadly, we need to complete research that will protect trees growing in our forests, protect future generations of trees, and empower mana whenua and communities to do so using a variety of mātauranga Māori and Western science methodologies. We need to answer the following questions:

- Can we cure diseased trees?
- Can we stop the spread of the pathogens?
- Can we stop trees becoming diseased?

- Are any trees resistant to disease?
- How do we establish resistant trees in natural forests?
- How do we prioritise conservation efforts?
- Can we establish trees in refugia outside of the range of the pathogen?

We have identified activities that are grouped into seven themes. These are: Oranga (health, wellbeing, livelihood); Mobilising for action; Integrated surveillance; Conservation and restoration; Risk assessment/ecosystem impacts; Host, pathogen and environment; Control, protect, cure.

1. Oranga

Developing a mātauranga and kaupapa Māori-led programme by Māori, with Maori, for Māori supports the work to restore the mauri of the species threatened by these pathogens and their associated environments. Bringing together mana whenua, researchers, councils, and other landowners and stakeholders enables Oranga. A core activity in this area will be to develop a shared understanding and direction of the work within a kaupapa Māori framework that will provide a model across the other goals for best practice in how to engage with and involve mana whenua in determining what success of the programmes looks like. In addition, it will explore explicit mātauranga solutions, such as rongoā, underpinned by maramataka in response to the pathogens. We view this as three complimentary workstreams within the theme:

i. Social science: carry out research design to set and measure impact, develop the research approach in partnership through hui and wānanga, complete surveys at the start and throughout, monitoring success according to the agreed impact measures.
ii. Taiao tuatahi (Pathogen Trials 1): carry out pathogen assessments on sanctuaries and kauri seed cones in partnership with kauri landowners and land managers, engage in knowledge transfer with the landowners to enable the communities, develop community level expertise to sustain the impacts.
iii. Mātauranga Māori: for example, development of a Mātauranga Māori Surveillance Framework, form Vision Mātauranga expert teams, rongoā trials, developing Cultural Health Indicators (CHI), impact assessments and distinctive communications.

While there has been investment in these areas in both the kauri dieback and myrtle rust space, there has been limited coordination, especially in the case of kauri dieback. This has resulted in mixed levels of stakeholder and partner engagement, and the need to substantially reset relationships with Māori. This work will be essential for the success of other workstreams within the report.

2. Mobilising for action

Engagement of mana whenua, community, councils and industry and creating a level of buy-in that prompts people to take action is critical for the success of the programme. Without a sufficient segment of the population having interest and being willing to act it is unlikely that any biophysical science activity will provide the impact required in the response. A key aspect of this will be development of social and cultural indicators that will result in a strong understanding of the connection between ecosystem and community health. It will also create the environment of trust required for activities such as germplasm collection and genetic / genomic studies, with the underpinning cultural authority agreements in place to ensure the wishes of the mana whenua are represented. To achieve these outcomes to support the goal, recommended key activities are:

i. Design and carry out multi-faceted national campaign & local actions, based on stakeholder mapping and surveying, leading to community and council co-design for protection/restoration programmes.
ii. Develop an end-user accessible, geo-reference map of positive sites, sampled sites and hazard ratings to help inform and drive community initiatives to combat kauri dieback and myrtle rust.
iii. Engage with community and school groups through participatory science teaching methods e.g. Unlocking a Nation of Curious Minds. Social science to trial communication and behaviour change methods.

Similarly to Oranga, there is substantial work to be done to increase public engagement with the response. In contrast, while there is some strong community engagement around kauri dieback (i.e. Keep Kauri Standing, and Kauri Rescue), some have suggested that there is "myrtle rust fatigue" within the wider community. Previous funding for social science around both diseases has been limited compared to biophysical work, and many of the science system funding mechanisms do not lend themselves to this area. The Challenge has an excellent track record in enabling such areas and can substantially change the footing of this part of the system.

3. Integrated surveillance

Development of a mātauranga Māori surveillance framework for kauri dieback and myrtle rust, co-designed with mana whenua hapū/iwi kaitiaki and central and local government will be informed by traditional understanding of land and forest management and use. Surveillance and modelling of the distribution of pathogens, diseases and hosts, will be developed and ground-truthed using mātauranga and improved detection technologies. An integrated surveillance approach allows up-to-date and accurate knowledge of the extent of kauri dieback and myrtle rust based on both mātauranga Māori and Western science resulting in better management of threatened species and ecosystems and better support for community action.

