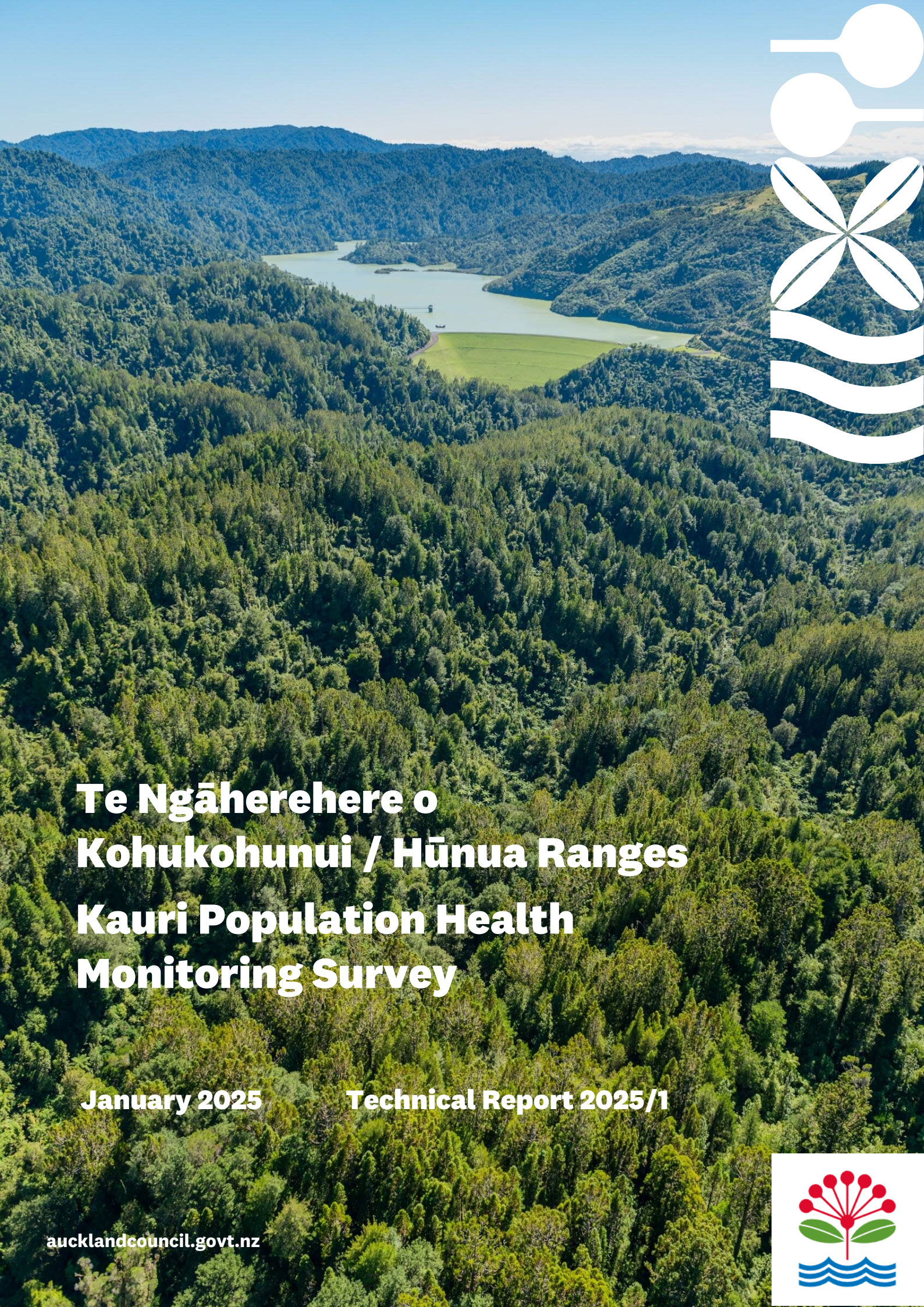


Te Ngāherehere o Kohukohunui / Hūnua Ranges Kauri Population Health Monitoring Survey

January 2025 Technical Report 2025/1

aucklandcouncil.govt.nz

Te Ngāherehere o Kohukohunui / Hūnua Ranges Kauri Population Health Monitoring Survey

January 2025 Technical Report 2025/1

Karyn Froud[1], Yue Chin Chew[2], John M. Kean[3], Jane Meiforth[2], Hugo Geddes[2], Alastair Jamieson[2], Eddie Manukau[7], Martin Te Moni[6], Zaelene Maxwell-Butler[4], Gavin Anderson[6], Lisa Tolich[2], Edith Tuhimata[5], Isabella Penrose[4], Suliana Teasdale[8], Jess Le Grice[2], Miranda Bennett[2], Sarah Killick[2]

[1]Biosecurity Research

[2]Auckland Council

[3]AgResearch

[4]Ngāi Tai ki Tāmaki

[5]Ngāti Tamaoho

[6]Ngaati Whanaunga

[7]Ngāti Tamaterā

[8]Department of Conservation

Auckland Council

Technical Report 2025/1

ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-991146-92-2 (Print)
ISBN 978-1-991146-93-9 (PDF)

The Peer Review Panel reviewed this report

Approved for Auckland Council publication by:

Phil Brown
Acting General Manager, Environmental Services | Community Directorate

Sarah Killick
Principal Advisor Biosecurity, Environmental Services | Community Directorate

Date: 24 January 2025

Recommended citation

Froud, K., Y.C. Chew, J. Kean, J. Meiforth, H. Geddes, A. Jamieson, et al, S. Killick. (2025). Te Ngāherehere o Kohukohunui / Hūnua Ranges kauri population health monitoring survey. Auckland Council technical report, TR2025/1

Image credits

Front cover: Kauri forest in the Kauri Stream catchment, with Hūnua Ranges and Mangatangi Reservoir. Photo: Alastair Jamieson.

Back cover: Kauri forest in the Mangatāwhiri catchment, southern Hūnua Ranges. Photo: Alastair Jamieson.

Executive summary

Kauri dieback disease and the pathogen *Phytophthora agathidicida* (*P. agathidicida)* have been detected in most regions where kauri grow in Aotearoa New Zealand. Once established in a forest system, the pathogen cannot be eradicated and infection often results in the death of kauri trees.

Auckland Council has made significant investments into both kauri protection and *P. agathidicida* delimiting surveillance since 2009. In 2021, the Waitākere Ranges Kauri Population Health Monitoring Survey determined pathogen and disease prevalence across the kauri population and set a baseline for future assessment of change. The 2023 Te Ngāherehere o Kohukohunui / Hūnua Ranges Kauri Population Health Monitoring Survey was similarly designed to survey for symptoms of kauri dieback disease and monitor kauri health and had the additional aim of establishing whether *P. agathidicida* was present in the Hūnua Ranges.

The Hūnua survey was co-designed by Auckland Council, Department of Conservation, and ngā iwi mana whenua o Te Ngāherehere o Kohukohunui Ngāi Tai ki Tāmaki, Ngāti Tamaoho, Ngaati Whanaunga, and Ngāti Tamaterā.

We collected baseline kauri tree health, kauri dieback disease symptoms, potential risk factors, and ecological impact factors, and conducted soil testing for 561 kauri trees. We also conducted LAMP (Loop Mediated Isothermal Amplification)-based stream baiting in 20 stream locations within the study area. We found no evidence of *P. agathidicida* in the Hūnua Ranges and the extent of testing gives us 97-99.9 per cent confidence that we would have detected it in the study area if present at a prevalence of 1 per cent or more. This confidence is extremely important for informing ongoing forest management between all partners and landowners in Hūnua.

More than 95 per cent of the kauri surveyed were very healthy. More than 92 per cent of sites surveyed had seedlings or saplings beneath the monitored trees, indicating a healthy population with good recruitment. This was a much higher rate than the 55 per cent of sites observed in the 2021 Waitākere survey.

Kauri appear to be more prone to poor health in places that have been disturbed and these trees may be more vulnerable to disease in the event of *P. agathidicida* introduction. In Waitākere, the detection of *P. agathidicida* was strongly associated with historical and contemporary disturbance events, and in those places, kauri are in poor health and many are dying. The results of both studies suggest that minimising disturbance to the forest, especially to kauri root systems, is important for kauri health and general resilience.

We have successfully built a risk profile for Hūnua that identifies areas of highest risk for future introduction or detection of *P. agathidicida*, enabling partners to target introduction and subsequent spread prevention. This will also inform protected areas strategies around identified high-risk areas.

We now have a baseline of kauri health which can be used for ongoing monitoring, considering both the risk of introducing *P. agathidicida* and the detection of other potential impacts on kauri.

Monitoring current kauri health is essential to track any change over time and allow adaptive management. Long-term health monitoring will also help us determine how other factors affect kauri health, such as land use, environmental management, and climate change.

Ngā iwi mana whenua o Te Ngāherehere o Kohukohunui advocate for rāhui should *P. agathidicida* be detected and support ongoing monitoring, cleaning stations, pest control and exploring other initiatives to ensure the Hūnua Ranges remain free of *P. agathidicida*.

In conclusion, we did not detect *P. agathidicida* in the Hūnua Ranges, and the kauri population in areas of low disturbance are in good health. As most other large kauri forests have *P. agathidicida* infection, this study has highlighted the importance of the Hūnua Ranges for kauri protection. Long-term monitoring of kauri in Hūnua is critical for adaptive management and to prevent pathogen spread within-forest, should the establishment of *P. agathidicida* occur.

Mihi

Ka kohukohu nui te poho o Te Ngāherehere o Kohukohunui
Ko Kōiwiriki nō tuawhakarere
Rātou mā i te pā whakairo ā ō tātou tūpuna
Kauri mate ki te pō
Ka hoki ki te ahikā ā Te Hūnua
Kauri ora ki te ao.

Behind the veil of Te Ngāherehere o Kohukohunui
Our ancestor Kōiwiriki from the ancient times
They who are carved into our memories
Our taonga shrouded within the darkness
We return to the warmth and heart of Te Hūnua
Our taonga flourishing.

Acknowledgements

Ngā mihi

We acknowledge the detailed and ongoing discussion with and sharing of their mātauranga of Ngāi Tai ki Tāmaki, Ngāti Tamaoho, Ngāti Te Ata Waiohua, Ngaati Whanaunga, and Ngāti Tamaterā first and foremost as mana whenua and kaitiaki of Te Ngāherehere o Kohukohunui/ the Hūnua Ranges. We acknowledge the treaty settlements of Ngāi Tai ki Tāmaki, Ngāti Tamaoho, Ngāti Te Ata Waiohua, Ngaati Whanaunga and Ngāti Koheriki to Te Ngāherehere o Kohukohunui.

Thank you to Dr Emilie Vallee for expert opinion and review of our sample size calculations and pathogen freedom analysis.

We thank everyone who shared their expertise with us in different workshops and hui as we developed our survey methods and identified potential risk factors for inclusion in the study. Thank you to Professor Bruce Burns from the University of Auckland who helped compile the common species list for Hūnua. We would also like to thank Lee Hill and Fredrik Hjelm from BioSense who helped refine the monitoring form. Thank you to the Auckland Council Corporate Records and Archives team as well as the National Forestry library at Scion for providing historical material. Thank you also to the Southern Parks team, Kerry O'Connor and Ian Barton for providing historic knowledge to help build risk maps.

Many thanks to kaitiaki Analisa Rawiri and Rangimahora Rawiri from Ngāti Tamaoho, Anaru Kingi from Ngāi Tai Ki Tamaki, and Stuart Renata, Hautu Martin and Mokopuna Graham from Ngaati Whanaunga. Many thanks also to Alysha Jurgeleit, Ben Yorke, Elijah McDean, Fredrik Hjelm, George Wilson, Marcel Kerrigan, Olivia Hossin, Sean Thomson and Lee Hill from BioSense; as well as Adam Brown, Andrew Kokiousis, Ben Lavin, Cristabel Godoy, Grace Colmer and Jeff Willis from the Department of Conservation, our survey field team members who spent many long days in the bush collecting our field data.

We also thank the Plant & Food Research Ltd Havelock North, Ampersand Technologies, and BioSense Limited pathology teams who processed the soil samples.

