Te Rangahau Aroturuki i ngā Rākau Rangatira o Te Wao Nui ā Tiriwa

2021 Waitākere Ranges Kauri Population Health Monitoring Survey

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Chapter 1

Long-term kauri health monitoring framework and objectives of the 2021 Waitākere Ranges Monitoring Survey

Te anga karioi e aroturuki ana
ki te hauora o te kauri
Ngā whainga o te rangahau aroturuki i ngā rākau
rangatira o Te Wao Nui ā Tiriwa

1.1 Introduction

Te whakataki

The iconic and endemic kauri (*Agathis australis*) is a dominant keystone conifer species in northern Aotearoa / New Zealand forests (Ecroyd, 1982). Kauri is also a culturally significant taonga species to Māori and highly valued by New Zealanders across its natural range from the Far North to the southern 'kauri limit' in the Waikato (Waipara et al., 2013, Lambert et al., 2018). Mature kauri typically reach around 30 m in height with a trunk diameter of up to 3 m and are known to live longer than 1000 years; however, very large trees of up to 60 m tall and a trunk diameter of up to 7 m are known (Ahmed and Ogden, 1987).

Historically, much of the Auckland region was covered in kauri forest, particularly in areas such as the Waitākere Ranges, the Hunua Ranges, northern Auckland, Awhitu Peninsula as well as Hauturu/Little Barrier Island and Aotea/Great Barrier Island. These highly biodiverse ecosystems are unique and distinct, with some species found only in association with kauri, such as the kauri greenhood orchid (*Pterostylis agathicola*).

The discovery of kauri timber being a valuable wood by settlers in the early 1800s meant that New Zealand kauri forests became the backbone of a major industry. Much of the original range of kauri was reduced in the late 19th and early 20th centuries due to timber harvesting, clearance of land for other use and fire (Steward and Beveridge, 2010). In 2010 it was estimated that only 7,500 ha of virgin kauri forest (less than 1%) and 60,000 ha of regenerating kauri forest remained of the 1,000,000 ha estimated at the time of European settlement of New Zealand (Steward and Beveridge, 2010).

1.2 The Waitākere Ranges

Te Wao Nui ā Tiriwa

Te Wao Nui ā Tiriwa / the Waitākere Ranges is highly significant as one of the largest remaining tracts of native forest in the Auckland Region. Substantial modification of the native vegetation has occurred over time. Extensive logging of native timber, particularly of kauri, occurred across the Ranges with the first logging operations beginning in the late 1830s. Land clearance for farming and horticulture also occurred with increasing settlement, mostly around coastal areas. The rugged land and poor soils made agriculture difficult, and many farms were subsequently abandoned, reverting to native scrub and subsequently were succeeded by regenerating kauri forest. Settlers also undertook flax milling, gum digging and bled kauri for gum.

The intensive deforestation of the ranges in the 1800s led to public concern and advocacy for the protection of the remaining bush. In 1895, a tract of native bush in the Nihotupu area was vested in the Auckland City Council for conservation of native flora and fauna in perpetuity. The eventual decline in logging led to many properties being abandoned or purchased by Auckland City Council for water supply in the early 1900s. In 1940, the Centennial Memorial Park was created in the Waitākere Ranges to commemorate the Auckland City centennial, covering 6400 hectares of parkland.

Today, the Waitākere Ranges Regional Park consists of more than 17,000ha of parkland. Despite the significant disturbance that occurred, it is still one of the largest areas of remaining kauri forests in Auckland and New Zealand. Kauri forests have been substantially fragmented in the rest of the Auckland region. Kauri occur in the Waitākere Ranges as mature old-growth forest, intermittently with other podocarps and broadleaf species, and dense young ricker stands in regenerating forest. The long-term survival of these remaining kauri and associated ecosystems are now under threat by kauri dieback (Beever et al., 2009).

