Kauri dieback science plan

Prepared by the Kauri Dieback Strategic Science Advisory Group

Tāne te Waiora, Tāne te Oro-oro, Tāne te Waenga, Tāne Whakapiripiri, e tū mai nei, Tāne Nui ā Rangi i hanga ai te tangata me te manu, Tāne Mahuta i tū i te wao nui, hei rākau Kauri.

Aro mai ki te tangi a te manawhenua e nohotahi nei, me te motu katoa, aroha tonu mai mō te kiriwaewae ō Papatūānuku e hemo haere ana ki tēnā moka, ki tēnā pito o te whenua, tae ki uta, ki tai hoki.

Ōrite te katoa ō mātou a wawatia ana, kia pau rawa ō mātou kaha ki te whakaora ake ia Kauri tō mātou tuakana.

Excerpt from karakia composed by Haami Piripi; full version on page 30.

Tāne the bearer of light the constructor of biology, the repository of knowledge the producer of natural resources, the conception of birds and human kind alike. Tāne Mahuta is reflected in Kauri, standing with pride amidst a forest of ecological liberty.

Harken to the cries of the people of the land as we collaborate across the entire nation to pursue the principle of ecological integrity through our environmental management. We acknowledge the already existing evidence of destruction that forms a patchwork of degradation in places both inland and at sea.

We are of one mind to give and commit our human energy in order to give life to our ecological elder, Kauri.

Introduction, context and purpose

Kauri trees in kauri forests are dying from kauri dieback. The pathogen suspected to cause the disease is *Phytophthora agathidicida*. In addition to *P. agathidicida,* other *Phytophthora* species including *P. multivora* and *P. cinnamomi,* have been found to be associated with dying kauri trees. There is no known cure for the disease, and most, if not all, kauri trees suffering from kauri dieback do not survive. While we have learnt a lot about kauri dieback, there is much more critical information that we do not have. For example, the causes and factors associated with the spread of the disease, and the dynamics and significance of these factors within kauri forests, need to be better understood to inform effective long-term management approaches. We still do not know what the overall direct and indirect impacts of kauri dieback will be.

Why the science plan was developed

The objective of the kauri dieback science plan is to build on existing knowledge (New Zealand and international), operational research and management, and to identify the science needed to save kauri and its associated biota. The science identified in this plan will provide a comprehensive understanding of kauri dieback and its impact on forest health. The plan prioritises the research needs, provides indicative costings, and suggests outcomes achievable from the research that should be undertaken.

How the science plan was developed

The plan was developed through an iterative and integrated process of:

- understanding and building on current knowledge (including reference to the Black and Dickie 2016 'Independent review of the state of kauri dieback knowledge' report);
- convening a 2-day kauri dieback science workshop in July 2018 involving more than 50 leading researchers (including from Australia) and related parties including Māori (with a concurrent separate process that also identified Māori research interests) to identify immediate and longer term strategic science needs; and
- using the Kauri Dieback Strategic Science Advisory Group (SSAG)[1] to focus the outputs from the workshop and Māori research input into a set of draft themes and priorities.

This draft plan was then circulated amongst workshop attendees and others with specific interests for comment before being finalised by the SSAG and submitted to the Kauri Dieback Programme Governance Group.

Summary of research to date

Research undertaken over the past nine years has concentrated on determining the taxonomy, lifecycle, relationships, and pathogenicity of *P. agathidicida* – it has largely been successful in these areas. There is still a need to conduct similar research with the other *Phytophthora* species associated with dying kauri to understand their role in kauri dieback. Research contributions have also made significant improvements in diagnostics, detection and surveillance, but further research is required to develop these areas to enable more effective and efficient management tools and strategies. We have improved, but still incomplete, knowledge of risks and pathways. In terms of tools, tactics, and strategy, there has been ongoing investment in: phosphite as a chemical control; oospore deactivation; biological control; and track management as a strategy to control humans as a vector to reduce the spread of *P. agathidicida* and other species. These have not proved sufficient to control the spread of the disease. The use of prioritisation tools, such as Bayesian modelling, has been limited. There is important research underway looking for potential resistance in kauri and alternative hosts, but this needs to be much more extensive. Although cultural health indicators and some aspects of rongoā have been initiated, there has not been enough understanding or investment in appropriately exploring mātauranga Māori knowledge and the practices of Māori kaitiaki. Social science aspects in general have not been explored and there is an urgent need to investigate appropriate models for community collaboration, effective communication strategies, and people's values and social practices that drive behaviours.

Implementing this science plan

Implementation of this plan will rely on:

- connection, alignment, and participation in partnership with Māori;
- connection, alignment, and participation by end users such as the Crown and local government who are administrators of public land;
- collaborative and multi-disciplinary research between Crown Research Institutes, universities, National Science Challenges and other science providers;
- an emphasis on science quality, peer review, and robust science processes;
- strengthening international linkages;
- appropriate and enduring funding;
- focus on the priorities identified; and

[1] See https://www.kauridieback.co.nz/strategic-science-advisory-group/ for membership

- the SSAG, Māori, and stakeholders monitoring implementation and where necessary rapidly and adaptively responding to research findings to ensure best practice management of kauri dieback is occurring at all times.

Intellectual property

In keeping with NZGOAL, this plan seeks to ensure that "government data and information should be open, readily available"[2]. This principle applies to research undertaken in the programme by government departments, Crown Research Institutes, National Science Challenges, regional councils and universities. As per Section 24 of NZGOAL (Restrictions), the availability of research undertaken for and by iwi/hapū will be at the discretion of the iwi or hapū. It would be beneficial to have an agreement that allows all knowledge to be shared for use in the management of kauri dieback – this is a matter for ongoing dialogue.

A new way of working with Māori

A conclusion from all phases of development of this science plan, including both the workshop and webinar and other interactions, was the need for a Kāhui or expert Māori research advisory collective to evaluate all research to ensure outcomes for kauri consistent with Te Ao Māori. The Kāhui would monitor participation, delivery, and performance on behalf of Māori. In the Kauri Dieback Programme, mātauranga Māori priorities are informed by the Tangata Whenua Rōpū who are represented at all levels of the Programme. There is also an independent mātauranga Māori panel who take part in evaluating mātauranga Māori projects. This Kāhui could absorb the mātauranga Māori panel, and broaden its work to encompass not just evaluating mātauranga Māori projects but providing an advisory role on the mātauranga Māori components of all projects. The Kāhui could also help to integrate mātauranga Māori in the research phase. This plan does not affect the role of the Tangata Whenua Rōpū, but would ensure co-ordination and integration of the various threads across the programme as a whole and the science plan.

The proposed Kāhui signifies a new way of operating. It would require dedicated resourcing. The Kāhui would both consider the whole science plan, and have greater involvement and oversight of research needs of particular relevance to Māori.

In this science plan, the ticks (✓) under the Kāhui column in each theme denote priorities which may have particular relevance to the Kāhui.

Criteria to ensure Māori research is supported and promoted

In the first instance we should expect to see Māori research priorities and Vision Mātauranga (VM) expectations reflected across all themes in this science plan as all themes have implications for Māori (iwi/hapū).

Research funded and or supported by this Plan should endeavour to be VM category 3 or more, meaning at a minimum it should be research involving Māori where mātauranga Māori may be collected and incorporated in the project, but not central to the project.[3] Moreover, in the Te Ao Māori theme it should aim to be VM category 5, that is it should be kaupapa Māori research or research that is independent and free from undue influence, undertaken by Māori, for Māori, and with Māori. Such an approach is complementary, as evidenced in the Biological Heritage National Science Challenge where the VM3+ criteria also exists. This aligns with the Vision Mātauranga science policy and our Treaty obligations. The establishment of a Kāhui Māori would ensure that all research is able to meet this expectation.

[2] See https://www.ict.govt.nz/guidance-and-resources/open-government/new-zealand-data-and-information-management-principles/

[3] See category at www.biologicalheritage.nz/about/vision-matauranga

Participants at the kauri dieback science workshop and Māori kauri dieback webinar supported the establishment of a panel of Māori experts who will, for the lifetime of this plan and subsequent research programmes, seek to ensure:

1. appropriate resourcing and decision-making for Māori at all levels of research activities;
2. support for co-innovation with Māori entities;
3. development of Māori (iwi/hapū) led research;
4. a Māori review and approval process for all research proposals, to ensure that they are VM 3+, and that they enable and fairly resource kaitiaki (hapū/iwi) to participate;
5. rangatiratanga and kaitiakitanga is enabled; and
6. contributions are regularly reviewed and assessed against the Te Ao Māori vision and goal.