Thank you to James Shepherd and Jan Schindler from Manaaki Whenua Landcare Research who contributed to the remote sensing host detection research.

Thank you also to the Te Ngāherehere o Kohukohunui / Hūnua Ranges Monitoring Survey steering committee members for excellent advice throughout the design, delivery, analysis and reporting of the survey.

We thank the private landowners surrounding the ngahere, many of whom provided access to their property for survey and for easier access to the forest. Thank you to everyone who, through actions large and small, have protected the wellbeing of this ngahere.

We gratefully acknowledge the ratepayers of Auckland who provided funding for this study via the Natural Environment Targeted Rate, without which this work would not have been possible.

Contents

Te ripanga ihirangi

Figures

He ripanga mō ngā tau

Tables

He ripanga mō ngā ripanga hoki

Glossary of te reo Māori

Te Rārangi Kupu Māori

The list below defines Māori terms and concepts used within the text.

Hapū	Subtribe, the primary political unit in traditional Māori society
Hui	Meeting
Iwi	Tribe comprising a number of hapū (subtribes) related through a common ancestor and associated with a distinct territory
Kaitiaki	Guardians
Kaitiakitanga	Guardianship. The practice of looking after the environment, rooted in tradition
Kauri ora	Kauri health
Mātauranga Māori	The body of Māori knowledge; referring to all things physical, emotional and spiritual in a Māori context
Moana	Sea
Mana whenua	Territorial rights, power over the land / by extension: Māori who have customary authority over land through ancestral links
Ngahere	Forest
Puruheka	Pathogen
Rāhui	A temporary ritual prohibition to restrict access and separate people from things that are tapu; for example, the prohibition placed by Te Kawerau ā Maki on Te Wao Nui ā Tiriwa as a measure to protect and restore balance to the forest
Rākau	Trees
Rākau rangatira	Chiefly trees
Tapu	Sacred or prohibited
Taonga	A treasured item
Tikanga	Cultural values, customs and practices
Te Ngāherehere o Kohukohunui	The great forest of Kohukohunui, known as the Hūnua Ranges
Whakapapa	Genealogy, ancestral links
Whare	Building or residence

Terminology

Ngā kupu whāiti

The definitions below are specified in accordance with standard epidemiological usage. Where the same word is defined differently between different disciplines, the definition used for this study and the alternative definition are provided for context.

Baseline	The first comprehensive measurement of symptomatic tree prevalence, pathogen prevalence and impact variables in a population. A baseline is set so that future measurements can be compared against it to detect a change over time.
Case definition	The consistent criteria by which the health condition of an individual tree is included as a 'case' in a disease outbreak or study.
Confounding	Refers to the distortion of the true association between an exposure and an outcome, because of the influence of a third factor. A key difference of confounding from correlation is that the exposure variable and confounder should have a separate causal relationship or association mechanism from the outcome variable.
Cross-sectional study	Cross-sectional studies are a type of observational study, rather than an experimental study. They provide a snapshot in time. Individuals in the study are examined for the presence of an outcome of interest, such as a pathogen or cases of disease. At the same time data is collected about the presence or absence of factors that may increase or protect from the risk of disease. These are called risk factors.
Delimiting surveillance	Surveys designed to determine the extent and distribution of a new biosecurity risk outbreak or incursion.
Disease	A dynamic development of abnormal life processes due to a **pathogen** or **abiotic** disorder, lasting long enough to cause vital disturbances in the life of the host, possibly leading to its death (Tronsmo et al., 2020).

HiRAMS	High Resolution Airborne Multispectral Sensor.
Ill-thrift	Ill-thrift describes plants that fail to thrive. For the purposes of this study, ill-thrift refers to kauri trees that are not healthy, but their poor health is caused either by other biotic or abiotic causes, or very early kauri dieback, where conclusive symptoms are not yet apparent.
Incidence	The number of new cases of disease (i.e. trees that meet the case definition) in a defined population over a defined period of time. NOTE: This should not be confused with incidence as defined in plant pathology, as the number of diseased/symptomatic individuals within a defined population at a point in time. This is much closer to the epidemiological definition of prevalence (Madden et al., 2007).
Incubation period	The time between an individual (tree) being infected by a pathogen and when symptoms become visible (also referred to as the asymptomatic period).
LAMP	Loop Mediated Isothermal Amplification, a technique for the amplification of DNA to assist diagnostic analysis.
Latency / Latent period	The time period between an individual (tree) being infected by a pathogen and when the pathogen has completed its lifecycle and becomes infectious, in that it releases reproductive structures (e.g. zoospores) and can infect other trees. Note that the pathogen can spread prior to the host tree becoming symptomatic (during the incubation period).
Misclassification bias	A type of measurement error where a study unit (e.g., kauri tree) is classified into the wrong group e.g., being classified as diseased when healthy. Or when an imperfect test is used to detect a pathogen and the pathogen is classified as absent when it is present. Misclassification can bias estimates of disease or pathogen prevalence or measures of association between variables (Haine et al., 2018).
Monitoring	Repeated surveys to determine changes in the frequency and distribution of a disease over time.

NIR	Near-infrared
Pathogen	An infectious agent that causes disease in a host. In plants, this includes oomycetes, fungi, viruses, virus-like organisms, bacteria, and nematodes.
Positive predictive value	The probability that an individual (tree) with a positive test is actually positive; e.g., the proportion of trees identified as kauri through remote sensing that are actually kauri.
Precision	A description of random error, a measure of statistical variability.
Prevalence	The number of individuals in a defined population having a specified outcome at a given point in time. Where the outcome may be presence of a pathogen (pathogen prevalence) or meeting the case definition for diseased (disease prevalence). NOTE: This should not be confused with prevalence as defined in plant pathology, which is the count of geographical sampling units where disease is present (e.g., fields, plots, regions, countries) divided by the number assessed.
Raster	Geographical data comprising a series of equally-sized cells.
Risk factors	Any factor or variable that is associated with either an increase or decrease in disease prevalence or pathogen prevalence.
Sensitivity (Se)	This is the diagnostic sensitivity of a test. It is estimated by the proportion of trees with the disease that will test positive, where false negatives are trees that test negative but do have disease: $$\frac{True\ positives}{True\ positives + false\ negatives}$$ Highly sensitive tests can be used to rule out disease because they will have few or no false negatives. Less sensitive tests such as the soil bioassay may fail to detect *P. agathidicida* even when it is present. Typically, if a test has high sensitivity, it will have lower specificity (i.e., you will find

	almost all cases of disease (high Se), but you will also call lots of things diseased that are not (low Sp). NOTE: Diagnostic sensitivity should not be confused with analytical sensitivity which is the lowest level of target agent that can be measured accurately by the test (Cardwell et al., 2018).
Specificity (Sp)	This is the diagnostic specificity of a test. Proportion of healthy trees that will test negative $$\frac{True\ negatives}{True\ negatives + false\ positives}$$ Where false positives are trees that test positive but do not have disease. Highly specific tests will have very few or no false positives e.g., if we detect *P. agathidicida* in a soil sample using culture and sequencing it is almost certain that *P. agathidicida* is present. Typically, if a test has high specificity, it will have lower sensitivity (i.e., the cases you find are truly diseased, but you will miss quite a few cases of disease). NOTE: Diagnostic specificity should not be confused with analytical specificity, which is similar, but is concerned with performance around excluding non-target species and cross-reactions (false positives) in laboratory testing (Cardwell et al., 2018).
Surveillance	Surveillance is the systematic ongoing collection, collation and analysis of information related to health (plant health in this case) and the timely dissemination of that information to those who need to know so that action can be taken.
Symptoms/ symptomatic	Physiological or structural changes in a plant that indicate the presence of disease by reaction of the host, e.g., canker, leaf spot, wilt, lesion, dieback.

Section 1: Long-term kauri health monitoring framework and objectives of the 2023 Te Ngāherehere o Kohukohunui / Hūnua 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 Ngāherehere o
Kohukohunui

1.1 Te Ngāherehere o Kohukohunui / Te Hūnua

Te Ngāherehere o Kohukohunui means the great forest of Kohukohunui, the maunga tapu that stands within the shrouded mists and forest. It is the highest point in Tāmaki Makaurau and yet cannot be seen because the forest has wrapped itself around the maunga. Hūnua means 'the scorched tribe' and was named following a great battle – Te Pakūranga Rā Hihi / the battle of the sun's rays.

The cultural significance for iwi cannot be underestimated; their whakapapa, the ancient stories held within, provide physical and spiritual connections for iwi not only to the ngahere but to each other. Each iwi holds their own stories and therefore engaging with them directly is the best way to learn and understand their unique connections.

Iwi recall through their ancient stories a difference to the landscape throughout Te Ngāherehere o Kohukohunui. Mangatangi Dam, for example, has had significant impact on the waterways, the natural flows of awa, and their ecology (e.g. tuna and kōkopu). Local marae are now unable to harvest fresh water or native food species. Roads and farms have replaced once heavily forested areas and destroyed natural wetlands. Rural living bordering the ngahere has seen the introduction of pest species such as cats and stoats that have impacted the native manu population.

The loss of resources for iwi is immeasurable; being prohibited from harvesting native timbers directly for carving waka and their ancestral whare impacts their customary practices.

The health of Te Ngāherehere o Kohukohunui must be protected; however, it is an ongoing challenge because of the encroachment of human activities and our increasing population. Our view from the outset of the kauri ora survey is that the total health of Te Ngāherehere o Kohukohunui must be considered with the intention of managing any spread of *Phytophthora agathidicida* (*P. agathidicida*).

The potential loss of kauri, a taonga species, is comparable to the loss of the huia and moa, the whakapapa ends. In examining what has so far protected the kauri, one could assume it is 'pure luck', but the data shows that locations of kauri and disturbance are key to the spread of dieback disease.

The implementation of mātauranga Māori, wānanga, kaitiakitanga, karakia, and education all contributed towards the successful outcomes achieved to date. The experiences from Te Kawerau ā Maki in Te Wao nui ā Tiriwa (the Waitākere Ranges) helped guide and inform our tikanga.

What is good for the ngahere is good for the kauri, and what is good for the kauri is good for the ngahere.

Kauri mate ki pō, Kauri ora ki te ao. E ora ana Te Ngāherehere o Kohukohunui e ora ana te iwi.

1.2 Introduction to kauri

Te whakataki

Kauri (*Agathis australis*) is a culturally significant taonga species to Māori and highly valued by New Zealanders across its natural range from the far north of Aotearoa New Zealand to the southern 'kauri limit' in the Waikato and Bay of Plenty (Waipara et al., 2013, Lambert et al., 2018). Kauri is a dominant keystone conifer species in highly biodiverse and unique ecosystems and is endemic to our northern forests (Ecroyd, 1982). Kauri trees are ecologically important, not only for carbon sequestration and water storage, but as drivers of the plant communities surrounding them (Macinnis-Ng and Schwendenmann, 2015; Wyse et al., 2014). Mature kauri trees typically achieve heights of around 30m, accompanied by trunk diameters reaching up to 3m. These trees are recognised for their impressive longevity, often surviving for over a thousand years.

Kauri forest was originally widespread throughout Northland, Auckland, and the Coromandel Peninsula. Following human settlement and associated forest clearance, mature stands of kauri forest are largely restricted to Te Tai Tokerau / Northland hill country (e.g. Warawara and Waipoua Forests), Aotea / Great Barrier Island, Hauturu / Little Barrier Island, and in Te Wao Nui ā Tiriwa / the Waitākere Ranges and Te Ngāherehere o Kohukohunui / Hūnua Ranges. Fragmented areas of regenerating kauri forest are present throughout Auckland, generally replacing mānuka and kānuka scrub on land that was previously burnt (Singers et al., 2017).

The indigenous forest of the Hūnua Ranges and nearby areas contains several ecosystem types reflecting a combination of underlying abiotic factors such as soil type, altitude, topography, climate and geology as well as the history of clearance and disturbance. Kauri forest predominates in lower altitude areas along the eastern and southern slopes of the Hūnua Ranges and within the Mātaitai Forest Conservation Area. A few scattered stands of mature kauri and regenerating kauri forest occur on the western and northern edges of the ranges.

