Independent review of the state of kauri dieback knowledge

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1.0. Executive summary

The Kauri Dieback Programme (KDP) commissioned an independent review to assess the state of knowledge of kauri dieback research, including sharing and aligning mātauranga Māori, understanding of disease distribution, tools for managing the disease, use of regulatory tools, and understanding of effectiveness of management interventions. The resulting report contains a literature review based on all published relevant literature and grey literature provided by the KDP Planning and Intelligence team, as well as unpublished updates and dialogue with scientists leading aligned and KDP funded research programmes. From this we have identified key knowledge gaps and well resolved areas and made recommendations on future research directions and prioritised accordingly. We have also assessed how the KDP has approached the development of knowledge and tools and how these have been implemented in the management of kauri dieback and *Phytophthora agathidicida.* As an overall observation, the initial response to kauri dieback and the identification of *P. agathidicida* can be characterised as a crisis-mode response, which is appropriate following a precautionary principle. As a result the focus of the KDP has been almost exclusively on *P. agathidicida* as the sole causal agent, rather than on other drivers of dieback or the status of kauri overall. This is based on the hypotheses that *P. agathidicida* is a recently introduced, range expanding pathogen that will result in widespread collapse of the kauri population.

The evidence base for the continuation of the above approach is less robust than would be ideal as the programme moves from initial crisis to long-term management. Most critically the factors outlined below must be considered and integrated into future research planning:

- The role of other drivers of kauri dieback has not been sufficiently considered, particularly cohort dynamics, root disruption, and other invasive species;
- The origin of *P. agathidicida* remains uncertain, although the weight of evidence still suggests it is likely to be a non-native species;
- The presence of *P. agathidicida* in alternative hosts and in healthy forest remains unknown;
- Insufficient consideration has been given to the long-term forest demography of kauri (with and without *P. agathidicida*);
- Although there have been discussions of implementing mātauranga Māori, this has yet to be progressed despite proposals put forth for consideration;
- The current approach to developing knowledge and tools has strengths (excellent web based sharing), but also weaknesses in taking a single-pathogen focus, and in relatively low-profile publication of findings. Increased research exposure would help leverage greater international linkages to assist in problem solving.

We recommend the following areas as **high-priorities** for research, attempting to provide a balance between increased understanding of other drivers of dieback and kauri populations, with a continued focus on key questions remaining around *P. agathidicida.*

- Increased understanding of natural, background *Phytophthora* populations in kauri and alternative hosts, particularly any potential occurrence of *P. agathidicida* in healthy kauri forest in the absence of symptoms of dieback.
- Long-term demographic modelling of kauri populations allowing scenario modelling of different disease levels and management strategies.

- A larger-scale research programme around much better understanding of environmental factors driving the spread, adaptation, and virulence of *P. agathidicida* and of kauri dieback in the absence of *P. agathidicida.*
- Research on the economic and social implications of kauri disease and dieback.

Additional medium and lower-priority areas are identified in the main document. The KDP long-term strategy should include a recognition that the knowledge base for current management is based on a preponderance of evidence, but does not yet rise to a high level of certainty. Current management strategies are based on evidence, but to date there is no direct evidence they have slowed or halted kauri dieback. The KDP should continue to foster new and existing external collaborative partnerships to resolve key questions.

In summary, the current management strategy to kauri dieback has generally been an appropriate crisis-response focus. The KDP has recognised the need to move into longer-term thinking in the strategy document, which we endorse. However, the current strategy of the program confounds management of *P. agathidicida* spread and dieback with research priorities that should be identifying the underlying cause of kauri dieback and decline. We recommend nominating a current member of the planning and intelligence team to focus on coordinating research efforts and on linking the KDP to the broader scientific community, with a role of encouraging collaboration on research bids and fostering scientific debate to achieve best possible outcomes for kauri conservation, and in particular the preservation of these iconic ancient trees.

2.0. Scope of review and introduction

The purpose of the review is to provide an independent appraisal of the state of knowledge and make recommendations on investment in areas that show the greatest potential to deliver on the outcomes specified in the Kauri Dieback Strategy, over the life of the Strategy. The review will assist the Kauri Dieback Programme in setting the high-level budget for the 'Building knowledge and tools' portfolio and allocating resources within it.

Starting from the perspective of forest dieback, and including both KDP funded research and research outside the KDP and internationally this review covers forest dieback, the biology and ecology of *P. agathidicida*, diagnostics and surveillance, current knowledge of distribution, host resistance, environmental influences on the pathogen, vectors of spread, management tools (from a state-of-knowledge perspective), long-term impacts (including ecosystem, social and cultural, Tangata Whenua, and economic), mātauranga Māori, and long term forest dynamics. The approach of the KDP to developing knowledge and tools is briefly reviewed. Finally, recommendations for research programmes are made, ranked by priority.

2.1. Kauri dieback strategy outcomes

The stated strategy outcomes of the KDP include:

- maintaining currently kauri dieback-free areas,
- signficantly reducing the spread of kauri dieback,
- significantly reducing the impact of kauri dieback within infected sites,
- protecting iconic trees and stands from *Phytophthora agathidicida,*
- maintaining effective working relationships and increasing public participation

For the purposes of this review we address knowledge that underpins the first four of these strategy outcomes, but do not address the working relationships within the KDP or public participation. We do discuss the need for a more focused relationship with the research community. As this review was conducted as an independent exercise, we note that our review is primarily of completed and communicated outcomes. Some *in progress* projects of the KDP may already address parts of our recommendations, particularly including and ecological panel held early in 2015 and epidemiological research.

3.0. A literature review of the current state of knowledge

We conducted a review of current knowledge of kauri dieback. The purposes of the review were to summarise available KDP data and discuss key knowledge gaps and well-resolved areas. We also have included a description of how the KDP has approached the development of knowledge and tools. For the scope of this report, we have reviewed literature available directly from the Kauri Dieback Programme, conducted a literature search of Web of Knowledge and of Google Scholar, and contacted key researchers via email or other means to obtain knowledge and viewpoints (these included Bellgard SE, Bradshaw RE, Burns BR, Gerth M, Horner IJ, Hill RA, Lockhart P, Padamsee M, Perry G, Waipara NW, Weir BS, Wilcox PL, Williams N, Wilson S). Our literature search strategy and notes on key papers is included in Appendix 1. We did not review minutes of KDP meetings. We included some review of general literature on forest pathogens (including *Phytophthora*) and ecology of kauri as relevant to this review, but did not attempt to comprehensively review all knowledge of either forest dieback or kauri forest ecology.

3.1. An initial, crisis-mode focus on pathology

Kauri (*Agathis australis*) trees in the Waitakere ranges were observed to have severe gummosis (bleeding from stem) and death in 2006, leading to the re-discovery of *Phytophthora agathidicida* (as *Phytophthora* taxon *Agathis*) by Beever (2009). The pathogen had been previously reported by Gadgil (1974), but not recognized as a new species. After the 2009 observation, it was established that *P. agathidicida* is lethal to kauri when directly inoculated onto seedlings (Horner et al, 2014). The disease is of particular concern due its potential to kill entire stands of trees, not just individuals.

Much of the initial response to *Phytophthora agathidicida* has been based on incomplete knowledge. Faced with an unknown pathogen and recognising that pathogens can result in widespread loss of forest dominants, the focus has been on preventing spread despite incomplete knowledge. This is a highly appropriate response following a precautionary principle. Although the origin of the species was unknown, it was assumed to be a new pathogen and, under the precautionary model, significant efforts made to understand the pathogen.

Significantly less effort has been made to understand the other elements of the disease, notably the role of other biological agents, the role of abiotic environmental changes in kauri health, or the role of stand development (Stewart 1989). As such, it is somewhat unclear if *P. agathidicida* is precipitating or *only* hastening kauri death. It was also assumed that the death of individual kauri would likely lead to the decline of the population, but the trajectory of the population does not appear to be known.

Following the observation of kauri tree death and gummosis, the isolation of *P. agathidicida* from dying trees, and the observation that *P. agathidicida* was lethal to seedlings when inoculated, the initial focus of research has been pathology driven. In particular, research has examined the identity of *P. agathidicida*, its origin and spread and its current distribution.

Knowledge gap:

- ***The role of other causes of kauri decline is largely unknown and appears not to have been addressed in any publication.***

3.2. Identity of *P. agathidicida* and definition of dieback

The identity of *P. agathidicida* as a novel species of *Phytophthora*, phylogenetically related to *P. castaneae* (= *P. katsurae*), *P. heveae, and P. cocois*, is established (Weir et al. 2015), despite earlier confusion and delays. The initial misidentification as *P. heveae* (Gadgil 1974) was corrected by Beever et al. (2009) and the working name 'Phytophthora taxon agathis' or 'PTA' established. This informal name was the only way to refer to the species until Weir et al. (2015) formally described the species and published the name *P. agathidicida.* The somewhat slow publication of the scientific name has created unnecessary communication difficulties that could have been avoided. Further, the name 'PTA' is significantly easier to pronounce and remember than *P. agathidicida.* Nonetheless, the paper by Weir et al. (2015) is of a high calibre, published in a leading international journal, and sets a firm nomenclatural and phylogenetic baseline for understanding the identity of *P. agathidicida*.

From an international context, the number of named *Phytophthora* species more than doubled between 1999 and 2012 (Martin et al. 2012), largely reflecting advances in molecular tools and phylogenetic understanding.

The KDP strategy document (Kia Toitū He Kauri – Keep Kauri Standing, 2015) implicitly defines kauri dieback as synonymous with *P. agathidicida*. This may be problematic. First, reports of 'dieback' based on symptoms may or may not be later confirmed to be caused by *P. agathidicida* (Waipara et al. 2013). Unless these symptoms are always confirmed to be related to *P. agathidicida*, it would be incorrect to term them kauri dieback under the implicit KDP definition. We believe this is unworkable. Second, the term dieback is already widely used for other forms of forest ill-health (including Rata-Kamahi dieback, *Nothofagus* dieback), and hence restricting the usage for kauri to only one cause of dieback is inconsistent with general usage. Finally, as discussed below, several cases of dieback internationally have been initially attributed to a single pathogen, but have later been found to be a more complex, multiple-driver phenomena (e.g., Ohia decline,). For the purpose of this review, we therefore take a deliberate choice to define kauri dieback as the symptoms typically associated with *P. agathidicida* (regardless of whether the pathogen is confirmed to be present) and refer to the actual organism by name where it is confirmed to be present.

One other name, 'kauri collar rot' is used to refer to *P. agathidicida* induced symptoms (Beever et al. 2009), but not as widely used as kauri dieback. Beever and co-authors were explicit in stating that kauri collar rot was a symptom of *P. agathidicida*, without excluding the possibility of other pathogens being found to cause the same disease.

Knowledge gap:

- ***The identity of P. agathidicida is well resolved (no gap).***

3.3. Origin of *P. agathidicida*

Whether *P. agathidicida* is native or exotic remains unresolved (Bellgard et al. 2013). Beever et al. (2009) stated that 'It is proposed that PTA may be introduced to New Zealand, but too few isolates are available to determine whether genetic variability of this species provides support for this hypothesis'. The proposition that *P. agathidicida* was exotic had been based on the belief that this was a new detection with a known distribution consisting of a single population, high mortality of kauri stands, a perception of decline in kauri populations, and a low level of genetic variability.

The proposal by Beever et al. that *P. agathidicida* is non-native has probably been viewed as somewhat more definitive than current evidence suggests. Indeed, evidence since Beever's proposal suggests that *P. agathidicida* was much more widespread than the first published report (Beever et al. 2009) and has been present in NZ since at least the 1950s. There is also evidence of some genetic variability within the population, as Weir et al. (2015) show two clades within the population, albeit differing in only 5 nucleotides over 7534 aligned bases in that study (Weir personal communication). Further, in communication from Peter Lockhart et al. (Massey University) have assembled the mitochondrial genomes of six isolates of PTA – and there appears significant genetic diversity among these'. In a presentation of these results to the Bio-Protection Research Centre (November 2015), they reported 65 nucleotides differing among isolates, supporting 3 different genetic groups in NZ and suggesting the Great Barrier population is genetically distinct from the main island. The observation of a more widely dispersed and high genetic diversity species is suggestive that either *P. agathidicida* could be a native species or, alternatively, that there have been multiple introductions to New Zealand.

Knowing whether *P. agathidicida* is native or not has profound implications for management. The current focus on managing spread of *P. agathidicida* is predicated on the belief that *P. agathidicida* is non-native and still spreading. Further, most management has focussed on the pathogen on the assumption that it is the precipitating cause of decline. However, if *P. agathidicida* is a native, potentially widespread, pathogen that is being increasingly observed, then management should focus on understanding the predisposing and precipitating causes of forest dieback.

From an international perspective, lack of knowledge on the origin of pathogens, fungi and other microorganisms is common (Pringle and Vellinga 2006, Lantieri et al. 2012). It is also becoming increasingly common for species to be first described outside their native range. Resolving the origin of species can prove an expensive and slow task. As such we suggest that the focus should be on looking for evidence that *P. agathidicida* is, either widespread and genetically diverse in NZ (as evidence for native status), or more restricted to disturbed sites and low genetic diversity (as evidence for exotic status). We do not recommend an extensive effort to search for *P. agathidicida* overseas.

Knowledge gaps:

- ***We believe that P. agathidicida is likely to be non-native, but this remains unclear. Forthcoming data from Winkworth and Lockhart may help resolve. This is an important piece of knowledge in underpinning appropriate management.***
- ***Consideration should be given as to what evidence would be required to confirm native or exotic status, not only for P. agathidicida, but also for the myriad new potential pathogens likely to be described in coming years.***

3.4. Diagnostics and surveillance

Essentially all diagnostics and surveillance has been focused on dieback or disease symptoms, and the detection of *P. agathidicida* in areas of dieback and disease. The symptoms of dieback are not synonymous with the detection of *P. agathidicida*. For example, Waipara et al. (2013) presents data on the frequency with which *P. agathidicida* was recovered from 428 public reports of properties with dieback. Of these, 217 properties were assessed as having no symptoms, ill health of kauri due to non-dieback causes, or no kauri present (7 cases). From properties showing symptoms, 168 soil samples were taken, of which 42 had *P. agathidicida* detected (25%), a total of 102 samples had other *Phytophthora* species present, 5 had *Armillaria*, and 28 (17%) had no pathogen recovered. Recovery of multiple co-occurring species of *Phytophthora* or co-occurrence of *Phytophthora* and other pathogens is also reported in other examples of forest dieback (Hodges et al. 1986, Jung et al. 2015).

It is unclear whether dieback in the absence of detected *P. agathidicida* means that other agents are driving the dieback, or at least in part problems with detection probability of current methods (Beauchamp 2012). However, given the only partial correlation between kauri dieback and the presence of *P. agathidicida* it is important to consider *P. agathidicida* as being present only when confirmed by culturing or DNA methods. The observation by Waipara et al. (2013) that 50% of reports of kauri dieback were not confirmed also indicates that caution in interpretation of public reports is critical.

We found no published studies that described the abundance of *P. agathidicida* in soils or roots of plants in healthy forests. In a not-yet-released report, Bellgard et al. (2013) found PTA in 19% of asymptomatic trees, compared with 60% of symptomatic trees. Nonetheless, all of those samples were taken within a stand with many unhealthy kauri in proximity (<50 m linear distance) to asymptomatic tree samples; hence these results cannot be extrapolated to stands of entirely healthy trees. Knowing how widespread *P. agathidicida* is in asymptomatic forests would have potentially profound impacts on the management strategies. For example, if *P. agathidicida* is widespread in a non-symptomatic state, then management of spread would be a lower priority and suggest a greater focus on precipitating causes of forest dieback.

There was a concerted effort to develop a reliable quantitative PCR method for quantification of PTA in samples (Than et al. 2013), which required subsequent revision in order to be applied (McDougal et al. 2014). In direct comparison of quantitative PCR with bioassay techniques, neither technique was found to be particularly reliable (McDougal et al. 2014). Than et al. (2013) used a garden soil spiked with oomycete DNA, which may have failed to appropriately model PCR inhibitors present in field soil. There were a number of choices made in the development of the quantitative PCR method that seem at odds with standard environmental DNA sampling. The vast majority of soil sampling is now done using a standardised kit-based method (MoBio PowerSoil), allowing easy standardisation. The method described by Than et al. (2013) used a manual shaking of soil in buffer method, which had the advantage of extracting DNA from a much larger volume of soil, but had a number of serious drawbacks discussed in McDougal et al. 2014. However, it is widely acknowledged that extracting nucleic acids from soils is extremely difficult and often results in low yields (c.f. 20%) even with the latest extraction kits (Nannipieri et al. 2014).

Although McDougal et al. (2014) concluded that both the bioassay and quantitative PCR methods were 'both effective methods', this conclusion is somewhat difficult to understand in light of the non-reproducibility of results across two laboratories for two different methods. The bioassay results, for example, showed positive signal in 7 soils tested by SCION but only 3 tests by Landcare (one of which tested negative by SCION). Similarly, the quantitative PCR methods showed positive results in 9 soils tested by SCION, but only 4 non-equivocal positive results for Landcare. The Landcare stored soils were particularly concerning, in that they were known to contain *P. agathidicida* yet only 1 soil showed presence of PTA in the quantitative PCR method, and then in only 1 of 2 duplicate samples tested at 1 of the 2 labs. Further concerns over PCR based methods were raised by Williams (2015) due to detection of DNA from deactivated spores.

Quantitative PCR can be difficult to apply to soil samples, and the advantages of using quantitative PCR over using direct (normal) PCR (i.e., not involving fluorescent markers) and sequencing (Arcate et al. 2006) are not clear. RT-PCR also has the disadvantage of only giving results on one species, whereas current environmental DNA techniques (next-generation sequencing based meta-barcoding) would allow assessment of all species of oomycetes present in a sample. Many of these techniques are undergoing rapid change and development, which may prove problematic from an applications viewpoint.

Knowledge gaps:

- ***The cause of the inconsistent relationship between detection of P. agathidicida and symptoms of dieback is unclear. It may may reflect detection issues but equally might indicate dieback in the absence of P. agathidicida.***
- ***The occurrence of P. agathidicida in healthy forests remains largely un-investigated.***
- ***Alternative molecular methods, including direct PCR and environmental meta-barcoding (eDNA) should be investigated.***

3.5. Distribution of dieback and *P. agathidicida*

The initial report of *P. agathidicida* (as *P. heveae*) on Great Barrier Island recorded presence in a diseased ricker stand, and in an asymptomatic forest site (Gadgil 1974). That report also noted 'one earlier collection' but gives no detail on location. The current view, expressed by Beauchamp and Waipara (2014), is that *P. agathidicida* may have initially established in a nursery in Waipoua from which it was spread to Great Barrier Island and other sites on New Zealand Forest Service plantings from the 1950's, along with secondary spread by cattle or pigs. A recent paper by Jung et al. (2015) finds *Phytophthora* are widespread in commercial nurseries and subsequent plantings in Europe, supporting this possible pathway. On the other hand, the preliminary results of Winkworth may suggest that the Great Barrier population is genetically distinct from the Waipoua population. The two Waipoua isolates are also distinct from other populations in Weir et al. (2015), but only 11 isolates were examined in that study and the level of genetic differentiation was small.