Science themes

A framework has been developed to show key themes under which research programmes could be grouped (Figure 1). The three vertical boxes in Figure 1 show themes covering strategic science. The Te Ao Māori and building public/community engagement and social licence themes are cross-cutting and engage with all other parts of the plan.

The control and management theme is shown encompassing the inner five themes, as this theme will be informed by the research from each of these five themes. All research outcomes in the other themes will need to be evaluated and assessed for impact – this is shown by an 'evaluating impacts and responses' component.

There are interrelationships across themes and some priority areas could equally be at home in a different theme area. These cross-theme relationships will need to be taken into account when investment into programmes and eventual contracting take place. Potential research programmes will likely incorporate more than one priority area.

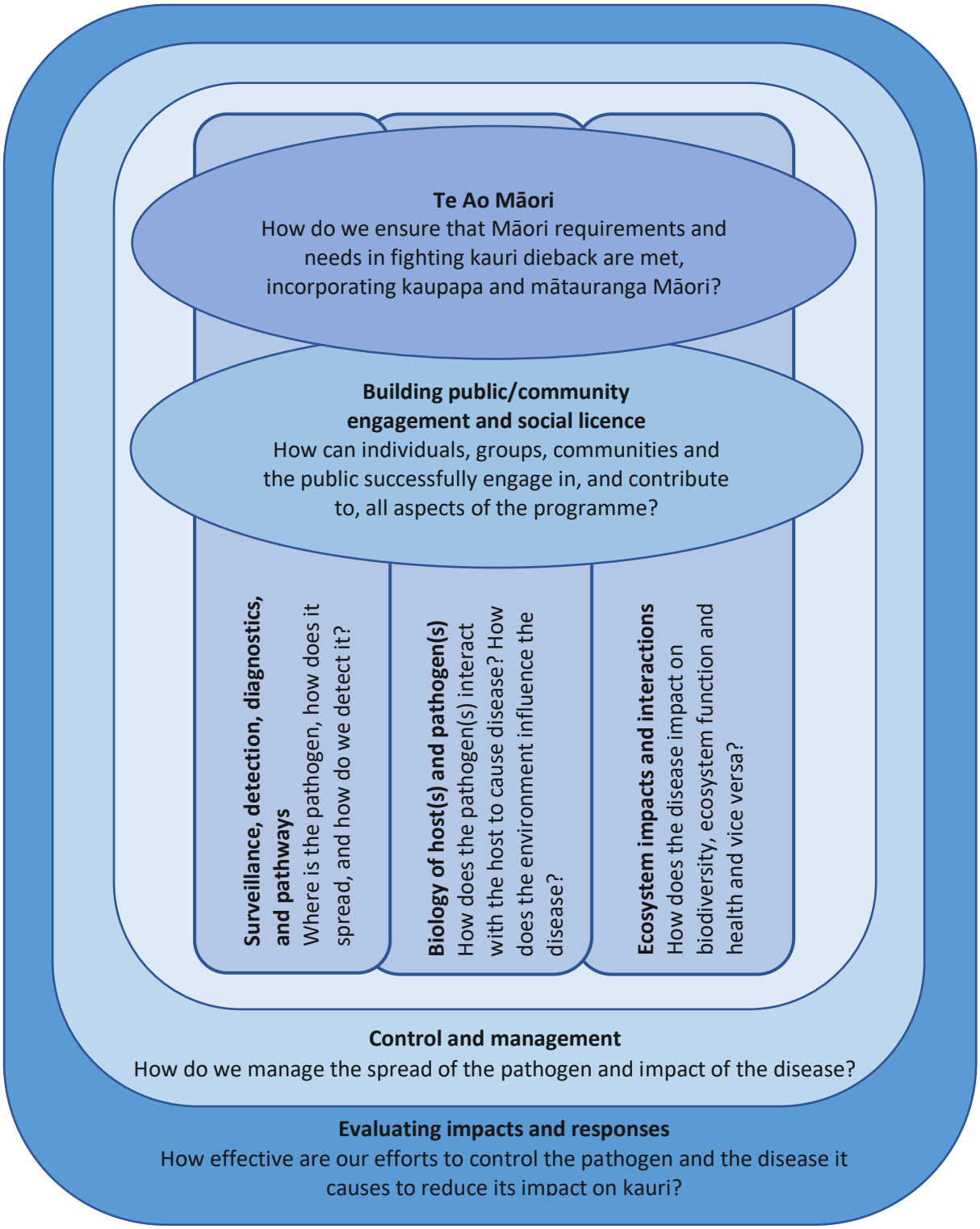

Figure 1: Themes framework

Priorities

The science priorities identified in this science plan were developed through wide input from experts at a science workshop and separate Māori webinar, and include relevant priorities in the Kauri Dieback Programme. Participants in the workshop and Māori webinar identified key science needs and collectively prioritised these based on the following criteria (drawn from the Biosecurity Science Strategy):

- Strategic fit
- Net benefit – what is the overall net benefit (environmental, social, economic, cultural)?

Prioritisation also took into account:

- Feasibility – is it feasible and what is the probability of success?
- Resources – what resources/capability are required – can the research be done?
- Barriers – are there any significant barriers to success and how could these be overcome?

While the priority research needs listed in this science plan were identified as being high priority by workshop and webinar participants, these needs have been further prioritised in the document as follows:

*** = highest priority

** = medium priority

* = lowest priority

These are all priorities for further funding. Work is underway in some of the research needs listed but not of sufficient scale or duration to deliver the outcomes desired.

Timeframe

The timeframes listed in the sub-themes below are defined as follows:

- Short = up to two years.
- Medium = up to five years.
- Long = more than five years.

The timeframes indicate that we would expect outputs from research by two years, five years or beyond (from the start of the research programme), with subsequent outcomes for kauri dieback. Longer-term research will extend beyond five years with long-term outcomes, although where possible immediate insights will be promoted for management consideration. The timeframes do not determine when individual research programmes should start. For example, some short-term high priority projects may begin at a later stage after other pre-requisite or dependent research has been completed.

Type of research

Each priority is listed as operational (O), strategic (S), or both to indicate the nature of the research and possible funding avenues. Strategic research is medium- to long-term underpinning research and builds the scientific knowledge base as the foundation for new and improved tools and methods to save kauri and associated forest species, and to reduce impact on forest health. Operational research translates current knowledge to practical application in kauri dieback management. To this end, there is a continuum from strategic to operational research and implementation. Māori input will be critical across this spectrum.

Costs

Costs for each research programme listed in the sections of this science plan were estimated by the Kauri Dieback Strategic Science Advisory Group. The plan should be adaptive, with the ability to shift funding as needs change and new findings become available.

Summary of themes

Themes and sub-themes	Funding required (per annum)
Theme 1: Surveillance, detection, diagnostics, and pathways **1.1 Can we make disease and pathogen testing cheaper, faster and better?** **1.2 Using surveillance to inform science and management** **1.3 Pathways and vectors**	$3.0 m
Theme 2: Biology of host(s) and pathogen(s) **2.1. Biology, ecology, genetics, and pathology of *Phytophthora* species associated with declining kauri trees** **2.2. Kauri responses to *Phytophthora*** **2.3 Role of biotic and abiotic environment on predisposing kauri to decline**	$3.0 m
Theme 3: Ecosystem impacts and interactions **3.1 Assessing forest health and understanding the kauri ecosystem** **3.2 Ecological impacts of kauri dieback** **3.3 Kauri ecosystem health and resilience**	$1.5 m
Theme 4: Te Ao Māori **4.1 Māori leadership and participation** **4.2 Trust and confidence (cultural licence)** **4.3 Awareness and engagement** **4.4 Mātauranga Māori solutions for kauri dieback** **4.5 Control and management**	$1.5 m
Theme 5: Building public/community engagement and social licence **5.1 Facilitating community engagement and social licence** **5.2 Working in a transdisciplinary environment** **5.3 Understanding audiences** **5.4 Developing a knowledge base** **5.5 Developing, monitoring and evaluating management tools and social licence**	$1.4 m
Theme 6: Control and management **6.1 Developing control tools to stop the impact and spread of kauri dieback** **6.2 Developing management tools to stop the impact and spread of kauri dieback**	$2.0 m
Additional funding for procurement and management (5%)	$0.7 m
Total funding required to undertake research recommended in this plan	**$13.1 m**