The kauri ecosystem in this part of the Auckland region is mainly considered to be WF12: Kauri, podocarp, broadleaved, beech forest. It is differentiated from other kauri ecosystems mainly by the presence of hard beech. WF12 forest occurs predominantly

in eastern areas south of Auckland, from the Hūnua Ranges to Hapuakohe Ecological District in the Waikato region. It is also present in the Coromandel and Kaimai Ranges and on Mt Taupiri (Singers et al., 2017).

Kauri is naturally absent from large parts of the of the Hūnua Ranges, where tawa, kohekohe, rewarewa, hīnau podocarp forest ecosystem (WF13) predominates (Singers et al., 2017, Auckland Council, n.d.). The regenerating ecosystems of kānuka scrub/forest (VS2) and broadleaved scrub/forest (VS5) occur in various parts of the study area that are recovering from past logging and clearance for farming, notably around the edges of the Hūnua Ranges and in the Wairoa and lower Mangatāwhiri catchments. Broadleaved scrub/forest is also regenerating in the 'Thousand Acre Clearing' just east of the Kohukohunui summit which was logged between the 1920s and 1950s (Tyrell et al., 1999).

1.3 Kauri health in relation to *Phytophthora agathidicida,* the causal agent of kauri dieback disease

Te ora o te kauri e hāngai nei ki te kaikawe i te puruheka patu kauri, arā, ki te *Phytophthora agathidicida*.

The soil-borne pathogen *Phytophthora agathidicida* (*P. agathidicida)* causes ill-thrift and death in kauri, a disease phenomenon known as kauri dieback disease (Weir et al., 2015). *P. agathidicida* was first reported under the mis-identified name of *Phytophthora heveae* and associated with kauri health 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). The pathogen was then formally identified and named *Phytophthora agathidicida* (Weir et al., 2015). Since then, the disease and pathogen have been detected in most kauri forests in New Zealand, leading to severe kauri health impacts in many kauri (Froud, 2020, Bradshaw et al., 2020). Fortunately, the spatial spread of *P. agathidicida* within Te Wao Nui ā Tiriwa / the Waitākere Ranges appears patchy (Froud et al. 2022) and the pathogen has remained undetected in the Hūnua Ranges. Mapping and protecting kauri forests that are free from *P. agathidicida* is a top priority for kauri protection.

Kauri dieback is as a lethal root rot disease (Killick, 2023) for which there is no known cure (Bradshaw et al., 2020). Infection in kauri results in root and collar rot, leading to dysfunction in the outer vascular tissues of the host and disruption to the infected tree’s water uptake ability (Bradshaw et al., 2020; Killick, 2023). Visible

symptoms characteristic of kauri dieback include basal bleeding, yellowing foliage and canopy thinning (Gadgil, 1974; Beever et al., 2009). Above-ground symptoms are considered to be the chronic phase of the disease, observed to progress for 1-10 years before tree death (Bradshaw et al., 2020).

P. agathidicida is classified as an Unwanted Organism under the Biosecurity Act 1993. While the primary role of *P. agathidicida* as the causal agent has been confirmed (Beever et al. 2009, Bellgard et al. 2013, Gadgil 1974, Killick 2023), the epidemiology and the other contributing factors that may exacerbate disease such as disturbance, weather events, and other pathogens are still under investigation. While environmental conditions and human and animal interactions provide transmission risk into forest systems (Froud et al. 2022), it is also thought that such interactions may affect the pathogen-host relationship and ultimately exacerbate disease symptoms (Froud 2020). For these reasons, limiting disturbance to kauri root systems is considered critical for keeping kauri and the broader ngahere healthy.

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 implemented a National Pest Management Plan (NPMP) in August 2023 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

Auckland Council has made significant investments into both kauri protection and *P. agathidicida* delimiting surveillance since 2009. The 2021 Waitākere Ranges Kauri Population Health Monitoring Survey was designed to understand pathogen and disease prevalence across the kauri population, and to set a baseline for future assessment of change.

Prior to 2020, the objectives of kauri dieback surveillance were to delimit the extent of dieback and the presence of *P. agathidicida* in the Auckland region using 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 (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).

Due to this earlier 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. However, the pathogen has not been detected in areas such as the Hūnua Ranges and Waiheke Island. The 2021 Waitākere survey provided clarity on soil bioassay test performance and risks associated with a higher risk of *P. agathidicida* detection (Froud et al., 2022a). This was fundamental to designing surveillance in an area where *P. agathidicida* has not been previously detected.

1.5 Epidemiological approach to kauri dieback

Te huarahi matai tahumaero ki te puruheka patu kauri

Delivering a long-term disease management programme is complex and difficult. To manage this complexity, Auckland Council has adopted an epidemiological approach since 2020 to plan operational management and understand the impacts of management interventions for kauri dieback (Stevenson & Froud, 2020).

The strong pathogenic relationship between *P. agathidicida* and kauri dieback in kauri trees has been demonstrated (Bellgard et al., 2016, Gadgil, 1974, Horner and Hough, 2014).

The presence of *P. agathidicida* and the vulnerable host, kauri, is necessary to cause kauri dieback but it is considered likely that other factors may affect disease likelihood or severity. The presence of environmental conditions favouring the pathogen and increasing host susceptibility (e.g. drought, rainfall, disturbances) affect disease likelihood and outcomes (Rothman and Greenland, 2005, Martin, 2008). This is illustrated in Figure 1-1 below, the disease triangle. 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, so that kauri health management can be implemented.

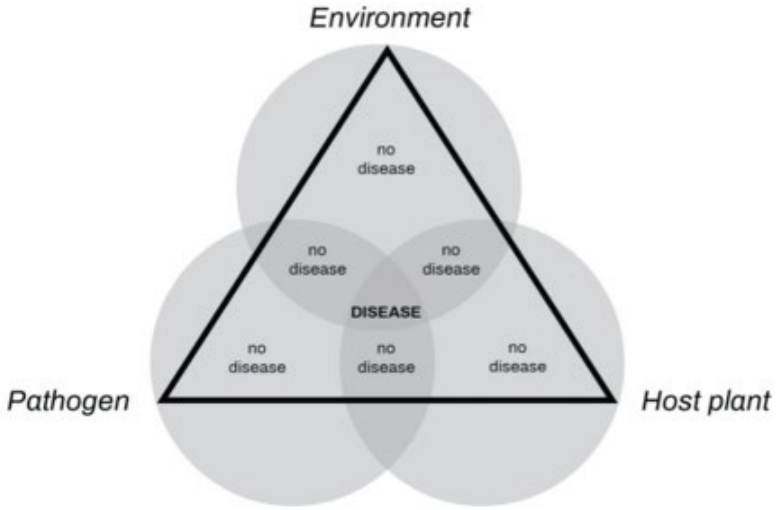


Figure 1-1. Disease triangle showing that disease only occurs when sufficient factors relating to a host, pathogen and environment (including management) intersect (Bhopal, 2016, p 136).

With the benefit of the Natural Environment Targeted Rate, Auckland Council is now applying a statistically robust 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 in 2020 (Froud et al., 2022a) to address four objectives:

- To understand kauri health, pathogen prevalence, disease prevalence and other impacts in order to monitor changes over the long-term.
- To identify risk factors which are associated with disease or pathogen prevalence to inform potential management intervention options.
- To identify ecological impact variables to provide better information on the long-term impacts of kauri dieback within the forest.

- 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, including 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, Ngaati 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 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, Froud et al., 2022a), the baseline monitoring recommendations of Stevenson and Froud (2020), and significant progress in applicability of remote sensing from Meiforth (2020) and 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. It also included research from the late Ross Beever and Stan Bellgard, Ian Horner, Margaret Dick, Nick Waipara, Nari Williams, Tony Beauchamp, Lee Hill, Alastair Jamieson, Andrew Macdonald, Nhā Rākau Taketake (NRT) National Science Challenge integrated surveillance workstream members, and many others (Froud, 2020, Black & Dickie, 2016, Bradshaw et al., 2020). Three key components form the basis of the monitoring framework as illustrated in Figure 1-2.

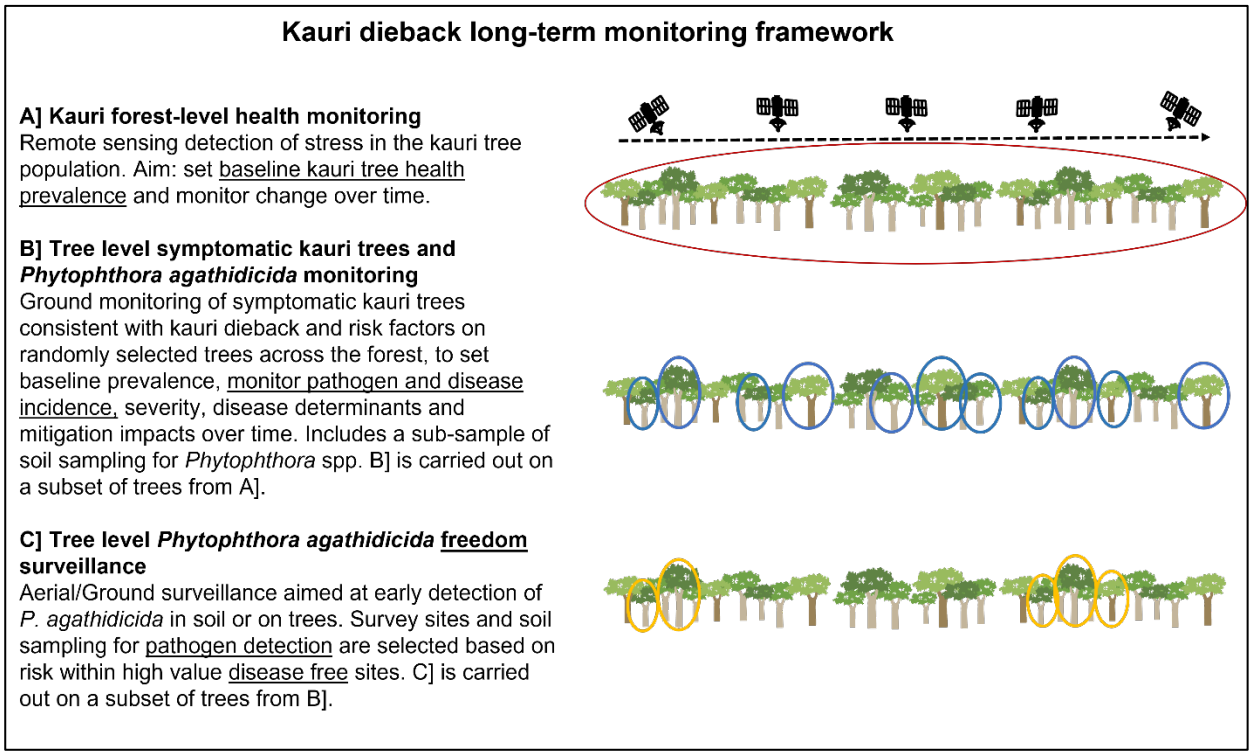


Figure 1-2. Long-term kauri health monitoring framework.

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.

Level B of the monitoring framework was rolled out in the 2021 Waitākere Survey. Research to enable Level A is progressing in 2023/2024. The 2023 Hūnua Survey is the first opportunity to roll out a mix of Level B and Level C, enabled by the additional knowledge gained during the 2021 Waitākere Survey (Froud et al., 2022a).

A. Kauri forest-level health monitoring

Kauri forest-level health monitoring is aimed at detecting an early change in 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 have been advanced for host detection in Hūnua (described in Section 2 of this report), alongside additional change detection analysis that is nearing completion in 2024. We need to validate stress detection and set a consistent stress index before a baseline can be set and change detection can be used at the forest level. The Hūnua study will provide additional validation data points.

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

The roll out of tree-level symptomatic kauri trees and *P. agathidicida* monitoring was first applied in the 2021 Waitākere Survey and used a repeated cross-sectional study design (Diehr et al., 1995). We used a similar design in Hūnua to set the baseline population health. A repeated cross-sectional study is a type of observational study that measures pathogen and/or 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 or pathogen introduction risk (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 pathogen and disease estimated on each occasion (Diehr et al., 1995). The results of the study are described in Chapter 3 of this report.