The most current map of *P. agathidicida* distribution appears to be the one presented in Beauchamp and Waipara (2014). Other distribution maps of forest dieback and of *P. agathidicida* distribution are presented by Jamieson et al. 2014 (map of Waitakeres, showing areas of kauri with dieback observed and with *P.agathidicida* confirmed in soil testing) and a number of earlier publications. Aerial surveillance of dieback has been attempted, but appears somewhat limited by false positives and an inability to detect symptoms until they are reasonably advanced (Jamieson et al. 2014). Absence is impossible to show with absolute certainty. Nonetheless, current data suggests *P. agathidicida* is absent from the Hunua range (Jamieson et al. 2014).

Knowledge gaps:

- ***Due to a lack of knowledge of the distribution of P. agathidicida in healthy forests, it is difficult to know the true distribution of the species.***
- ***Dieback should be considered and mapped separately and overlain with confirmed P. agathidicida outbreaks.***

3.6. Host resistance and susceptibility

In greenhouse trials, Horner et al. (2014) and Horner and Hough (2014) have established that *P. agathidicida* is much more aggressive and causes much stronger effects than three other *Phytophthora* species frequently isolated from kauri. When injected into the stem, *P. agathidicida* kills 100% of kauri seedlings in 4-6 weeks, and when inoculated into soil, *P. agathidicida* kills 100% of kauri within 10-12 weeks. None of the other three *Phytophthora* assessed killed two year old kauri seedlings following soil inoculation, although root damage was observed. These studies have clearly established that *P. agathidicida* at relatively high inoculation levels is much more lethal than other species of *Phytophthora* associated with kauri, such as *cinnamomi* and *multivora*.

For obvious reasons, trials have been restricted to young trees in artificial conditions. It is possible that trees under more natural conditions would be less susceptible compared to seedlings in the greenhouse. Nonetheless, while greenhouse studies may over-estimate the lethality of *P. agathidicida*, the direct comparison with other *Phytophthora* species is robust evidence that *P. agathidicida* is unusually lethal.

Current efforts are underway under the Healthy Trees, Healthy Future (HTHF) programme of SCION are underway to identify and screen for broad *Phytophthora* resistance (SCION 2015). Nonetheless, at present the degree to which resistance to *P. agathidicida* is present in the natural population remains largely unknown. Gough et al. (2012) provide information on how kauri can be propagated from vegetative clones if resistance is found at some future date. An intriguing possibility suggested for *P. ramorum* dieback in California live oak is that plant phenolic chemistry may be predictive of resistance (Nagle et al. 2012, Conrad et al. 2014, Conrad 2015), which might serve as a tool for rapid screening.

Very little is known about the role of other plant hosts in supporting *P. agathidicida* populations. Experimental trials were attempted in the Bellgard et al. Landcare Research

Report (2013, not released), but these findings have been reviewed and specifically rejected by the PandI group (internal, confidential memo dated 12 January 2015). The grounds for rejecting these findings appear robust. Nonetheless, alternative hosts may play an important role in supporting *P. agathidicida* populations and potentially as nursery-trade vectors to be considered. Alternative hosts may also be an issue in long-term kauri regeneration and/or restoration.

Knowledge gaps:

- ***Natural resistance to P. agathidicida infection remains largely unknown. Less-invasive methods to screen for resistance would help rapidly identify potential gene lines that could be bred. Nonetheless, the extremely long generation time of kauri makes the re-establishment of the population from resistant seedlings a challenging propositi***
- ***The lack of knowledge of alternative plant hosts of P. agathidicida is a major gap. Alternative hosts may provide vectors of movement through the nursery trade and prevent restoration of stands.***

3.7. Vectors for the spread of *P. agathidicida*

Findings from Bellgard, et al. (2013) demonstrated how susceptible kauri are to *P. agathidicida* infection and how easy it is to transmit oospores between infected roots to non-infected plants. These findings are also supported by observations made by members of the Kauri Dieback Planning and Implementation Team (Beauchamp per comms) that infection zones appear closest to tracks and areas of significant soil disturbance (Auckland Council - Kauri local sports draft report). The pathway of oospore infection through soil pore water and into the roots of healthy plants and hence root health and protection of the root zones has a significant effect on the susceptibility of trees to *P. agathidicida* to infection (Beauchamp, 2013; Bellgard, et al. 2013; Waipara et al. 2013)

Human activities including nursery transfers (contaminated soils), recreational use, track building and maintenance appear to be the single biggest vector in *P. agathidicida* spread. The irregular distribution and location of *P. agathidicida* positive sites. Results from surveys of Walk Boot wash stations revealed that soil collected in the grates contained *P. agathidicida* and other *Phytophthora* species that were still viable after one year. While during the winter months, the wetter conditions resulted in an increase of a number of *Phytophthora* species including *P. agathidicida* being detected on soil from boots. Te Roroa Cultural Impact assessment report (Ngakuru and Marsden 2010) also noted a direct correlation between trees exhibiting signs of infection and human interactions with the forests. The report also commends the effort to protect and enhance root health via the construction of boardwalks, however there was concern that the process of construction may lead to further contamination.

Interviews with former kauri plantations and nursery employees were carried out to identify possible links if any between nurseries, nursery practices, plantations and plantation management and the introduction and spread of PTA (Ngakuru 2011). The interviews detailed inconsistencies in hygiene practices among nurseries that lead to significant mortality rates of seedlings. Soil health and type also had a big influence on the viability of plants, as did the location. The proximity of the water table appeared to adversely impact on plant vigour. While pigs and feral goats have been mentioned as possible vectors of *P.*

agathidicida there was little agreement on the habitat preference of either animal, i.e. kauri versus nikau. A study carried out by Krull et al. (2013) on feral pigs as vectors of *P. agathidicida* was not strongly convincing of the role that pig play in the spread of *P. agathidicida* in kauri forests. While there was evidence of pig rooting, there was no strong correlation with *P. agathidicida* positive sites, partly due to the absence of comparative sampling. Beauchamp (2013) noted that remnants of kauri on pastoral rural properties were often subject to soil compaction caused by livestock, leading to severely damage sensitive surface feeder kauri roots. Moreover, *P. agathidicida* has been frequently isolated from kauri root zones exposed to significant soil disturbance by livestock. This activity could conceivably increase the potential for soil borne vectoring of *Phytophthora* pathogens between unfenced rural kauri fragments. Understanding biological invasions requires information on the history of spatial spread, movement ecology (animal and human vectors), as well as measures of landscape and biotic features that control habitat invasibility including increased connectivity between invasible sites (Kauffman et al. 2002).

International literature on the spread of *Phytophthora* species/taxa have highlighted the significant role that nurseries and other human activities (vehicle movement and foot traffic) have in the spread of these pathogens (Jules et al. 2002; Jung et al. 2015). A recently published large-scale analysis of *Phytophthora infestations* in Europe (732 European nurseries based from 23 European countries between 1972 and 2013) demonstrated that nursery stands across Europe are almost ubiquitously infested by a large array of *Phytophthora* species representing a significant biosecurity threat. One potential solution offered is the adoption of a pathway regulation approach based on pathway risk analyses, and risk-based inspection regimes performed by an adequate number of skilled staff using molecular high-throughput detection tools.

Knowledge gaps:

- ***Vectoring by human movement of soil is well established and should now move into the management phase of the programme. It needs to be informed by better understanding of asymptomatic occurrence of P. agathidicida in healthy forest and alternative hosts.***
- ***Vectoring by feral animals such as pigs and goats have yet to be quantified sufficiently.***

3.8. Management tools

A number of management tools have been widely established, including signage, phytosanitary stations, decontamination tools, area closures, and treatments for infected trees. The effectiveness of these strategies is mixed, with the Auckland Council (2012) reporting around 30-50% compliance. Trigene at stations is believed to be effective against primarily mycelium and zoospores, but has been shown to be ineffective against oospores (Williams 2015, Bellgard et al. 2010). Decontamination of equipment and soil has been considered by Williams (2015), who find that high temperature treatments are effective at deactivation of spores.

Closure of disease free areas to the public has also taken place – the Auckland Council (2012) report gives a useful overview of the basis for this strategy as opposed to closing areas with disease. A high level of investment has been put into track upgrades, including installation of boardwalks at high-traffic sites.

There is an extensive literature on regulation compliance in natural areas internationally (Winter 2006; Marion and Reid 2007) and in NZ (Espiner 1999). The degree to which current signage and newsletters are based on evidence of effective communication strategies is not clear. Kauri dieback may also present unique aspects of communication, including the need for long-term compliance, the invisible nature of the pathogen itself, and cultural issues of both locals (Māori and non-Māori) and different international tourist groups.

Current management to reduce spread is based on a combination of research-based mechanistic knowledge (e.g., tri-gene effectiveness at killing spores) and logical conclusions based on what might be termed ‘common sense (e.g., role of foot traffic and pigs in vectoring disease). However, none of the present management strategies have been shown to be correlated with a reduction of the actual spread of kauri dieback symptoms. At least in part, the lack of an evidence base of reduced spread following management reflects a pragmatic necessity to implement management as widely as possible; leaving any large areas intentionally without management as research controls would be socially and politically untenable.

Phosphite injection has been an effective management tool in Australia for *P. cinnamomi*, and results from trials with *P. agathidicida* on kauri appear promising (Horner and Hough, 2013; Horner et al. 2015). Problems with cracking of stems remain a concern, but may be managed through modification of injection technique. The necessary frequency of injections of phosphite is not clear, as Horner et al. (2015) used a single injection. More broadly, the economic long-term viability of phosphite injection does not appear to have been considered in detail – it is unclear how much investment would be needed over how-long a period in order to keep large areas of kauri in forests healthy. Modelling of labour costs to find and inject trees along with data on broad scale efficacy would help address this. Given that many diseased trees are associated with farms and/or trails, access is likely to be feasible at least in the early stages of spread, but long-term sustainability if kauri dieback moves deeper into the forest may be questionable. Social and cultural acceptance of phosphite injections, including any possible concerns over non-target effects should be considered in a pre-emptive sense. Nonetheless, phosphite injections may be a pragmatic solution for iconic trees, forest plantations, and in more urban settings.

Long-term modeling of kauri dieback management has not, to the best of our knowledge, been undertaken. Mathematical models developed for *Phytophthora ramorum* could provide a model for similar model development here (Filipe et al. 2013).

Knowledge gaps:

- ***The effectiveness of management strategies has been considered in the short-term, and appear to be somewhat effective based on current evidence, however evidence of long-term effectiveness at reducing spread are non-existent.***
- ***Factors leading to lack of compliance (hygiene stations, staying on trails, closures) and methods to improve compliance need social research.***

- ***The long-term practicality and effectiveness of management tools needs to be modelled to insure that investment into management is sustainable over the long-term.***

3.9. Environmental context of forest dieback

Large scale forest diebacks have occurred in various tree species in New Zealand and overseas (Stewart 1989). Prominent examples include rata-kamahi dieback in NZ, *Nothofagaceae* forest dieback in NZ (Wardle 1983), sudden oak death in the western USA, *Metrosideros* decline in Hawaii (Boehmer et al. 2013), *Eucalyptus* decline in Australia, and *Fagus* decline in Europe (Jung et al. 2015). In most cases the underpinning reasons for dieback are complex (Mueller-Dombois, 1987), but have often been attributed to the spread of plant pathogens, such as *Hymenoscyphus pseudoalbidus* and *Cryphonectria parasitica* (e.g ash dieback, United Kingdom, chestnut blight, U.S.A, respectively), severe droughts (e.g. banksia and tuart dieback, Australia), insect attack (New England dieback, Australia), acid rain, pollution, or a combination of two or more variables (e.g. jarrah dieback, Australia). As a general pattern, initial single-driver explanations are frequently revised with time to recognise the importance of multiple, interacting drivers of decline.

Stewart (1989) provides a useful vocabulary for understanding different causes of dieback – distinguishing predisposing, precipitating, and hastening causes – and how they interact. Forest stand developmental stage or age is an important example of a *predisposing cause*, with pole-stage stands and older stands frequently undergoing widespread senescence (Stewart 1989, Boehmer et al. 2013). The physical environment also plays an important role, both as a *predisposing cause* of decline due to drought, excessive moisture, or pollution and as a *precipitating cause* due to severe events. Finally, biological factors such as herbivores and pathogens can either be a *precipitating cause* or a *hastening cause* of forest decline. Plant pathogens are particularly prominent among biological factors precipitating and hastening forest decline, including *Phytophthora ramorum* (sudden oak death), *P. cinnamomi* (Ohia decline, Jarrah Dieback), and phytoplasmas (Cabbage Tree sudden decline).

From international literature, environmental conditions, host resistance and the presence and abundance of pathogens are the three key factors in epidemic development (Aguayo et al. 2014; McConnell and Balci 2014; Amoroso et al. 2015; Fall et al. 2015). In Chile, *Aristotelia chilensis* (Chilean wineberry) mortality is a forest decline process driven by complex interactions between abiotic and biological processes, autogenic stand development processes and are predisposing factors that likely interact with the pathogen *Phytophthora* (Amoroso et al. 2015). In Europe, Alder decline caused by *P. alni* is one of the most important emerging diseases in natural ecosystems, where it has threatened riparian ecosystems for the past 20 years. In this instance, environmental factors, such as mean site temperature and soil characteristics, play an important role in the occurrence of the disease (Aguayo et al. 2014). In a study comparing soil types and the occurrence of *Phytophthora* species from U.S.A (California), Portugal, Germany and Sweden it was noted that *Phytophthora* spp such as *P. cinnamomi* was isolated more frequently from soil types that hold more moisture and nutrients (e.g., silts and loams). In Germany, a significant association was found between *Phytophthora* spp. and their presence in soils with a loamy, silty, or clayey texture but not for sandy or sandy loam soils. Similarly, in Swedish oak forests, *Phytophthora* spp. were isolated from all textures but sandy (McConnell and Balci 2014). More specifically, in sites with better drainage, the disease was clustered and associated with flat microtopographies and the progression of symptoms was influenced by soil type and precipitation.

Perhaps the most widely cited example of a single pathogen being the driver of widespread forest mortality is the spread of Chestnut blight in North America. However, even the Chestnut blight example may be more complex, as Wolfgang (2011) notes the species began to decline 75 years before the detection of the blight, with over logging and increased fire frequency likely contributing to decline. Indeed, widespread forest dieback can also reflect normal cohort dynamics, with severe initial mortality of pole-stands (rickers in the context of kauri) or over-mature trees rejuvenating a population. This is described by Boehmer et al. (2013) in the context of *Metrosideros* (Ohia) decline in Hawaii. Notably, *Metrosideros* decline was initially assumed to be a cataclysmic population decline driven by a novel pathogen, but, as stated by Boehmer and colleagues: 'The early hypothesis (Burgan and Nelson 1972) that the Hawaiian rain forest decline was caused by a virulent pathogen or a combination of biotic disease and pest agents was ruled out after a decade of intensive disease research'. The *Metrosideros* example is a prominent example of the risk of taking a single-driver view of forest decline. Despite early predictions of the elimination of the species by the year 2000 (Petteys et al. 1975), the forest regenerated and decline is no longer widely observed.

To date there has been no specific research commissioned by the Kauri Dieback Programme (KDP) on external environmental factors that may influence the virulence or spread of *P. agathidicida* or the occurrence of dieback. Relevant information from the KDP surveillance reports (Beauchamp 2011; 2012), historical nursery interviews (Ngakuru, 2011) and Te Roroa Cultural Assessment Report (Ngakuru and Marsden 2010) cite soil integrity and root health as being paramount protection against pathogens such as *P. agathidicida.* Land use changes, root damage from compaction and treading is strongly linked to the health of the trees. Ngakuru and Marsden (2010) observed that tracks and roading changes are a factor in the death of trees, for example in Waipoua, road trees were cleared to give a better view of the big iconic trees, the removal of these trees appeared to coincide with further tree deaths. From the preliminary assessment reports on the symptomatology and detection of *P. agathidicida*, Beauchamp (2011) noted sites in Waitakere Ranges, thought to have been degraded by *P. cinnamomi* in the late 1960s are now infected with *P. agathidicida*, which is now having a substantial impact on ricker (<100-year-old trees). Soil moisture and soil type, slope and proximity to sites of infection appear to be other critical factors in the occurrence and spread of *P. agathidicida.*

Research carried out by staff at Auckland University (Macinnis-Ng and Schwendenmann, 2015) has studied the effects of future climate scenarios would have on drought frequencies and the impact on forest health and productivity, with a particular focus on kauri. Under future climates, droughts will be more frequent and severe in parts of New Zealand, especially in Northland. This could have significant repercussions with respect to the spread of *P. agathidicida* and dieback. The occurrence of severe droughts has been linked to the frequency of large dieback events in Australia, and around the world with rural dieback first achieved widespread notoriety in the New England area of NSW during the 1970s and 1980s (Mackay et al. 1984). This dieback was attributed to agricultural practices such as grazing, fertilisation and understorey clearing that upset the balance of insects and their predators.

Knowledge gaps:

- ***The single-pathogen focus of most KDP research and management may overlook many other interacting factors***
- ***The occurrence of dieback in the absence of P. agathidicida should be a key area for research, to determine the role of other factors in forest decline***
- ***The possible occurrence of P. agathidicida in the absence of dieback on both kauri and alternative hosts is also critical to establish in order to understand multiple drivers of decline.***
- ***The role of soil disturbance and other external environmental factors in kauri dieback remains primarily anecdotal. This knowledge is critical to guiding how tracks and roads are placed and managed in kauri forests.***
- ***Climatic drivers of dieback are largely unknown, but are important to long-term forecasting and planning.***

3.10. Long-term forest stand dynamics and outcomes

The operational model of the KDP is based on a series of premises, first that *P. agathidicida* is a non-native pathogen, introduced post-European arrival and still spreading from a few isolated populations. Second, that *P. agathidicida is* the primary cause of kauri dieback. And third, that the result of kauri dieback will be decline in the population of kauri and loss of iconic large trees. As reviewed above, there is some evidence to support the first and second point, but the level of evidence does not rise to as high level of certainty as would be ideal. Given the potential risk, taking a precautionary management approach based on the preponderance of evidence was, and remains, a logical decision. However, as the program continues it should be a high priority to revisit and question these premises and, in particular, to consider alternative scenarios.