1.3 Kauri dieback and *Phytophthora agathidicida*

Te puruheka patu kauri

Kauri dieback, a soil-borne root rot disease caused by *Phytophthora agathidicida* (Weir et al., 2015), was first reported, under the mis-identified name of *Phytophthora heveae*, causing kauri stand decline on Aotea / Great Barrier Island, in Tīkapa Moana / the Hauraki Gulf in 1974 (Gadgil, 1974) and again in Te Wao Nui ā Tiriwa / the Waitākere Ranges in 2006 (Beever et al., 2009). Since then, the disease and pathogen have been detected in most kauri forests in New Zealand (Froud, 2020, Bradshaw et al., 2020), yet both disease and the pathogen remain undetected in some areas.

Kauri dieback has been described as a lethal root rot disease for which there is no known cure (Bradshaw et al., 2020). Kauri dieback is not evident until the onset of visible above-ground symptoms which form following infection of the roots, leading to dysfunction in the outer vascular tissues of the host (Bradshaw et al., 2020). Dieback is considered to be the chronic phase of the disease, observed to progress for 1 to 10 years before tree death (Bradshaw et al., 2020).

Kauri dieback affects all size classes of kauri (Bradshaw et al., 2020). Field trials have shown that phosphite injections can halt and reverse disease progression with healing of lesions and regained canopy health (Horner and Arnet, 2020, Horner et al., 2017). However, this treatment does not eliminate the pathogen from the site and at present, neither natural nor treated recovery to a healthy state from kauri dieback is known to be present in the kauri population.

Phytophthora agathidicida, the causal agent of kauri dieback, has been classified as an Unwanted Organism under the Biosecurity Act 1993. *Phytophthora agathidicida* is believed to be an introduced pathogen, rather than native, and sits within Clade 5 of the genus *Phytophthora*, which has host and geographic associations that suggests a centre of diversity in the East Asia-Pacific region (Weir et al., 2015), and overlaps with the postulated centre of diversity of *Agathis* (Bellgard et al., 2013). Recent research into the mitogenome of *P. agathidicida* has suggested that *P. agathidicida* has potentially been present in New Zealand for several hundred years (Winkworth et al, 2021). However, kauri dieback is a relatively recently reported disease. While the primary role of *P. agathidicida* as the causal agent has been confirmed (Gadgil 1974, Beever et al. 2009, Bellgard et al. 2013), the epidemiology and the other contributing factors are still under investigation. It is thought that environmental conditions and possibly human and animal interactions affect the pathogen-host relationship and may contribute to the risk of a tree becoming symptomatic (Froud 2020). At present, there is no field evidence of *P. agathidicida* infecting other alternative host species, however infection of some native species has been observed under ideal laboratory conditions (Bellgard et al., 2013, Ryder et al., 2016).

Kauri dieback has been the subject of a joint agency biosecurity response since 2009, currently under Tiakina Kauri, a partnership programme with Māori, led by Biosecurity New Zealand (as part of the Ministry for Primary Industries) involving iwi and hapū with an interest in kauri lands, the Department of Conservation, Auckland Council, and the Northland, Bay of Plenty and Waikato Regional Councils (previously called the National Kauri Dieback Programme). Tiakina Kauri invests in kauri protection activities and aims to implement a National Pest Management Plan (NPMP) to help protect kauri from the disease caused by *P. agathidicida*.

1.4 Auckland Council kauri dieback surveillance

Te tūtei i te korenga o te puruheka patu kauri

There has been significant investment by Auckland Council on kauri protection and *P. agathidicida* delimiting surveillance over the past 12 years. To date, the objectives of kauri dieback surveillance have been to delimit the extent of kauri dieback and the presence of *P. agathidicida* in the Auckland Region (Hill et al., 2017, Hill et al., 2014, Jamieson, 2014c, Jamieson, 2014a, Jamieson, 2012b, Jamieson, 2012a, Jamieson, 2014b, Jamieson et al., 2014, Jamieson et al., 2012). The delimiting surveillance used a risk-based approach, focused on sampling trees close to the track network as well as aerial identification of kauri with canopy ill-thrift (signs of canopy decline and yellowing), followed by ground survey to confirm disease symptoms and maximise *P. agathidicida* detection. The risk-based approach was particularly useful to identify areas where symptomatic trees were highly prevalent and narrow down sites with the pathogen present.