For both kauri dieback and myrtle rust there has been substantial effort in development of tools and technologies for surveillance. This has often focused strongly at the detection end of the spectrum, but with less emphasis on how to draw inference on presence / absence of the diseases at scale, and how this can be made relevant to local community. We see a strong opportunity for both to be improved, and that this would make a substantial contribution to management. If this could be achieved it would also provide an excellent opportunity for outreach via 1. and 2.

4. Conservation and restoration

This research will help prevent the extinction of iconic species and protect 'at risk' species and ecosystems, and taonga trees and locations.

Protocols for the effective long-term storage of kauri and Myrtaceae species will be developed to ensure that, in even the worst-case scenario, that species survival can be maintained. This involves development of cultural authority agreements around the protocols and holding of material. A mātauranga Māori-led exploration of whakapapa for kauri and key myrtle species, and how this may or may not relate to genetic/genomic understanding of species diversity, must be undertaken to inform potential genetic research and conservation practice. An understanding of genetic diversity in kauri and key Myrtaceae species will inform other Essential Activity areas, especially around selection

of material for conservation, resistance screening, and understanding of population histories and potential future trajectories. This would also underpin future breeding programmes for species where these were deemed to be culturally appropriate. Ultimately this would lead to field trials of potentially resistant plants for evaluation.

This research will facilitate the collection and preservation of seed of kauri, myrtles and other ecosystem dependent species, and will include access to germplasm for research on threatened species and potential breeding. Co-development and implementation of a multi-year plan with hapū, to explore what research options for conservation and restoration are culturally acceptable is crucial.

This workstream will work from the perspective of the host and ecosystem, incorporating conservation biology principles to ensure the survival and persistence of susceptible species. Application of more productive sector approaches may also be appropriate, but all activities will follow a co-design principle with Māori.

5. Risk assessment/ecosystem impacts

Standardised impact measures will be developed using existing work and strengthening incorporation of kaupapa Māori approaches to increase their relevance to a wider range of communities. These will inform more comprehensive risk assessment for ecosystem impact, and identify more comprehensively where risk lies, either geographically in the case of kauri but also in regard to possible host species for myrtle rust. They will also examine broader ecological impacts such as to associated flora and fauna. Ecosystem impact assessment will be comprised of measures of ecosystem health and resilience, both in a Western science and mātauranga Māori framework.

This work will build substantially on some of the MPI-funded work for myrtle rust, which will feed into 4. for informing host species management. For kauri dieback, it will form part of a more holistic approach to the response, by taking an ecosystem resilience approach. There has been some focus on this to date, but at limited scales (often microbial). An ecosystem-level approach to kauri dieback and myrtle rust has long been advocated for by mana whenua, and in this workstream we would incorporate more of a kaupapa Māori / ecosystem approach, focused at site to landscape-scales.

6. Host, pathogen and environment

Understanding the current and evolving diversity of the pathogens populations is essential for long-term management of both diseases, and for kauri dieback, the origin of the pathogen. Similarly knowledge of the host populations is required for both management, conservation and restoration efforts.

The role of factors such as disturbance associated with animal and human activity, topography, weather, soil type, aspect, pest control, other bio-physical factors in disease development will be determined, both under current conditions and under a changing climate. The influence of multiple abiotic and biotic stressors on disease latency and expression, and host responses will be investigated. This activity area will directly inform several other workstreams, particularly 2 and 5, and will be complimentary to 4 in setting conservation priorities.