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 done in the 2021 Waitākere Ranges survey which identified a range of risk factors for the introduction of *P. agathidicida*. In addition, the diagnostic test performance parameters of the soil bioassay test used to detect the pathogen was quantified during the 2021 Waitākere survey and can now be used to calculate the number of trees to be tested and found to test negative to quantify confidence in disease freedom. The risk factors and test parameters from the 2021 Waitākere survey can be applied to Hūnua to inform pathogen freedom. Section 3 reports on a mixed study design for pathogen freedom using both the randomly selected trees (from the repeated cross-sectional prevalence study) and risk-based trees to provide confidence in *P. agathidicida* freedom in Hūnua.

1.7 Updating the long-term kauri health monitoring framework

Te whakahou i ngā kōrero o te anga hei aroturuki i te ora tauroa o te kauri

This report concludes with a section that weaves together the new knowledge gained from this survey, along with those of the 2021 Waitākere Ranges Survey and updates the strategy for implementation of the long-term monitoring framework for kauri dieback in the wider Tāmaki Makaurau region.

Section 2: Baseline prevalence study of *Phytophthora agathidicida*, kauri health and ecosystem health in Te Ngāherehere o Kohukohunui / Hūnua Ranges using a cross-sectional study

Te mātai i te horapatanga o te puruheka patu kauri, i te ora o te kauri me te pūnaha hauropi i Te Ngāherehere o Kohukohunui mā te whai i tētahi mātai motuhanga

2.1 Introduction
Te whakataki

2023 marks the third time Auckland Council has done ground surveillance in the Hūnua Ranges to detect the presence of the pathogen *P. agathidicida* or symptoms of disease caused by infection of *P. agathidicida* (kauri dieback disease), and the first using an epidemiological approach. The first ground surveys, carried out during 2011 and 2012, did not detect the presence of *P. agathidicida* in the forest (Jamieson et al., 2012), although there were some trees with ill-thrift. In addition, an aerial and smaller-scale ground survey in 2017 concluded that the distribution and degree of ill-thrift did not indicate the likely presence of *P. agathidicida* (Jamieson, 2017). These surveys indicated that the Hūnua Ranges were potentially one of the most significant kauri forests in the country that had not been infected by *P. agathidicida* and showed its importance as a stronghold against the pathogen. The epidemiological approach taken in the 2023 survey was co-designed to verify whether the Hūnua Ranges was free of *P. agathidicida* and to inform future management and protection.

The 2023 Hūnua Ranges survey, detailed design, delivery and analyses of data was carried out in partnership by Auckland Council with ngā iwi mana whenua o Te Ngāherehere o Kohukohunui, Ngāi Tai ki Tāmaki, Ngāti Tamaoho, Ngāti Te Ata Waiohua, Ngaati Whanaunga, and Ngāti Tamaterā, and the Department of Conservation (DOC). 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 steps of this epidemiological approach were to apply a cross-sectional survey aimed at determining the *P. agathidicida* freedom status of the Hūnua Ranges and set a baseline prevalence and distribution of kauri and ecosystem health and *P. agathidicida* (if present).

The objectives for this study were:

- To verify **pathogen freedom** from *P. agathidicida* in the Hūnua Ranges
- To assess baseline kauri health and set the baseline **symptomatic tree prevalence** by identifying and counting the number of symptomatic mature trees and describing the prevalence and spatial distribution of mature symptomatic kauri (and of *P. agathidicida,* if present) at a point in time.

- **Risk factors for symptomatic kauri study** – to screen risk factors and generate hypotheses of why some trees are at greater risk of ill-health compared to others and whether any additional kauri health modelling to test hypotheses or control interventions could be applied to enhance kauri health.

As well as verifying pathogen freedom, this study measured the health status of individual kauri trees so that an increase or reduction in the number of symptomatic trees in the population over time can be assessed. The study tested for the presence of *P. agathidicida, P. cinnamomi*, and other *Phytophthora* species in soils surrounding both healthy and unhealthy trees to increase the likelihood of early pathogen detection and inform management. Ongoing freedom can be assessed over time with repeated surveys.

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). Because of the importance of the environment to disease outcomes, key environmental conditions were explored in relation to kauri health in the Hūnua Ranges.

The methods for the 2023 Hūnua Ranges survey were co-designed with mana whenua and subject matter experts. It aimed to provide evidence to inform management strategies and interventions and provide baseline data to measure change in disease and efficacy of control measures in the future alongside mātauranga Māori measurements of forest health.

2.2 Methods
Ngā tikanga

2.2.1 Study design

As part of our co-design approach, the aims of the survey were agreed during a survey initiation hui in 2022 with the main objective being proof of pathogen freedom, and secondly, setting a baseline of kauri and kauri ecosystem health. We then agreed an area of interest and defined the study area for the survey. The study objectives led to the development of a mixed surveillance design combining

both a randomised tree-level sample group to set a baseline for kauri health and pathogen freedom and a risk-based sample group for proof of freedom/early detection of *P. agathidicida.*

Our collaborative approach to co-design was used throughout the survey, as illustrated in Figure 2-1.

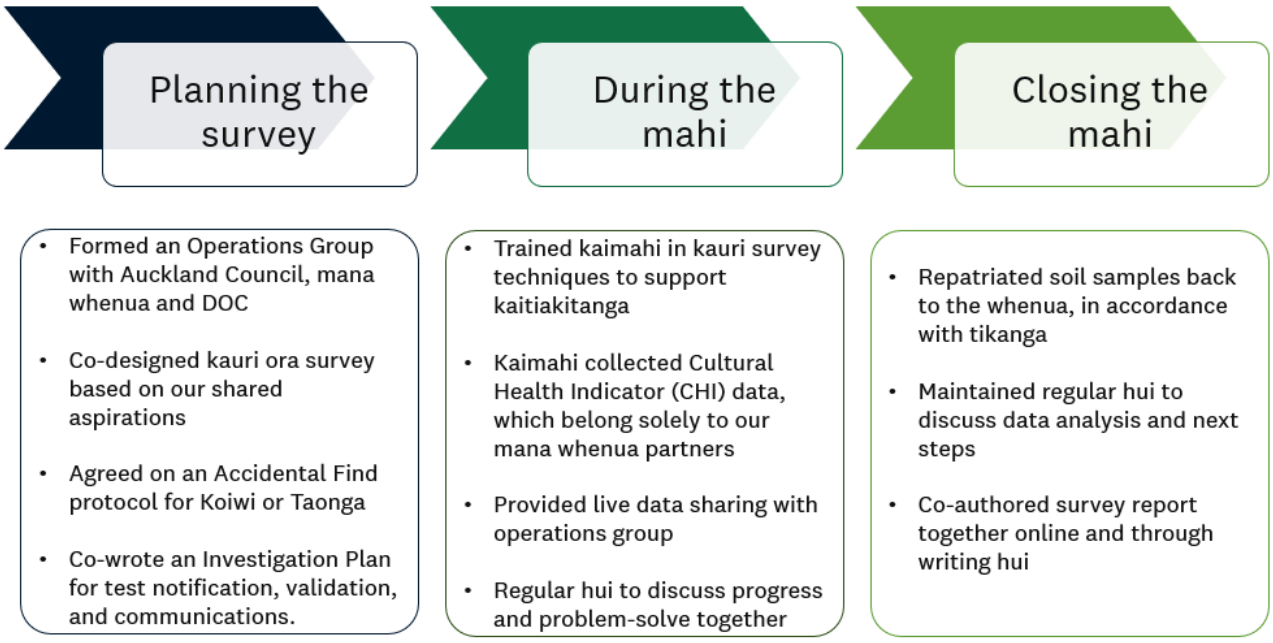


Figure 2-1. Co-design and delivery model through the Operational Group.

2.2.2 Area of interest and study area

The area of interest was defined using a co-design approach, where a potential area of interest centred on the Hūnua Ranges Regional Park was proposed at a working group hui using a large A2 sized map to guide discussion. The area of interest was then expanded to include contiguous kauri beyond the park's boundary. The area of interest for this survey includes a combination of regional park land, public conservation land and privately owned forest contiguous with the main forested areas as shown in Figure 2-2 below.

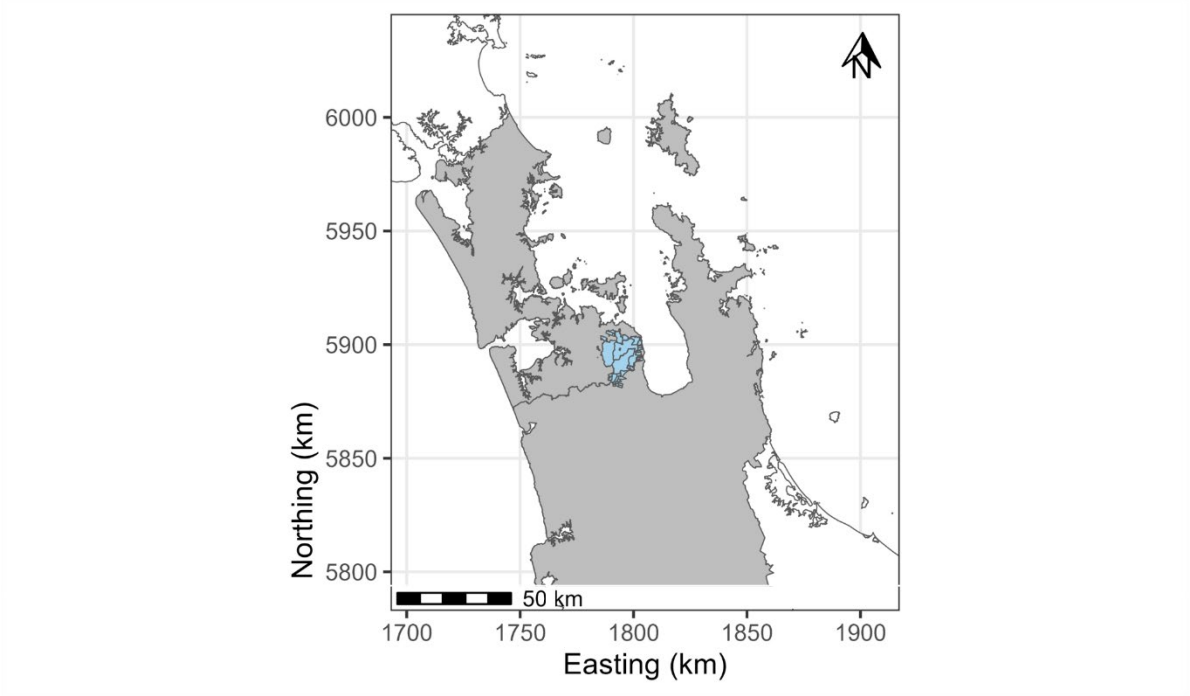


Figure 2-2. Hūnua kauri area of interest (shown in blue) located within the Auckland and Waikato regions (grey).

Likewise, the final study area was refined to fit within the wider area of interest, under a co-design approach to contain only the native forested areas within the area of interest over 125ha. It was agreed that the survey would not be limited to Auckland Council parkland because we were interested in pathogen freedom and therefore it was necessary to investigate whether the pathogen was present in contiguous forest (Figure 2-3).

Specifically, they included:

1. Auckland Council managed land: Hūnua Ranges Regional Park, Waharau Regional Park and Whakatiwai Regional Park.
2. DOC reserves contiguous with council managed land: Mangatāwhiri Forest Conservation Area, Paparimu Conservation Area, Richard Sylvan Memorial Scenic Reserve, Vining Scenic Reserve.
3. DOC reserves north of the Hūnua Ranges Regional Park: Mātaitai Forest Conservation Area, Mātaitai Scenic Reserve, Whakatiri Scenic Reserve, Te Morehu Scenic Reserve, Richardson Scenic Reserve.
4. Private property (with kauri) immediately contiguous with areas in 1 and 2 (but accessed only where permission was obtained).