Due to this surveillance effort, we know symptomatic kauri and *P. agathidicida* were spread across the wider Auckland region, including within Te Wao Nui ā Tiriwa / Waitākere Ranges, Āwhitu

Peninsula, and northern Auckland. Severe symptoms consistent with kauri dieback have not yet been detected in areas such as Kohukohunui / Hunua Ranges and Waiheke Island and there have been no detections of the pathogen in these areas to date either.

However, this approach resulted in one of the identified constraints of the existing kauri dieback surveillance data, in that, information on non-symptomatic trees was severely limited, particularly away from the track network to form a comparison group for epidemiological analysis (Cogger et al., 2016). Another constraint of a risk-based approach to surveillance is that prevalence of disease or pathogen detection cannot be calculated to measure change over time (Lázaro et al., 2020, Cogger et al., 2016). To measure change or risk after a pathogen has established, the baseline prevalence of disease symptoms and pathogen presence must be understood (Stevenson and Froud, 2020, Lázaro et al., 2020).

1.5 Epidemiological approach to kauri dieback

Te huarahi matai tahumaero ki te puruheka patu kauri

The delivery of a long-term disease management programme is a complex and difficult task, particularly when the disease is widespread (Hill et al., 2017), cryptic (Beever et al., 2010), has extended latency and incubation periods (Bradshaw et al., 2020, Lázaro et al., 2020) and is within a heterogeneous natural ecosystem (Froud, 2020). To manage this complexity, Auckland Council adopted an epidemiological approach to plan operational management and understand the impacts of management interventions for kauri dieback (Stevenson and Froud, 2020).

This epidemiological approach follows 8 steps as illustrated in Figure 1-1. It has been clear since 2006 that a problem exists, and the initial steps to establish a consistent case definition for kauri dieback has been completed based on existing observation and knowledge of disease expression from a range of experts (Stevenson and Froud, 2020), which will allow disease and symptoms to be recorded consistently over time. Designing a baseline survey and ongoing monitoring plan will enable us to progress through steps 2 to 6 in the short term with evidence-based and mātauranga-informed management strategies. The baseline survey will then provide a framework for steps 7 and 8 to adaptively manage kauri health over the decades and generations to come.

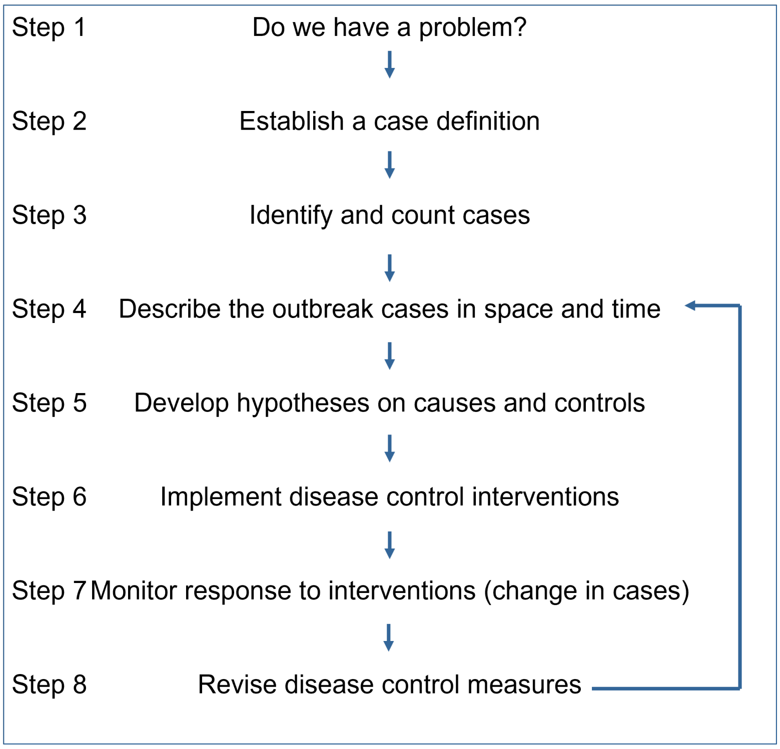

Figure 1-1. The epidemiological approach adopted for this study, showing the steps taken to investigate and manage a disease outbreak, adapted from Stevenson and Froud (2020).