In contrast to the first and second point, which both focus on the pathogen, we were unable to find any evidence on whether the population of kauri is increasing, stable, or decreasing; either with or without the presence of *P. agathidicida*. A long-term focus on *P. agathidicida* presupposes that the population of kauri would either increase or remain stable in the absence of *P. agathidicida*, but is declining in the presence of the pathogen. If, in the absence of *P. agathidicida*, the population of kauri is decreasing, this would indicate that *P. agathidicida* is contributing to a larger problem that requires concurrent management, accelerating an already occurring decline. Alternatively, if the population of kauri is increasing, despite the presence of *P. agathidicida*, this might indicate some optimism for the future despite a reduction in the rate of increase.

A better understanding of kauri stand dynamics in the context of *P. agathidicida* is also critical to understanding the pathogen itself. In the case of Ohia (*Metrosideros polymorpha*) decline in Hawaii, Boehmer et al. (2013) suggest that dieback is a natural part of normal stand dynamics of Ohia, even though *P. cinnamomi* can be isolated from dieback areas. Notably, the areas that suffered dieback eventually regenerated to healthy forest and the population has persisted. The KDP should consider the possibility that dieback could be a normal part of kauri forest dynamics. This will requiring engaging with forest population ecologists, as a high level of expertise will be required. It should also be recognised that even if dieback was part of sustainable natural forest cohort dynamics when kauri was a widespread forest dominant these same dynamics may not be sustainable in a fragmented and reduced population. There is extensive literature on forest cohort dynamics and expertise exists within the ecosystems group at Landcare Research, SCION, and Universities that could be profitably integrated into the KDP understanding of the health of the tree population. Part of understanding stand dynamics should include a long-term understanding of different kauri dieback management scenarios from an economic and social sustainability viewpoint.

Knowledge gaps:

- ***The long-term population dynamics of kauri remain largely unknown. Views that P. agathidicida is causing a collapse of the kauri population need validation with data on the actual current distribution and stand dynamics of kauri in areas with and without P. agathidicida. (Distribution is currently being addressed through a tendered research programme, but not stand dynamics).***

3.11. Long-term impacts of dieback

Ecology of kauri forests and ecological impacts of dieback

Kauri (*Agathis australis*) forests represent a major ecosystem in northern New Zealand and are considered ecosystem engineers acting as foundation species (Claessens et al. 2006; Macinnis-Ng and Schwendenmann, 2015; Wyse et al. 2014). This is largely owing to their longevity and ability to change the soil environment, through the formation of podzols (known as podzolisation). Podzolisation occurs as a result of the thick layers of litter under kauri producing acidic humic substances which promotes soil leaching, decrease in plant available nitrogen, and also can lead to the formation of anaerobic conditions within the soil (Molloy 1988) This extreme effect on the soil environment strongly influences the surrounding plant community structure resulting in a distinct mix of podocarps (totara, rimu and miro), conifers (Tanekaha) and hardwoods (towai, taraire, northern rata, puriri, tawa and hard beech) (Molloy 1988; Wyse et al. 2014). The ecological diversity of these ancient forests is poorly documented in the literature, with fewer than 10 published articles. However, what is available indicates a diverse array of highly endemic and co-dependent species that include plants, in particular epiphytes, invertebrates and fungi (MacKenzie, et al. 2002; Verkaik and Braakhekke, 2007; Ward et al. 2014; Wyse and Burns, 2011; Wyse et al. 2014).

The only KDP commissioned and specific mention of any long-term ecological effects that *P. agathidicida* and dieback may have on these forests are reported in Te Roroa Cultural Impact Assessment (Ngakuru and Marsden, 2010) and an unpublished poster that demonstrates the effects of changing kauri litter composition can have on soil ecosystems (van der Westhuizen et al. 2013). Te Roroa raise several concerns relating to changes in the composition of the surrounding regenerative vegetation which has been made apparent during vegetation surveys near *P. agathidicida* infected trees. Long-term, this may result in permanent changes in forest composition in Waipoua as well as significant changes to soil structure (water holding capacity), chemistry (nutrient status) and the soil microbial community. The Iwi are also concerned about the potential impacts of *P. agathidicida* and currently used phosphite treatment, may have on the availability of mahinga kai and rongoa, and especially their bioactivity. The report also highlights the iwi’s concern regarding past land disturbances combined with predicted climate change that potentially lead to a decrease in the ecological resilience to pathogens such as *P. agathidicida*, suggesting that the disease itself could be a potential ecosystem engineer.

Literature describing the ecosystem dynamics of kauri forests have mostly focused on the impacts of drought and climate change. They concluded that both phenomena would have a pronounced effect on litter fall and this in turn would significantly impact upon forest carbon (C) budgets as well as nitrogen and phosphorus as leaf litter in the main source of C for soil microorganisms. (Wyse et al. 2013; Macinnis and Schwendenmann, 2015). As kauri contribute to more than 80% of the litter, any significant change in litter quantity would have a pronounced effect on soil processes and plant community composition. From this, we could consider the strong possibilities that the spread of *P. agathidicida* and occurrence of dieback would result in similar ecological changes (i.e. loss of endemic species, change in plant community structure, increase in soil erosion, change in hydrology) hypothesised due to prolonged droughts associated with climate change. Moreover, the effects of dieback would be further exacerbated by more frequent and severe summer droughts under future climates.

Global examples of large-scale forest dieback events suggest some common ecological impacts; 1. a permanent shift in species distribution, with lost species never able to regenerate; 2. the speed at which dieback occurs leaves little time for co-existing, or dependent species to adapt, and 3. Vegetation linked to dieback had a negative effect on fungal community structure and biodiversity (Anderson et al. 2010). In the case of jarrah dieback, there is no evidence that other tree species will fill that niche and attempts to replant local species have largely been unsuccessful.

Knowledge gaps:

- ***There exists little information on the long term impacts of P. agathidicida and dieback on species composition and diversity in kauri forests.***
- ***The current assumption is that the loss of kauri will cause a loss of many aspects of kauri ecosystems, which should be tested in areas where kauri has actually declined.***
- ***The potential to significantly and negatively impact on carbon sequestration, forest productivity and prevention of soil erosion.***

3.12. Social and cultural impacts

Kauri forest dieback and the decline of kauri trees and other iconic trees in urban areas, from either disease or land development has received significant public attention. An internet search using the words 'Save Kauri' returns over 300,000 hits, many of these media items, personal blogs, social media sites with 10,000 followers all dedicated to saving kauri as well as other popular native trees such as rimu and pohutukawa (Project Crimson). It is evident from the media and internet coverage that iconic species such as kauri can evoke strong feeling among the public, even to the extent of organising protests (Lloyd 2015), which attracted the attention of the former Prime Minister, Helen Clark *tweeting her support: 'Extraordinary in this day and age that a 500 and a 300 year tree can be designated for felling in NZ!'* Saving Kauri also became part of the 2013 Labour election campaign, where a pledge of $20 million was made towards kauri dieback (Fox 2014). Furthermore, the social and aesthetic benefits of having large mature trees such as kauri present in urban settings are significant and wide ranging, from educational purposes to an increase in property values

(Tryväinen, et al. 2005; Roy, et al. 2012; Wyse et al. 2015). Thus any large scale disease and dieback would certainly negatively impact upon these associated benefits.

Impacts on the Tangata Whenua of Kaurilands

The only specific document to outline the cultural impacts on the tangata whenua of kaurilands is Ngakuru and Marsden (2010) Te Roroa Cultural Impact Assessment report. More than 75% of remaining kauri lies within Te Tai Tokerau (Northland) mostly as fragmented remnants of ancient forests. To the Iwi and hapu of these rohe (area), kauri is the centrepiece of cultural and spiritual beliefs. Here, tangata whenua have environmental obligations to fulfill by acting as kaitiaki of these taonga tuku iho (kauri). Of these forests, Waipoua, within Te Roroa rohe, is home to the famous 1500 year old Tane Mahuta, standing at 51.5 metres tall and having a girth of 13.77 metres. Waipoua is also home to the second and third largest kauri. The kauri tree to Te Roroa is a taonga (treasure) of immeasurable and irreplaceable value and if often referred to in whaikorero (speech), haka (dance), waiata (song), patere (chant), whakatauki (proverbs). Te Roroa have established a relationship to the Waipoua forests as mana whenua, tangata whenua and ahi kaa. Thus they feel they hold the mana and responsibility for all kauri in their rohe *Ko te Kauri Ko Au, Ko te Au ko Kauri.* The health of Waipoua, the mauri of kauri forests and the mana of Te Roroa are inextricably linked. For Te Roroa the kauri dieback phenomenon and the presence of *P. agathidicida* represents a negative scenario and one that is comparative to the land losses of the 1800s where the iwi was essentially landless with little or no resources and struggling to practice traditional concepts of mana whenua and mahinga kai. A failure to protect kauri will reflect on the mana of the kaumatua and generations to come.

Economic impacts

No specific literature or commissioned reports were provided on the long term economic impacts that *P. agathidicida* and kauri dieback will have to the regions. Te Roroa have signalled in their 2010 Cultural Assessment Report that they are economically threatened by *P. agathidicida* and dieback. However, for commercially sensitive reasons the report did not go into specific details. Te Roroa are also investigating sustainable ways to bring their people home and these opportunities are linked both directly and indirectly through kauri, through tourism, forestry, land management, conservation contractors and forest based research are all primary targets currently invested in. Thus, *P. agathidicida* and dieback represents another challenge for economic prosperity of the tangata whenua and the communities that reside in these regions.

Knowledge gaps:

- ***There has been very little research worldwide on the impacts of forest dieback on public perception, sense of belonging and indigenous health and wellbeing.***
- ***An economic analysis on the benefits of actively managing sites of significance such as Waipoua, through increased guiding and concession fees with public outreach could assist in the region's economic development as well as compliance. .***

3.13. Mātauranga Māori.

Māori have developed practices and methods such as the use of ritenga (customs, laws, and protocols) and whakapapa (species assemblages within a holistic ecosystem paradigm) to sustainably manage their rohe (area). Practitioners (Tohunga and Kaitiaki) of traditional knowledge and its application (matauranga Māori) are the individuals tasked with the responsibility to implement mātauranga Māori (MM). International peer reviewed literature on the use of MM in conservation is limited and mainly focuses on the customary harvest of endemic land and seabirds, commonly referred to as the kereru (New Zealand Wood Pigeon, *Hemiphaga novaeseelandiae novaeseelandiae*) and titi (Sooty Shearwater, *Puffinus griseus)* (Moller 2009; Moller et al. 2009a,b,c; Lyver, et al. 2008; 2009), although there are papers describing the customary harvest of harakeke (*Phormium tenax*) and karengo (*Bangiaceae***)** which results in maximum yield and regeneration (O'Connell-Milne and Hepburn, 2015) . While the representation of MM and forest conservation in New Zealand even less represented in peer reviewed scientific literature (Walker 2009; Walker et al. 2013; Chetham and Shortland 2013) and discourse around the adoption of MM limited to the review of governance models and advocacy for adoption into mainstream science (Taiepa et al. 1997; Muru-Lanning 2012; Broughton and McBreen 2015).

The concept of using cultural health indicators (CHI) as a way of expressing Māori views on ecosystem well-being has been described using studies based on freshwater ecosystems (Harmsworth 2002; Tipa and Teirney, 2003; Harmsworth and Tipa, 2006). The Ministry for the Environment has published guidelines for assessing the state of the environment based on the development and use of CHI by three Ngāi Tahu rūnanga in the South Island and Ngāti Kahungunu in the North Island (Tipa and Teirney 2006) The development of these guidelines for measuring ecological health has since been adopted by several iwi and hapu (Te Runanga o Ngai Tahu, Ngāti Kahungunu, Tainui, Te Runanga o Ngati Hine, Patuharakeke, Ngati Rehia and Nga Hapu o Ahipara) (Shortland 2011) and in the case of the Mouteka and Riwaka catchments, both CHI and mainstream scientific approached exhibited correlations (Harmsworth, et al. 2011). The use of both approaches proved to share the same overall objective of managing and mitigating ecosystem degradation. Both approaches were complementary and reflected two different knowledge systems and perspectives (Harmsworth et al. 2011).

The existing literature that has specifically dealt with the application of MM for kauri conservation is restricted to three reports commissioned by the Ministry of Agriculture and Forestry: 1. Te Roroa Kauri Dieback effects assessment (Ngakuru and Marsden 2010), and 2. Kauri dieback cultural indicators (Shortland 2011), with the third report commissioned by the Ministry of primary Industries on behalf of the Kauri Dieback Agency, 3. Kauri cultural health indicators (Chetham and Shortland 2013). The assessment of effects from kauri dieback as described by Te Roroa researchers deals with the wider implications and management of kauri dieback effects, from loss of cultural integrity through loss of whakapapa, to the Treaty of Waitangi partnership models. Reports authored by Shortland (2011) and Chetham and Shortland (2013) outline a rationale and framework specifically for kauri dieback and based entirely on MM. Chetham and Shortland's methodology and framework take an holistic approach (based on the domains of Atua (Gods)) and recommend the inclusion of the monitoring of other species within the kauri forests (i.e. minor plants, birds, insects, reptiles), surrounding environmental conditions (i.e soil characteristics, leaf litter and decaying wood detritus), the proximity of significant water bodies, levels of sunlight, human activities and tree condition. This sampling design is reflective of the desire to incorporate all ecological variables that may influence the health of the trees and the presence and/or spread of *P. agathidicida.*

International literature on indigenous communities using their own methods of assessment and applying their own style of management for conservation is still largely about scientists studying the effects of western paradigms of conservation efforts on indigenous communities, or researchers working alongside documenting indigenous knowledge for the purpose of gaining insight into aspects of ecology and natural history (Walter and Hamilton, 2014; Camara-Leret et al. 2014; de Freitas et al. 2015; Falkowski et al. 2015). Most recently an example described from the Solomon Islands around a joint management between a Western NGO and the indigenous community highlights the critical need to bridge the 'culture gap' in order for such partnerships to succeed (Rochmyaningsih 2015) Those studies published that do examine alternative (i.e bicultural or mixed model) approaches to forest conservation (Souto et al. 2014; Lund et al. 2015; Singh et al. 2015; van Schie and Haider, 2015) document positive impacts to managing the forest resources, including minimising the loss of biodiversity. Thus a bicultural approach to Forest Conservation is certainly one worthy of further investigation in the case of managing kauri dieback.

Knowledge gaps:

- ***No specific kauri dieback mātauranga Māori or research adopting cultural health indicators has been implemented to date.***
- ***Further work on collating kaitiaki perspectives of what constitutes a healthy forest is needed.***
- ***Discussions are needed to determine what form a bicultural model of forest management would take.***

3.14.Approach of the KPD to developing knowledge and tools

The KDP has taken a crisis-mode precautionary approach to understanding kauri dieback. Following the detection of a novel pathogen observed to be killing trees, the focus of research has been almost exclusively on that one pathogen, the prevention of spread (including detection), and treatment of infected trees. The KDP has made most reports, posters, and papers readily available through their website (http://www.kauridieback.co.nz). This is an important and strong aspect of knowledge development, ensuring the availability of findings both within and outside the programme

A highly focussed strategy for *P. agathidicida* was probably appropriate up until the current time, but *P. agathidicida* is now recognised as being widespread, with populations detected as patches spread across most of the areas where kauri is found. This suggests that a longer-term view is now required to consider the long-term viability of the kauri population and the economic and cultural viability of long-term management interventions. The Kia Toitū He Kauri – Keep Kauri Standing (2015) Strategy document begins to recognise this in a disease triangle context – disease is a product of environment, host and pathogen, not a pathogen in isolation. Nonetheless, the understanding host and environment effects needs to look beyond simply increasing resistance to or environmental effects on one pathogen, and consider the broader picture of kauri health in a changing environment.

The approach of the KDP to knowledge appears to focus very closely on kauri dieback as a unique problem distinct from other diebacks in NZ forest ecosystems. Stewart (1989), for example, provides valuable frameworks for understanding dieback in NZ indigenous forest, but has rarely been cited by KDP researchers. This situation may be improving, as we note the Kia Toitū He Kauri – Keep Kauri Standing Strategy document (2015) gives explicit mention of dieback in other countries.

A number of outputs for KDP research have been published as reports, meeting abstracts, and posters while peer-reviewed articles have tended to be in lower-tier journals. While the goals of the KDP are not necessarily to produce high-impact science, there is potential value in having research undergo rigorous peer review and international scrutiny. Perhaps as a result of relatively low level peer-reviewed publications, there has been relatively low uptake of knowledge on kauri dieback by international reviews. For example, kauri dieback is not even mentioned in Lamour et al.'s 2013 book '*Phytophthora*: a global perspective'. This is a lost opportunity to gain international perspectives and knowledge from forest dieback in other countries. Steps appear to be underway to improve the international connections, including linking to Professor Everett Hansen, the former head of forest pathology at Oregon State University (KauriKonnect 2015)

Table 1. Summary of established knowledge areas, highlighting progress areas

Area of knowledge	**Summary of key progress**	**Limitations (if any)**
Identity of *P. agathidicida*	Species detected, linked to earlier detection, named	N/A.
Origin	Knowledge of genetic diversity is expanding	Origin (incl. native/exotic status remains unknown).
Ability to detect	Bioassay methods developed and reliability (or lack thereof) somewhat understood	DNA based methods require further work, current methods slow and imperfect
Current distribution	Maps of current distribution of diseased trees developed for multiple areas,	Asymptomatic occurrence largely unknown at least at stand scale
Historical records	Great Barrier population found to be same species, Waipoua forest nursery populations tracked, including proposed spread model on forest plantings	Inherently difficult area of knowledge given lack of records.
Host resistance and susceptibility	Pathogenicity in kauri well established in greenhouse trials, including demonstration of much greater mortality in comparison with other Phytophthoras.	Alternative hosts need investigation (partially repeating questionable earlier findings)
Vectors for spread	Spread along trail suggests movement by foot traffic, belief in pig transmission documented.	Lack of direct evidence of vectoring
Management tools for managing spread	Trigene disinfectant developed, trail closures implemented, heat treatment developed, board walks and trail upgrades implemented	Although based in mechanistic evidence, no evidence yet of actual effectiveness at slowing spread
Management of trees	Phosphite injections developed and trialed.	Social acceptability, large scale practicality, and long-term modeling needed
Environmental context	n/a	Larger context, including other factors leading to decline largely unknown

Long-term kauri population dynamics	n/a	Trajectory of kauri population either with or without dieback largely unknown
Long-term ecological impacts	Kauri podzols described, flora, fauna and mycota of kauri forests described, effects of loss of litter input described	Mostly based on inference, need quantification in stands with dieback
Social and cultural impacts	Evidence of social importance clear	
Tangata Whenua impacts	Te Roroa Cultural Impact Assessment report assessed cultural impacts	Effects on indigenous health and wellbeing need further consideration
Economic impacts	Risk, particularly to Te Roroa, indicated.	Long term impacts on tourism and other economic sectors need modeling, including mitigation measures
Mātauranga Māori	Cultural health indicators partially developed, including need for holistic ecosystem perspective	Potential to be world-leading by implementing specific kauri dieback Mātauranga Māori.