There has been limited work to date on the environmental drivers of kauri dieback, with the exception of studies looking at animal vectors. One outstanding question that needs to be addressed is the role of other biotic stressors, in particular, the role of other phytophthoras in kauri dieback dynamics. Work on the mediation of infection for both diseases by other microbes has been begun, but in a very

limited way. The NRT scoping group believes this is potentially of high value (see also 7) in attempting to identify novel methods for halting the decline of kauri and Myrtaceae species.
The genomes of both pathogens have been sequenced and offer unique insights into how these pathogens are able to infect and cause disease, as well as open opportunities to investigate new ways to control or manage these pathogens. The genome for *Austropuccinia psidii* is the largest fungal genome sequenced to date, and can be used to investigate how this species has evolved to become invasive on a pandemic scale with a host range of over 580 plant species. Investigation of Myrtaceae hosts genomes already sequenced will compliment these investigations.

7. Control, protect, cure

A suite of fully integrated management tools and approaches will be developed to protect our kauri and myrtles growing in coastal and interior ecosystems through to urban landscapes. We aim to provide effective tools that are culturally appropriate and informed by mātauranga Māori. Undertaking hui and workshops with mana whenua, community and stakeholders to socialise new technologies and assess important values and concerns will ensure integration with operational activities. Tools developed will cover a raft of management needs from slowing or preventing spread through to protection of trees themselves. These are expected to include a variety of different methods such as site manipulation, alternative disinfectants, chemical and biological control, mātauranga Māori-based bioactives and other rongoā solutions. This activity will incorporate work from many of the previous six activities, but with an emphasis on novel tools and approaches to kauri dieback and myrtle rust management. Two key areas with a high degree of novelty will be the extension of both the biological control and rongoā research. Baseline measures to determine effectiveness of methods will be crucial and decision support, modelling approaches will be developed to determine the most appropriate management intervention based on factors such as disease spread and treatment efficacy.

Essential partnerships and relationships

Partnerships with mana whenua, both within rohe affected by the pathogens and at the national scale, will be essential to the programme. These partnerships are critical because mana whenua hapū/iwi are kaitiaki with tino rangatiratanga over their taonga kauri and myrtle species. In keeping with the core values and principles of the Challenge, these ensure at all times that mana whenua retain full authority over their intellectual property and taonga species material. As kaitiaki, mana whenua will be key partners guiding the direction of research and implementing the strategies and tools which are eventually developed. This also requires a respectful approach with tohunga and kaumātua to share their knowledge of the forests and their expertise in mātauranga and kaupapa Māori research so that this knowledge can be utilised alongside Western science throughout the programme. Therefore, the entire programme is dependent on the strength of our partnerships with mana whenua groups. Growing these partnerships and supporting kaitiaki to participate effectively in the programme must be a high priority.

Government organisations are key partners from the national to local scale. The Kauri Dieback Programme (KDP) - the joint agency approach to managing kauri dieback nationally since 2009 – includes MPI, mana whenua, DOC and four regional councils (Northland, Auckland, Waikato, Bay of Plenty), and are an important partner, including their programme to develop a National Pest Management Plan (NPMP) for kauri dieback. DOC as managers of the Crown Estate, along with

regional and local councils, are responsible for large swaths of forest lands. Much of the operational work needed to manage the pathogens will be undertaken, funded or otherwise facilitated through these organisations. Likewise, they lead most of the education and communication campaigns that interact with the public. Their operational staff represent a wealth of experience and knowledge that will be valuable resources to researchers. Most importantly, they will be the end users for much of the research. Government involvement extends far beyond those organisations directly involved in biosecurity work, however, and includes agencies such as LINZ and StatsNZ, which provide the data and support infrastructure needed to undertake risk assessments and monitoring, and MBIE, which funds the Challenge and will be a key connection for the affected industries. It is necessary, therefore, that the strategies and tools we develop complement the work that government organisations are already doing and seek out areas where our resources can be combined for greater effect.

Non-Government Organisations, community and conservation groups, including Forest and Bird, Landcare Trust, QEII, Tane's Tree Trust, Project Crimson and Trees That Count as well as informal local volunteers and landowners, will be invaluable resources. Through their work, they hold considerable expertise and practical knowledge, particularly related to restoration. Their planting records may prove valuable data for future work, and their networks will be essential for connecting with communities and involving them in both research and management. Similarly, recreation-based groups represent large numbers of forest users and also frequently engage in track maintenance and restoration activities. As the backbone of labour for citizen science and restoration work, their assistance will be key in helping to monitor the diseases and affected ecosystems, to support strategies for mobilising the public and to implement the tools developed through the programme.