The strong relationship between kauri dieback and *P. agathidicida* and pathogenicity has been demonstrated (Bellgard et al., 2016, Gadgil, 1974). A key principle of the epidemiological approach to disease management is to focus on expression of disease in the population to understand impacts on the health of the population, rather than having a pathogen-centric view. Quantifying the prevalence (the number of individuals in a defined population having a disease or a pathogen at a given point in time) of kauri dieback and *P. agathidicida,* along with other potential component causes (risk factors), can help clarify their relationship and generate hypotheses for control. Kauri dieback has an extended incubation period (the time between initial infection by *P. agathidicida* until symptoms become visible). Therefore, there will be a lag period between detection of *P. agathidicida* in soil and the detection of kauri dieback symptoms on trees if disease develops. Measuring disease symptom prevalence separately to pathogen prevalence allows a comparison of disease development over time.

The presence of *P. agathidicida* is necessary to cause kauri dieback but it is rare in nature for a single pathogen to be sufficient to cause disease in the absence of other factors. Other component causes such as a vulnerable host and environmental conditions favouring the pathogen and increasing host susceptibility (e.g., drought, rainfall, disturbances) are generally required for disease to develop (Rothman and Greenland, 2005, Martin, 2008). This is illustrated in Figure 1-2, the disease triangle, where you can see that disease (in the centre) only occurs when host, pathogen and environmental factors suitable for infection align. For a cryptic disease like kauri dieback, where many of the symptoms could have other biotic or abiotic causes, it is also useful to determine what else could be contributing to poor health in kauri where *P. agathidicida* may not be the cause.

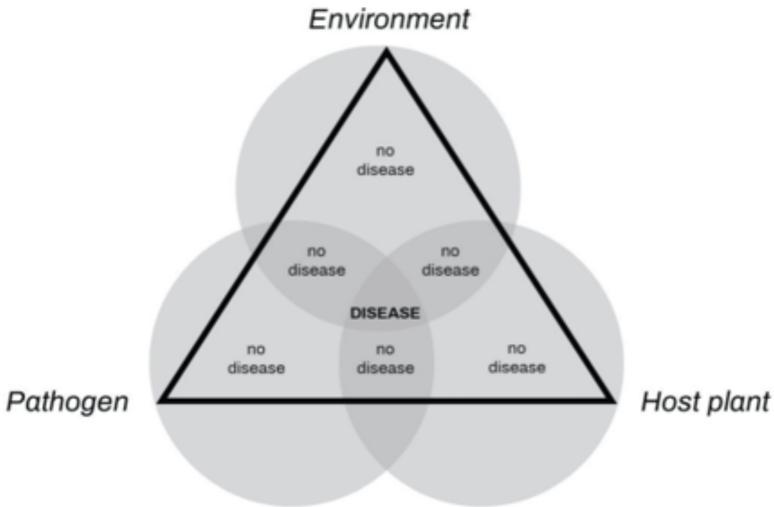

Figure 1-2. Disease triangle showing that disease only occurs when sufficient factors relating to a host, pathogen and environment (including management) intersect (Bhopal, 2016, p 136).

With the benefit of the Natural Environment Targeted Rate, Auckland Council is rescoping its kauri dieback surveillance and monitoring approach to better understand and manage kauri health.

1.6 Design of the long-term kauri health monitoring framework

Te hoahoa i te anga karioi e aroturuki ana ki te hauora o te kauri

Using the described epidemiological approach, a multi-level cascading and modular design for monitoring kauri health was developed to address four objectives:

1. To understand kauri health, pathogen prevalence, disease prevalence and other impacts in order to monitor changes over the long term.