Table 2. Summary of research areas, their effectiveness, uptake and implementation in management

Research area	**Research**	**Review / Status**	**Management implementation and risks**	**Past and future investment recommendation**
Initial crisis mode response	Initial description of pathogen and dieback	Single pathogen focus, lack of understanding of stand dynamics	Initial response driven by crisis management appropriate on precautionary principle	Move away from crisis mode to long-term focus [Decrease]
Identity of *P. agathidicida*	Slow publication of name caused unnecessary confusion	Identity now well established	Communication issue to resolve (retiring of 'PTA' name)	Resolved [Terminate]
Origin of *P. agathidicida*	Native vs. non-native status unclear.	Need to follow up on recent molecular evidence of genetic population structure	Management presumes non-native, spreading pathogen. Needs to recognise this is probable but not certain	Important to understanding ecology and spread. [Maintain]
Diagnostics and surveillance	Diagnostics focused on diseased trees, not detection elsewhere	High priority to find better surveillance techniques, particularly for low-level occurrence without symptoms	Management requires better tools to confirm PTA rapidly	Build links to NSC BioHeritage project for DNA, diversify investment to seek better tools [Increase]
Distribution of Dieback and *P. agathidicida*	Currently focused on dieback disease, with little knowledge of pathogen occurrence in absence of disease.	Need to establish why dieback occurs without *P. agathidicida,* and whether *P. agathidicida* occurs without dieback	Management risk in presuming dieback and *P. agathidicida* are a 1:1 equivalence. Areas without symptoms may not be *P. agathidicida* free.	Resolving and improving knowledge of distribution key to management [Increase]

			Underpins a great deal of management decisions.	
Host resistance and susceptibility	Well established that inoculation with *P. agathidicida* is lethal, and more so than other *Phytophthoras*.	Natural resistance in population remains unknown, no strong basis for understanding alternative hosts	Urgently need better understanding of natural resistance and alternative hosts to guide management.	Move research out of lab and into field [Maintain], identify alternative hosts [Increase]
Vectors for spread of P. agathidicida	Role of soil movement as primary vector appears well established	Should move into management	Current management tools appear appropriate	[Decrease]
Management tools	Short term effectiveness of various tools established	Need long-term practicality and effectiveness established	Short term fixes are being implemented, phosphite should be moved to larger scale trials	Move to larger trials, model long-term outcomes [Maintain]
Environmental context of forest dieback	KDP research has not taken a broader context view	Need to consider other drivers of dieback and put kauri dieback in context of other forest dieback in NZ and overseas	More knowledge needed on how environmental factors contribute to dieback to guide management	Need to engage with broader forest ecology [Increase]
Long-term forest stand dynamics	No research on kauri stand dynamics in KDP, no knowledge of kauri population trajectory	Major gap	Management has not considered total population	Need to engage with broader forest demography [Increase]
Long-term impacts of dieback	Research has established unique aspects	Assumption that loss of kauri will	Underpins public understanding, risk of incorrectly	Establish research in limited number of dieback and

	of kauri ecosystems	result in loss of other ecosystem components needs direct confirmation	stating the impacts and backlash.	healthy stands to directly measure while minimising risk [Increase]
Social and cultural impacts	Clear and large social and cultural relevance, required to gain increases in public compliance in management of spread.	Recognised impacts, and require quantification of social and cultural impacts.	Increase in importance to justify future investment.	[Increase]
Impacts on Tangata Whenua of Kaurilands	Important to recognise the unique relationship of Tangata Whenua with kauri.	N/A	Should be partly addressed by investment into co-management of the forests.	Need to initiate MM research and increase tangata whenua participation in KDB research, [Maintain and merge into Social and Cultural Impacts]
Economic impacts.	No recent and specific quantification of potential economic impact has been undertaken.	Potential synergies between increased guiding and outreach activities and economic benefit to Northland economy should be considered	The potential for management activities to have economic benefits for rural communities should be considered. Economic quantification could become priority if needed to justify future investment	[Maintain]

Mātauranga Māori	Proposal to utilise cultural health indicators as Kauri ecosystem assessment has been put forth	Potential to contribute to the understanding of long term ecological impacts of dieback and disease causing *phytophthora* species	yet to be implemented. Members of the TWR may benefit from a research partnership with a Research Institute(s) to assist in the implementation of MM alongside mainstream science.	Need to implement with assistance from external advisors. [Increase]

4.0. Identified research priorities for the kauri dieback programme

4.1. High priority

Better understanding of *Phytophthora* ecology and relationship to kauri dieback disease

There is an urgent need to understand the background levels of potential pathogens in healthy forests, and the presence of *P. agathidicida* on roots of both healthy kauri and on other plant species. The current detection methods focus on *P. agathidicida* in the presence of disease symptoms. This includes both a broad-scale sampling (species distribution) but also fine-scale sampling (e.g., position in soil profile). Modern DNA techniques are available that make this highly feasible. This was similarly suggested in the 2010/2011 Surveillance Plan.

E.g. The scale of this project would be a 3-year project with 0.2 FTE researcher time supported by a 2.5 year Post Doc and operating

Long-term demographic modelling of kauri populations allowing scenario modelling of different disease levels and management strategies.

There is an urgent need to understand the current and future trajectory of the kauri population. This builds on the current tendered project for mapping the population of kauri, which we endorse, but mapping of what is there, without knowing how it is changing, is of limited value. The forest demography model should be designed to allow including future disease, management intervention, and climate change scenarios.

E.g. The scale of this priority is likely to be a 3-year PhD.

The influence of environmental factors on the spread, adaptation and virulence of *P. agathidicida*

The role of environmental factors in both forest dieback and *P. agathidicida* has only been partially addressed, largely in a piecemeal fashion. The forest environment has undergone multiple environmental changes, including increased use by hunters and trampers, cattle trampling of roots, agricultural encroachment and increased edge effects, changes to understory vegetation, fertilizer and chemical drift from adjacent agricultural land, invasive herbivores, and climate change. Rather than approach these piecemeal, we recommend a comprehensive assessment through a concerted research programme. To link to the other two high priority recommendations, this project should consider forest dieback and *P. agathidicida* presence independently, as not all dieback is due to *P. agathidicida.*

E.g. The scale of this project would be a minimum of a 3-year project with 0.2 FTE researcher time and two 3 year PhD students, but could potentially be larger.

Social and economic impacts

There will be high cultural, social and economic costs if kauri is lost from the landscape. However, it is unclear that quantifying these impacts would impact management. Further, it is likely that the greatest impacts of kauri decline will be in the area of social and cultural ecosystem services. These services are notoriously difficult to quantify economically, but can be recognised and considered. While, there is already recognition of the social, cultural and economic importance of kauri and that quantifying this impact would help secure additional funding and determine key influences in changing public behaviour towards maintaining healthy, pathogen free forests.

<u>E.g. This could be achieved with a relatively smaller budget c.f $50,000.</u>

4.2. Medium priority

Long-term strategies, costs and outcomes

The KDP needs a long-term vision of the economic and social sustainability of management over the long-term, addressing where the project is going and what are the potential outcomes. This needs to consider whether the best long-term aspiration is simply delaying the inevitable, or whether there is a realistic hope to reverse either pathogen spread or forest decline. This project would logically be a multi-investigator review, and could be linked directly to long-term demographic modelling. Including multiple disciplinary approaches is critical, particularly forest ecology, economics, and social science along with a strong Māori perspective and participation at the heart of long-term planning as outlined in Goal 2 of the KDP. The scale of this project would probably be best suited to a small amount of time from a wide range of researchers, combined with a one to two year post-doctoral fellow to collate, analyse, and produce a report.

Ecological impacts in decline areas and the presence of asymptomatic host species.

The ecological impacts of kauri decline have only been partially addressed. A few projects have measured ecological communities around healthy kauri and then extrapolated impact on the assumption that these communities would be lost if kauri populations decline (e.g., Wyse et al. 2014, Padamsee et al. in preparation). Direct measurement of the response of biodiversity in areas actually suffering kauri dieback would increase understanding of the broader implications of kauri dieback and could underpin management of the impact of forest dieback. The scale of this project is hard to estimate, as it would depend on the breadth of response taxa measured.

Mātauranga Māori

Interviews with Kaitiaki and Tohunga to built a greater in depth picture of kauri ecosystem dynamics and cultural health indicators based on interviews to be implemented to assist in long term management of dieback and disease incursions. This will partially fulfill the goals

(Goal 2) outlined in the KDP strategy - alignment of mātauranga Māori and provide a bicultural approach to forest management..

4.3. Lower priority

Vectoring

Management of pigs and other animals, closure of forests, and expensive track and cleaning station maintenance will generate push-back from hunters, other forest users, and from within departments competing for limiting conservation funding. Responding to that pushback will require a stronger evidence base than is currently available. The evidence that pigs, in particular, disperse *P. agathidicida* (Krull et al. 2013) remains weak and may not be sufficient to diffuse potential concerns. Despite recognising the importance of the topic, we have ranked this lower priority based on the difficulties encountered in prior research. Improved detection techniques may be needed before the topic of vectoring can be fully resolved.

Host resistance and susceptibility

Current research by SCION is focussing on finding a genetic basis for kauri resistance to dieback. This is an important area in terms of developing planting stock for restoration plantings and potentially for high-value wood production. Nonetheless, we view this as a lower priority for research on the basis that it will do little to replace iconic big trees within the next few centuries.

Management tools

Some management tools show strong promise (e.g., Phosphite) or potential (e.g., *Trichoderma or* biochar), and there is scope for developing other non-invasive biological control methods. We believe phosphite is very close to being ready for large scale trials. We believe other techniques could be useful to develop, but these might be best approached through small scale trials with small grants. Early in the development of any management tool there should be some reality check against research on long-term costs, strategies and outcomes. Adopted management tools need to focus on the efficacy of efforts aimed at impeding the spread of pests or infectious agents such as *Phytophthora*. Biological incursions are typically scale–dependent; so what 'works' at one scale of host may have no effect at another. Social research is needed to improve compliance - see High Priorities.

4.4. Non priority

Site of origin

Although we believe it is important to establish whether *P. agathidicida* is a widespread taxa in healthy forests, which might suggest it is native, we don't recommend high investment in determining the actual site of origin. Discussions with researchers overseas suggest this would be a high-cost exercise with low probability of success.

4.5. Additional, overarching recommendations

- There is a need to differentiate between research and research for management tools (i.e. tools such as phosphite, oospore deactivation, wash stations) and research (pathogenicity, ecology - including surveillance, host resistance, vectoring).

4.6. Research recommendations

- More effort to determine and differentiate kauri dieback (the disease) from *P. agathidicida* (the pathogen), as it is not yet clear that there is a 1:1 correspondence.
- Move 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.
- Consider other historical forest dieback in NZ and overseas and how kauri dieback is similar and dissimilar from these processes.
- Designate a member of the Planning and Implementation Team, or the Tactical Advisory Group to oversee and coordinate efforts and invite groups to submit proposals. Insure that the best available teams of researchers.
- Manage sites to allow research to proceed in restricted areas of infected and uninfected stands without having researchers become vectors (collaborative research on a few low- to moderate-value sites, rather than dispersed research on widespread sites).

4.7. Management recommendations

- We largely endorse the current management strategies, which are based on the current best available knowledge. That said, it is important to be open to changing understanding of *P. agathidicida* biology and ecology, as the state of knowledge remains in flux, but move forward with management based on best available evidence.
- Continue with management of root protection.
- Continue with closures of uninfected stands, sites of cultural and ecologcial significance and lower-importance tracks.

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Wyse SV, Beggs JR, Burns BR, Stanley MC (2015). Protecting trees at an individual level provides insufficient safeguard for urban forests. *Landscape and Urban Planning* 141: 112-122. doi:10.1016/j.landurbplan.2015.05.006

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Appendix A. Kauri dieback annotated bibliography

Methods and structure

We obtained published literature through direct searching of Web of Science, using the search string ‘TS=(Phytophthora OR die back OR dieback OR PTA OR Pathogen OR oomycete OR oomycota) AND TS=(Kauri OR Agathis)’ on 7 Oct 2015. In addition we conducted the same search on Google Scholar. Google Scholar returns many more hits, most of which are not relevant. We therefore examined the first 100 hits in brief. Additional published literature was found by searching individual authors and tracing citation networks forwards and backwards through time.

Unpublished literature was obtained through a request from Travis Ashcroft to members of the P and I group and directly from Travis, and requests for any additional literature were emailed to Bruce Burns, George Perry (Auckland University), Stanley Bellgard, Mahajabeen Padamsee, and Bevan Weir (Landcare Research. Auckland), Ian Horner (Plant and Food). Not all researchers responded to these requests.

Literature is organised in four broad sections: *Phytophthora agathidicidia* biology, *Phytophthroa agathidicidia* management, general *Phytophthora* and forest dieback literature, and general kauri ecology. References are not repeated across sections, despite some references fitting within multiple sections. Within each section, literature is organised in reverse chronology (most recent first), with un-dated literature last. For each citation we give citation, the abstract, and a few notes where appropriate.

Phytophthora agathidicidia biology and ecology

Weir BS, Paderes EP, Anand N, Uchida JY, Pennycook SR, Bellgard SE and Beever RE (2015). A taxonomic revision of Phytophthora Clade 5 including two new species, Phytophthora agathidicida and P. cocois. Phytotaxa 205(1), 21-38

Phytophthora Clade 5 is a very poorly studied group of species of oomycete chromists, consisting of only two known species P. castaneae (equivalent to P. katsurae, nom. illegit.) and P. heveae with most isolates from East Asia and the Pacific Islands. However, isolates of two important disease-causing chromists in Clade 5, one of kauri (Agathis australis) in New Zealand, the other of coconut (Cocos nucifera) in Hawaii, poorly match the current species descriptions. To verify whether these isolates belong to separate species a detailed morphological study and phylogenetic analysis consisting of eight genetic loci was conducted. On the basis of genetic and morphological differences and host specificity, we present the formal description of two new species in Clade 5, Phytophthora agathidicida sp. nov. and Phytophthora cocois sp. nov. To clarify the typification of the other Clade 5 species, an authentic ex-holotype culture of Phytophthora castaneae is designated and P. heveae is lectotypified and epitypified.

Notes:

- Overview of the history of P. agathidicida. Builds on first detection by Gadgil (1974) as *P. heveae* and first discrimination of PTA as separate from P. heveae by Beever et al. 2009.
- Range of 28 Phytophyhora clade 5 isolates obtained and sequenced, 5-gene phylogeny constructed, established separation of P. agathidicida and P. cocois from previously known species.
- No difference in ITS barcode from P. Castaneae, but diff in COX1, ENL and ND1
- Basic description of traits, including some physiological traits.
- See: Weir, B. Undated. How to pronounce *Phytophthora agathidicida*. https://www.youtube.com/watch?v=hwnQ7JNR8UU

Jamieson A, Bassett IE, Hill LMW, Hill S, Davis A, Waipara NW and Horner IJ (2014). Aerial surveillance to detect kauri dieback in New Zealand. *New Zealand Plant Protection*, *67*, 60-65

The causal agent of kauri dieback, Phytophthora 'taxon Agathis' (PTA), poses a signi cant threat to kauri (Agathis australis) in northern New Zealand. Ground-based eld surveys have previously con rmed PTA presence at several locations across Auckland and Northland. However, ground surveys are limited to areas adjacent to tracks because of dificulty and cost associated with off-track access in steep terrain, along with concern about furthering spread of PTA. A methodology for aerial photographic surveillance of kauri dieback was developed and implemented in Waitākere Ranges, Hunua Ranges and adjacent forest areas. Using recently developed GPS technology, photographs were embedded with position data so unhealthy trees were easily located later for ground-truthing. Aerial survey was found to be a time- and cost-effective method for surveying large, inaccessible areas of forest for kauri dieback. The methodology would also be applicable for detection of visible disease or damage symptoms in other canopy tree species.

Notes:

- Helicopter based survey of kauri dieback in Waitakere and Hunua ranges.
- For cost reasons, survey is not complete but rather focused on known areas of kauri
- In ground truthing, 26 out of 59 samples from trees exhibiting dieback tested positive for *P. agathidicidia.* This raises some questions, as only trees at a fairly advanced state of disease would have been detected in aerial surveys. Does the 44% detection rate imply that 66% of dieback is not caused by *P. agathidicidia*, or is the detection method seriously flawed?
- Waipara et al. 2013, where 42 out of 177 soil samples with symptomatic trees had *P. agathidicidia* isolated (24%).

Jamieson A, Hill L, Waipara NW and Craw J (2012) Survey of Kauri Dieback in the Hunua Ranges and Environs. Auckland Council report

Survey of the Hunuas finds 55 possible unhealthy spots of Kauri, of which 53 visited.
Most of the sites found to not have sufficient evidence of dieback to warrant soil sampling after ground truthing. Of 12 soil samples taken, 9 had other Phytophthoras and 3 had no *Phytophthoras*, but no *P. agathidicida* recorded.

Beauchamp T and Waipara N (2014). Surveillance and management of kauri dieback in New Zealand. Available from http://www.kauridieback.co.nz/media/43700/r55172_tony%20beauchamp_science%20poster_v1.pdf [Accessed 21 March 2016]

Notes:

- Combination of a summary of the program, but also some apparently new data (or at least few links to any sources of that data).
- Suggests that the movement of trees from Waipoua nursery in the 1950's caused the spread of *P. agathidicidia*. This suggests a very different scenario from an earlier view of the pathogen moving from Great Barrier Island and spreading to the mainland.
- Find that many trees show dieback but are not assessed as PTA positive. Conversely, some trees assessed as good condition are PTA positive.
- Field surveillance detection of PTA positive trees is detected in 22-100% of lab detections. More recent survey range 56-100%. No data given on how often labs detect PTA in the absence of any field detection (controls).
- Map on poster shows two important points: (1) PTA negative trees, and (2) the occurrence of PTA in the Coromandel.