Theme 1: Surveillance, detection, diagnostics, and pathways

Context:

- Fundamentally, we do not know if we are dealing with a pathogen(s) that is discretely distributed causing disease wherever it is present, or if it is ubiquitous and only causes disease when one or multiple unknown factors combine to enable the pathogen(s) to overcome host defences. Current pathogen distribution knowledge is based on soil sampling, ground-truthing and aerial surveillance, but that has usually been limited to stands of kauri showing symptoms, at a coarse scale. Aerial surveillance has not used multi- or hyperspectral imagery or change detection. These tools can be used to robustly and accurately assess forest health changes over time, and consequently rates of spread and efficacy of mitigation measures. There are areas of kauri that have not been surveyed and not all have been ground-truthed or surveyed in a stratified, consistent manner.
- Vector control is critical. If *P. agathidicida* (and potentially other *Phytophthora* species) is discrete, then this is critical, but even if we find *P. agathidicida* is ubiquitous, vectors are still going to be important as they cause root damage and forest ecosystem impacts that could affect disease risk. We cannot afford to wait and see; management decisions need to be made on uncertain evidence while scientists work to build greater understanding on the causal relationships between vectors and disease risk, so that evidence based decision making can occur.

Potential gain from the research:

- Detection of symptomatic plants using the soil and baiting technique is expensive and time consuming. A cheap, fast, diagnostic method suitable for high throughput is critical to support an expanded surveillance programme that could run to tens of thousands of samples.
- Surveillance informs targeted management and control. This is underpinned by improved diagnostics, understanding the performance of surveillance methods, and statistically robust sampling protocols.
- Many of the current Kauri Dieback Programme management tactics (boot sanitation, track closure, pig control, etc) were developed on the assumption that the pathogen is relatively new and has a discrete distribution. Addressing this fundamental assumption will inform the future direction of the Kauri Dieback Programme, i.e., whether we should invest in pathogen containment or put effort into improved forest health and control tools.
- An understanding of an appropriate baseline monitoring methodology to measure changes in disease rates over time to assess the impact of management interventions on disease spread and impact, i.e., so we can tell if we are succeeding (or not) in managing the pathogen(s) and the disease.

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
1.1 Can we make disease and pathogen testing cheaper, faster and better? **Outcomes**: Cheaper faster detection tools and diagnostics will allow more samples to be taken and processed and thus provide more reliable and comprehensive data. **Current state**: The test is reliable but slow and expensive at ca. $135/sample. There is lack of lab capability because samples arrive inconsistently and there is no long term commitment for provision of samples. **Recommended funding:** $0.4 m per annum for 5 years					
a) Estimation of the sensitivity and specificity of current soil and baiting techniques before developing new tests	Medium	S/O	***	Links to Theme 2	

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
b) Exploration of alternative diagnostics - metabolomics, DNA, identification of plant volatiles, sniffer dogs, etc., across multiple sample types (not just targeting the soil)	Medium	S/O	***	Links to Theme 2	
c) Faster and more robust detection, and diagnostic tools for the pathogen(s) in soil and plant tissues, including presence/absence, and levels of infection	Short	O/S	***	Links to Theme 2	
1.2 Using surveillance to inform science and management **Outcome:** Surveillance is one of the highest research priorities. Until the distribution of the pathogen(s) and disease are well understood, and the relationship between them determined, disease control tactics and strategies cannot be developed with confidence. **Current state:** Current distribution is based on soil sampling, ground-truthing, and aerial surveillance, but only on limited symptomatic stands and at a coarse scale. There is inadequate knowledge of how existing methodologies perform – i.e., the effect of soil moisture when sampling, or sample storage temperature, and statistical evaluation of diagnostic test performance. There is uncertainty of whether we are assessing the disease or the pathogen. There is bias due to sampling near symptomatic trees and tracks. There are competing paradigms of 'an ubiquitous pathogen, present in all areas' versus 'active spread and areas currently pathogen free' – knowing this will inform how we manage the pathogen(s) and disease it causes, i.e., pathway management or forest health management? **Recommended funding:** $2 m per annum for 5 years					
a) Survey design: Define management and surveillance units so that we can measure intervention success/impact. Determine which areas should be surveyed systematically for the presence of *P. agathidicida* (and other *Phytophthora* species), informing sampling design. Standard methodologies needed (detection, soil sampling) to inform disease status. Develop an advisory group for national surveillance strategy – develop standards/approach as a priority	Short – Medium	O	***		✓
b) Disease surveys: Comprehensive assessment of disease incidence and severity through a range of surveillance methods and technologies, e.g., remote sensing, ground assessments, etc, and an understanding of test performance to set sample sizes	Short – Long	S/O	***	Links to Theme 2	
c) Pathogen surveys: Detection of the pathogen(s). Important to do this in conjunction with disease surveys	Short	O	***	Links to Theme 2	
d) Can disease be picked up before visible symptoms? E.g., multi- or hyperspectral imagery	Medium	S	**	Links to Theme 6	

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
e) Analyse rate of spread that has already occurred in disease patches using dendrochronological techniques e.g., if a new infection, we should see older infection dates at the core of the infection and younger infection dates at the periphery	Medium	S	**		
f) Determine spatial distribution of *P. agathidicida* and other *Phytophthora* species in the kauri tree	Medium	O/S	**		
g) Analysis and communication: Map where disease and pathogen(s) are and are not, and monitor spread. Determine the sites, population, soil types and vegetation types at risk. Test soils outside kauri forests	Short	O	**	Links to Theme 2 and 4.4a	✓
1.3 Pathways and vectors **Outcome:** If it is shown that the pathogen(s) is not widespread then pathway management will be one of the most effective tools to maintain kauri health in pathogen-free areas. The outcome will be disease-free kauri. **Current state:** Currently there is a focus on the critical role of biotic vectors based on an assumption that the causal agent(s) are limited in distribution and that vectors have a significant impact on kauri tree vulnerability to disease (e.g., via root damage). This theme ties very closely with the host-pathogen biology theme. An understanding of latent period, amount of inoculum needed to initiate infection, pathogen genetic diversity (i.e., will mixing of pathogens lead to increased pathogen virulence) is needed but should not preclude immediate investment in pathway and vector management. **Recommended funding:** $0.6 m per annum for 5 years					
a) Vector Indexing: Determine the level of risk associated with key vectors, including different types of users. Determine the primary and secondary vectors. Determine what vectors can realistically be managed. Identify and assess rural and urban vectors	Short	S/O	***		
b) Role of nurseries, especially in spread in terms of revegetation. Can we certify that materials are pathogen free to inform management?	Short	O	***	Links to Theme 2	
c) Mode of natural spread: Mechanisms and rates across landscapes, topography, soil types, vegetation types, etc.	Long	S/O	***	Links to Theme 2	✓
Total funding required for Theme 1: $3.0 m per annum					

Theme 2: Biology of host(s) and pathogen(s)

Context:

- Forest disease epidemics are a consequence of the interaction between three factors: a susceptible host plant, a virulent pathogen(s), and a favourable environment. The interaction between these three factors over time and in response to management can be visualised and described as a disease triangle. In order to manage a disease epidemic, it is essential to understand the biology of the host(s) and the pathogen(s) and how these are impacted on by the surrounding biotic and abiotic environments for the disease to occur.
- We know *Phytophthora* species are a key driver of kauri dieback, with an emphasis on *P. agathidicida*. There have been pathogenicity trials involving *P. cinnamomi*, *P. multivora* and *P. cryptogea,* with results showing that *P. agathidicida* is a highly aggressive pathogen on kauri while the other species are weaker pathogens. However, further robust testing of *Phytophthora* species found in association with kauri dieback is required to inform whether a disease syndrome is apparent. We do not currently have a good understanding of the environmental factors that predispose disease to occur.

Potential gain from the research:

- A sound understanding of the biology, ecology, and pathology of *Phytophthora* species associated with kauri and how it (and other hosts) responds to the pathogen(s) under different environmental conditions will provide the tools to implement robust long-lasting management strategies.