2. To identify risk factors which are associated with disease or pathogen prevalence to inform potential management intervention options.

3. To identify ecological impact variables to provide better information on the long-term impacts of kauri dieback within the forest.

4. To understand the long-term impacts of management interventions and then focus intervention efforts on those identified as effective.

The long-term kauri dieback monitoring framework was developed through co-design hui with mana whenua o Tāmaki Makaurau, which included further discussions with mana whenua representatives of Te Kawerau Iwi Tiaki Trust, Pou Tāngata Ngāi Tai ki Tāmaki Community Development Trust, Ngāti Paoa Iwi Trust Board, Ngāti Whanaunga Incorporated Society, Ngā Maunga Whakahii o Kaipara Trust, Te Ākitai Waiohua Waka Taua Inc, Ngāti Maru Rūnanga Trust and Environs Te Uri o Hau. The framework acknowledges that mātauranga Māori will also contribute to measuring forest health and intervention efficacy outside/alongside this monitoring framework.

The design of this monitoring framework was based on core epidemiology surveillance approaches; in particular the application of an observational study design using a repeated cross-sectional study (Dohoo et al., 2009, Cogger et al., 2016), the baseline monitoring recommendations of Stevenson and Froud (2020) and significant progress in applicability of remote sensing from Meiforth (2020), Meiforth et al. (2020). It was also informed by reviewing the last 10 years of kauri dieback surveillance, particularly contributions from Tiakina Kauri Partners, Planning and Intelligence team members and the Technical Advisory Group and research from Ross Beever, Stan Bellgard, Ian Horner, Margaret Dick, Nick Waipara, Nari Williams, Tony Beauchamp, Lee Hill, Alastair Jamieson, Andrew Macdonald, NRT integrated surveillance workstream members and many others (Froud, 2020, Black and Dickie, 2016, Bradshaw et al., 2020).

The use of an observational study design, such as a cross-sectional study is most appropriate when an experimental design is not feasible (Froud and Cogger, 2015, Dohoo et al., 2009a) for reasons including:

(i) Risk factors are not easily manipulated in the field for practical (difficult to implement), ethical (kauri is a slow-growing and threatened endemic species) or economic reasons.
(ii) The disease cannot be practically manipulated in field trials, such as controlled pathogens during a biosecurity incursion (*P. agathidicida* is an Unwanted Organism under the Biosecurity Act 1993).
(iii) Interactions between multiple factors are of interest but are too complex to manipulate experimentally, such as complex native ecosystems.
(iv) Some factors of interest cannot practically be manipulated experimentally, e.g. soil type, temperature, distance to waterways and elevation.
(v) Where disease is multi-factorial and not all potential causative factors of a disease outbreak are known, and the aim is hypothesis generation.
(vi) When large-scale management interventions have been applied and their efficacy needs to be quantified.

In the case of kauri dieback in natural indigenous forest, all these reasons are relevant.

Three key components form the basis of the monitoring framework as illustrated in Figure 1-3.