The affected industries will also be key partners. Not only must nurseries and propagators participate in controlling the spread and/or impact of the diseases, they will also be essential in helping grow resistant seedlings for restoration and sanctuary development, and in helping educate their customers about good disease management practices. The tourism industry is an important partner for educating visitors and encouraging compliance with control measures. The honey and mānuka oil industries can provide surveillance over the vast plantations they operate and ensure their plantings support species resistance and resilience.

Other researchers outside the Challenge will also be essential partners. The Challenge will not have the capacity to support all the research identified as necessary to address each pathogen by their respective science strategies. We will need to work closely with researchers and research providers working in related areas and through other sources of funding, such as the MBIE and MBIE-funded Myrtle Rust Catalyst Programme (led by Plant and Food Research) and the Beyond Myrtle Rust Programme (lead by Manaaki Whenua Landcare Research).

Essential resources

Essential resources are people, funding, and materials. If any of those resources are lacking our goals will not be achieved. People provide the impetus and enthusiasm, capability to undertake the research and support to implement it. Research will not happen without funding, nor will findings be taken up and adopted to save our taonga. Because work on these pathogen challenges is already underway, a large number of researchers, kaitiaki, agency staff and community members have already contributed or shown eagerness to be involved. A considerable pool of expertise and supporting infrastructure is

available for us to draw upon in our work—though not all have been included, resourced or otherwise enabled to contribute to their full potential. We have an opportunity to unleash these ready resources.

Mana whenua and communities have been vocal in their wishes to fight kauri dieback, resulting in an open letter to the Prime Minister calling on the Government to prioritise the protection of our taonga. The letter described the essential infrastructure needed to fight kauri dieback – a funded National Pest Management Plan and an agency to implement it. However, this infrastructure needs to have the tools at its disposal to achieve impact. This programme can provide those tools through broad capability. We need to harness mātauranga Māori to cure and protect from these diseases. We need multi-disciplinary teams that include pathologists, geneticists, statisticians, biochemists, social scientists, data scientists, modellers, ecologists, hydrologists and engineers working together to achieve the outcomes. Finally, we need the adopters of the research, those who will take the research to our forests and through their actions implement plans and strategies that will save our natural heritage. Project Crimson and Trees That Count work with communities to plant myrtles and other trees, and can contribute to community-based monitoring of myrtle rust.

Both kauri dieback and myrtle rust are difficult to combat. A great deal of funding is needed to if we are to be successful. The Strategic Science Advisory Groups estimated that for myrtle rust alone, $40 million per year would be necessary over the next 4 years. Investment of $13 million per year is needed to protect kauri. We need co-investors to provide the funding needed to fully resource our people and materials. Essential partnerships with MPI, DOC and councils need to be strengthened, and opportunities for support from additional cash and in-kind funding explored. Working closely with these agencies will further deliver impact through their adoption of the research. The BioProtection Centre of Research Excellence is preparing an eight-year funding rebid that includes kauri dieback research. The Centre is a potential funder of MSc, PhD and post-doctoral projects aligned to the Challenge's goals and is a critical research partner. Other funding opportunities include philanthropists and aligned organisations. For example, Big Fish Creative (a Whangarei based company) have partnered with Northland Rugby union to promote kauri dieback awareness, Z Energy, Mazda and Tindall Foundation have contributed to initiatives to protect pōhutukawa and rātā. Increased funding is needed for wānanga/hui focused on enabling mana whenua engagement, focused resourcing for tohunga support and enablement by way of tools, equipment, resources, and access to technology.

Infrastructure and materials needs are diverse. To conserve and restore our taonga we need seedbanks, inoculation and screening facilities, biosecure nurseries. Other research projects need surveillance tools, laboratories, data platforms, geographical systems and computing resource to handle big data. Our research teams have the facilities but funding is needed to operate them. Finally, we need new infrastructure developed to support engagement, logistics and to share protocols, data and management tools.