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
2.1. Biology, ecology, genetics, and pathology of *Phytophthora* species associated with declining kauri trees. **Outcome**: Improved understanding of *Phytophthora* species lifecycles and pathology in kauri informing management strategies. **Current state**: Incomplete knowledge of *Phytophthora* species involved in kauri dieback and their biology, ecology, genetics, pathology, and interactions with kauri and other potential hosts. **Recommended funding:** $1.8 m per annum for 5 years					
a) Understanding latency (the time from infection to first visible disease symptoms) in kauri and host physiological stress	Long	S/O	***		
b) Alternative hosts. Identifying symptomatic and asymptomatic hosts other than kauri (to include all *Phytophthora* species). Can other hosts be used as indicator species for presence of *Phytophthora* and can the increase or decrease in the population of other hosts be used as an indicator of *Phytophthora* infestation?	Medium – Long	S/O	***		✓
c) Risks from other *Phytophthora* species. Pathogenicity screening of other *Phytophthora* species (e.g., *P. multivora*) using adequate numbers of isolates to definitively show whether they are also contributing to kauri dieback	Short – Medium	O/S	***		

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
d) Infection process in kauri roots. How *Phytophthora* species get attracted to roots, infect, colonise and cause disease (enzymes, toxins, other); host/pathogen communication at the molecular level	Medium – Long	S	**		
e) Determine the genetic variability among isolates obtained from the surveys, over the landscape level and also throughout the overall kauri region (including stability and phenotypic variation of isolates in culture) – use same isolates of *P. agathidicida* (and other *Phytophthora* species) across studies	Medium – Long	S	**		
f) Co-locate isolate library data with sequence data (held between Manaaki Whenua Landcare Research, Scion and Plant & Food Research – many isolates have ITS and some have been sequenced)	Medium – Long	S	***		
g) Detailed life cycle and biological studies of *P. agathidicida* and other *Phytophthora* species associated with kauri; e.g., investigating whether it/they can survive as a saprobe, how long do oospores survive in soil and roots, are oospores formed in free soil, are there other survival structures (e.g., stromata) formed, how much inoculum is required to cause disease. This is to include infection process, symptom expression and host range in different soil types and vegetation communities	Medium	S	***		
h) Determine how widely distributed *P. agathidicida* (and other *Phytophthora* species) are across New Zealand. Is the pathogen(s) ubiquitous or not – to include sampling of all vegetation types	Medium	O/S	***	Links to Theme 1	
2.2. Kauri responses to *Phytophthora*. **Outcome**: Improved kauri health, and reduced spread and impact of the pathogen(s). **Current state**: Inadequate understanding of the disease cycle, host responses, and predisposing environmental conditions. Inadequate understanding of whether *P. agathidicida* is the only *Phytophthora* species involved in kauri dieback. Screening and resistance work is ongoing. Alternative approaches to resistance detection and breeding need to be considered, leveraging on resistance detection and breeding in similar forest pathosystems overseas, to ensure that all possibilities are considered in constructing a cohesive resistance and breeding strategy. **Recommended funding:** $0.9 m per annum for 5 years					

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
a) Assessing the genetic variation and genetics of resistance in kauri, and between kauri and naturally-resistant *Agathis* species, including non-New Zealand species; resistance breeding; germplasm; seed preservation and storage	Long	S	***	Links to Theme 3	✓
b) Map genetic diversity of kauri (quantitative or molecular genetics)	Medium	S	***		✓
c) Looking for resistance across gymnosperms: what can we find in the sequence to look for in kauri? Physiology of gymnosperms to disease effects. Tanekaha/sub-lethal infections	Medium	S	*		
d) Use integrated phenotyping approaches (including mātauranga-based characterisations) to identify resilient genotypes. Novel and unique methods are possible and have been demonstrated in other pathosystems that avoid time consuming greenhouse screening which may not predict *in situ* resistance	Medium – Long	S	*		
e) Screen areas to find places free of *P. agathidicida* (and other *Phytophthora* species); investigate use of sanctuaries and of planting and establishing new stands	Short	O/S	**	Links to Themes 2.1a and 3	
f) Ecophysiology of healthy and diseased kauri trees (to include different aged trees)	Short – Medium	S	**	Links to Theme 3	
2.3 Role of biotic and abiotic environment on predisposing kauri to decline **Outcome**: Robust understanding of the biotic and abiotic factors that contribute to kauri dieback. **Current state**: Inadequate understanding of the disease cycle, host responses, and predisposing environmental conditions. **Recommended funding:** $0.3 m per annum for 5 years					
a) Soil microbiome (and root-associated microbe) function and diversity in relation to disease incidence and severity	Short – Medium	S	***	Links to 2.3b and Theme 3	
b) Soil microbiome (and root-associated microbes) – Determine if *P. agathidicida* and other *Phytophthora* species are present on sites with no disease symptoms and whether changes in soil microbiome relate to host susceptibility	Short – Medium	S	***	Link to 2.1b, 2.3a and Theme 3	

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
c) Determine if sites exist with long-term presence of *P. agathidicida* and other *Phytophthora* species without obvious infection or expression of disease symptoms. If these exist, determine the predisposing factors to kauri dieback: temperature, soil matric potentials, soil types including 'oneone', litter depth, drought, soil microflora, soil nutrients, soil compaction, pH, soil physical characteristics, other	Medium – Long	S	***	Links to Themes 3 and 4	✓
Total funding required for Theme 2: $3.0 m per annum					

Theme 3: Ecosystem impacts and interactions

Context:

- Kauri forests represent a major ecosystem in northern New Zealand and are considered ecosystem engineers, acting as foundation species. Long-term forest stand dynamics within the kauri ecosystem is a major knowledge gap and there is an urgent need to understand the current and future trajectory of the natural kauri population dynamics with and without the impact of the disease.
- Kauri dieback does not occur in isolation, and to ensure we have successful management of the disease we need an underpinning knowledge of kauri forest ecology and function, including the ecosystem associations with other species, soil types, and microbiota.
- As *P. agathidicida* and the other *Phytophthora* species associated with kauri dieback are soil-borne microorganisms, understanding the ecological impacts of the disease on the health and function of the kauri soil ecosystem, including the soil food web and the unique podzolised soil communities, is critical.
- Understanding the external factors that influence the growth and survival of the pathogen(s) is paramount to controlling the impacts and spread.
- Mātauranga Māori is critical within this theme as there is a significant body of traditional and contemporary Māori knowledge and understanding of kauri ecosystem health. Empowering Māori knowledge holders will assist in how and where this knowledge may be used alongside conventional biosecurity approaches to protect all kauri. Comparisons of indicators among disease free and infected forest areas are proposed to be part of this approach.
- Ecosystem research provides an overdue balance to research on the pathogen(s) and host biology. It also provides a context for understanding resilience, in terms both of the forest and its environment, and the genetics and potential resistance of kauri itself. Understanding what forest health means also allows for an assessment of the impact of the disease – a reverse view of the impact on forest infrastructure, other species, and regeneration.

Potential gain from the research:

- Moving beyond a single-pathogen focus to understand the long-term dynamics of kauri and the contribution of environmental drivers and forest stand dynamics to kauri dieback will unlock fundamental knowledge of kauri health and resilience that can inform future management of kauri.
- Understanding the fundamental ecology and function of the kauri soil ecosystem will inform and enhance soil-borne disease management methods as well as maintain overall soil health for all kauri.
- Recognising and empowering Māori knowledge and experience on how to measure ecosystem and ngahere (forest) health, with a Te Ao Māori approach to soil, water, plant and environmental factors, will provide the goal for long-term management, kaitiakitanga and bioprotection of kauri ecosystems as well as ensure a holistic system approach for adaptive pathogen and disease management.
- Resolving ecological characteristics of health and resilience of kauri may also provide longer term solutions for management of kauri that overcome the disease as well as ensure resilience against future environmental and biological threats including predicted climate change.