Horner IJ, Hough EG and Zydenbos SM (2014). Pathogenicity of four Phytophthora species on kauri: in vitro and glasshouse trials. New Zealand Plant Protection, 67: 54-59

In kauri forest soils surveys, Phytophthora taxon Agathis (PTA), P. cinnamomi, P. multivora and P. cryptogea were detected frequently. In vitro and glasshouse studies determined that all four Phytophthora species produced lesions on excised kauri leaves and stems. Lesion advance was significantly slower with P. cinnamomi, P. multivora and P. cryptogea than with PTA. When 2-year-old kauri seedlings were trunk-inoculated, lesion spread was rapid with PTA, trunks were girdled, and all trees died within 4-6 weeks. Phytophthora cinnamomi, P. multivora and P. cryptogea produced substantially smaller lesions than PTA, no trees died, and plant growth was only slightly suppressed. Following soil inoculation with PTA, all kauri seedlings died within 10 weeks. There were no deaths following soil inoculation with P. cinnamomi, P. multivora or P. cryptogea, although feeder root damage was observed and the respective pathogens were re-isolated. Results suggest that PTA is an aggressive pathogen, and the other three species are weaker pathogens of kauri.

Notes:

- Test PTA, P. cinnamomi, *P. multivora* and *P. cryptogea* and show that PTA is a more aggressive pathogen on 2 year old seedlings.
- This is an important paper in considering the Waipara 2013 citation, as it shows that PTA is clearly much more aggressive than *P. multivora* when inoculated onto 2-year old seedlings (at least).
- Note that *P. multivora* was not particularly aggressive, despite being obtained from a large lesion in the forest.

Krull CR, Waipara NW, Choquenot D, Burns BR, Gormley AM and Stanley MC (2013).
Absence of evidence is not evidence of absence: Feral pigs as vectors of soil‐borne pathogens. *Austral Ecology* 38(5): 534-542

Invasive soil-borne pathogens are a major threat to forest ecosystems worldwide. The newly discovered soil pathogen, Phytophthora taxon Agathis' (PTA), is a serious threat to endemic kauri (Agathis australis: Araucariaceae) in New Zealand. This study examined the potential for feral pigs to act as vectors of PTA. We investigated whether snouts and trotters of feral pigs carry soil contaminated with PTA, and using these results determined the probability that feral pigs act as a vector. We screened the soil on trotters and snouts from 457 pigs for PTA using various baiting techniques and molecular testing. This study detected 19 species of plant pathogens in the soil on pig trotters and snouts, including a different Phytophthora species (Phytophthora cinnamomi). However, no PTA was isolated from the samples. A positive control experiment showed a test sensitivity of 0-3% for the baiting methods and the data obtained were used in a Bayesian probability modelling approach. This showed a posterior probability of 35-90% (dependent on test sensitivity scores and design prevalence) that pigs do vector PTA and estimated that a sample size of over 1000 trotters would be required to prove a negative result. We conclude that feral pigs cannot be ruled out as a vector of soil-based plant pathogens and that there is still a high probability that feral pigs do vector PTA, despite our negative results. We also highlight the need to develop a more sensitive test for PTA in small soil samples associated with pigs due to unreliable detection rates using the current method.

Notes:

- No evidence of transmission of PTA by bigs was found on any field collected sample
- Pressing pig snouts into soil resulted in only 3% detection (1 out of 33).
- ‘Expert’ opinions were obtained from 22 people, mostly ‘managers’, who had a mean opinion of 26% probability that pigs would be found to transmit PTA
- The authors assume a 90% probability that pigs DO transmit PTA based on their own opinion, which appears to be at odds with the experts they interviewed.
- Base on the initial assumption of 90%, they conclude that there is a 35-90% probability that pigs transmit PTA despite no evidence found.
- It isn't clear what the value of this paper is -- essentially it shows that the authors started with an opinion and found no evidence to support it, but still conclude that their opinion is valid. It might have been better published without any experimental data, simply as an opinion piece. A frank assessment might conclude that, on the whole, this paper resulted in a loss of credibility for the programme. This is a risk in relying on students for major research output, as the student has a strong incentive to publish regardless of outcome.

Waipara NW, Hill S, Hill LMW, Hough EG and Horner IJ (2013). Surveillance methods to determine tree health, distribution of kauri dieback disease and associated pathogens. New Zealand Plant Protection 66: 235-241

Notes:

- Describes surveilance program on private land in Auckland and Northland, comprising 164 soil samples and 16 tissue samples from 436 properties with field observations only at around 282 sites and soil or tissue sampling at ~177 (numbers don't seem to quite add up in table from that paper).
- Record the presence of *P. multivora*, *cinnamomi* and *cryptogea* in samples. PTA is recorded as present at 107 sites, but 65 of these are based on diagnosis with field symptoms. Only 42 isolates of PTA were obtained. This is curious in that it is only

slightly higher than the recovery rate of P. multivora (40 samples) and unidentified phytophthora (38 samples).

- Describes initial 2005-6 discovery in Waitakere and gives some valuable background from internal reports.
- Describe sudden collapse of kauri at 34 properties, commonly in amenity plantings, and often associated with P. multivora (11 sites), environmental stress (13 sites), other phythopthora (9 sites) but only 1 case of PTA. Conclude sudden collapse not a common symptom of PTA.
- Note the presence of Armillaria, also P. cinnamomi as being linked to ill health and death.
- Note human health and safety risk presented by standing dead trees near roads, buildings, etc
- Note difficulty of containment and control given widespread nature of disease and numerous disease foci.
- The title is well thought -- 'Kauri Dieback Disease and associated Pathogens'. This is an accurate reflection of the level of knowledge and the findings.

Beever RE (2010). Phytophthora taxon Agathis and management of kauri dieback. *Forest Health News* 208. Available from http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/diseases/Phytophthora/kauri-dieback---phytophthora-taxon-agathis/phytophthora-taxon-agathis-and-management-of-kauri-dieback/

Notes:

- Reply to Gadgil 2009.
- Argues that P. agathidicida is a problem on the basis that (1) it is no longer isolated to the initial observation location and hence cannot be considered isolated occurrence, (2) that the detection of P. agathidicida under healthy trees by Gadgil was then later followed by disease, and hence does not show lack of pathogenicity, and (3) that the reported 'recovery' of trees on Great Barrier island was based on natural cycling of leaf coloration and not actual recovery (noting that the area of dead and dying trees increased over the next 30 years).
- Notes that the investment in P. agathidicidia is based on a precautionary principle despite very little information being available to guide the response.

Gadgil P (2009). Phytophthora 'taxon Agathis', a new pathogen of kauri? No, just an old one under a different name. *Forest Health News* 199: Available from http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/diseases/Phytophthora/kauri-dieback---phytophthora-taxon-agathis/phytophthora-taxon-agathis-a-new-pathogen-of-kauri-no-just-an-old-one-under-a-different-name/

Notes:

- This is an important early criticism of the PTA literature.
- First documentation that the 'new' P. agathidicida is actually the same as in Gadgil 1974.
- Argues that there is no expansion in Great Barrier island, as the oomycete was present but not pathogenic in 1972.
- Argues that presence in Waitakere Ranges is not a recent introduction, but rather the expression of disease by an organism that was already present.

Dick M. (2009). Resinosis on *Agathis australis* (kauri). *Forest Health News* 201: Available from http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/diseases/Armillaria/resinosis-on-agathis-australis-kauri/

Notes:

- Sort report on the observation of severe gummosis on planted kauri in the absence of any canopy dieback.n Note that the pattern of gummosis is very similar to that caused by *P. agathidicidia.*
- Isolations recovered *Armillaria* but not *Phytophthora*.
- For context, see Waipara et al. 2013 who also report Armillaria in unhealthy kauri.

Beever RE, Waipara NW, Ramsfield TD, Dick MA and Horner IJ (2009). Kauri (Agathis australis) under threat from Phytophthora? Proceedings of the Fourth Meeting of the International Union of Forest Research Organizations (IUFRO) Working Party S07-02-09, Phytophthoras in Forests and Natural Ecosystems, Monterey, California, USA, 26-31 August 2007, p 74-85

Notes:

- Conference proceedings.
- Describe pathogen effects in Waitakeres and isolation of PTA from margin of lesions.
- Conduct size class evaluation for gummosis and death. No statistics presented, but gummosis and dead trees observed in all size classes > 2.5 cm DBH. Visually suggests gummosis and death increase on larger trees.
- Revisit Gadgil 1974 site, conclude spread is ~3 m per year.
- Suggest PTA present in Waitakeres for many years. Note that gummosis is common on Kauri, hence symptoms may have been present but not noted for some time.
- Contrast with P. cinnamomi, which can also cause some Kauri mortality. Also note the presence of other Phytophhtora (cinnamomi, cryptogea, kernoviae, nicotianae)
- Note Gadgil recovered PTA from soils some distance from symptomatic stand, and concluded environmental factors were determining symptomology.
- Find that the evidence for whether PTA is native or exotic is insufficient. Evidence for is the recent detection (1974) and identical ITS sequence to *P. katsurae*.

Gadgil PD (1974). *Phytophthora heveae*, a pathogen of Kauri. *New Zealand Journal of Forestry Science* 4(1): 59-63

Notes:

- This is the first published record of *P. heveae*, although it cites 'it has been isolated once before in New Zealand (A. Johnston, pers. comm.)' with no date or other details.
- Isolated *P. heveae* from both a diseased stand AND from a healthy forest. The diseased stand was noted in 1972 and had an area of 1.5 ha. 'A few saplings and rickers from 5 to 30 cm diameter at breat height were dead and the rest had pale green to yellowish foliage and thin crowns'.

- Confirm pathogeneicity in trials showing 100% mortality. Contrasted with *P. cinnamomi*, a *Pythium* species, and *Rhizopus nigricans*, none of which caused mortality.
- Assuming a rate of linear spread of 3 m / year, a 1.5 hectare stand would be about 23 years old, so a 1951 establishment date.
- 21 citations in google scholar.

Phytophthora agathidicida management

Williams N (2015). Client report: Deactivation of Oospores of *Phytophthora* Taxon *Agathis* – Phase 2. Rotorua, New Zealand: Scion (New Zealand Forest Research Institute, Ltd)

Notes:

- Validation of heat inactivation of spores.
- Concludes that long-time >50 C temperature does reduce viability substantially.
- qPCR largely fails as quantification technique due to persistence of DNA in non-viable spores.
- Suggest need for studies on field soils and plant tissue, as lab grown oospores may not be valid test.

Horner IJ, Hough EG, Horner MB and Zydenbos SM (2015). Forest efficacy trials on phosphite for control of kauri dieback. New Zealand Plant Protection, 68: 7-12

In 2012, trials were established in four kauri forest sites severely affected by kauri dieback (Phytophthora agathidicida = P . taxon Agathis, PTA) to determine the potential of phosphorous acid (phosphite) as a control tool. Baseline assessments of 162 trial trees included canopy disease rating, trunk lesion dimensions and lesion activity (recent bleeding/ oozing). Phosphite (Agrifos.600) at concentrations of 7.5% or 20% was injected (20 ml) at 20-cm intervals around the trunk. Control trees were left untreated. After 1 year, half the previously injected trees were re-injected, in all cases with 7.5% phosphite. Phytotoxicity symptoms (leaf yellowing, browning or leaf/twig abscission) were noted in some phosphite injected trees, particularly where the 20% concentration was used. After 3 years, many more trunk lesions remained active (expressing ooze, continued expansion) in untreated trees (58.5%) than in phosphite-treated trees (0.8%). Average lesion expansion after 3 years was 12.7 cm in untreated and 0.4 cm in phosphite-treated trees.

Notes:

- Establishes the phosphite can reduce symptoms of PTA, but has its own toxicity effects.

Than DJ, Hughes KJD, Boonhan N, Tomlinson JA, Woodhall JW and Bellgard SE (2013). A TaqMan real‐time PCR assay for the detection of *Phytophthora* 'taxon Agathis' in soil, pathogen of Kauri in New Zealand *Forest Pathology* 43(4): 324-330

Kauri Agathis australis, an iconic tree of New Zealand, is under threat from an introduced disease-causing pathogen provisionally named Phytophthora 'taxon Agathis' (referred to as PTA). This soilborne, Pythiaceous species belongs to the Chromista and causes a collar rot resulting in yellowing of the foliage and thinning of the canopy, which eventually causes death of the infected tree. The management and containment of this pathogen requires rapid and reliable detection in the soil. The current method for soil detection utilizes a soil bioassay involving lupin baits and soil flooding in a process that takes between ten and twenty days. We describe a real-time PCR assay based on TaqMan chemistry for the specific detection of PTA, which targets the internal transcribed spacer (ITS) region of the nuclear ribosomal DNA. This TaqMan real-time PCR assay could be used with DNA extracted directly from bulk soil samples to enable rapid quantification of PTA within soil. The detection limit was 2 fg of PTA DNA from pure culture, or 20 fg in the presence of DNA extracted from soil. The assay was validated using soil samples taken from a PTA-infested site and soil spiked with a known concentration of oospores. We conclude that the TaqMan real-time PCR assay offers a more time-efficient method for detection of PTA in soil than existing methods.

Notes:

- Attempt to develop rtPCR method to replace a complicated up to 20 day detection protocol.
- Spiked a single soil with oomycetes and then used a CTAB DNA extraction to establish recovery and quantification.
- One possible explanation for failure of others to achieve similar results might lie in the soils used -- the brown sandy loam described here may be easier to recover DNA from than a sample containing higher phenolic levels.
- Problems with primers noted in PandI response to Belgard report. Despite the publication, the rtPCR technique has not become widely utilized by the program.
- 6 citations in GoogleScholar.

Horner IJ and Hough EG (2013). Phosphorous acid for controlling Phytophthora taxon Agathis in kauri: glasshouse trials. *New Zealand Plant Protection* 66: 242-248

Phytophthora taxon Agathis (PTA) is a serious problem in Auckland and Northland kauri forests. Phosphorous acid (phosphite) is a potential treatment for infected or threatened trees. In vitro tests on phosphite-amended agar showed that PTA was more sensitive to phosphite than other Phytophthora species commonly controlled by this chemical. Before progressing to forest trials, phosphite eficacy was tested on PTA-inoculated kauri seedlings in the glasshouse. Two-year-old kauri seedlings were inoculated with PTA applied directly to trunk wounds or by soil application. Phosphite was applied as a foliar spray, as a trunk injection or as a soil drench either 5 days before or 5 days after inoculation. All untreated control trees died, whether trunk- or soil-inoculated. With phosphite injection, survival was 100% following PTA soil inoculation and 67% following trunk inoculation. Foliar spray and soil drench-applied phosphite treatments were less effective than trunk injection, although some trees survived.

Notes:

- Inoculate seedlings with PTA, show that Phosphite prevents death. Both confirms strong pathogenicity of PTA and possible control. See follow up papers on use in forest.

Dick MA and Kimberley MO (2013). Deactivation of oospores of Phytophthora taxon Agathis. SCION report. MPI 15775: 23pp.

Objective
The objectives of this work were to determine the efficacy of a variety of treatments to deactivate oospores of PTA:

- Determine if high concentrations of Trigene will kill ooospores
- Determine if exposure to seawater (seawater equivalent) for periods of 1 or 15 minutes will kill oospores
- Determine the effect of the liquid fumigant metam sodium on oospores in soil
- Determine effect of high and low pH levels on oospore viability
- Determine the time/temperature combinations required to kill oospores in solution
- Determine the time/temperature combinations required to kill oospores in soil

Key Results
Sensitivity of PTA oospores to Trigene:
Trigene was tested at a range of concentrations (2%, 5%, 10% product) using two exposure times (30 min and 120 min). None of these Trigene treatments had any significant effect on the percentage of positively stained oospores compared with a deionised water control.

Salt water immersion:
A short immersion in salt water had a negligible effect on PTA oospore survival.

Fumigation with metam sodium
Fumigation of soil and a soil/sand mix with metam sodium applied at three rates did not reduce the percentage oospores staining positive in either soil type or at any of the rates tested. Fumigated samples actually had significantly higher counts than untreated samples in soil.

Immersion in solutions of differing pH:
The effect of eight solutions with pH ranging (increments of one) from 3 to 10 and with exposure times of 2, 4, 12, 24 and 48 hours on oospore survival were tested. At the lowest tested level (pH=3) the percentage of positively stained oospores was moderately reduced to 14% and did not differ significantly with exposure time. Although there was also a reduction in staining at higher pH levels, this only occurred for extended exposure times. At pH levels 9 and 10 the 24 and 48 hour treatments reduced viability to levels below all other treatments. There were no viable spores after 48 hours exposure to pH 9 or pH 10. The optimum pH for oospore viability tended to be in the middle ranges (pH 6-8).

Heat treatments
Exposure to temperatures of 55°C for 4 hours in solution was effective at reducing viability to extremely low levels. Shorter exposure times were applied with increasing temperature (e.g., 0.5 hours at 70°C), and all time/temperature combinations were equally effective. Oospores embedded on micromesh and buried in soil were almost as responsive to temperature as those in heated solution with a 4 hour treatment at 60°C and 70°C giving

mean stained spores of only 3-6%. Wet soil gave significantly better results than dry soil though the differences were small. Occasional stained spores were observed in some replicates of many treatments though it is possible that these occasional stained spores were more of an artefact than a reality. Exposing oospores embedded on micro-mesh to a dry heat of 70°C for 4 hours gave a reduction in viability of only 30%, emphasising the importance of moisture in achieving the desired result.

Conclusions
For practical purposes the application of heat is likely to be the most effective and practical treatment for deactivation of PTA oospores in samples of contaminated soil collected from equipment or footwear. Results of this work indicate that temperatures of 60 - 70°C applied to wet soil or through a steam applicator for periods of 4 hours would result in total kill. A safety margin could be applied. At temperatures higher than 70°C shorter treatment periods are likely to be effective.

Notes:
- The failure of Trigene to kill oospores even after 120 min is consistent with Bellgard et al. 2010.

Bellgard SE, Paderes EP and Beever RE (2010). Comparative efficacy of disinfectants against *Phytophthora* taxon Agathis (PTA). Available from http://www.kauridieback.co.nz/media/3133/comparative%20efficacy%20of%20disinfectants%20against%20pta.pdf [Accessed 21 March 2016]

Notes:
- Reports that Trigene at 2% inhibits mycelial growth and is ‘lethal to all zoospores’ but had ‘little effect’ on oospores.
- Finds Phytoclean is as effective as Trigene.
- Virkon and Janola are effective, but recommended against due to damage to metal and fabric.

Auckland Council (2012) Parks Recreation and Heritage Forum 13 March, Kauri Health in Regional Parks File No.: CP2012/03054

Notes:
- Provides data on use of phytosanitary stations (30-50%).
- Summary of the logic behing closure of disease free areas, rather than quarunteen of diseased areas
- Discussion of track management

Gibbison L (2010). Fighting Kauri disease -- one year on. *Biosecurity* 101: Available from http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/diseases/Phytophthora/kauri-dieback---phytophthora-taxon-agathis/fighting-kauri-disease---one-year-on

Notes:
- Short note on the formation of the management programme. No real new information.