Section 3: Quantifying Cost Elements

Budget details and cost narrative

The funding allocated by the government to support Ngā Rākau Taketake represents the largest single source of funding for research into these two pathogens. However, this funding alone will not

be enough to undertake all the work that is necessary. The myrtle rust and kauri dieback science strategies have estimated that more than $100 million over five years will be needed. The surge funding available to Ngā Rākau Taketake and other investment already committed to projects underway amount to approximately half that amount. It will be essential, therefore, to use these resources efficiently and to attract additional investment and support from other sources.

Table 1. Current and future funding for myrtle rust and kauri dieback ($,000 ex GST)

	Funding needed	Funding for current projects	Funding available	Budget shortfall
Myrtle rust	39.5	13.0	5.0	21.5
Kauri dieback	65.5	5.0	29.6	30.9
Total	**105.0**	**18.0**	**34.6**	**52.4**

A portion of this gap may be addressed by finding synergies between the pathogens and with other Challenge strategic outcomes. Though research is at different stages for the two pathogens, there are several areas where resources and effort can be shared. For example, much of the work to empower and engage with mana whenua and communities will benefit efforts against both pathogens as well as other current and future biosecurity threats. Similarly, biosecure nursery facilities built to support resistance testing and possible future breeding for kauri may easily be used for Myrtaceae species, if and when that research is undertaken. These synergies can help us use what we have efficiently and reduce the overall estimated costs.

There are also significant opportunities to leverage existing and future research investment. Existing programmes such as Genomics Aotearoa and Te Uru Rākau (Billion Trees programme); Beyond Myrtle Rust and Catalyst Myrtle Rust MBIE programmes are multiple provider programmes that are doing important research that contribute and align to our impact goals. There is also opportunity to create efficiencies through that programme, i.e. undertake additional fieldwork while travelling to avoid having to make two separate visits. Philanthropic funding has been forthcoming to protect pōhutukawa (Project Crimson), opportunities for that type of funding are available. For kauri research the opportunity to attract co-investment is even stronger, particularly if the Kauri Dieback National Management Agency and the National Pest Management Plan are enacted. MPI, DOC, Auckland Council have also provided their specific research priorities related to both pathogens, and have previously/currently allocated budget to those priorities which may provide further opportunities for co-funding and/or alignment. The BioProtection Centre is preparing a rebid and their programme is very closely aligned with the Challenges goals and objectives. There is a strong case to leverage resources and expertise in the BioProtection Research Centre to carry out some of the more fundamental science needed to underpin and support this programme. All research providers, including the tertiary education sector (Universities, Polytechnics, Wānanga) should be engaged. CRIs may have an opportunity to use SSIF to provide the impactful science needed to deliver the goals of this programme. Tertiary education providers have the structure in place to provide resources through studentships/postgraduates to undertake very focussed research projects at lower cost.

2024 Goal Metrics

Oranga:

Mātauranga and kaupapa Māori-led methodologies based on the maramataka, that protect and restore the mauri of our taonga trees, their ecosystems and their people (in a manner that aligns with Te Tiriti, indigenous people's rights, Wai 262 etc.) have been developed. Methods for measuring social/cultural indicators developed and tested.

- Number of hui held for each pathogen and the number of people participating.
- Number of hapū/iwi with management frameworks in place.
- Number of surveillance plans developed with leadership from mana whenua hapū/iwi and with Mātauranga and Kaupapa Māori-led methodologies based on maramataka embedded.

Mobilising for action:

The role of mana whenua kaitiakitanga is appropriately recognised and supported, and includes rangatiratanga, IP and ownership of native plant species and germplasm. The drivers of social dimensions underpinning community engagement and interactions, including the management of those areas and the connections between the ecosystem's health and that of their communities will be understood and adopted. Social and cultural indicators of wellbeing will be documented and measured.

- Number of kura/schools engaged and community-based myrtle and kauri protection or restoration programmes launched.
- Community surveillance and monitoring tools developed and plans put in place.
- Stakeholder mapping and analysis completed.
- Level of awareness about the pathogens and actions that individuals and communities can take.
- Number of people and groups actively involved in monitoring, management and restoration projects.