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
3.1 Assessing forest health and understanding the kauri ecosystem **Outcome:** Healthy resilient kauri forests managed to reduce the spread of kauri dieback. **Current state:** Knowledge of functional and ecological health of kauri ecosystems is incomplete and considered a fundamental science gap. There is also inadequate knowledge of factors predisposing kauri to the disease, occurrence of the pathogen(s) in apparently symptomless forests, and potential impacts of the pathogen(s) on other species and parts of the ecosystem. **Recommended funding:** $0.5 m per annum for 5 years					
a) Measuring ecosystem health with long-term ecological monitoring including use of mātauranga Māori and cultural health indicators	Long	S/O	**	Links to Themes 2, 4 and 6	✓
b) Understand basic ecology of kauri in a healthy kauri forest. Natural background mortality of a healthy forest versus a diseased forest	Medium	S	***		✓
c) Identify ecological and functional linkages between forest ecosystem, soil, climate, water, and kauri 'resilience' to *P. agathidicida* and other *Phytophthora* species – a systems perspective	Medium	S	***	Links to Themes 2 and 4	✓
3.2 Ecological impacts of kauri dieback **Outcome:** Kauri forests managed to maintain and increase species diversity, ecosystem functions, and minimise/eliminate impacts of dieback on the whole ecosystem. **Current state:** Kauri is a keystone ecosystem engineer, but there is little knowledge on whether *P. agathidicida* or other *Phytophthora* species have impacts on diversity and forest structure and functions of the ecosystem. **Recommended funding:** $0.5 m per annum for 5 years					
a) Assessing the ecological impacts of kauri dieback, including on forest diversity and population dynamics, ecosystem productivity, and effect on recruitment, mortality and fecundity of kauri populations; modelling kauri population dynamics under kauri dieback infection scenarios	Long	S	**	Links to Themes 2 and 4	✓
b) Characterise the kauri soil ecosystem to identify soil health and functional bioindicators including mātauranga Māori of kauri 'oneone' soils, and develop methods to quantify the impacts of kauri dieback on the kauri soil ecosystem	Long	S	**	Links to Themes 2 and 4	✓
c) Identify the possible role, diversity and impact of all endophytic biota naturally present in kauri (e.g., mycorrhizae, dark septate endophytes, *Trichoderma* spp., etc.) on kauri health and susceptibility to the pathogen	Medium	S	*	Links to Themes 2 and 6	

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
d) Characterise the role of water and hydrological processes within the kauri ecosystem that may influence spread, survival of the pathogen(s), health of kauri and disease expression	Medium	S/O	**	Links to Theme 2	
3.3 Kauri ecosystem health and resilience **Outcome:** Kauri ecosystem health is protected, maintained and restored through long-term management approaches that overcome the disease as well as ensure resilience against future environmental and biological threats. **Current state:** Very little knowledge of ecological characteristics that define kauri resilience. **Recommended funding:** $0.5 m per annum for 10 years					
a) Assessing the size of a forest fragment: determine whether there is a size limitation to maintain core stand resilience, how you protect these fragments, and what can or can't be planted next to fragments	Medium	S	**	Links to Themes 2, 4 and 6	✓
b) Investigate whether forest structure, particularly soils and differences in disturbed versus undisturbed forests, impact on kauri resilience. Determine the implications for kauri restoration and the potential use of nurse crops	Long	S	**	Links to Themes 2, 3.2b, and 4	✓
c) Investigate kauri ecosystem processes (e.g., litter decomposition and litter quality) that influence pathogen(s) growth, survival, advancement, and disease expression	Long	S	**	Links to Themes 2 and 4	✓
d) Investigate the relationship between *Agathis* host-specialists (e.g., plants, fungi, invertebrates, birds) and their survival in infected forests and the consequences of disease impacts e.g., phytophagous beetles that are involved in nutrient cycling in these forests	Long	S	*	Links to Themes 2 and 4	✓
Total funding required for Theme 3: $1.5 m per annum					

Theme 4: Te Ao Māori

Context:

- Mātauranga Māori has had little opportunity to be included in an integrated disease management plan due to the lack of understanding of current research procurement requirements and limited funding. Very few studies exist on the impacts of plant disease on cultural identity, and the only specific documents to outline the cultural impacts on the tangata whenua of the remaining ancient stands of kauri forests are the Nuttall, Ngakuru and Marsden (2010) Te Roroa Effects Assessment report and the Shortland and Wood (2011) Kauri Dieback Tangata Whenua Rōpū Cultural Impact Assessment report. Independent preliminary work currently underway has indicated a significant potential for mātauranga Māori to contribute to an integrative research and management programme, including novel tools to prevent disease spread. For example, private rongoā trials have provided some success in healing lesions and stopping bleeding.
- Māori have been clear in their expectations of this plan and subsequent plans/programmes. They expect the Crown, councils, scientists, research institutes, and communities to collaborate with tangata whenua to 'save kauri and the kauri forests' from extinction.

Potential gain from the research:

- The importance of integrating and using mātauranga Māori (Māori knowledge) is that it:
    1. recognises the unique role Māori have as Treaty partners with the Crown;
    2. enables Māori to honour/fulfil their role as kaitiaki (guardians) and tangata whenua (people of the land); and
    3. represents a body of knowledge that has been proven to provide an important role in environmental management including the protection of our biological heritage from biosecurity risks and threats (e.g., Rena/Environment Court report[4]).
- The vision of this plan for Māori is to "maimoatia Te Kauri, me te wao tapu a Tāne Mahuta" ("save kauri and the kauri forests").
- The goal of this theme is to ensure that Māori are able to contribute as full Treaty partners within kauri dieback research initiatives so that they can participate in decision-making and activities at all levels, and that their unique contribution to the response is valued.
- If this is achieved we will see Māori and their mātauranga being used to measure forest health, to treat and manage the disease, and ultimately to eradicate kauri dieback.

[4] https://www.justice.govt.nz/assets/Documents/Publications/2017-NZEnvC-206-Ngai-Te-Hapu-Incorporated-v-Bay-of-Plenty-Regional-Council.pdf

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
4.1 Māori leadership and participation **Outcome**: A Treaty partnership is evident throughout kauri dieback research programmes and planning, and Māori are participating at all levels including investment. **Measures of success:** • Māori feel as if their contribution is valued, there is a place for them in the kauri dieback research plan and programmes. • Māori feel able to fully contribute to research programme decision-making and delivery. • Iwi, hapū, Māori have the capability to effectively participate in the plan and subsequent research programmes. • Te Tiriti o Waitangi is embedded throughout kauri dieback research planning and programmes. • Vision Mātauranga policy is visible throughout the plan and research programmes. **Current state**: Māori are currently represented at the governance level, though representation at other levels needs to be improved. There are concerns by some post-settlement iwi that their Treaty relationship, as defined in legislation, has not been appropriately recognised. Māori participation in research has been limited to date due to under-resourcing, lack of integration, and the delayed implementation of mātauranga Māori research (refer also to 5.1 current state). **Recommended funding:** $0.3 m per annum for 5 years					
a) Leadership – Establish and implement an iwi and hapū led framework or process, including a Kāhui of Māori expertise to ensure kauri dieback research activities and methodologies effectively incorporate mātauranga Māori into all aspects of kauri dieback research activities	Short	O	***		✓
b) Participation – Developing opportunities to enable mātauranga Māori-led community engagement	Medium	S/O	***	Links to Theme 5	✓
c) Tino Rangatiratanga – Giving effect to Māori rights and interest (as articulated in Te Tiriti and Wai262) in the protection and management of kauri, including development of best practice protocols for research that uses or impacts taonga	Short – Medium	S/O	***		✓
d) Participation – Ensuring Māori have the capability and capacity to utilise relevant information for iwi/hapū decision-making about kauri dieback	Short – Medium	O	**	Links to 4.2a	✓
4.2 Trust and confidence (cultural licence) **Outcome**: Māori willingly engage because they have trust and confidence in the kauri dieback research plan and research programmes, knowing that it is continually improving. **Measures of success:** • Māori see that their values are reflected in the research plan and its priorities. • Māori believe that they can participate in and influence kauri dieback research programmes. • Māori feel a sense of ownership in the plan. • Māori consider plan decisions and actions to be fair. **Current state**: While the Tangata Whenua Rōpū group is represented within the Kauri Dieback Programme, there are differing views by iwi/hapū/Māori on the levels and success of engagement. Some iwi/hapū/Māori communities have historically expressed distrust in the programme, and a lack of faith in the ability of the research programme to save kauri (refer also to 5.1 current state). **Recommended funding:** $0.15 m per annum for 5 years					