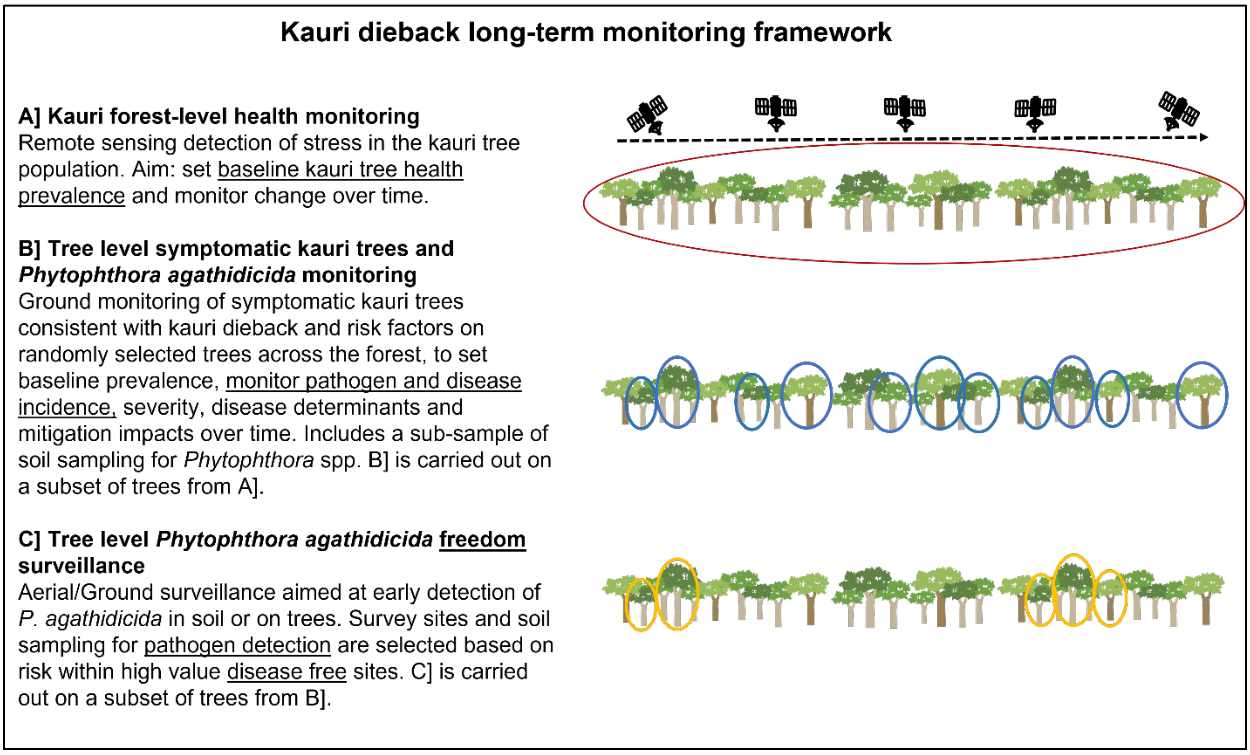

Figure 1-3. Proposed long-term kauri health monitoring framework.

The modular design of the framework means that the same methodologies and three-level system may be applied at different scales, whether at a regional or national level, if deemed appropriate. This could be within a single kauri forest, or across multiple kauri forests and kauri forest remnant areas. It may also be adapted to include possible alternative hosts if host detection methods are developed for them and could be adapted to other canopy tree species such as *Myrtaceae* or for assessing full forest ecosystem health.

The proposed monitoring framework will be rolled out over time as the methods required to deliver it are refined. In particular, the A and C levels require additional knowledge before they can be implemented.

1.1.1 (A) Kauri forest-level health monitoring

Kauri forest-level health monitoring is aimed at early change detection of canopy stress symptoms in kauri. It may help to reduce the reliance of future monitoring on intensive ground surveys. This is underpinned by new remote sensing host detection methods which were applied in the 2021 Waitākere Ranges survey and are described in Chapters 2-5 of this report. Validation of stress detection and the setting of a consistent stress index is required before a baseline can be set and the steps to deliver this are detailed in the future steps section of this report (Chapter 6).

1.1.2 (B) Tree-level symptomatic kauri and *P. agathidicida* monitoring

The roll out of tree-level symptomatic kauri trees and *P. agathidicida* monitoring was applied in the 2021 Waitākere Ranges Regional Park survey and uses a repeated cross-sectional study design

(Diehr et al., 1995). This is a type of observational study that measures disease prevalence (or another outcome) in a population at a point in time and is often referred to as a prevalence study. A cross-sectional study can also measure potential disease determinants (risk factors) and ecological impacts. A repeated cross-sectional study is a study in which the same group of trees is examined at different time points with the prevalence of disease estimated on each occasion (Diehr et al., 1995). The results of the study are described in Chapter 2 of this report and the steps to deliver ongoing tree level monitoring across Tāmaki Makaurau are detailed in the future steps section (Chapter 6).