Gibbison L (2010). Kauri dieback programme moves into long term management. Farm Forestry New Zealand website. *Biosecurity* 96: Available from http://www.nzffa.org.nz/farm-forestry-model/the-essentials/forest-health-pests-and-diseases/diseases/Phytophthora/kauri-dieback---phytophthora-taxon-agathis/kauri-dieback-programme-moves-into-long-term-management/

Notes:

- Short note on the funding of P. agathidicida management. Not much new information, although worth highlighting the early involvement of Māori as an integral part of management.

Horner IJ (1985). Fungal pathogens influencing establishment of kauri and kahikatea. *New Zealand Journal of Ecology* 8: 152

Notes:

- Abstract from annual meeting only. Notes P. cinnamomi as a cause of Kauri death.
- Interestingly, notes that continuously wet soils favoured both high infection and high growth and survival of the tree, although Ridomil (fungicide) increased growth particularly under these conditions.
- Mortality highest in soils with alternating wet/dry cycle.

General Phytophthora and forest dieback literature

Boehmer HJ, Wagner HH, Jacobi JD, Gerrish GC and Mueller‐Dombois D (2013). Rebuilding after collapse: evidence for long-term cohort dynamics in the native Hawaiian rain forest. Journal of Vegetation Science 24(4): 639-650

Questions:
Do long-term observations in permanent plots confirm the conceptual model of Metrosideros polymorpha cohort dynamics as postulated in 1987? Do regeneration patterns occur independently of substrate age, i.e. of direct volcanic disturbance impact?

Location
The windward mountain slopes of the younger Mauna Loa and the older Mauna Kea volcanoes (island of Hawaii, USA).

Methods
After widespread forest decline (dieback), permanent plots were established in 1976 in 13 dieback and 13 non-dieback patches to monitor the population structure of M. polymorpha at ca. 5-yr intervals. Within each plot of 20 × 20 m, all trees with DBH >2.5 cm were individually tagged, measured and tree vigour assessed; regeneration was quantified in 16 systematically placed subplots of 3 × 5 m. Data collected in the subplots included the total number of M. polymorpha seedlings and saplings (five stem height classes). Here we analyse monitoring data from six time steps from 1976 to 2003 using repeated measures ANOVA to test specific predictions derived from the 1987 conceptual model.

Results

Regeneration was significantly different between dieback and non-dieback plots. In dieback plots, the collapse in the 1970s was followed by a 'sapling wave' that by 2003 led to new cohort stands of M. polymorpha. In non-dieback stands, seedling emergence did not result in sapling waves over the same period. Instead, a 'sapling gap' (i.e. very few or no M. polymorpha saplings) prevailed as typical for mature stands. Canopy dieback in 1976, degree of recovery by 2003 and the number of living trees in 2003 were unrelated to substrate age.

Conclusions

Population development of M. polymorpha supports the cohort dynamics model, which predicts rebuilding of the forest with the same canopy species after dieback. The lack of association with substrate age suggests that the long-term maintenance of cohort structure in M. polymorpha does not depend on volcanic disturbance but may be related to other environmental mechanisms, such as climate anomalies.

Notes:

- This is potentially a really important paper to consider in the context of P. agathidicida.
- One sentence that should haunt the KDP is 'The early hypothesis (Burgan and Nelson 1972) that the Hawaiian rain forest decline was caused by a virulent pathogen or a combination of biotic disease and pest agents was ruled out after a decade of intensive disease research (Kliejunas and Ko 1973, 1974; Papp et al. 1979; Hodges et al. 1986).

Martin FN, Abad ZG, Balci Y and Ivors K (2012). Identification and detection of *Phytophthora*: reviewing our progress, identifying our needs. *Plant Disease* 96(8): 1080-1103

Notes:

- International effort to review science knowledge on *Phytophthora*.
- Notes increase in species numbers from 55 known *Phytophthora* in 1999 to 117 known species by 2012.

Hüberli D, Lutzy B, Voss B, Calver M, Ormsby M and Garbelotto M (2008). Susceptibility of New Zealand flora to *Phytophthora ramorum* and pathogen sporulation potential: an approach based on the precautionary principle. *Australasian Plant Pathology* 37(6): 615-625.

Phytophthora ramorum, the cause of sudden oak death in the western USA and a damaging pathogen in Europe, is a biosecurity threat of unknown magnitude to New Zealand and Australasia because of its presence in traded ornamental plants. Knowledge of potential hosts acting as carriers and of symptoms caused by the pathogen on such hosts will strengthen precautionary quarantine regulations to prevent inadvertent introductions of P. ramorum into the region. Also, the identification of potential hosts will permit determination of areas at risk within countries that do not have P. ramorum. Susceptibility of New Zealand plants, including 17 endemic and three commercial species (Eucalyptus globulus, Pinus radiata and Acacia melanoxylon), as well as two known Rhododendron cultivar hosts, was determined by analysing the size of lesions on inoculated excised leaves and branches, while *infectivity was determined by counting sporangia produced on leaves. In order to identify extremely susceptible hosts, seven species were inoculated using three concentrations of zoospores ranging from low (1 102 zoospores/mL) to high (5 103 zoospores/mL). In branch inoculations, P. radiata and Nothofagus fusca were as susceptible as the Rhododendron cultivars. Pseudopanax arboreus, Fuchsia excorticata and one Rhododendron cultivar were equally susceptible in leaf inoculations. However, F. excorticata was the only species with 100% infected leaves, high foliar sporulation and was highly susceptible at all three zoospore concentrations. Leptospermum scoparium was the only asymptomatic foliar host that had high reisolations of the pathogen. F. excorticata, P. radiata, N. fusca, P. arboreus and L. scoparium should be added to the potential host list for P. ramorum and monitored for symptoms and sporulation in gardens and nurseries in the USA and Europe. As part of a precautionary strategy, these species are suitable candidates for targeted surveillance programs in high-risk incursion areas of New Zealand. Furthermore, the sympatry of foliar hosts with high infectivity and of highly susceptible stem hosts was identified: these areas may be at risk for the development of a forest epidemic.*

Notes:

- Precautionary test of host susceptibility of NZ species to *P. ramorum*
- Used NZ native species and australian species from a US campus garden to test susceptibility of excised branch material to P. ramorum inoculation.
- Find Fuchsia excorticata particular susceptible, but also a number of other native species.
- Note that Leptospermum is an asymptomatic carrier of the disease.
- Note that there is little or no true replication within plant species.
- Should be considered as evidence for broad host range and lack of symptoms of *Phytophthoras* -- relevant to *P. agathidicida* in that context.

Beever RE, Forster RLS, Rees-George J, Robertson GI, Wood GA and Winks CJ (1996). Sudden decline of cabbage tree (*Cordyline australis*): search for the cause. *New Zealand Journal of Ecology* 20(1): 53-68.

Many cabbage trees (Cordyline australis) are dying throughout much of the North Island and the northern South Island of New Zealand. The symptomatology of those dying in urban environments is described, and is concluded to be consistent with the hypothesis that death is caused by a biotic agent entering through a leafy tuft of the branch system. This disease, which has been named Sudden Decline, usually leads to almost total defoliation of affected trees within 2-12 months. Disease incidence has increased linearly at about 11% per annum since 1987/88. Cultivated trees of C. kaspar, C. obtecta, and various Cordyline hybrids have also been observed dying with Sudden Decline symptoms. Investigations aimed at identifying the causal agent are described, and the hypothesis is advanced that a phytoplasma (mycoplasma-like organism or MLO) is the cause. Sudden Decline is contrasted with the widespread ill-health apparent in many pastoral populations of cabbage tree throughout the country. This Rural Decline is characterised by a general loss of branch and leaf vigour and occasional tree death. It is suggested that Rural Decline is a complex disease (decline disease) caused by various biotic and abiotic agents interacting with an ageing population growing in situations where regeneration is prevented. In many pastoral situations Sudden Decline is superimposed on Rural Decline. The ecological implications of Sudden Decline are discussed.

Notes:

- Not reviewed in detail. Recorded here as another example of decline -- but in this case one that has faded from the public view over time. Figure 2 in this paper would suggest that cabbage trees should now be essentially extinct north of Whangarei -- it would be interesting to know if they are.
- Fairly little of the kauri dieback literature has considered other diebacks in NZ or overseas.

McBree KS (1999). *Kamahi decline in Tongariro National Park*. Doctoral dissertation. Massey University

Notes:

- Not reviewed. Recorded here as another example of decline

Stewart GH (1989). Ecological considerations of dieback in New Zealand's indigenous forests. *New Zealand journal of forestry science* 19(2/3): 243-249.

Three types of factors influence the dieback of forest stands — factors that predispose stands, trigger factors that initiate dieback, and factors that contribute to further decline. All known examples of dieback in New Zealand Nothofagus spp., Metrosideros spp., and beech/hardwood forests can be explained using this three-factor framework.

Notes:

- This is not a PTA or Kauri focused paper, but reviews large scale forest diebacks in NZ forest. Notes that the first suspect in decline in typically a pest or pathogen, but environmental stress and **natural stand structure and dynamics need to be considered**.
- Differentiates 'predisposing' (climate, nutrients, stand structure), precipitating (severe events, pathogens, pests), and hastening factors in forest decline.
- Note that dieback is common in any seral community and on young soils, In beech, dieback is particularly during pole stage and during over-mature stages, with a 120-150 year cycle.'Any investigation of dieback should therefore include the roles of predisposing, trigger, and hastening factors'
- Notes, in passing, dieback of Kauri caused by *Phytophthora cinnamomi* after high rainfall on impeded drainage sites, cited to Newhook and Podger 1972.

Hodges CS, Adee KT, Stein JD, Wood, HB and Doty RD (1986). Decline of ohia (*Metrosideros polymorpha*) in Hawaii: a review. Gen. Tech. Rep. PSW-86. Berkeley, Calif.: U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Exp. Stn. 22 p

Portions of the ohia (Metrosideros polymorpha) forests on the windward slopes of Mauna Loa and Mauna Kea on the island of Hawaii began dying in 1952. Little mortality has occurred since 1972. About 50,000 ha are affected by the decline. Individual trees exhibit several symptoms, from slow progressive dieback to rapid death. Seven types of decline have been identified on the basis of differential response of the associated rainforest vegetation.

Two of the types, Bog Formation Dieback and Wetland Dieback, make up more than 80 percent of the decline area. The decline has affected bird populations and plant species in some areas, but has had no major effect on runoff or water quality. Ohia decline appears to be a typical decline disease caused by a sequence of events. Poor drainage is probably the major cause of stress and is followed by attack of the ohia borer (Plagithmysus bilineatus) and two fungi (Phytophthora cinnamomi and Armillaria mellea), which kill the trees. Except for controlling introduced plants and feral animals that spread them, little can be done to ameliorate the effects of the decline.

Notes

- This gives a good background on a similar forest decline in Hawaii, which was attributed, in part, to P. cinnamomi. See notes on Boehmer et al. 2013

Petteys EQ, Burgan RE and Nelson RE (1975). Ohia forest decline: its spread and severity in Hawaii. Research Paper: PSW-105. Berkeley, CA, U.S. Department of Agriculture, Forest Service, Pacific Southwest Forest and Range Experiment Station. 11 p

Notes:

- Predicts the elimination of Ohia (*Metrosideros*) by the year 2000. See Boehmer et al. 2013

General kauri ecology and biology

Macinnis-Ng C, Wyse S, Veale A, Schwendenmann L and Clearwater M (2015). Sap flow of the southern conifer, *Agathis australis* during wet and dry summers. Trees: doi:10.1007/s00468-015-1164-9

Notes:

- Shows that kauri has multiple adaptations to tolerate drought, which is logical given that long-lived trees must be able to survive infrequent severe events
- No mention of dieback, but make an important observation that remaining kauri stands may be more restricted to dry sites (e.g., ridgetops) than historically. Despite this, the high tolerance of drought suggests this is not a factor.

Wyse SV, Burns BR and Wright SD (2014). Distinctive vegetation communities are associated with the long-lived conifer *Agathis australis* (New Zealand kauri, Araucariaceae) in New Zealand rainforests. *Austral Ecology* 39(4): 388-400

Notes:

- Tests whether Kauri is a foundation species, creating soil environments that favour a particular plant community
- Find evidence that the plant community under kauri is distinctive compared to surrounding forest and compared to under rimu. However, most (all?) of the plants under kauri are also found elsewhere.
- Main driver appear to be low soil nutrient availability under kauri.
- Link to kauri dieback is by extrapolation. Suggest that loss of kauri could lead to loss of a distinctive type of community in lowland, relatively high-fertility forest.

Steward GA, Kimberley MO, Mason EG and Dungey HS (2014). Growth and productivity of New Zealand kauri (*Agathis australis* (D. Don) Lindl.) in planted forests. *New Zealand Journal of Forestry Science* 44(1): 27

Background: The establishment of even-aged planted stands of New Zealand kauri (Agathis australis (D.Don) Lindl.) for timber has been constrained by a lack of quantitative information on productivity and rotation length on which forest management and investment decisions could be made.
Methods: Stand-level models of height and basal area against time were developed (as well as a stand-volume function to calculate volume from height and basal area) based on planted stands that were up to 83-years old and represented planting sites both within and outside the current natural range of the species.
Results: Planted kauri was shown to be slow to establish with little height growth for the first five years after planting. Similar trends were observed for basal area and whole-tree volume development. A Schumacher equation with local slope parameter and asymptote bounded at 45 m gave the best fit for height, while a von Bertalanffy-Richards equation in difference form with local slope parameter gave the best fit for basal area. For plantations with an average site index (20.4), height was predicted to be 22.3 m in height at age 60, with a basal area of 78.1 m2 ha−1. Whole-tree volume was predicted to be 702 m3 ha−1. Predicted volume mean annual increment was 11.7 m3 ha−1 yr−1for all stands at age 60. From age 20–60 years, stands with a higher site index had a volume mean annual increment of 18.6 m3 ha−1 yr−1. The best stand exceeded 20 m3 ha−1 yr−1.
Conclusions: This study indicates an opportunity to grow kauri in plantations on selected good-quality sites over rotations of 60–80 years or less.

Notes:

- Reviews previous literature on kauri plantations for production of wood. Earlier assumption was very long rotation periods.
- Note that there is not a large effect of site location, and that kauri was once widespread (pre-glaciation). Suggest that could be suitable for wider range of sites than currently on.
- Notes P. agathidicida as a threat to plantation establishmet of kauri, but also potential role of plantations in preserving genetic diversity
- Mortality rate in plantations averaged 22.1%, with higher density stands having higher mortality. Often attributed to drought.

Nayagar T (2014). *A proteomics study of hormone induction of defence related proteins in Kauri (Agathis australis)*. Doctoral dissertation. Auckland University of Technology, New Zealand.

Kauri (Agathis australis) is currently threatened by a pathogen, Phytophthora Taxon agathis (PTA) against which there are few effective treatments. Hormone induction may potentially induce the plant defence system and provide some resistance against the pathogen. The objective of this thesis was to determine if treatment with the hormones, methyl jasmonate (MJ) and ethylene (ethephon, ET) induces defence related proteins. A proteomics study was carried out to identify potential defence related proteins using SDS-PAGE and LC-MS. Numerous proteins were identified including common plant proteins such as RuBisCO as well as two potential defence related proteins, a super oxide dismutase and an acid phosphatase. This protein study was the first of its kind done in Kauri. Acid phosphatase was selected as a target for an enzyme induction kinetics study. Kauri plants were treated with the *hormones MJ and ET alone and in combination. A spectrophotometric acid phosphatase assay was carried out to quantify enzyme concentration changes with time over a period of twelve days. The results of the enzyme assay showed a statistically significant increase in acid phosphatase activity when Kauri was treated with MJ alone and also when treated with a combination of MJ and ET. The treatment with MJ alone caused an induction of enzyme activity of 1.2 times higher than that of the control. The treatment with MJ and ET in combination caused an induction of enzyme activity 1.8 times higher when compared to the control. In conclusion, hormone treatment with MJ and ET has been shown to induce a plant defence related protein in Kauri which may have potential application in Phytophthora disease management. Further research will be required to determine if it is possible to prime Kauri defence related proteins by hormone treatment in order to confer PTA disease resistance.*

Notes:

- Essentially preliminary data showing that treatment with hormones does induce possible defense compounds in kauri, but no testing against P. agathidicida was undertaken.

Wyse, S. V., Macinnis-Ng, C. M., Burns, B. R., Clearwater, M. J., and Schwendenmann, L. (2013). Species assemblage patterns around a dominant emergent tree are associated with drought resistance. *Tree physiology*, *33*(12), 1269-1283.

Notes

- Tests the role of drought tolerance in vegetation associated with kauri.
- Find drought tolerance is associated with plants found associated with kauri
- No link to dieback made (not mentioned).

Wyse, S. V., and Burns, B. R. (2013). Effects of Agathis australis (New Zealand kauri) leaf litter on germination and seedling growth differs among plant species. *New Zealand Journal of Ecology*, 178-183.

Agathis australis (A. australis, New Zealand kauri, Araucariaceae) exerts a substantial in uence on soil properties and nutrient cycling, and mature specimens form an acidic organic soil layer beneath them that can be up to 2 m deep. We investigated whether phytotoxic compounds occurred in A. australis leaf litter and organic soil, and whether allelopathy may explain the distinctiveness of plant communities surrounding A. australis. We extracted water-soluble compounds from fresh litter, and conducted bioassays of seed germination and seedling growth in these extracts on both A. australis-associated and non-associated species. Germination of all species except A. australis was inhibited by extracts from A. australis litter, which probably contains phytotoxic compounds. Germination of a forest species that is not associated with A. australis was inhibited by the low pH organic soils collected from beneath mature A. australis, but when these soils were neutralised using lime, its germination was not inhibited. Lactuca sativa, a species highly sensitive to phytotoxic compounds, was negatively affected by both the low pH of the organic soil and the presence of phytotoxic compounds. In contrast, there was no effect of the organic soil on the germination and growth of A. australis-associated species. These results suggest that the high acidity of A. australis organic soil plays a considerable role in structuring the composition of plant communities associated with A. australis, and also that A. australis litter probably contains *unidenti ed phytotoxic compounds that may exert additional direct allelopathic effects on sensitive species.*

Notes:

- Tests for both pH and allelopathy effects of Agathis on other plants. The use of water extracted compounds from leaves is fairly questionable, which is discussed.
- Garden lettuce (Lactuca sativa) is inhibited by leaf extracts from Agathis, but no conclusive evidence of allelopathy for native Melicytus macrophyllus is found.
- Main effect of kauri on seedling establishment may be via pH effects of litter.
- No link to dieback made (not mentioned).

Gough K, Hargreaves C, Steward G, Menzies M, Low C and Dungey H (2012). Micropropagation of kauri (*Agathis australis* (D. Don.) Lindl.): in vitro stimulation of shoot and root development and the effect of rooting hormone application method. *New Zealand Journal of Forestry Science* 42: 107-116.