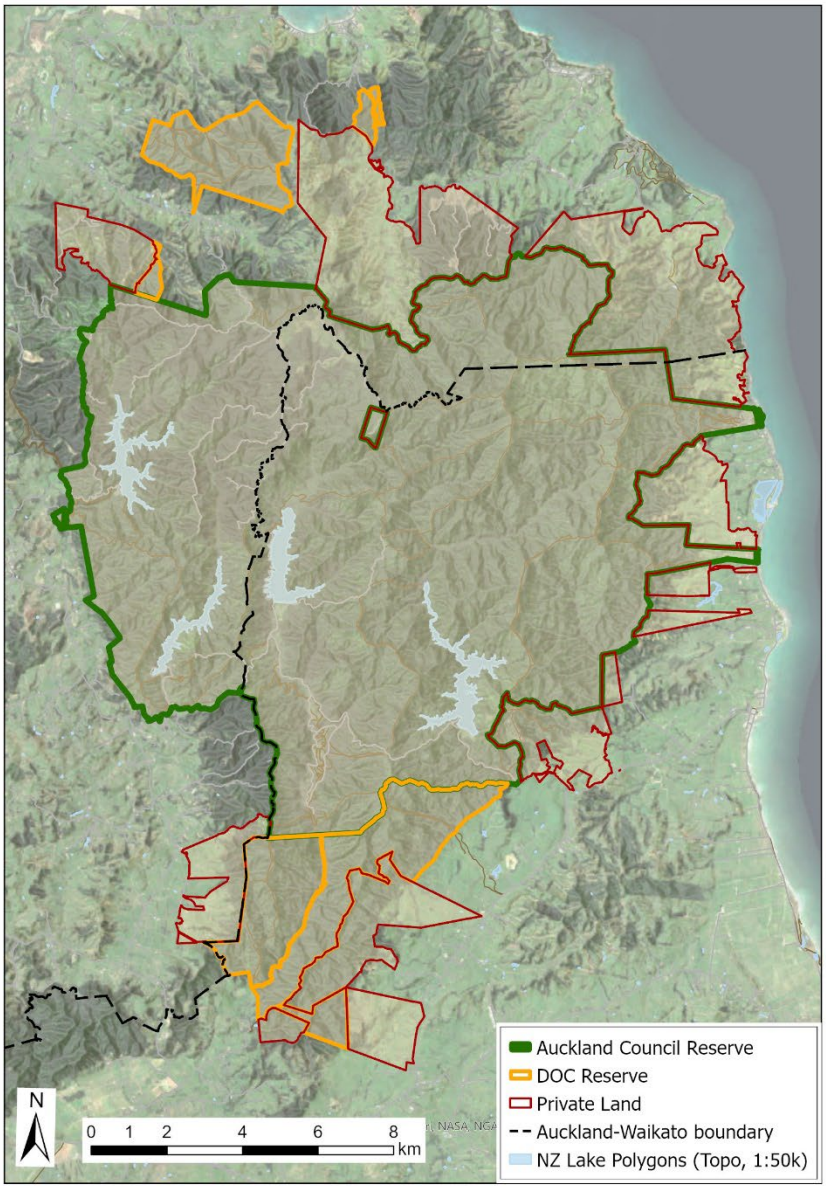


Figure 2-3. Map of the area of interest for the Hūnua study where the light areas are within the area of interest.

2.2.3 Management units

Stream sub-catchments (watersheds) were used as the management unit for the study (Figure 2-4).

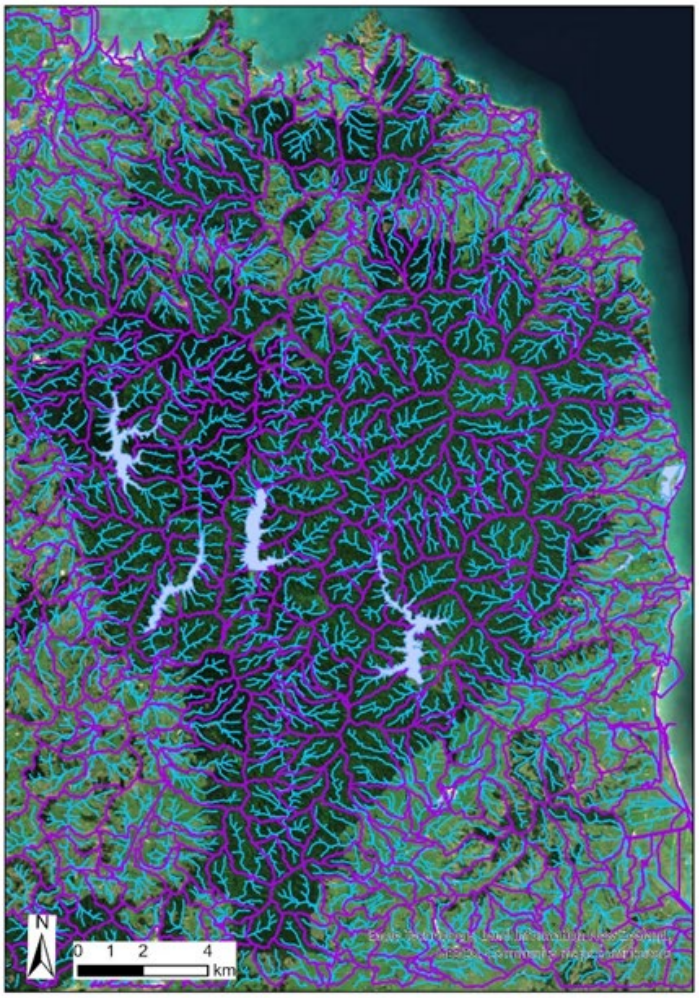


Figure 2-4. Watersheds (purple) and permanent streams (blue) in the Hūnua Ranges, calculated on a LiDAR terrain model.

2.2.4 Unit of interest (observations/rows of data)

The units of interest are individual kauri trees and sites. Individual kauri is consistent with the recommended unit of interest for the National Kauri Dieback Programme (NKDP) baseline surveillance (Stevenson & Froud, 2020). The classification of individual trees was further refined by size with a minimum diameter at breast height (DBH) of 10 cm. This is consistent with historical tree

assessments in native New Zealand forests of mature trees (Ahmed & Ogden, 1987).

2.2.5 Identifying the kauri host population

A set of 27,164 point-locations form the kauri baseline population for the Hūnua analysis. This dataset is based on polygons of estimated kauri crowns and stands that were determined with deep learning on RGB HiRAMS/HiRES aerial images flown in 2022 (MWLR 2022). The workflow to convert these polygons into crown locations is documented in Figure 2-5. The initial 40,545 polygons were reduced to 24,699 by combining clusters or outliers of small crown polygons that belong to a larger kauri unit and the removal of tiny crown polygons (< 1sqm) which were unlikely to be kauri. Remaining crown polygons smaller than 3sqm were converted via the centre location to tree points. For larger polygons, the highest points on a LiDAR Crown Height Model were detected and converted to tree crown locations. For polygons larger than 100sqm with less than two detected peaks, it was assumed that individual crown locations within a kauri stand were not detected. In this case, additional crown peaks were defined and randomly placed within the polygon, based on the roundness and area of the smoothed crown polygons. Crown locations that were misclassified as kauri according to a manual check of a subset were removed. The resulting baseline population of 27,164 crowns within the area of interest was eligible to be selected for the risk-based trees analysis and for the survey Figure 2-5 and locations are illustrated in Figure 2-6.

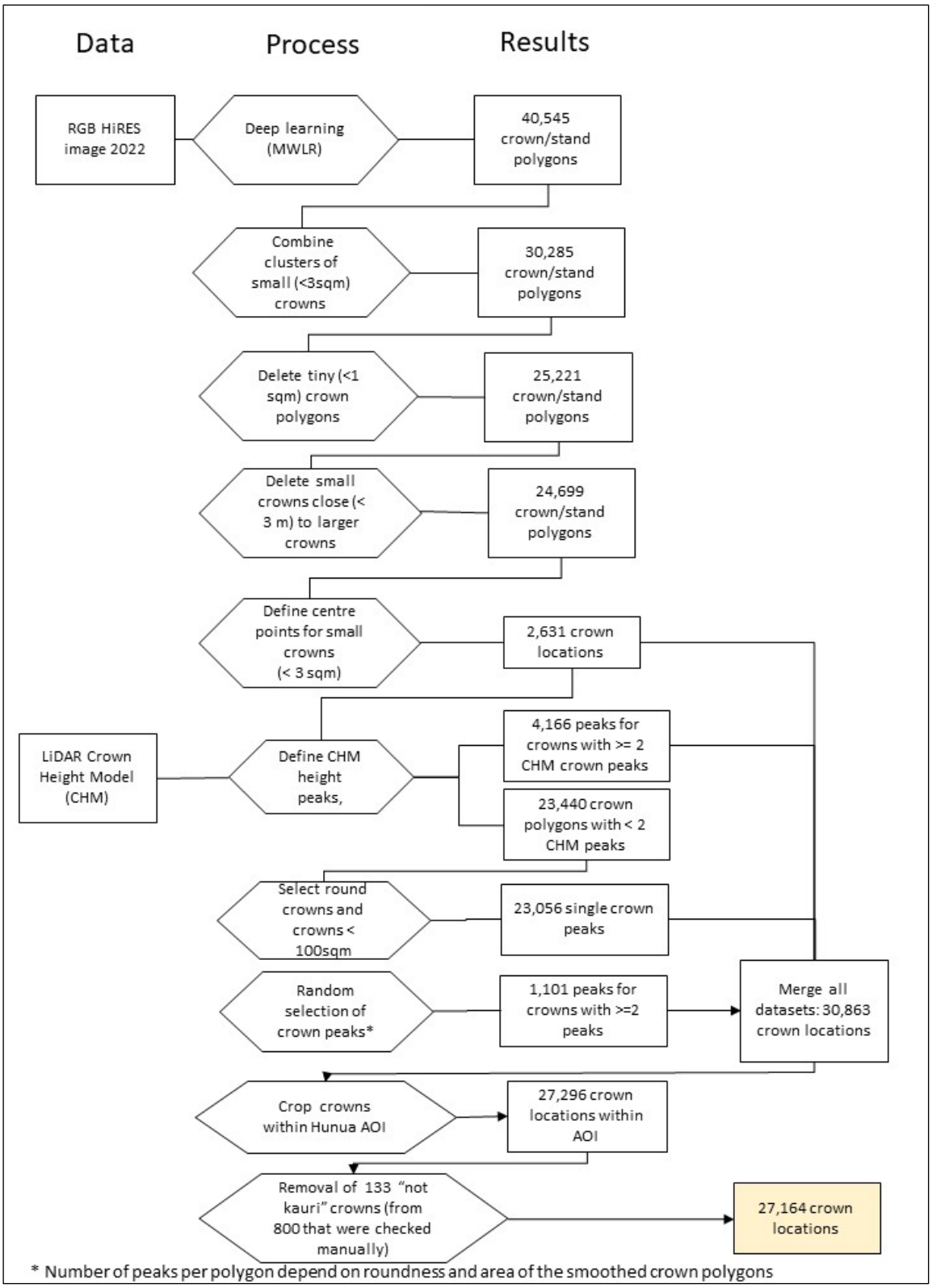


Figure 2-5. Process diagram for risk-based tree selection.