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
a) Building trust and confidence – ensure that transparency of information influences trust and confidence in the research programme and leads to better integration and decision-making by Māori (iwi, hapū, whānau) about how to manage their lands, and develop their environmental research plans/priorities	Short-Medium	S/O	***	Links to Theme 5 and 4.1	✓
b) Understanding your audience – Determine who the key Māori audiences are that can influence the research programme's success (high risk and influencers) and what the barriers are to their engagement in the research programme	Medium	S/O	**	Links to Theme 5.3 and 5.4	✓
c) Cultural/social acceptance – Continue work with iwi and hapū to identify which tools are most acceptable within each context	Short – Medium	S/O	***	Links to Theme 5	✓
4.3 Awareness and engagement **Outcome**: Māori understand what kauri dieback is and how it is being dealt with, and non-Māori understand the role and importance of Māori and mātauranga in the research programme. **Measure of success:** • Māori awareness of kauri health and kauri dieback is increasing (by more than 15% pa). • Māori compliance and adoption of key messages are reflected in their actions and management of their whenua. • Non-Māori researchers in kauri dieback research programme are being supported to integrate mātauranga Māori and Vision Mātauranga into their research, and can report the benefits of doing so. **Current state**: There is anecdotal evidence that other than in the kauri dieback areas, Māori are unaware of the full impact of the disease on their taonga and whenua. This means that the programme is potentially not getting access to mātauranga that may hold the solution for protecting kauri from or managing the disease. There is also evidence that non-Māori researchers and agencies do not understand the benefits mātauranga can offer to the research, nor the role of Te Tiriti or Vision Mātauranga in their work. **Recommended funding:** $0.15 m per annum for 5 years					
a) Awareness – Determine whether awareness and understanding of the disease amongst Māori has increased, and is reflected in increased engagement in the programme, and compliance with management measures	Medium	S/O	**	Links to 4.2c	✓
b) Engagement and awareness – Supporting non-Māori (people and agencies) to better engage with Māori and understand the benefits of mātauranga Māori in the protection and management of kauri, resulting in new innovative solutions for forest management	Medium	S	***		✓

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
c) Engagement – Determine the role tamariki and rangatahi play in increasing awareness of kauri dieback	Long	O	*		✓
4.4 Mātauranga Māori solutions for kauri dieback **Outcome**: Mātauranga Māori and Kaupapa Māori methodologies are a key component of all kauri dieback research programmes. **Measures of success:** • Solutions and tools are developed in partnership with Māori. • Mātauranga Māori has created solutions for the protection of kauri and management of kauri dieback. • Mātauranga knowledge holders are empowered to develop solutions for kauri forest management. **Current state**: Finding solutions for kauri dieback based on or using mātauranga Māori has largely been limited to the work funded by the Biological Heritage National Science Challenge and at the discretion of the lead researchers. However those that have embraced mātauranga Māori have seen benefits. **Recommended funding:** $0.5 m per annum for 5 years					
a) Disease spread – Determine how disease spread maps can be incorporated into Māori (iwi/hapū/communities) land and environmental management plans to ensure they mitigate potential spread of the pathogen. Detailed maps for iwi/ hapū environmental plans which influence council and agency planning	Short	S/O	**	Links to 1.2	✓
b) Whakapapa (kauri responses to *Phytophthora*) – Determine what we can learn from the resilience of kauri relatives and their kaitiaki in the Pacific	Medium	S	*	Links to Themes 2.2 and 3	✓
c) Whakapapa (kauri responses to *Phytophthora*) – Determine whether the lineage of kauri offers us insight into alternative hosts, sentinels', defence, solutions etc.	Short-Medium	S	**	Links to Themes 2 and 3	✓
d) Role of environment on kauri decline (forest demography/population dynamics) – Determine the population structure of kauri forests, what stage the forests are currently in, and what effects will the disease have on these natural cycles (birth and death rates)	Short-Medium	S	***	Links to Themes 2 and 3	✓
4.5 Control and management **Outcome and measure of success**: The mauri or hau ora of kauri ecosystems is protected **Current state:** Some of these measures are already being used, but use is sporadic and there is a lack of coordination. **Recommended funding:** $0.4 m per annum for 5 years					
a) Rāhui – Determine the role rāhui (forest closures) play in healing the ngahere	Medium	S/O	***		✓
b) Rongoā solutions – Rongoā practices provide solutions for the management of the disease	Short – Medium	S/O	***	Links to Theme 6.2j	✓

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
c) Tree removal – Determine how Māori can be empowered to, and assess the risks associated with the extraction of diseased or dead trees	Short – Medium	S	***	Links to Theme 6.2b	✓
d) Hygiene – Determine what tools/methods are needed to effectively clean footwear, machinery, etc., and whether the existing tools/methods are fit for purpose	Short	S/O	**	Covered in Theme 6.2h	✓
e) Mana motuhake – Determine how Māori are empowered to exercise their duties as kaitiaki, and whether the tools and methods support them	Medium	S/O	*		✓
f) Resilience – Defining resilience for Māori in relation to forest health	Medium	S	*		✓
Total funding required for Theme 4: $1.5 m per annum					

Theme 5: Building public/community engagement and social licence

Context:

- Kauri dieback is a complex problem. Not only because of its bio-physical uncertainties, but also because of its social complexities, as it affects multiple stakeholders from inside and outside the science sector, who often hold differing perspectives about how the disease or forest should be managed. Understanding and managing this social complexity is critical for the ongoing management of kauri dieback. To successfully achieve this will require meaningful engagement with affected communities to facilitate their ongoing involvement in programme planning, decision-making, and delivery. It will also require understanding of human behaviours, so as to encourage people to positively contribute and/or comply.
- Managing kauri dieback requires community and public buy-in. Fostering this engagement requires robust social science research to inform, guide, monitor and evaluate this engagement. To date much of the social science research has focussed on assessing public response to footwear cleaning stations and track signage to address low rates of public compliance to these biosecurity control measures. This work has been particularly valuable for informing agency management of control measures, but in general these studies have been ad hoc, and the evidence not made widely available. Very little research has been undertaken to inform and guide community engagement in the programme.

Potential gain from the research:

- Engaging and communicating with affected communities and the wider public is challenging. By exploring the social dimensions of the programme, social science research can inform programme decision-making to ensure it is based on sound, robust and rigorous evidence. This research will provide:
    - Effective methodologies/models for community engagement and ways to incorporate a variety of knowledges into the management programme (both explicit and tacit) – including scientific, mātauranga and local knowledge.
    - Effective understanding of human behaviours that influence how people engage with the programme and with management tools and strategies.
    - Effective strategies for science communication.
    - Identification of key target audiences and high-risk groups to understand their drivers and barriers and benefits to their engagement.
- This social science research will provide evidence-based information to assist and shape programme planning and implementation, and help monitor and evaluate its effectiveness. While the social science aspects of kauri dieback are very under-researched, so too is the international literature on the social aspects of biosecurity programmes, and so kauri dieback social research may offer a valuable contribution to wider international discussions.
- Social science research will also need to be integrated across the other themes in this science plan as they all have human dimensions, including the need to interact with communities/public and the challenges presented from working in transdisciplinary teams. Social science methodologies can be employed to enable multiple participants from inside and outside the science sector to work collaboratively and collectively towards the common vision of protecting kauri from kauri dieback.

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
5.1 Facilitating community engagement and social licence **Outcome**: A coordinated holistic programme that fosters trusting partnerships where community feel valued members and can fully contribute to programme delivery. Different participatory science methodologies employed (including citizen science and participatory action research) which facilitate community engagement and collaboration and the integration of different knowledges into programme planning and implementation – including scientific, mātauranga and local knowledge. Development of models of engagement to identify "best practice" to inform operational strategies. **Current state**: To date community engagement has been managed largely at an operational level and evidence suggests working relationships between current programme governance and community have become strained, despite continued community concern for the state of kauri and interest in wanting to be actively engaged in protecting kauri. The Biological Heritage National Science Challenge has funded a citizen science project investigating treatment options on private land and already the outcomes from this project show the value of facilitating community engagement and building trust. **Recommended funding:** $0.5 m per annum for 5 years					
a) Determine what approaches to collaboration and co-development resonate with different communities	Medium	S/O	***	Links to Theme 4	✓
b) Determine how Māori can become better integrated as partners in science, engagement and management, ensuring greater trust/confidence	Medium	S/O	**	Links to Theme 4	✓
5.2 Working in a transdisciplinary environment **Outcome**: A reflexive integrated programme across the governance and operational levels that provides a cohesive plan for a multi-disciplinary programme where knowledge is known and shared. Social science approaches are employed to guide, monitor and evaluate the ongoing effectiveness of this cohesive and integrated approach that ensures effective communication and collaboration across all levels in the programme. **Current state**: Incomplete knowledge base with minimal knowledge sharing. Siloed approach to research and programme delivery. **Recommended funding:** $0.15 m per annum for 5 years					
a) Create an effective transdisciplinary environment that facilitates collaborative processes across all science themes and into the Kauri Dieback Programme as a whole	Short	S/O	**	Links to all themes	✓
b) Determine social science methodologies that can be employed to effectively incorporate social science into all aspects of the Kauri Dieback Programme	Medium	S/O	***	Links to all themes	
5.3 Understanding audiences **Outcome**: Identification of: target stakeholders; high-risk groups and pathways; barriers to people's engagement, behaviour change and social practices (individual, community, institutional, policy) that drive current behaviours. **Current State**: General biosecurity surveying captures some understanding of audiences but this is ad hoc, difficult to access and not always rigorously captured. **Recommended funding:** $0.4 m per annum for 5 years					
a) Identify target audiences to inform social engagement and behaviour change initiatives	Medium	O	***	Links to Theme 4.3	
b) Identify key stakeholders and their values, barriers to engagement, and social practices that drive current behaviours	Short	O	***	Links to Theme 4.3	✓