Integrated Surveillance:

A surveillance framework will be developed based on the mana whenua traditional holistic understanding of land and forest management and use. Pathogen distribution, definitive diseased and disease-free areas (proof-of-freedom), including disease severity, will be mapped and predictive models developed for both kauri dieback and myrtle rust to inform mana whenua kaitiaki and other land owners or managers, allowing targeted operation plans to be developed and implemented. Tools to enable iwi/hāpu, communities, central and local government and industry to detect pathogens and survey their lands will be developed, and surveillance data collected will be compiled nationally and used in appropriate community level management plans.

- Mātauranga Māori and Western science surveillance plans developed for implementation.
- Percentage of land area covered by species and ecosystem mapping.
- Percentage of land area covered by mana whenua and/or community-based surveillance plans.
- Maps of host, pathogen, and disease distribution available at different scales.
- Percentage reduction in cost of diagnostic tests.

- Throughput of samples for *Phytophthora* identification increased to greater than 10,000 samples per year.

Conservation and restoration:

Tikanga-based frameworks and protocols for germplasm & seed storage have been developed, including methods to ensure safe viability of all germplasm in long term storage. Mātauranga Māori guided and authorised exploration of kauri whakapapa has defined population structure and variability throughout land and forests as a basis for understanding resistance and guidance for conservation of species. Population level susceptibility of Myrtaceae to myrtle rust has been identified and storage of seed or germplasm for species that have a high risk of being lost because of myrtle rust have been prioritised. Appropriate methods to store Myrtaceae seed and germplasm over the long-term have been developed.

- Set of priorities established for protection, conservation and restoration of hosts and dependent species and ecosystems.
- Protocols for preservation, conservation and restoration activities developed which appropriately recognise rangatiratanga and support kaitiakitanga.
- Management plans developed for implementation of highest priority taxa.
- Framework established for managing other taxa.
- Safe storage of representative germplasm samples across the genetic spectrum of priority species.
- Rangatiratanga, IP and ownership appropriately recognised for all collected germplasm.
- Identification of resistance and tolerance in key species.

Risk assessment/ecosystem impacts:

Standardised methods to determine impact in broad socio-ecological systems have been developed. The monitoring and mapping framework combined with host range testing contributes to defining the long-term ecological impacts of kauri dieback and myrtle rust, including ecosystem health and resilience. Kauri and Myrtaceae ecosystems have been characterised and non-host species at risk of decline or extinction have been identified. These assessments will inform prioritisation of species for conservation. Bioindicators of impact have been identified, tested, and proved.

- Risk analysis methodologies have been tested and applied.
- Biological indicators have been identified, tested and proven, and are accepted by mana whenua and communities.
- Indicators of social, cultural and economic impacts have been developed, agreed-upon, validated and prioritised, and then applied in other workstreams and/or research programmes to assist with decision-making.
- Ecosystems have been characterised with high-risk species identified, and this information has informed conservation and restoration work.

Host, pathogen and environment:

The landscape diversity of host and pathogen populations, and pathogen origin has been determined, and attributes that influence disease expression, including pathogen latency and host growth phenology are defined. The role of environmental biotic factors such as disturbance from animal and human activity or the interaction of other associated pathogens and microbial communities on disease development is understood. Combined with monitoring and modelling disease in relation to

abiotic factors such as topography, weather, soil type, aspect, and other bio-physical factors, this has increased the effectiveness of management activities and interventions. Genome-level assessments of pathogen traits and hosts responses are providing new ways to manage these diseases.

- The genetic diversity of pathogen populations and select host populations are known.
- Environmental factors affecting each disease have been identified.
- The origin and whakapapa of *Phytophthora agathidicida* has been identified.
- Interrogation of genomes has revealed key traits associated with pathogen virulence or host susceptibility.

Control, protect, cure:
Social and cultural license to operate has been gained for management plans, actions and tools developed. Of the wide range of control options available, including cultural, chemical and biological techniques, those that are acceptable and have the greatest potential for effectiveness have been developed or are under development. Alternative disinfectants; mātauranga Māori-based bioactives and other rongoā solutions are shown to control disease or limit soil borne pathogen spread. The rate of decline of kauri and myrtle ecosystems has reduced.

- Tools for control, protection or cure have been developed for both pathogens.
- Mana whenua, communities, central and local government, and industry accept and support the use of the control tools developed.
- Working models to predict and map pathogen and disease distribution are developed and being used by land managers.

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