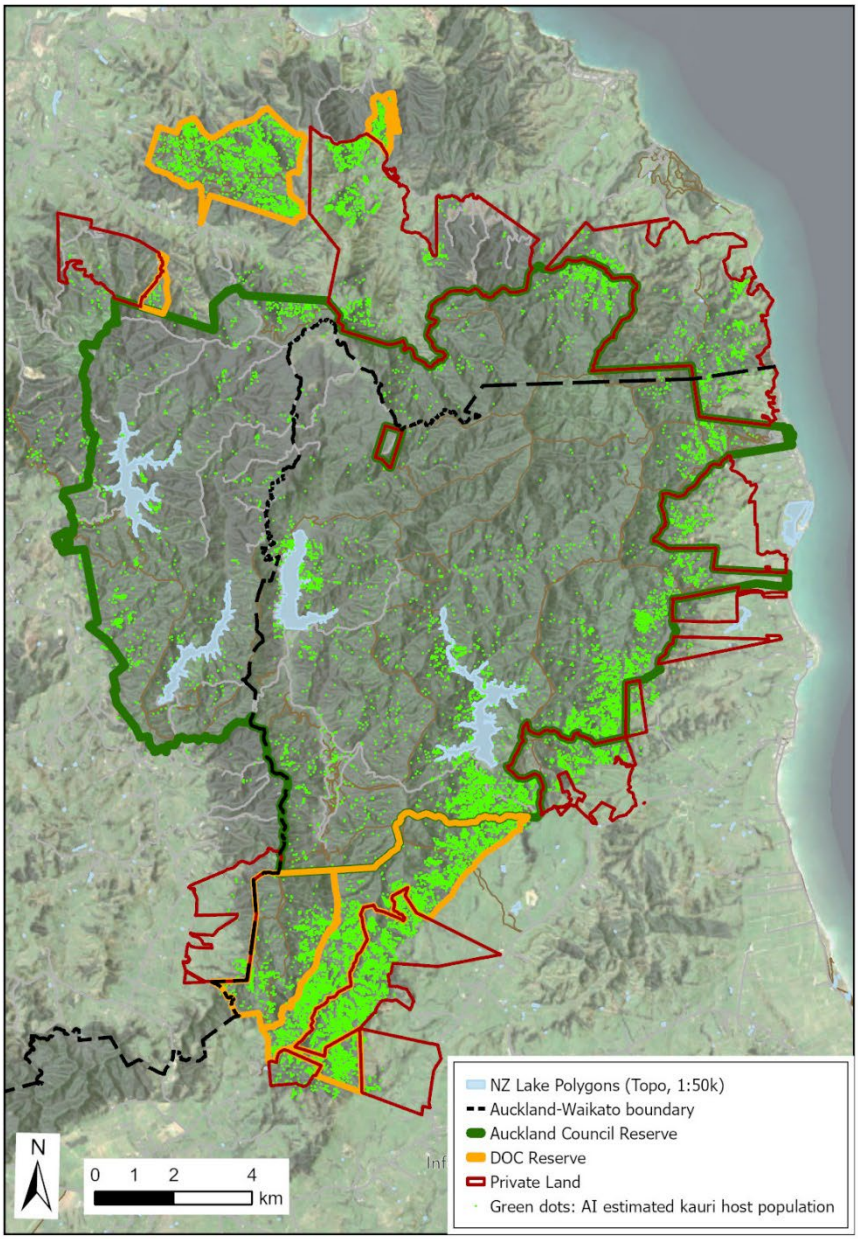


Figure 2-6. Remote sensing and AI estimated kauri host population within Hūnua Ranges, overlaid with land management types.

2.2.6 Sample size calculations

These methods aimed to estimate the number of soil sample bioassays that would be needed to detect *P. agathidicida* with high confidence if it is present at low prevalence. Since soil bioassays are taken from below kauri, potential sample sites are referred to as 'trees'. When the initial sample size estimates were made, the number of mature kauri (visible using remote sensing) in the study area was estimated to exceed 40,000 trees (this was prior to the processing of imagery);

however, if the total population size is more than a few thousand, the actual number does not affect the sample size calculations.

In a co-design hui, it was agreed that the level of detection and confidence required was "we want to be 95 per cent confident that if *P. agathidicida* is present in the survey area at a prevalence of 1 per cent or higher we would detect it". This is because it is not possible to gain 100 per cent confidence in a 0 per cent prevalence. Given the main objective of the survey was pathogen freedom as it was uncertain if *P. agathidicida* was present, two approaches could be applied to calculating the sample size required for pathogen freedom. One was a completely random approach assuming equal risk of introduction of *P. agathidicida* across the forest (homogeneous risk) versus a risk-based approach that the risk of introduction varies across the forest (heterogenous risk) based on factors determined to be associated with an increased risk of detection of *P. agathidicida* based on the results from the Waitākere survey (Froud et al., 2022a). We selected a hybrid of these two approaches, which addressed both the primary objective of pathogen freedom and the secondary objective of setting a baseline for kauri ora. The theories of the sample size approaches and the hybrid approach are provided below.

2.2.6.1 Homogeneous risk theory

If all trees have the same likelihood of being infected, then the sensitivity of the survey (i.e. confidence in detecting *P. agathidicida* if it is present at a particular prevalence) can be estimated from a binomial formula (McArdle, 1990, Reed, 1996, Barrett et al., 2010) as

$$s = 1 - (1 - qP)^n \qquad (1)$$

where s is the survey sensitivity, q is the test sensitivity, P is the prevalence of *P. agathidicida* in the kauri population, and n is the number of samples taken. Avoiding selection of the same tree more than once, the number that need to be sampled to demonstrate freedom from *P. agathidicida* can be estimated from an approximation to the hypergeometric formula (Brunk et al., 1968, Venette et al., 2002) as

$$n = \left\lceil (N/q)\left(1 - (1 - s)^{1/NP}\right)\right\rceil \qquad (2)$$

where N is the total population size and the braces mean to round up to the next highest integer. Note that when, as here, we specify P it is referred to as the *design prevalence* and corresponds to the level of infection that we are aiming to detect.

2.2.6.2 Heterogeneous risk theory

If different trees have different likelihoods of being infested by *P. agathidicida*, then we can use knowledge of the relative risk (relative likelihood of being infected) of each tree, R_i, to target sampling at those trees that are most likely to be infected. The probability of tree *i* being infected is

$$h_i = R_i / \Sigma R \times PN \qquad (3)$$

and if we sample only those *n* trees with the highest relative risk *h*, then we may estimate the *effective* design prevalence in the sampled trees P^* as

$$P^* = \frac{1}{n} \sum_{i=1}^{n} h_i \qquad (4)$$

It is unnecessary to know the relative risk of every tree in the population; instead, we need to estimate the relative risk of the sampled group, $\Sigma R_i / \Sigma R$, since equation 4 can be written

$$P^* = \frac{\Sigma R_i}{\Sigma R} \times \frac{NP}{n} \qquad (5)$$

Now, over the *n* trees that are sampled, the probability of detection in at least one sample is

$$s = 1 - (1 - qP^*)^n \qquad (6)$$

If risk is homogeneous (*R* is the same for all *i*), then from equations 3 and 4 $h_i = P = P^*$ and equation 6 reduces to equation 1. Similarly, if risk is heterogeneous but sampling is random with respect to risk (for example, if risk factors are not understood) then the mean sensitivity is given by equation 1, though there will be variance around the mean that derives from the relative risks of the particular trees sampled. But if the highest risk trees are preferentially sampled, then $P^* > P$ and survey sensitivity is increased, or fewer samples are needed.

2.2.6.3 Hybrid approach

When the degree and nature of risk heterogeneity is uncertain it may be pragmatic to take a hybrid approach by selecting n_R trees at random, and then selecting a further n_H trees that are thought to be at the highest risk of infection. The random trees should be selected first so that we can rely on the robustness of these samples if our understanding of risk proves faulty. It also allows a more spatially balanced baseline population to be sampled. We should also identify which group each sample belongs to so that Bayesian latent class analysis can be used to refine the estimated test sensitivity *q*, should the pathogen prove to be present at sufficient prevalence.

If a sufficiently small proportion of the tree population is sampled ($n_R + n_H << N$), then we can consider the high risk and random samples as being from separate populations with different effective design prevalences. The effective design prevalence of the high-risk sample P^*_H is estimated by equation 4 or 5, and after some algebra that of the random sample is

$$P_R^* = \frac{NP - n_H P_H^*}{N - n_H} \qquad (7)$$

The component sensitivities of the random and high-risk sampling are calculated from equation 6, then the overall sensitivity of the hybrid sampling is

$$s = 1 - (1 - s_R)(1 - s_H) \qquad (8)$$

If a relatively large proportion of the population is sampled, then there is likely to be significant overlap between the two groups, as random sampling may select many high-risk trees. If the variance in risk is large, then this approach may underestimate overall sensitivity. In this case sensitivity may be estimated by considering each sampled tree *j* individually

$$s = 1 - \prod_j (1 - qh_j) \quad (9)$$

but this requires estimation of the relative risk of all trees in the population, rather than just the proportion of total risk embodied by the trees selected for the high-risk sample, as in Equation 5.

2.2.6.4 Homogeneous risk calculation

The Hūnua kauri lands are estimated to contain around $N = 40{,}000$ sizeable kauri trees (Alastair Jamieson, pers. comm.). From the Waitākere kauri survey, the soil sample bioassay for *P. agathidicida* was estimated to have sensitivity $p = 63.8\%$ (95% CI 42.6-88.1%) (Froud et al., 2022a). The remaining two parameters may be varied, but the Operational Group indicated a desire to be $s = 95$ per cent confident in detecting *P. agathidicida* at a prevalence of $P^* = 1$ per cent. With these values, and assuming homogeneous risk, a sample size of $n = 468$ would be required. This result is not sensitive to the estimated number of kauri in the population.

Figure 2-7 shows how the sample size varies across the 95 per cent confidence interval of the test sensitivity estimate for different disease prevalences. Uncertainty in the sensitivity of soil bioassay suggests that up to 700 samples would be needed to ensure 95 per cent confidence in detecting a 1 per cent infestation, but if the test sensitivity conforms to our best estimate this many

samples would be sufficient to detect a smaller 0.67 per cent infestation with 95 per cent confidence.

P	*q* = 0.426	*q* = 0.638	*q* = 0.881
0.1%	6531	4261	3158
0.2%	3388	2262	1639
0.5%	1386	926	670
1%	698	467	338
2%	351	234	170
5%	141	94	68

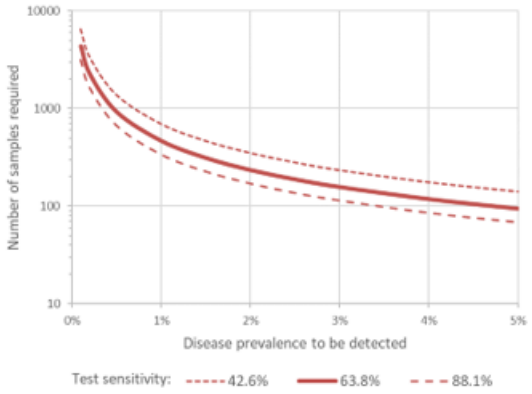


Figure 2-7. Number of samples required to detect *P. agathidicida* in the Hūnua Ranges with 95 per cent confidence, depending on the disease prevalence P. Dotted lines indicate to the 95 per cent confidence interval for the estimated sensitivity of the soil bioassay test q (Froud et al., 2022a).

2.2.6.5 Heterogeneous risk calculation

Figure 2-8 shows how heterogeneity of risk (x axis) can substantially reduce the number of samples required to detect *P. agathidicida* with 95 per cent confidence (blue line), but only if sampling can be effectively targeted at the highest risk trees. Even a little heterogeneity of risk can have a big effect on the number of samples required, providing the risk of each tree is accurately characterised. If risk is well understood and the highest risk trees can be targeted, then substantially fewer samples may be needed to achieve the desired survey sensitivity. This is demonstrated by the rapid decline in the blue lines in Figure 2-8 as the heterogeneity of risk increases. However, if risk is poorly understood, then mis-targeted sampling may substantially reduce the sensitivity of the survey (red line).