Kauri (Agathis australis (D.Don.) Lindl.) is a coniferous forest species endemic to New Zealand. This unique resource is currently under threat from Phytophthora taxon Agathis infection that causes kauri die-back. This situation highlights the need not only for reliable clonal propagation methodologies to amplify genotypes exhibiting disease resistance but also the development of protocols that could be used for mature material for ex situ conservation of important genotypes. Understanding the viability of previously stored seed for culture initiations is also critical if trees subsequently die.
Six agar-based culture media were compared for their effects on shoot production from in vitro germinated mature zygotic kauri embryos. All root and some hypocotyl tissue was removed from the germinated embryos prior to initiation onto the culture medium. The number of shoots produced was highest (10 per embryo) in a full-strength, modified Quiorin and Lepoivre medium containing 3.5 g L-1 activated charcoal.
Four treatments incorporating use of rooting hormones were compared for their effects on root development from shoots produced in vitro. The dipping of stem ends in rooting powder containing talc plus 2% indole-3-butyric acid before transfer to potting mix stimulated root development in 68% of the shoots. Only 5 - 14% of shoots maintained in agar-based cultures with added rooting hormones before transfer to potting mix produced roots. Rooted plants continued to grow vigorously when transferred to standard nursery conditions. Variability among seed sources was high and there was no evidence that genotype influenced in vitro production of either shoots or roots.

Notes:

- Uses PTA as a justification for study, but not a study of PTA.
- Established very pragmatic guidelines on how to use tissue culture micropropagation to produce Kauri seedlings.
- Some interesting notes on slow initial establishment vis a vis slow development of fibrous root system.

McKenzie EHC, Buchanan PK and Johnston PR (2002). Checklist of fungi on kauri (*Agathis australis*) in New Zealand. *New Zealand Journal of Botany* 40(2): 269-296

A brief account of fungi associated with kauri (Agathis australis) in New Zealand is followed by an annotated listing of all fungi known to grow on living or dead parts of this endemic tree. Records have been gleaned mainly from the New Zealand Fungal Herbarium (PDD), Herbarium of Forest Research (NZFRI(M)), and the literature. The fungi include few pathogens, mainly Phytophthora spp., and few agarics, as Agathis does not form ectomycorrhizae. Most fungi associated with A. australis are saprobes found on dead and fallen wood and litter. A total of 189 named species of fungi and 75 species identified only to genus, distributed within 199 genera, have been recorded. Many of the fungi are commonly found on other plant substrata within New Zealand, or elsewhere. Nineteen species have been described with A. australis as the type substratum. These species are saprobes and, apart from the Australasian endemic, Heterobasidion araucariae, all are currently considered to be endemic to New Zealand. Of these, most (12 species) are restricted to A. australis, with only 7 species known on wood or litter of other plants.

Notes:

- 189 species + 75 species ID'd to genus have been found on Kauri. Only 12 species restricted to Kauri. Most are wood decay fungi on wood and litter.
- A few pathogens noted.
- Includes brief review of distribution and ecology (47,000 ha of forest with Kauri but ¾ of trees in Waipoua forest), cited to Newsome 1987 and Ecroyd 1982..
- Notes P. cinnamomi as a major cause of kauri damage.
- Note Gagil 1974 P. heveae collections, and effect on seedlings.
- Also note the presence of two potential pathogenic rust fungi present on other Agathis (Aecidium balanse in New Caledonia and Aecidium fragiforme from most other areas where Agathis grows).

Ahmed M and Ogden J (1987). Population dynamics of the emergent conifer Agathis australis (D. Don) Lindl.(kauri) in New Zealand I. Population structures and tree growth rates in mature stands. *New Zealand Journal of Botany* 25(2): 217-229

Twenty five plots of mature kauri Agathis australis (D. Don) Lindl. covering the range of the species in northern New Zealand, were sampled for density, basal area, and species composition using a modified point-centered quarter technique. Two increment cores were taken from at least ten trees at most sites, and used to estimate tree ages and growth rates. The density of kauri and the basal area from 23 to 127 m ha~' in the 25 stands. Diameter distributions ranged from highly skewed and unimodal to flat and multi- modal, with all size classes represented in most plots. Combined frequency distributions suggest that two or three kauri generations (cohorts) may be present on many sites.
There is only a weak relationship between age and diameter; individuals in the same 10cm diameter class may vary in age by 300 years, and the largest individual on the site is often not the oldest. Mean annual diameter increments range from 0.15 to 0.46 cm yr~'on different sites with an overall average of 0.23 cm yr~>, equivalent to 8.7 annual rings per cm of core, about half the commonly quoted figure for growth rate. Periodic mean annual increment and mean annual increment curves are presented. It is concluded that the 'normally attainable age' is >600 years. Individuals > 2 m d.b.h. probably often exceed 1000 years, but there is no reliable evidence for trees >2000 years in age.

Notes:

- Documents the reduction of kauri to 5% of pre-european forests, largely restricted to fragmented forest on inaccessible sites and ‘over-mature’ stands.
- Suggest that the maximum attainable age may normally 6-700 years, despite some much longer lived individuals.

Ogden J, Wardle GM and Ahmed M (1987). Population dynamics of the emergent conifer *Agathis australis* (D. Don) Lindl.(kauri) in New Zealand II. Seedling population sizes and gap-phase regeneration. *New Zealand Journal of Botany* 25(2): 231-242

The view that kauri {Agathis aus- tralis) is a successional species which does not regenerate in mature forest is entrenched in the New Zealand literature. However, seedling and sapling populations ranging from c. 200 to >2000 stems ha’1 were recorded in 25 mature kauri stands throughout the species' range in the North Island. Higher densities were recorded in gap-phase and successional communities. Gaps created by the fall of mature kauri trees at Trounson Kauri Park averaged 0.04 ha, and a few contained abundant kauri seedling and sapling populations. Denser seedling aggregates were sometimes associated with rotting stumps or logs on the forest floor. Trays placed in gaps showed kauri germination and survivorship rates greater than those placed beneath adjacent canopies.
Our data support a ‘cohort regeneration model’ in which dense regeneration occurs in successional communities following large-scale disturbance. This leads to self-thinning ‘ricker’ stands in which seedling recruitment is rare, producing a localised ‘regeneration gap’. Continued mortality, increasing as the initial survivors begin to senesce, creates a higher frequency of canopy gaps, allowing a second less synchronous wave of recruitment to occur. However, many gaps may be lost to hardwood species so that succeeding cohorts are less dense. Despite a low efficiency of gap capture, the great longevity of kauri (^ 600 years) implies that the species will survive on any site for 1500 to 2000 years, long enough for large scale stochastic disturbance by landslip, storm, or fire to reinitiate the process.

Notes:

- This seems to be the most widely accepted model of kauri forest dynamics, which recognised the early successional establishment if kauri into Leptospermum, but supports a cohort model with gap-phase regeneration occurring for at least several hundred years.
- Loss of gaps to hardwoods results in successive cohorts being smaller and smaller.

Other summaries

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http://www.kauridieback.co.nz/media/44696/kauri%20konnect%2028.pdf

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Bellgard SE, Paderes EP, Beever RE 2009. Kauri dieback: kauri hygiene – small project. Landcare Research Contract Report LC0910/017, Landcare Research, Auckland, New Zealand. 10 p.

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Appendix B. Correspondence with Researchers

1. Ian Horner (Plant & Food Research) KDB Programme funding

List of outputs, Kauri dieback, Ian Horner 2014-15.

Horner IJ, Hough EG. October 2015. Testing transmission of Phytophthora agathidicida in pig faeces. A Plant Food Research report prepared for Auckland Council. Milestone No. 58011. Contract No. 30870. Job code: P/345129/01. PFR SPTS No. 12254.

Horner IJ, Hough EG and Horner MB 2015. Forest efficacy trials on phosphite for control of kauri dieback. New Zealand Plant Protection 68: ##-##.

Horner IJ. 2015. Kauri dieback, giant killer: potential of phosphite for control. Abstract and presentation at the Dieback Information Group Meeting, Perth, July 2015.

Bassett IE, Hill S, Shields B, Vette M, Avery K, Horner IJ 2015. Assessing the potential of detector dogs for use in forest pathogen management programmes: Paddy the kauri dieback dog. Abstract for NZ Ecological Society Conference, 2015.

Horner IJ, Hough EG. June 2015. Assay of stored soils for presence of Phytophthora agathidicida. A Plant and Food Research report prepared for: The Ministry for Primary Industries. Contract No. 32294. Job code: P/345061/01. PFR SPTS No. 11718.

Horner IJ 2015. Potential for control of kauri dieback. Abstract and Presentation at the second Kauri Dieback Symposium, Omapere, February 2015.

Horner IJ and Hough EG 2015. Phosphite for control of kauri dieback. Extended Abstract for the Australasian Plant Pathological Society Conference, Perth, September 2015.

Horner IJ, Hough EG. 2014-15. Multiple reports for Auckland Council on kauri soil testing for Phytophthora

Jamieson A, Bassett IE, Hill LMW, Hill S, Davis A, Waipara NW, Hough EG and Horner IJ. 2014 Aerial surveillance methods to detect kauri dieback in New Zealand. New Zealand Plant Protection 67:60-65

Horner IJ, Hough EG 2014. Pathogenicity of four Phytophthora species on kauri: in vitro and glasshouse trials. New Zealand Plant Protection 67: 54-5

Horner IJ and Hough EG. August 2014. Phosphorous acid for controlling Phytophthora taxon Agathis in kauri: field trials 2½ years on. A Plant and Food Research report prepared for MPI. Milestone No. 47655. Contract No. 28262. Job code: P/345061/01. PFR SPTS No. 10397

Horner IJ and Hough EG. 2014. Phosphite for control of kauri dieback: forest efficacy trials. Abstract for the seventh meeting of the International Union of Forest Research Organizations (IUFRO) Working Party S07.02.09: Phytophthoras in forests and natural ecosystems.

Horner IJ and Hough EG. 2014. Pathogenicity tests of Phytophthora species on Agathis australis. Abstract for the seventh meeting of the International Union of Forest Research Organizations (IUFRO) Working Party S07.02.09: Phytophthoras in forests and natural ecosystems.

2. Scion's recent and current *Phytophthora agathidicida* and associated kauri research - receives KDB Programme funding

Contributors: Nari Williams, Peter Scott, Rebecca McDougal, Beccy Ganley, Cathy Hargreaves and Greg Steward

Diagnostics

Comparison of diagnostic efficiency (baiting and real-time PCR comparison)

(McDougal, Bellgard, Scott, and Ganley, 2014)

Optimisation of baiting

Peter Scott has performed numerous variations on the standard baiting protocol to optimise for improved detection. Suggestions for optimisation have been forwarded to the KDP.

Detection of *P. agathidicida* from wood

Peter Scott has done some work optimising recovery of *P. agathidicida* from wood

Real-time PCR and High-Resolution Melting

Rebecca McDougal has established a High resolution melting (HRM) assay that can distinguish *P. agathidicida* from other commonly isolated *Phytophthora* species in soil.

Early diagnostics research

Margaret Dick and Stan Bellgard determined if *Phytophthora* taxon Agathis (PTA) was present in the soil at selected kauri forest locations, the association of PTA in soil with symptomatic/asymptomatic trees and evaluation of site/disease associations. (Sidney 46230)

Survival of *P. agathidicida*

Nari Williams and Margaret Dick have had several studies investigating the conditions of survival of oospores (Dick, 2012) (Williams, 2014)

Margaret Dick has investigated deactivation of oospores of PTA using high temperature, pH, fumigation and steam cleaning (Sidney 49150)

The potential of kauri for indigenous Forestry

Greg Steward has ongoing research in this area

(Steward, 2014)

Screening for resistance to *Phytophthora agathidicida*

Ex situ screening of kauri tissues to establish if there is a genetic basis to susceptibility of kauri to infection by *P. agathidicida*.

Echo Herewini Masters (BPRC/ HTHF) (Herewini et al. 2015)

Scion and Landcare Research under the HTHF programme

Chemotaxis research on *P. agathidicida*

Beccy Ganley and Peter Scott are both working with **Monica Gerth** and Lab at Otago University on the chemotaxis of *P. agathidicida.* This including hosting a summer student at Scion.

Tissue Culture

Scion has an established tissue culture resource of kauri lines in tissue culture with which we're developing screening assays and performing host-pathogen interaction studies.

Genome Sequencing

Scion has sequenced the genomes of six species of tree-infecting *Phytophthora* from New Zealand, including two strains of *P. agathidicida.* (Studholme et al. submitted 27/10/15) These are being assembled and annotated progressively and included in our collaborations with the International *Phytophthora* genome sequencing consortium.

Rosie Bradshaw (Massey University, BioProtection CoRE) has funding for a postdoctoral researcher to perform re-sequencing of six further isolates of *P. agathidicida*, in collaboration with Scion (Rebecca McDougal) and LandCare Research. To commence in 2016.

Parallel and cross-informing research

Scion has a depth of research currently underway with collaborators under the HTHF programme which cross inform *Phytophthora Systems Biology.* Key members of the HTHF Kauri Tag are also on the KDP PnI team so are well aware of these, but if you'd like further details just let us know.

References

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Herewini, E. M., William, N. M., Bradshaw, R. E., Stewart, T. B., Wilcox, P. L., and Scott, P. B. (2015). *Foliar inoculation of Agathis australis infected with the soil borne pathogen Phytophthora agathidicida*. Paper presented at the Australasian Plant Pathology, Fremantle, Western Australia.

McDougal, R., Bellgard, S., Scott, P., and Ganley, R. (2014). Comparison of a real-time PCR assay and a soil bioassay technique for detection of Phytophthora taxon Agathis from soil.

Steward, G. (2014). *Kauri under threat, or a new opportunity?* Paper presented at the New Zealand Arboricultural Association Annual Conference, Rotorua.

Studholme, D. J., McDougal, R., Sambles, C., Hansen, E., Hardy, G. E. J., Grant, M., Williams, N. M. (submitted 27/10/15). Genome sequences of six Phytophthora species associated with forests in New Zealand. *Genomics Data*.

Williams, N. (2014). Deactivation of Oospores of Phytophthora Taxon Agathis – Phase 2.

3. Peter Lockhart (Massey University and the BioProtection Research Centre), non-KDB Programme funding

Update 28/10/15: Richard has now assembled the mitochondrial genomes of six isolates of PTA – and there appears significant genetic diversity among these, suggesting it should be possible to develop strain specific LAMP primers which could be used to monitor spread of specific strains. With Trish McLenachan, Richard has developed highly selective LAMP primers for 3 mitochondrial genome regions of PTA. These show no cross-reactivity to closely related species of *Phytophthora*, and are ready for field testing.

Richard has also used these scripts and other software to assemble and compare the mt genomes of two strains of *Phytophthora agathidicida* (PTA) and closely related species also in clade V (*P.cocois, P.castaneae, P.heveae).* These 5 mt genomes have been annotated and are in a state ready for submission to Genbank. The mt genome of PTA shows some rearrangement with respect to the mt genome of other *Phytophthora* species (see Fig 1.). It shows more than 600 substitutions with respect to its closest sequenced relative (and ~ 30 indels different, the larger indels are between 15-30 nucleotides in length). There are 18 substitutions differences and 7 indel (one 15 nucleotides long, the others shorter) differences between the mt genomes (~37 kb) of the two accessions of PTA that have been sequenced. The extent of these genetic differences give us confidence that we can develop specific DNA amplification diagnostics for detection of PTA and also other *Phytophtora* species based on mt genomes. Richard and Trish McLenachan (research technician in our lab) have begun designing LAMP primers specific to PTA.

Update 28/10/15 Data will be obtained from two final Illumina sequencing runs co-ordinated by Richard and Trish to close off projects. We have one Illumina MiSEQ run which will proceed in the next few weeks – sequencing templates have already been prepared and will be delivered to NZGL tomorrow (on 29/10/15). On this run will be 2 further accessions of PTA, *P. cryptogea, 2 x P. palmivora, 1 x P. colocasiae.* One further sequencing run is then anticipated (we may use Novogene so that it can proceed in December). This will include final PTA samples for comparative analysis and publication, samples from keygene industries (infected beet and lettuce), root knot nematodes and a further sample of *Didymosphenia.* We anticipate quality publications on PTA in New Zealand and also the evolution and emergence of *Phytophthora* pathogens. The later is possible because Richard has been able to make use of publically available raw reads to assemble mitochondrial genomes from representatives all clades of *Phytophthora.* Assembled and annotated genomes (these are publication ready) include those for 2 x *P. cinnamon*, 2 x *P. kernoviae*, 2 x *P. multivora*, 2 x *P. pluvalis*, 2 x *P.* taxon *Totora*, 2 x *P. parasitica*, 1 x *P. chlamydospora*, 2 x *P. cocois*, 1 x *P. heveae*, 1 x *P. castaneae.* We believe there is the opportunity here with these data and our other data we have determined for a high impact publication co-authored by researchers from all contributing NZ and overseas research institutions. These data additionally provide a genomic resource for developing LAMP primers for a range of *Phytophthora* pathogens that impact forestry and agriculture. Our priority for the remaining three months on the contract is to bring to fruition the anticipated publications and primer sets for *Phytophthora* species.

4. Bruce Burns (University of Auckland) KDB and non-KDB Programme funding

Hi Ian and Amanda,

Thanks for your email and requests. This will have to be a quick response as I've ended up on a jury for the next two weeks which is going to put me behind. I was asked to produce a briefing on University of Auckland kauri dieback research in February this year which I have attached. I also organised a meeting in Auckland of a range of people to discuss ecological and physiological research needs for the Kauri Dieback programme in April - the result of that (structured by the Kauri Dieback Programme Strategy) is also attached.

I can think of four other things to mention:

1. The establishment of monitoring plots by myself and George Perry is ongoing.

2. A paper on kauri mycorrhizae, first authored by Maj Padamsee has been revised and has been resubmitted to Fungal Biology for further review

3. I have a MSc student, Jessica Ryder, just started who will work on whether P. agathidicida has a wider host range than just kauri.

4. I have another MSc student, Vivian Han, working on comparisons of the root fungal community between kauri roots infected and not-infected by kauri dieback.

Hope this material is helpful.

Regards

Bruce

Briefing on kauri dieback research at University of Auckland and relationship to other providers

Overview of research portfolio
Current research on kauri dieback at the University of Auckland is largely focused on:

- understanding the fundamental ecology and physiology of kauri (*Agathis australis*), and
- assessing the resilience of kauri forest to kauri dieback disease caused by *Phytophthora* 'taxon Agathis' (PTA; about to be named *Phytophthora agathidicida*).