1.1.3 (C) Tree-level *P. agathidicida* freedom surveillance

Tree-level *P. agathidicida* freedom surveillance is carried out to quantify confidence that kauri dieback is absent from areas thought to be free of disease. The most efficient way to conduct a proof of freedom study is to use a risk-based approach where search effort is (logically) concentrated on individuals where the probability of disease is thought to be high. An initial investigation to identify risk factors for kauri dieback was undertaken in the 2021 Waitākere Ranges survey and the results are described in Chapter 2. In addition, the diagnostic test performance parameters of any tests used to detect the pathogen need to be quantified to calculate the number of trees to be tested and found to test negative to quantify confidence in disease freedom. A study to evaluate the Auckland Council visual assessment of disease and soil bioassay tests to detect *P. agathidicida* was also conducted as part of the 2021 Waitākere Ranges survey. The results of this study are described in Chapter 4 of this report.

1.7 2021 Waitākere Ranges monitoring survey

Te rangahau aroturuki i ngā rākau rangatira o
Te Wao Nui ā Tiriwa 2021

The year 2021 marks the third time Auckland Council has surveyed the Waitākere Ranges Regional Park for kauri dieback disease. However, this is the first time that an epidemiological approach has been used. Baseline monitoring provides a reference point to which future estimates of kauri dieback prevalence and *P. agathidicida* prevalence can be compared.

For the 2021 Waitākere Ranges survey, the detailed design, delivery and analyses of data occurred in partnership with Te Kawerau ā Maki, mana whenua and kaitiaki of Te Wao Nui ā Tiriwa / the Waitākere Ranges. This research supports the 2012 Auckland Council Indigenous Biodiversity Strategy's vision of He taonga, ka whaihua ngā rerenga ke o te Ao Tūroa i Tāmaki Makaurau (Auckland’s indigenous biodiversity is flourishing and treasured).

The next steps of this epidemiological approach are to implement steps 2 through 5 (Figure 1-1) using a single cross-sectional prevalence study. The 2021 Waitākere Ranges survey was designed as one survey with three inter-related studies. The objectives for these three studies were:

1. Prevalence study – to identify and count the number of symptomatic trees (Step 3) and describe the prevalence and spatial distribution of symptomatic kauri and of *P. agathidicida* at a point in time (Step 4). This is described in Chapter 2.
2. Risk factors study – to generate and test hypotheses of why some trees are at greater risk of disease compared to others and whether any additional control interventions could be applied (Step 5). This is described in Chapter 3.
3. Test performance study – to quantify the diagnostic test performance of visual assessment of symptomatic kauri trees consistent with kauri dieback and our soil sampling bioassay to detect *P. agathidicida.* This is described in Chapter 4.

The test performance study supports the epidemiological approach. A knowledge of diagnostic test performance allows 'apparent pathogen prevalence' estimates to be converted to 'true pathogen prevalence' estimates. This allows prevalence estimations to be compared for different populations and over different time frames using different diagnostic tests (if they are available). This is important because it is likely that new (improved) diagnostic tests for kauri dieback will become available in the coming years and there will be a need to ensure that the pathogen prevalence estimates derived using older test procedures are comparable with those derived from newer test procedures.

These three studies will provide evidence to inform management strategies and interventions (Step 6) and provide baseline data to measure change in disease and efficacy of control measures in the future (Step 7) alongside mātauranga Māori measurements of forest health and intervention efficacy.

These three studies are reported as separate chapters within this technical report, with different co-authors, based on specific expertise. The three studies are written in the format of scientific manuscripts which supports the Auckland Council commitment to a robust study design and peer review of methodological approaches and study inference.

The methods for the three studies within the 2021 Waitākere Ranges survey were co-designed with mana whenua, subject matter experts and then peer reviewed by international experts prior to field work. Each study has a specific introduction which goes into more detail of the study and specific discussions of the results and builds on the methods and knowledge of each other.

On completion of writing, the three studies were sent for final expert review to international experts. This full report concludes with a section that weaves together the new knowledge gained from these three studies and provides a strategy for implementation of the long-term monitoring framework for kauri dieback in the Tāmaki Makaurau region.

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