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
c) Employ a variety of social science research methods such as localised social network mapping, risk analysis and socio-economic impact assessments to identify high risk groups, target audiences, and how they inter-relate and the impacts that programme implementation and the possible loss of kauri have on these audiences	Short	O	***	Links to Theme 4	
5.4 Developing a knowledge base **Outcome:** Development of a comprehensive literature review of the social science undertaken to date on kauri dieback and other biosecurity issues in New Zealand, and an exploration of the international biosecurity literature to identify key learnings to inform kauri dieback operations, governance and research including identification of knowledge gaps. Development of a local register that contains key local experts and identifies their specialist area of knowledge. **Current**: Under-researched area as acknowledged by the Black and Dickie report. **Recommended funding:** $0.1 m per annum for 2 years					
a) Create a stocktake of the social science research that has been undertaken to date on kauri dieback and other biosecurity-related issues in New Zealand that appears in both the published and the grey literature	Short	O	***		
b) Undertake a review of the international biosecurity social science research to identify key understandings and knowledge gaps	Short	O	***		
c) Develop a 'local experts' register of key stakeholders and their specialist area that includes groups and individuals who hold critical tacit information relevant to kauri dieback management	Medium	O	***	Links to Theme 4.2	✓
5.5 Developing, monitoring and evaluating management tools and social licence **Outcome:** High public compliance and acceptance of programme control measures including foot stations, and track and area closures (rāhui). **Current:** To date, much of the social science research has focussed on assessing public response to footwear cleaning stations and track signage to address low rates of public compliance to these biosecurity control measures. **Recommended funding:** $0.25 m per annum for 5 years					
a) Robust and rigorous assessment of the social acceptance of tools (e.g., cleaning stations), management approaches (e.g., track closures) and technologies (e.g., phosphite), including, for example, undertaking social research to assess the effectiveness of management approaches and tools and engaging communities in conversations to gain a social licence for current and, in particular, new technologies	Medium	S	***	Links to Theme 4	✓
Total funding required for Theme 5: $1.4 m per annum					

Theme 6: Control and management

Context:

- There is great concern that current management tools have not been shown to reduce the spread of kauri dieback. There are very few tools and methodologies available. Trunk injections with phosphite into diseased trees has been shown to contain lesions and protect trees; however, whether there is an associated reduction in the pathogen and its inoculum potential is not known. Injecting trees over large areas may not be practical in many cases. Research has been conducted on the use of a phosphorous acid drench as well as a foliage spray, but they were not as effective as trunk injections. Further research should be conducted on foliar application, but there are ecological and societal concerns to be considered before such a measure is put into practice.
- Other management challenges include building public/community engagement to ensure there is strong social licence for developing and operationalising different management and control strategies that will be implemented.
- There is a need to develop integrated disease management practices that can be implemented effectively and sustainably across the kauri forest.
- There is a strong need to ensure operational research and adaptive management are closely aligned to ensure research findings are implemented in a rapid, effective and on-going way. For example, if findings from Theme 1 show that the pathogen is only contributory and naturally widespread, this will impact on control and management tools and strategies.

Potential gain from the research:

- Effective control and management tools will help reduce impact of the disease in already impacted kauri forest as well as prevent the spread of the pathogen into pathogen-free forests. The science will deliver forests free of kauri dieback.

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
6.1 Developing control tools to stop the impact and spread of kauri dieback **Outcome**: Healthy trees, healthy forests, healthy ecosystems. **Current state**: A growing disease epidemic with no robust and sustainable tools in place to manage the pathogen, or its impact or spread. **Recommended funding:** $1.0 m per annum for 5 years					
a) Investigate if trees and sites can safely and acceptably be saved by fungicide drenching and/or the use of phosphite as a barrier (e.g., injections, trunk and foliar spray and drenching), and applied to all understorey species as a foliar application to create a barrier	Short – Medium	S/O	***		✓
b) Investigate 'spot eradication' in areas of infestation that are small (<1 ha) and identified early enough, and if there is strong confidence in the pathogen distribution	Short	O	**		
c) Scale up of phosphite application efficacy, e.g., phosphite applications over (1) large areas of infested forest, and (2) disease-free forest at risk to kauri dieback	Medium	S/O	**		
d) Assess phosphite impact and toxicity	Short – Medium	S/O	***		

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
e) Assess Ridomil drench soil risks and efficacy (risk of selecting for resistance)	Short	O	**		
f) Chemical disruptor or pathogen attractant	Short – Medium	S/O	***		
g) Oospore deactivation – tools/methods needed to kill the oospore or reduce the viability to acceptable levels	Short – Medium	S/O	***		
h) Assess how 6.1a-g impact on pathogen(s) latency and biology, and soil health	Short – Medium	S/O	***		
i) Assess how 6.1a-g impact on ecosystem and micronutrient health	Short – Medium	S/O	***		
6.2 Developing management tools to stop the impact and spread of kauri dieback **Outcome**: Healthy trees, healthy forests, healthy ecosystems. **Current state**: A growing disease epidemic with no robust and sustainable tools in place to manage the pathogen, or its impact or spread. **Recommended funding:** $1.0 m per annum for 5 years					
a) Develop tools for surveillance for mapping and monitoring (including geospatial, hyperspectral and multispectral) that can be rapidly applied to determine efficacy of control treatments, including building mātauranga Māori for early detection of infected trees and other symptoms	Short	S/O	***	Links to Themes 1, 2, and 3	✓
b) Risks and cultural implications associated with extraction of dead trees	Short	O	*	Links to Theme 4	✓
c) Site modification research	Medium – Long	S/O	*		
d) Determine how far quarantine should be around infected (1) trees, and (2) forest	Short	S/O	***	Links to Themes 1, 2, and 3	
e) Define/determine a management unit, including mana whenua (when you have an infection, where do you want to draw the line? Implications for continuous forest and variable land tenure)	Short	O	***	Links to Theme 4 and 6.2d	✓
f) Other factors that could be removed to improve kauri resilience, including predator control	Medium	S/O	**	Links to Theme 3	
g) Surveillance, management and regulation of nurseries (nursery hygiene)	Short, on-going	S/O	**	Links to Theme 1	
h) Tools/methods needed to clean/disinfect machinery	Short	S/O	***		
i) Control of the pathogen (chemical and macro- and micro-nutrient supplements) and increase in kauri health and resilience, including alternative treatments such as natural remedies	Short – Medium	S/O	***	Links to 6.1c, 6.1d, 6.1f, and Themes 2 and 4	✓
j) Rongoā treatments (commenced)	Medium	S/O	**	Links to Theme 4	✓

Priority research needs	Timeframe	Research type	Priority	Links to other themes	Kāhui
k) Biocontrol agents and/or use of companion planting, including looking for suppressive soils	Long	S/O	**	Links to Theme 2.3a, b and 4	✓
l) Determine the persistence of phosphite in different aged and sized trees and the frequency of application required to keep trees healthy	Medium – Long	S/O	***	Links to 6.1c	
m) Improve efficacy of phytosanitary stations and hygiene protocols	Short – Medium	O	**		
n) Continued assessment (remote sensing and on-ground) of control treatments on kauri and ecosystem health	Medium – Long	O	**		
o) Implementation of management procedures (e.g., vector control, upgrades, cleaning stations, etc.) need to be rigorously monitored for effectiveness of pathogen control and spread	Medium – Long	O	**		
p) Data integration, machine learning and modelling, based on probabilistic/risk mapping of pathogen distribution; use of Bayesian modelling to develop risk prioritisation models; statistical modelling of disease control measures at a landscape scale	Medium	S/O	**	Links to Themes 1	
Total funding required for Theme 6: $2 m per annum					

Monitoring and evaluating the success of this science plan

Outputs generated across all six research themes need to be integrated to deliver a lasting solution for kauri dieback. In this context, it is critical to evaluate the effectiveness of individual and collective measures aimed at minimising the ecological, cultural, and social impacts of kauri dieback. Progress in achieving this plan will need to be tracked in order to capitalise on new knowledge and adaptively adjust future research priorities. To achieve this the following should be completed.