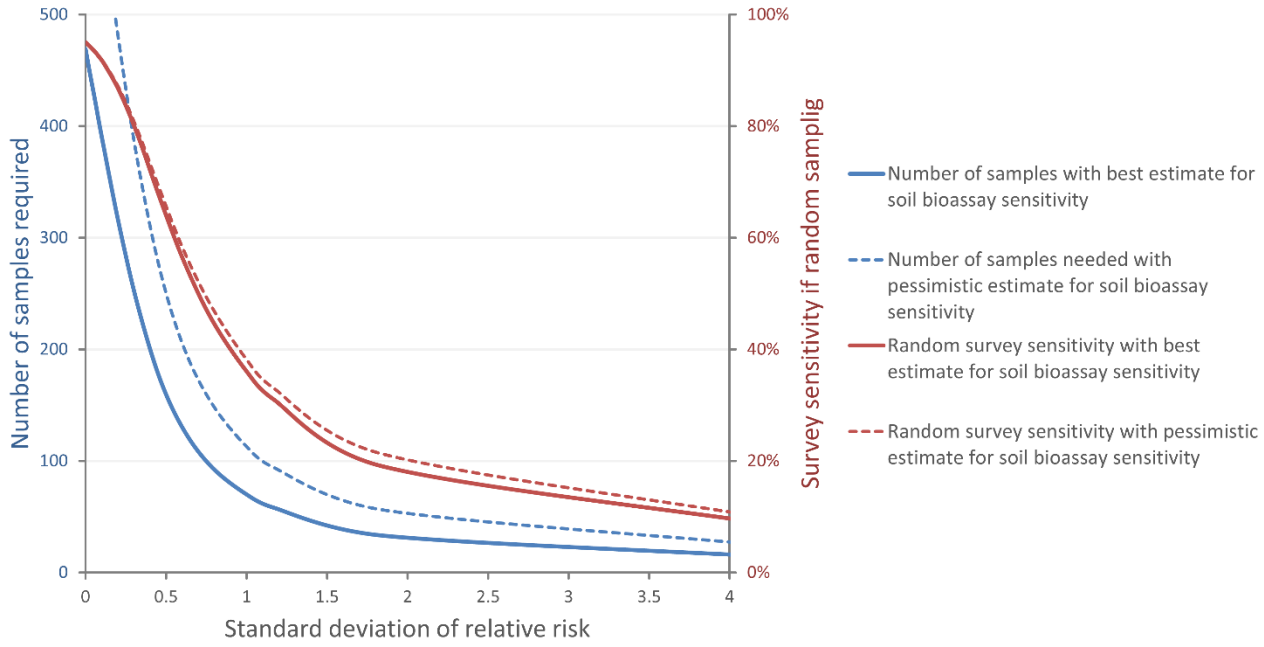


Figure 2-8. Effect of heterogeneity of risk on the number of risk-targeted samples required to achieve 95 per cent confidence in detecting *P. agathidicida* present with 1 per cent prevalence (blue line) and the mean survey sensitivity arising if those samples were taken randomly (red line). Solid lines show results with soil bioassay sensitivity at its most likely value, q = 63.8 per cent; dashed lines correspond to the lower threshold of the 95 per cent confidence interval for sensitivity, q = 42.6 per cent. Relative risk values were drawn from a Weibull distribution.

2.2.6.6 Hybrid approach calculations

From Figure 2-7, a little fewer than 500 samples would be needed to detect a P = 1 per cent infestation with s = 95 per cent confidence and a best-estimate soil bioassay sensitivity q = 63.8 per cent. Likewise, around 700 samples would be needed with a worst-case soil bioassay sensitivity q = 42.6 per cent. Basing a sample design on these numbers suggests selecting 500 trees at random, plus a further 200 trees of the highest risk. If the risk assessment is faulty, there would still be sufficient random samples to have 95 per cent confidence in detecting *P. agathidicida* at 1 per cent prevalence. But depending on the degree of heterogeneity of risk, the extra 200 high risk samples could bring confidence in detection close to 100 per cent, even with the worst-case soil bioassay sensitivity (Figure 2-9[a]). The best estimate for soil bioassay sensitivity would give similar results for half that disease prevalence, P = 0.5 per cent (Figure 2-9[b]).

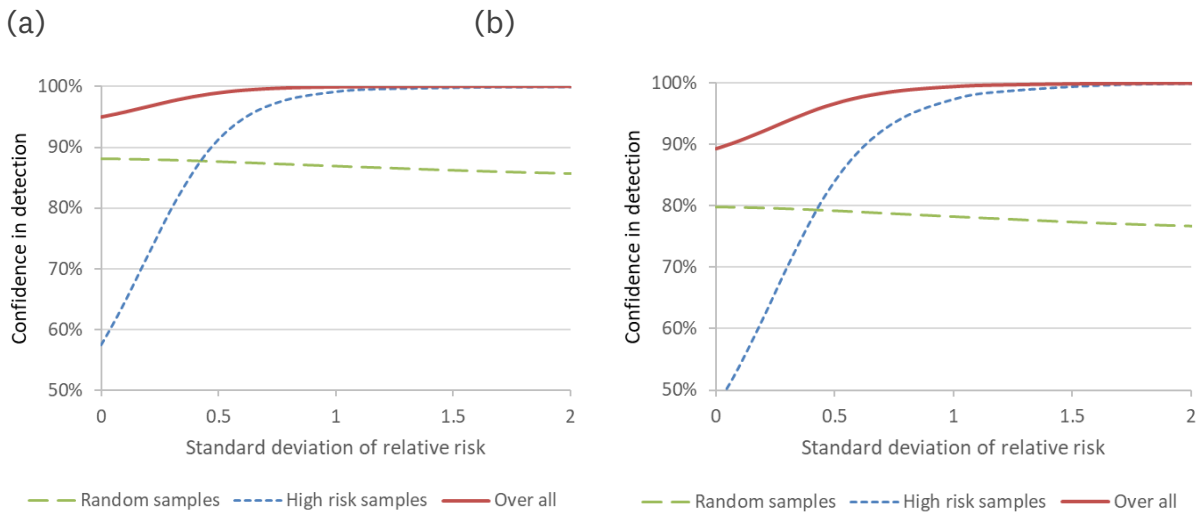


Figure 2-9. [a] and [b]. Effect of heterogeneity of risk on the sensitivity in a survey of 500 randomly selected trees plus a further 200 samples from the highest risk remaining trees. Relative risk values were drawn from a Weibull distribution. (a) worst-case soil bioassay sensitivity q = 42.6 per cent and *P. agathidicida* prevalence P = 1 per cent. (b) best-estimate bioassay sensitivity q = 63.8 per cent and prevalence P = 0.5 per cent.

2.2.6.7 Final sample size estimate

Assuming the best estimate for soil bioassay sensitivity, a total of 467 random trees would need to be sampled to give 95 per cent confidence in detecting *P. agathidicida* if present in 1 per cent of trees. Up to 700 random samples would be needed to account for uncertainty in the test sensitivity, but significantly fewer would be needed if there is heterogeneity of risk and if samples can be targeted at the riskiest trees. Therefore, investment in understanding and characterising *P. agathidicida* risk could be beneficial in substantially reducing the number of samples required for ongoing proof of freedom. Until risk factors can be quantified and tested, a hybrid approach of 500 random samples and 200 risk-targeted samples would give a high probability of detecting *P. agathidicida* under a range of circumstances.

2.2.7 Selection of random trees for sampling

Based on the remote sensing of kauri, we developed a sample frame of trees for random selection. These trees were randomly selected then validated using imagery to confirm a high likelihood of being kauri trees prior to physical survey. For the risk-based sample of trees we obtained risk information for each tree then selected the trees as detailed below, prior to validating that they were kauri trees

and adding them to our 700 tree sample (500 random and 200 risk-based). We then added a buffer to the random sample set to account for potential host misclassification or inaccessibility issues, resulting in 667 selected randomly for long-term monitoring (Figure 2-10).

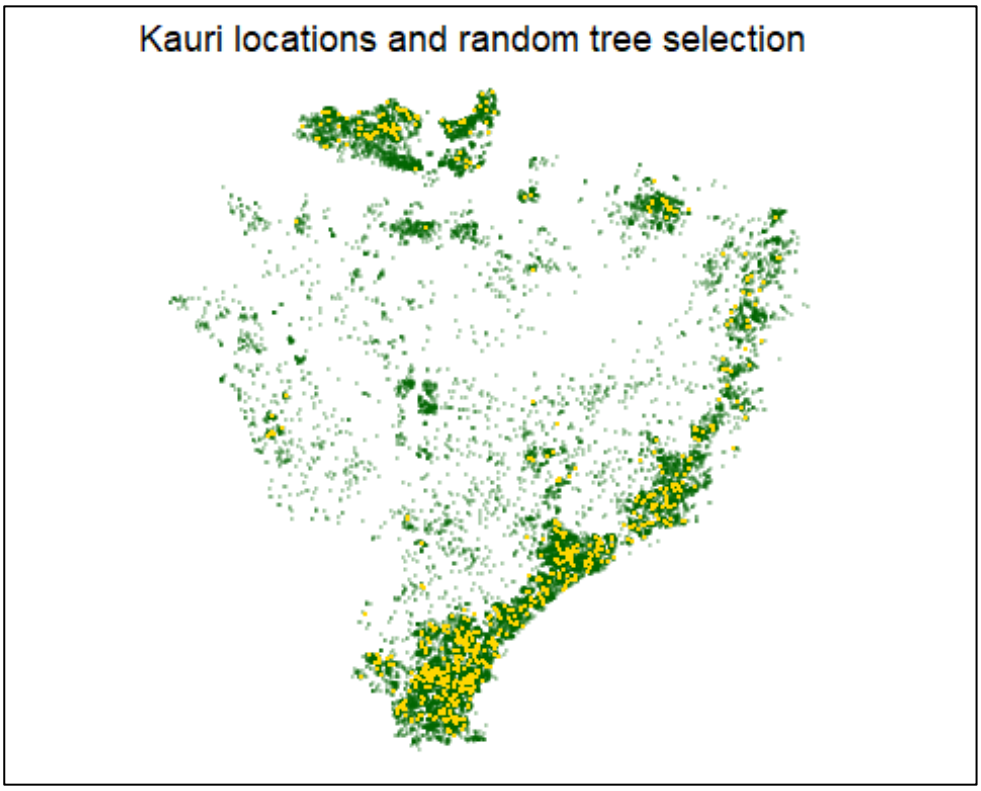


Figure 2-10. Canopy height kauri locations (in green) and 667 trees selected by random (yellow points).

2.2.8 Calculation of risk for risk-based trees

A number of risk factors associated with the detection of *P. agathidicida* in soil samples were identified from the recent Waitākere survey (Froud et al., 2022b), and from consultation with Ngā Mana Whenua o Te Ngāherehere o Kohukohunui. These were quantified for each tree in the population, using ArcGIS® Pro tools to build risk layers and calculate risk values for individual trees using the best available sources.

2.2.8.1 Calculating risk factors

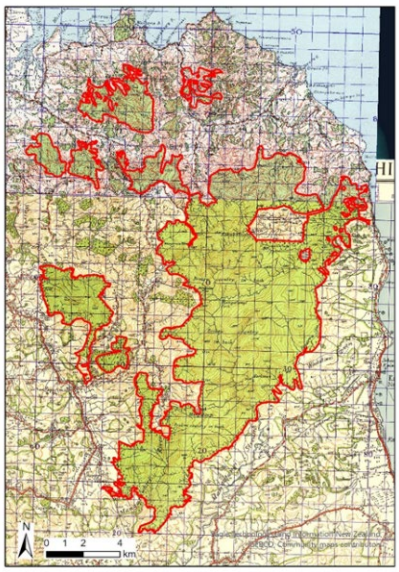
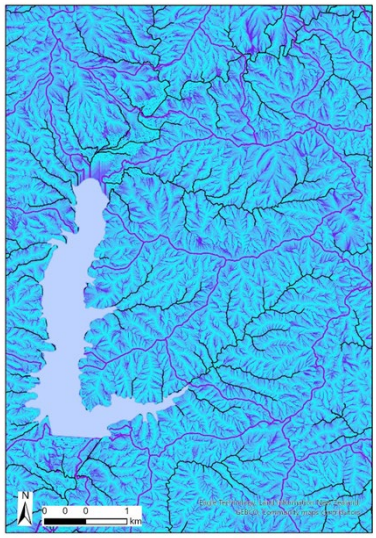
Existing data were used where possible to inform the calculations of raster-based risk layers. If not otherwise stated in Table 2-1, the data was sourced from the NZ Topo 1:50k data and LiDAR height models (Auckland Council, 2017, Waikato Regional Council, 2021) that can be downloaded on the LINZ data service website (https://data.linz.govt.nz/). Historical disturbance were obtained from Kerry

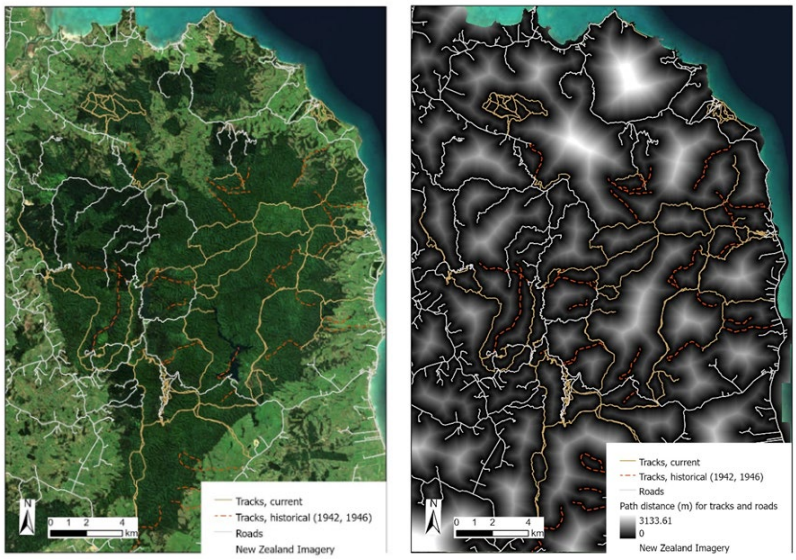
O'Connor (2023), a local historian, and cross-checked with Southern Regional Parks and ngā mana whenua o Te Ngāherehere o Kohukohunui. Historical data were edited on historical topographical maps from 1942 and 1946 (DOSLI, 1946, DOSLI, 1942).