This research is by nature medium to long-term in its scope as kauri forest grows and changes slowly, but it is of high importance as it underpins effective management of these ecosystems and the development of an effective response to the PTA disease itself. Social research exploring public adoption of kauri dieback biosecurity measures is also underway.

Specific projects include:

1. *How does PTA impact kauri populations and associated forest communities?* We have been establishing long-term monitoring plots in both PTA infected and uninfected forest to follow kauri response to PTA. The long-term information derived from these plots will help us to answer the following questions:
    a. Does PTA infect and kill all kauri individuals in a stand? Are any kauri individuals resistant to the disease within populations?;

b. How quickly does PTA move through a stand? And what 'spatial fingerprint' does it leave?;
c. Are there other plant species that are hosts to PTA in kauri forests?
d. What species are advantaged by PTA? What will the composition of forests replacing PTA-infected kauri stand be?

The data collected from these plots will also be used to develop numerical models of kauri populations to evaluate the long-term population response of kauri to PTA in natural forest. Some first steps in exploring some of these issues were undertaken in Monique Wheat's MSc thesis (2011).

2. *Does kauri dieback affect ecosystem services of kauri forest?*
   The dieback of kauri will have considerable long-term impacts on forest ecosystem functions and the provisioning of services such as carbon, water and nutrient cycling and forest health. A recent MSc thesis (van der Westhuizen, 2014) showed that tree growth, litter fall and the amount of throughfall differed between healthy and infected kauri trees. Ongoing research (Padamsee et al. 2015) is investigating changes in fungal communities in kauri leaf litter and their flow-on effect on litter decomposition and nutrient cycling. Research on dissolved organic matter chemistry and bioavailability is planned for 2015 to determine the effect of kauri dieback on the water quality in the water supply reservoirs (e.g. algal blooms).

   Long-term assessment of ecosystem processes is crucial if we are to understand the resilience of kauri ecosystems; estimate the future carbon sequestration potential of affected stands; assess the impact on water supplies in affected areas; evaluate the susceptibility/resistance of forest stands to *Phytophthora* and other plant pathogens; and develop strategies for disease containment and management.

3. *Effects of drought on kauri as a potential exacerbator of kauri dieback*
   A Marsden-funded project is exploring the physiology of drought in kauri trees. PhD student Julia Kaplick is measuring water use and carbon dynamics in kauri and associated species to determine what mechanisms these trees use to survive drought. Alongside other environmental pressures drought is likely to be a synergistic stressor that could exacerbate PTA impacts across broad areas.

4. *Can kauri mycorrhizae influence or prevent PTA?*
   Mycorrhizae are beneficial fungi that invade plant roots and form a symbiosis that assists plant nutrition. In some plants, mycorrhizae can assist plants to combat or resist plant diseases including *Phytophthora*. PTA acts against kauri roots, so the interaction between kauri mycorrhizae and PTA may be crucial to understand. However, we don't even know which mycorrhizae occur within kauri. This project has started by trying to identify the mycorrhizal species that occur with kauri. So far, we have DNA evidence of four previously unknown species of mycorrhizal fungus (Padamsee et al. submitted) that occur within kauri roots and are working to find out more about what they are and how they function. Further research would challenge kauri inoculated with these fungi with PTA to see whether they impart some form of resistance.

5. *What genetic variation occurs within and between kauri populations?*

A small research project to Ben Potter (PhD student) is analysing the level of genetic variation in kauri across its range. Preliminary results suggest that the genetic variation across the range of kauri is surprisingly small and suggests a genetic bottleneck occurred during past glaciation events. Understanding genetic structure is important in identifying any potential genetic refugia for the species (e.g. local/isolated populations with high resistance).

6. *Influencing public compliance to kauri dieback control measures*
   Research on what influences whether people comply with biosecurity measures to control kauri dieback (e.g. use of trigene stations) and how to change that behaviour for positive outcomes is also occurring at the University. An MSc student (Simon Wegner) carried out surveys and interviews with the public, analysed what motivated people to use trigene stations or not and developed key recommendations for managers to improve compliance.

Relationship to existing kauri dieback programmes
Despite the research described above being strongly prioritised by the MPI-led kauri dieback response programme (see Appendix) and by their Technical Advisory Committee (University of Auckland staff sit on this committee), only a small grant ($15,000) to a PhD student, Ben Potter has occurred to date. No formal partnerships exist with the SCION programme (Healthy Trees, Healthy Future) either, i.e. *no* funded contracts exist. As the research we are undertaking is still considered high priority, we have hoped that the MPI programme would eventually provide some funding support, but this hasn't occurred yet and there is no indication that it will. We have been fortunate (and grateful) to receive small amounts of funding and some support in kind for graduate students and summer interns from Auckland Council.

Engagement with the kauri dieback research community
Nevertheless, University of Auckland researchers are strongly embedded in the kauri dieback research community. Two (Bruce Burns and Marie McEntee) are currently members of the Technical Advisory Committee of the Kauri Dieback Response Programme. They and other researchers have regularly presented at Kauri Dieback Symposia (2013 and 2015) and the University of Auckland is listed as a collaborator with the SCION Healthy Trees, Healthy Future programme (http://healthytrees.co.nz/about-the-programme/research-partnerscollaborators/). SCION is planning on using some of our monitoring plots in their search for genetic resistance to the disease among kauri. In recent years, Auckland University staff have supervised 5 MSc and 2 PhD students on topics related to dieback.

Recent University of Auckland kauri dieback-related research outputs:

Burns BR 2013: *Kauri - natural ecology of an extreme species*. Presented at Auckland Conversations: Keep Kauri Standing - Kia Toitū He Kauri, Auckland Museum, Auckland. 6 August 2013.

Burns BR 2013: *The kings (and queens) of the forest: kauri biology and kauri forest ecology*. Presented at Kauri Dieback Symposium 2013, University of Auckland. 30 November 2013.

Burns BR, Perry, GLW 2013: *Ecology and epidemiology of Phytophthora 'taxon Agathis' in kauri forest*. Presented at EcoTas13, 5th joint conference of New Zealand Ecological Society and Ecological Society of Australia, Aotea Centre, Auckland, New Zealand.

24 November - 29 November 2013. http://www.kauridieback.co.nz/media/video-footage/kauri-dieback-symposium-talk-6

Krull CR 2012: The ecological impacts of the feral pig (*Sus scrofa*) in the Waitakere Ranges. Unpublished PhD thesis, University of Auckland.

Krull CR, Waipara NW, Choquenot D, Burns BR, Gormley AM, Stanley MC (2013). Absence of evidence is not evidence of absence: Feral pigs as vectors of soil-borne pathogens. *Austral Ecology 38*(5): 534-542

Mcentee M 2013: *The Challenge of communicating complexity*. Presented at Kauri Dieback Symposium 2013, University of Auckland. 30 November 2013

Mcinnes-Ng C 2015: Kauri and drought: lessons from summer 2013. Kauri Dieback Symposium 2015, 14 February, Hokianga, New Zealand

Padamsee M, Ajithkumar P, Schwendenmann L, Bellgard S 2015: Does the fungal community in kauri leaf litter change after invasion by a pathogen? 19th Annual New Zealand Phylogenomics Meeting, 1-6 February 2014, Portobello, Otago, New Zealand

Padamsee M, Johansen R, Stuckey A, Williams S, Hooker J, Burns B, Bellgard S submitted. The arbuscular mycorrhizal fungi colonising roots and root nodules of New Zealand kauri *Agathis australis. New Phytologist.*

Randall S 2011: The development of a stream-based sampling method for *Phytophthora* in New Zealand kauri-broadleaf podocarp rainforests. Unpublished MSc thesis, University of Auckland.

Schwendenmann L, van der Westhuizen D, Althuizen I, Macinnis-Ng C, Perry G, Waipara N 2013: Impacts of kauri dieback on key ecosystem processes. Kauri Dieback Symposium. 30 Nov 2013. Auckland.

Van der Westhuizen D 2014: Ecosystem processes within a *Phytophthora* taxon Agathis (PTA) affected kauri forest. Unpublished MSc thesis, University of Auckland.

Van der Westhuizen D, Althuizen I, Macinnis-Ng C, Perry G, Waipara N, L Schwendenmann L 2014: Microclimate and ecosystem processes within a *Phytophthora* Taxon Agathis (PTA) affected kauri forest. New Zealand Ecological Society Meeting. 16-20 November 2014. Palmerston North, NZ.

Van der Westhuizen D, I Althuizen I, C Macinnis-Ng C, G Perry G, N Waipara N, L Schwendenmann L 2013: The effects of Phytophthora Taxon Agathis (PTA) on kauri forest ecosystem processes. 5th joint NZ Ecological Society and Ecological Society of Australia. 25-29 Dec 2013. Auckland. http://www.kauridieback.co.nz/media/39244/ecosystem%20effects%20poster-%20donald%20van%20der%20westhuizen.pdf

Wegner S 2014: Factors influencing public responses to kauri dieback control measures. Auckland University report to Kauri Dieback Response Team http://www.kauridieback.co.nz/media/43703/kauri%20dieback%20forest%20visitor%20report%20-%20simon%20wegner.pdf

Wheat M 2011: *Exploring* Phytophthora *taxon Agathis* associated kauri dieback in the Waitakere Ranges using dendrochronology and spatial analysis. Unpublished MSc thesis, University of Auckland.

Wyse S 2013: The role of New Zealand kauri (*Agathis australis*) in structuring forest community composition. Unpublished PhD thesis, University of Auckland.

Wyse SV, Burns BR 2013: Effects of *Agathis australis* (New Zealand kauri) leaf litter on germination and seedling growth differs among plant species. *New Zealand Journal of Ecology*, *37* (2), 178-183.

Wyse SV, Burns BR, Wright SD 2014: Distinctive vegetation communities are associated with the long-lived conifer *Agathis australis* (New Zealand kauri, Araucariaceae) in New Zealand rainforests. *Austral Ecology*, *39* (4), 388-400.
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Research agenda for ecological research relevant to the Kauri Dieback National Strategy

1. Long term monitoring of PTA and kauri health
    a. Strategic goals:
        i. Implement long term monitoring methods to assess impact of PTA on kauri and kauri ecosystem
        ii. Undertake taxonomic and ecological assessments to determine presence of bioindicators of forest health
    b. Research questions
        i. How does PTA affect recruitment, mortality and fecundity of kauri populations? Is there any variation by size or age classes? Can we model kauri population dynamics under PTA?
        ii. If kauri is lost, what type of forest will replace a PTA-infected kauri stand? Which species are dependent on kauri for survival and what mechanisms drive associations of particular species with kauri?
        iii. What are the ecosystem consequences of the disease, e.g., changes in biodiversity, carbon storage (productivity), decomposition rates, nutrient cycling?
        iv. Is PTA host-specific or does it infect other species?
    c. :Research approaches recommended:
        i. Establish a set of permanent monitoring plots across representative kauri ecosystems including infected and uninfected plots and follow over time. Monitor kauri population dynamics, composition, growth rates, and structure. Use to populate population and community models.
        ii. Identify potentially susceptible plant species that occur in kauri forest based on phylogenetic relatedness to known *Phytophthora*-susceptible species and by field survey. Expand range of host testing based on these species.

2. Epidemiology and impact of PTA on iconic trees in old growth and other forest
    a. Strategic goals:
        i. Undertake tree and soil health assessments and sampling in old growth and other kauri to evaluate epidemiology and impact to iconic trees
    b. Research questions:
        i. What is the infection process by which PTA invades kauri?
        ii. How do kauri root systems work and grow (particularly fine roots)?

iii. What is/are the function/s of kauri root nodules?
iv. How does kauri respond to physiological stress, e.g. drought? Can such responses be used to increase the resilience of kauri to PTA?
v. How does PTA kill kauri? Is kauri killed by its own immune response?

c. Research approaches recommended:
i. Follow physiological responses of individual trees to infection including root and stem function, and determine the process by which kauri resin is produced in response to infection.
ii. Determine the physiological response of kauri to phosphite injection and why this is successful. What is different about phosphite-injected trees?

3. Impact of PTA on kauri soil ecosystem
a. Strategic goals:
i. Identify the role, diversity and impact of kauri mycorrhizae on PTA infection
ii. Develop methods to quantify the impacts of PTA on the kauri soil ecosystem
iii. Characterise kauri soil ecosystem to identify bioindicators of PTA infection

b. Research questions:
i. What is the soil biota of kauri with and without PTA, e.g. mycorrhizae, soil fungi, bacteria?
ii. What is the interaction between kauri soil biota and PTA?
iii. Does any native soil biota provide any antagonistic effects against PTA?
iv. Do mycorrhizae facilitate or reduce infection of PTA?
v. What other *Phytophthora* species (or other disease organisms) occur in kauri forest and does the presence of other *Phytophthora* species moderate the effect of PTA?

c. Research approaches recommended:
i. Establish the soil microbiota associated with kauri and how this changes with PTA infection.
ii. Isolate kauri mycorrhizae and challenge these cultures with PTA and other *Phytophthora* species.
iii. Compare infection rates of kauri seedlings with different mycorrhizal infections.
iv. Determine the Phytophthora community that occurs in kauri forest and its possible actions.

4. Landscape scale geospatial analysis to predict PTA spread and distribution
a. Strategic goals:
i. Undertake epidemiological and other modelling to determine abiotic and biotic factors that influence disease expression.

b. Research Questions:
    i. What is the spatial distribution of *Agathis australis*, and can we prioritise particular areas or ecosystems where we place the most effort to avoid the disease?
    ii. Is there ecological variation in susceptibility to PTA amongst kauri forest spatially or temporally? For example, is PTA only found in environmentally-stressed forests (e.g. is infection rate correlated with foliar N), forests on certain soil types or pH levels, forests under drought conditions, etc?
    iii. How is PTA dispersed at landscape and stand scales? What are the most important vectors at a landscape scale? Within a stand, are there any spatial preferences for PTA movement, e.g., downslope with water movement?

c. Research approaches recommended:
    i. Determine in greater detail the extent and variation of kauri forest in New Zealand.
    ii. Carry out an analysis of the distribution of PTA in relation to kauri distribution at the landscape scale to determine any large-scale factors related to PTA presence.
    iii. Test potential vectors for their ability to move PTA around the landscape, e.g. nursery stock, domestic cattle, etc.

5. Mahajabeen Padamsee (Landcare Research) - non KDB Programme funding

Hi Ian,

I have a couple of LCR and Univ of Auckland funded projects. One of them is the 'stuff in duff' project, which I am trying to write up this year. The other is a manuscript on AMF being reviewed by Fungal Biology.

If possible, I would be interested in reading your state of knowledge review.

Cheers.

Maj

A metagenomic analysis of the litter fungi associated with *Agathis australis* (to be presented at the NZ microbiology conference) (part of the stuff in duff work)

Mahajabeen Padamsee[1] Priyadarshana Ajithkumar[2], Luitgard Schwendenmann[2], Joseph Heled[3], and Stanley Bellgard[1]

Kauri (*Agathis australis*, Araucariaceae) is restricted in distribution to the Northern tip of the North Island of New Zealand. Living to 1,500 years or more and having trunks up to 3 m diam., *A. australis* exerts enormous influence on surrounding forest composition and structure. Individual kauri trees produce massive amounts of litter, up to 2m deep that represents a significant store of C and N and provide varying habitat niches for complex fungal communities. However, information on the diversity of fungi under *A. australis* involved in nutrient recycling is sparse. Additionally, since the 1970s these trees have been under threat from the exotic invasive pathogen, *Phytophthora agathidicida* that causes kauri dieback. We used pyrosequencing and soil analyses to investigate the kauri leaf litter fungi under asymptomatic trees and diseased trees. QIIME and UPARSE were used to assign sequence reads to OTUs. Concurrently, reads were also aligned with DNA sequences of known Southern Hemispheric Fungi to generate a phylogeny. The results give us our first glimpse at the enormous influence of *A. australis* on the fungal community and suggest what the impacts on fungal diversity might be after invasion by *P. agathidicida*.

The arbuscular mycorrhizal fungi colonising roots and root nodules of New Zealand kauri *Agathis australis* (In review, Fungal Biology)

Mahajabeen Padamsee[1], Renee B. Johansen[2], S. Alexander Stuckey[2], Stephen E. Williams[3], John E. Hooker[2], Bruce R. Burns[2], and Stanley E. Bellgard[1]

As the only endemic member in New Zealand of the ancient conifer family, Araucariaceae, *Agathis australis* is an ideal species to study putatively long-evolved mycorrhizal symbioses. However, little is known about *A. australis* root and nodular endophytes, and how mycorrhizal colonisation occurs. We used light, scanning and transmission electron microscopy to characterise colonisation, and 454-sequencing to identify the arbuscular mycorrhizal fungal (AMF) endophyte(s) associated with *A. australis* roots and nodules. Representatives of five families of Glomeromycota were identified via high-throughput pyrosequencing. Imaging studies showed that there is abundant, but not ubiquitous, colonisation of nodules, which suggests that nodules are mostly colonised by horizontal transmission. Roots were also found to harbour AMF. This study is the first to demonstrate the multiple Glomeromycota lineages associated with *A. australis* including some that may not have been previously detected.

6. Rosie Bradshaw (Massey University and BioProtection Research Centre) non KDB Programme funding

Hi Amanda,

Thanks for your email.

We have Echo Herewini's Masters project work on screening for resistance of kauri clones at Scion, and also some proposed work on effectors for the next round of the BioProtection CoRE. Pete Lockhart will also do some work on molecular evolution of Phytophthora species with some focus on PTA.

I am coming to Lincoln on wed 18 nov to give a seminar and am meeting with Mel at 3 pm - it would be great to see you as well then also if you have time. I'm keen to find out more about what you and Leo will be doing in the next CoRE project. Meanwhile if you need more detail on our projects please let me know.

Best regards

Rosie

7. Robert Hill (BioProtection Research Centre) - non KDB Programme funding

The use of native Trichoderma - currently ongoing, no tangible results to date.

8. Monica Gerth (University of Otago) - non KDB Programme funding

Plans to establish a molecule library for identifying chemical repellents for *Phytophthora agathidicida and cinammom*i

9. Stan Bellgard (Landcare Research) - receives KDB Programme funding

hi ian: the publications approved for release by the Kauri Dieback Response can be found on their website http://www.kauridieback.co.nz/publications

other reports and posters etc., (i.e. not on their website), cannot be released until approved for release by the Planning and Intelligence team (i.e. Travis Ashcroft MPI, Nick Waipara Auckland Council, Tony Beauchamp DoC).

Recently, Bevan published the species description, and we published a rt-pcr protocol in 2013.

With respect to the direction of the scientific research, this is led by the Planning and Intelligence team of the Kauri Dieback Response. it may be more apporpiate to get from them, the knowledge gaps identified by the Kauri Dieback Technical Advisory Group

Stan

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