Deliverable	Audience	Timeframe
Create a page on the Kauri Dieback Programme (KDP) website dedicated to tracking implementation of the Kauri Dieback Science Plan	SSAG members, researchers, mātauranga Māori experts, KDP partners, staff and general stakeholders	In place by 31 March 2019
Maintain a publicly accessible database of funded projects relevant to kauri dieback (irrespective of funding sources), which records: • high level title, objectives and milestones; • research organisations and lead researchers; • alignment with research themes; • investment (amount and sources); • timeframes and status; and • potential impact or a brief summary of key outcomes/findings of the research once completed.	SSAG members, researchers, mātauranga Māori experts, KDP partners, staff and general stakeholders	In place by 31 March 2019 and updated as new projects are confirmed
Track key outputs for projects, such as publications, and profile them on the Kauri Dieback Science Plan webpage and other relevant kauri dieback communication products	SSAG members, researchers, mātauranga Māori experts, KDP partners, staff and general stakeholders	Updated as outputs are finalised
Annual researcher workshop to collectively discuss emerging knowledge and implications for priorities	SSAG members, researchers, mātauranga Māori experts, KDP partners, staff and general stakeholders	Annually
Annual report that summarises: • Allocation of effort across priorities • Summary of new kauri dieback knowledge • Refreshed research priorities • Opportunities for coordination and alignment of science effort • Overall commentary on progress and sufficiency of effort to stop the spread of kauri dieback and/or cure diseased kauri	KDP Governance Group, SSAG members, researchers, mātauranga Māori experts, KDP partners, staff and general stakeholders	Annually

The Kauri Dieback Programme seeks to maintain currently kauri dieback-free areas, significantly reduce the spread of kauri dieback, significantly reduce the impact of kauri dieback within infected sites, protect iconic kauri and develop and maintain effective relationships and increase public participation. Evaluation of progress towards achieving these outcomes and also to detect changes in disease incidence and severity over time is an essential input into the overall Kauri Dieback Programme. Adaptive and timely management on-ground as new research findings become available will be important in the fight against kauri dieback.

Karakia for kauri, as presented at the kauri dieback science workshop

Composed by Haami Piripi	
Mai e, mai e, mai e te kāhui o ngā ariki i tataia, i pūtātara hei orokohanga o tēnei ao. Ko Ranginui e tū nei, ko Papatūānuku e takoto mai rā, he tuanui, he whāriki kia tū ai, te Taiao.	From the distant past, from ancient times, since the birth of the elemental deities the universe has continued to unfold into the world as we know it. The spaces above the planet, and below, form a roof and a floor between which exists the world as we understand it.
Mai i te rangi ki te whenua, te whenua ki te rangi, i taka iho nei, he aitanga maha ngā uri kei waenganui i nga tokotoko o te rangi. Nā Tāne i whakatū.	And from the skies to the earth, the earth to the skies, the deities have re-produced a myriad of progeny who occupy these places within the props which keep our world apart. The world that Tāne has put in place.
Nau mai e Tāne, kia noho mai koe ki te minenga nei, hei Atua Māori e tātai tonu ki tēnā, ki tēnā o ngā ngākau e arohatia ana ki Papatūānuku, ana ko Kauri e mate haere ake anō.	We welcome the presence of Tāne to rest among our gathering and manifest as an indigenous phenomenon who can affiliate to each and every heart that has a love for Kauri who ails, more dangerously as time elapses.
Tāne te Waiora, Tāne te Oro-oro, Tāne te Waenga, Tāne Whakapiripiri, e tū mai nei, Tāne Nui ā Rangi i hanga ai te tangata me te manu, Tāne Mahuta i tū i te wao nui, hei rākau Kauri.	Tāne the bearer of light the constructor of biology, the repository of knowledge the producer of natural resources, the conception of birds and human kind alike. Tāne Mahuta is reflected in Kauri, standing with pride amidst a forest of ecological liberty.
Nāu anō e Tāne i whiwhi ai te uwha, hei orangatonutanga mō āu uri katoa, puta noa. Heke iho.	It was you, Tāne who acquired the secret of perpetual re-productivity to achieve sustainability for all of your progeny.
Aro mai ki te tangi a te manawhenua e nohotahi nei, me te motu katoa, aroha tonu mai mō te kiriwaewae ō Papatūānuku e hemo haere ana ki tēnā moka, ki tēnā pito o te whenua, tae ki uta, ki tai hoki.	Harken to the cries of the people of the land as we collaborate across the entire nation to pursue the principle of ecological integrity through our environmental management. We acknowledge the already existing evidence of destruction that forms a patchwork of degradation in places both inland and at sea.
Ka whakarongo ake atu ki te ngu o te rākau rangatira nei e mau ana tō mātou ingoa mōu. Titiro ake atu ki a ia e tū ana ki te wao he pakoko/papaku noa, koi a ko koe, ko matou ki koe, kua kore e taea matou, te taurima tika, te manaaki pai, te awhiroa.	We listen through the deadened silence to this magnificent creature who we have named in honour of you, Tāne Mahuta. We see him/her standing so solitary, dying a slow death. Yet we are one with Kauri, and we confess as custodians of your domain that we have not cared enough, that we have not nurtured your presence and that our embrace of you has been short-lived.

Ana, nau mai rā, whakauru mai rā whakatau mai ra ki roto i a mātou. Kia whaimāramatanga mātou katoa Kia wakapiri, whakatata ngā whakaaro Kia ngākau nui te Iwi nei, ana, kia whiwhi ai he mea whakapai, oranga rānei mō tēnei taonga ā Kauri.	Welcome among our human imperfections, enter our thoughts, and abide with us in order that we may become enlightened enough to validate each others' perspectives, consolidating our efforts around a single objective that we can be one heart, and one mind in fulfilling what will be required to give a certainty of life back to Kauri.
Ōrite te katoa ō mātou a wawatia ana, kia pau rawa ō mātou kaha ki te whakaora ake ia Kauri tō mātou tuakana.	We are of one mind to give and commit our human energy in order to give life to our ecological elder, Kauri.
E Kauri e, i tū kia topatopa haere tāua ki runga. Tirotiro kau ana ki te memeha a te waoku, ki te mimiti o ngā puna wai, te urunga o ngā kīrehe, te whakatupuranga o ngā rākau atu me te kuare hoki o e whakahaeretanga na te wahangū a ngā Kaitiaki Māori.	Oh Kauri, arise let us fly aloft together to observe the diminution of forest density, the drying up of our mutual water sources, the invasion by animals and the inadequacy of conservation management history in the absence of Kaitiaki Māori participation.
Arā anō ko tōu tapu Māori, wehi rānei, e taka iho ki raro nei.	There lies your sacred and indigenous nature, and the awe of Māori creation reduced and disempowered to become legends of a fanciful people.
Anei tana hikinga, anei tana ohonga. Maranga mai, maranga mai e ngā tupuna e tatai iho nei ki te aho matua e heke iho nei ki te ira tangata e whaimana ana ki te whenua. Nāu nei e Tāne, i tukuna kia rere hei, oranga mō te Kauri.	Here now is our new ascendance, our awakening of the people to rise up and seek out our forebears, whose genealogy is bound by the divine intervention of Tāne and also descends to the yet unborn generations of the future connecting the mana to the land once more. In communion with Tāne Te Wānanga the potential of this knowledge can be released, of one heart and mind, to give new life to Kauri.
Whakatū tārewa tēnei kōrero. Ki te rākau aweko, ki te rangi kia kite rawa te ao, kia kite hoki te pō. Kia kaha ko te katoa. Uhi, uhi ka haere mai te toki o haumie, hui e, tui e, tāiki e.	We upraise these words into the skies, to be seen as a transparent call to action and a convergence of purpose, bound together as one, through Haumie, the unifier. It is done.