We used ArcGIS® Pro tools to calculate wall-to-wall distance rasters based on the path distance along the terrain or the direct Euclidean distance, e.g. to the coastline within the area of interest. Details are provided in Table 2-1. The density of kauri was calculated in R.

Table 2-1. Description and method of calculation for the three types of risk factors used to inform risk-based sampling.

Risk factor	Method of calculation
Individual tree factors	
Elevation (Elevation)	Extracted per tree location from a 1m LiDAR terrain model (ArcPro: Extract values per point).
Density of kauri (KauriDist)	An index of kauri density was estimated as the mean direct distance from each tree to its 10 nearest kauri neighbours (R script)
Environmental factors	
Distance to closest coastline (CoastDist)	The closest distance to the nearest coastline is calculated from the individual tree locations (ArcPro: Euclidean distance)
Distance to current or historic edge of native forest (EdgeDist)	For the distance to the closest outer and inner forest edge, we classified trees as located inside or outside forest areas with a minimum size of 125ha. For those trees inside forest areas, we measured their distance to the nearest forest edge along the terrain, as an indicator of potential disturbance. Trees outside the main forest areas were given a value of '0m distance', the same as being right on the verge of a forest, to indicate the risk associated with disturbance of these isolated trees. As inner forest edge we added historical clearances that are currently regenerating. These areas were identified via current regenerating ecosystems such as kānuka scrub/forest (VS2) and broadleaved scrub/forest (VS5) in the Auckland Council

Risk factor	Method of calculation
	Ecosystem layer (Auckland Council GIS) informed by Singers et al (2017) and the 'Broadleaved Indigenous Hardwood' in the Landcover database v5.0 (Manaaki Whenua Landcare Research, 2020). We also marked if a kauri tree is located within an area of regenerating vegetation. (ArcPro: Path distance)
Historic landcover (Cover1942)	Four categories of historic landcover were defined: Cleared land, scrub, remnant forest (< 125ha) and large forest (> 125ha). These areas were edited on historical topographical maps from 1942 and 1946. A positive distance was calculated for tree locations outside the historical areas and a negative distance for trees inside the historical forest areas (ArcPro: Path distance). 
Moisture (Moisture)	The Moisture parameter represents an estimate for the land area lying directly uphill from each tree, derived from a digital elevation model. In the Auckland area, a value above 50,000 m^2 is considered to indicate a permanent stream. The image shows the flow accumulation raster as an approximation of surface moisture showing the area around the Upper Mangatāwhiri dam, overlayed with watersheds (purple) and permanent streams (black). (ArcPro: Flow accumulation) 

Risk factor	Method of calculation
Distance to previous soil sample / ill thrift site (IllDist)	Distance along the terrain calculated from individual tree locations to the nearest soil sample (108 locations) or detected ill-thrift tree. We included locations of symptomatic kauri trees identified during a 2017 helicopter survey and at least 100m away from a soil sample location. (ArcPro: Path distance)
Distance to closest tree with recorded basal bleed (BleedDist)	Distance along the terrain, calculated from individual tree locations to the closest previous recorded basal bleed (86 locations) marked in the kauri layer in the Auckland Council 'Kauri ora database". (ArcPro: Path distance)
Human factors	
Distance to closest track, road, mana whenua route or tracks. (RouteDist)	Distance calculated along the terrain from individual tree locations to the nearest target feature. Target features are both current and historical tracks and roads. The images below are showing the current and historic features on a current aerial image (left) and the resulting path distance raster (right). (ArcPro: Path distance) 
Distance to dams, historical dam-earthwork sites (DamDist)	Distance calculated along the terrain for each tree location, to the closest dams. We also added a historical earthwork site for the Moumoukai Dam that was edited on aerial images from 1977. (ArcPro: Path distance)

Risk factor	Method of calculation
Distance to the four large reservoirs (ReservoirDist)	Distance for each tree location, along the terrain, to four large reservoirs within the Hūnua Ranges. (ArcPro: Path distance)
Distance to closest historical timber sites and other disturbances (TimbDist)	Distance calculated from individual tree locations to the nearest historical disturbance site from the following sources: • Kerry O'Connor 2023: Tunnel crossings (7x), historical sawmills (3x), Historic quarries and borrow pits (10x), Doolan's camp (6x). • Tūtangi Ora (Historic Heritage Information) – selected sites by Alastair Jamieson ('DAM KAURI', 'KAURI DAM ABUTMENTS', 'KAURI DAM REMNANT', 'Logging Site', 'LOGGING SITE', 'MINE', 'MANGANESE MINING', 'MINE SHAFT – Historic well', 'Pit Saw', 'Sawmill') (Auckland Council, 2023) • Historical maps from 1942 and 1946; additional locations of historical mines (3x) and sawmills (1x) (DOSLI 1942 and 1946).
Distance to closest site for vegetation monitoring (PlotDist)	Distance calculated from individual tree locations along the terrain to vegetation monitoring plot. Sources: RIMU Forest Monitoring Plots internal database at AKLC, accessed Feb. 2023 (56x) ,and Historical vegetation Transects (6x) (Newhook, 1972).
Distance to closest site with (experimental) planting/treatment (PlantingDist)	Distance calculated from individual tree locations to an experimental plot reported in Barton (2002).

2.2.8.2 Quantifying relative risk factors

For each risk factor, we specified whether relative risk of *P. agathidicida* presence was likely to increase or decrease with the value of that risk factor. For most factors, risk is expected to decrease, e.g. with distance to roads, tracks, historical

sites, forest edges and other features associated with disturbance. In this case, we modelled the relative risk response as

$$R = ae^{-4.6x/b}$$

where R is relative risk; x is the value of the risk factor (e.g. elevation, distance to a road); a is the 'weight', being the relative risk at the origin (x = 0); and b is the 'range', being the value beyond which the risk is negligible (formally, $R = 0.01a$ when $x = b$).

For features where risk of *P. agathidicida* presence is expected to increase with the value of that factor (e.g. moisture), we assumed

$$R = a\left(1 - e^{-4.6x/b}\right)$$

where the risk R approaches the weight a as x becomes larger, and the range b is the value beyond which the risk exceeds 99% of its maximum (formally, $R = 0.99a$ when $x = b$).

For binary (present/absent) risk factors, such as regeneration since 1942, the $R = a$ where the risk factor is present, otherwise $R = 0$.

The Waitākere survey (Froud et al 2022) used a multivariable logistic regression model to identify and quantify risk factors significantly associated with the detection of *P. agathidicida* in the soil. For risk factors identified as significant, we could use the fitted parameters to suggest appropriate values for a and b above: the regression coefficient measured the relative strength of each risk factor's influence, while the prevalence odds ratio suggests how the influence changes with the value of the risk factor. Importantly, the fitted values were based on the **odds** of *P. agathidicida* being present versus absent, but for estimating relative risk we need the **probability** of presence out of all samples. However, odds and probabilities are similar when prevalence is low, allowing us to utilise the Waitākere results on the assumption that this is true for the Hūnua Ranges.

Where possible, the values of a and b were informed by the results from the Waitākere survey. Parameter b was indicated by the prevalence odds ratio P as $b = -4.6s/ln(P)$ where s is the scale of the risk measure as used there (e.g. 100 m). Indicative values for a were derived from the Waitākere coefficients by assuming all other risk factors were at their mean values. These parameters, and those for risk factors that were not included in the Waitākere analysis, were discussed and weighting adjusted by a panel of experts that included Auckland Council ecologists and independent epidemiologists.

The parameters of each risk factor is provided in Table 2-2 and a descriptive summary is provided in Appendix D, along with risk value summaries for each individual risk factor.

Table 2-2. Risk factors and parameters.

Risk ID	Attribute	Type	Risk justification	PA response effect	Range	Weight
Elevation	Elevation	continuous, >0	Waitākere survey indicated less risk as elevation increases	Decreasing	500 m ASL	3.4
KauriDist	Density of kauri – Mean distance to nearest 10 kauri to indicate kauri density	continuous, >0	Transmission between trees is highest when trees are close together	Decreasing	100 m	2.0
CoastDist	Distance to nearest coastline	continuous, >0	Waitākere survey indicated less risk as distance from the coast increases	Decreasing	7700 m	2.0
EdgeDist	Distance to current edge of native forest	continuous, +ve inside forest, 0 outside	Proximity to the forest edge may increase disturbance and risk of *P. agathidicida* colonisation	Decreasing	200 m	1.0
Cover1942	Historic landcover	categorical: 0 = forest >125 ha, 0.2 = forest <125 ha, 0.8 = scrub, 1 = cleared	Indicates historical disturbance	Increasing	NA	1.5
Moisture	Moisture	continuous, >0	*P. agathidicida* dispersal may be facilitated by ground and surface water flow	Increasing	10 ha	5.0
IllDist	Distance to closest ill thrift record	continuous, >0	Ill thrift (suggested by soil samples being taken, or direct observation during AC helicopter survey) may indicate *P. agathidicida* presence	Decreasing	200 m	1.0
BleedDist	Distance to closest basal bleed record	continuous, >0	Basal bleeds may indicate *P. agathidicida* infection	Decreasing	200 m	4.0
RouteDist	Distance to closest track, road or mana whenua route	continuous, >0	Waitākere survey indicated increased risk of *P. agathidicida* presence close to roads and tracks	Decreasing	500 m	1.5
TimberDist	Distance to closest historical timber site or other disturbance	continuous, >0	Waitākere survey indicated increased risk of *P. agathidicida* presence close to known historical disturbance sites	Decreasing	500 m	1.5
DamDist	Distance to current dam structures	continuous, >0	Waitākere survey indicated increased risk of *P. agathidicida* presence close to known historical disturbance sites	Decreasing	500 m	3.0
ReservoirDist	Distance to the edge of the nearest reservoir	continuous, >0	Waitākere survey indicated increased risk of *P. agathidicida* presence close to known historical disturbance sites	Decreasing	500 m	1.0
PlotDist	Distance to closest site with vegetation transects	continuous, >0	Visits to transects could have introduced *P. agathidicida* to the area	Decreasing	500 m	0.5
PlantingDist	Distance to site with experimental kauri plantings	continuous, >0	Experimental plantings could have introduced *P. agathidicida* to the area	Decreasing	1500 m	2.0

2.2.8.3 Overall relative risk

The component risks were summed to give a combined risk score for each tree. The component and combined risk scores are illustrated in Figure 2-11.

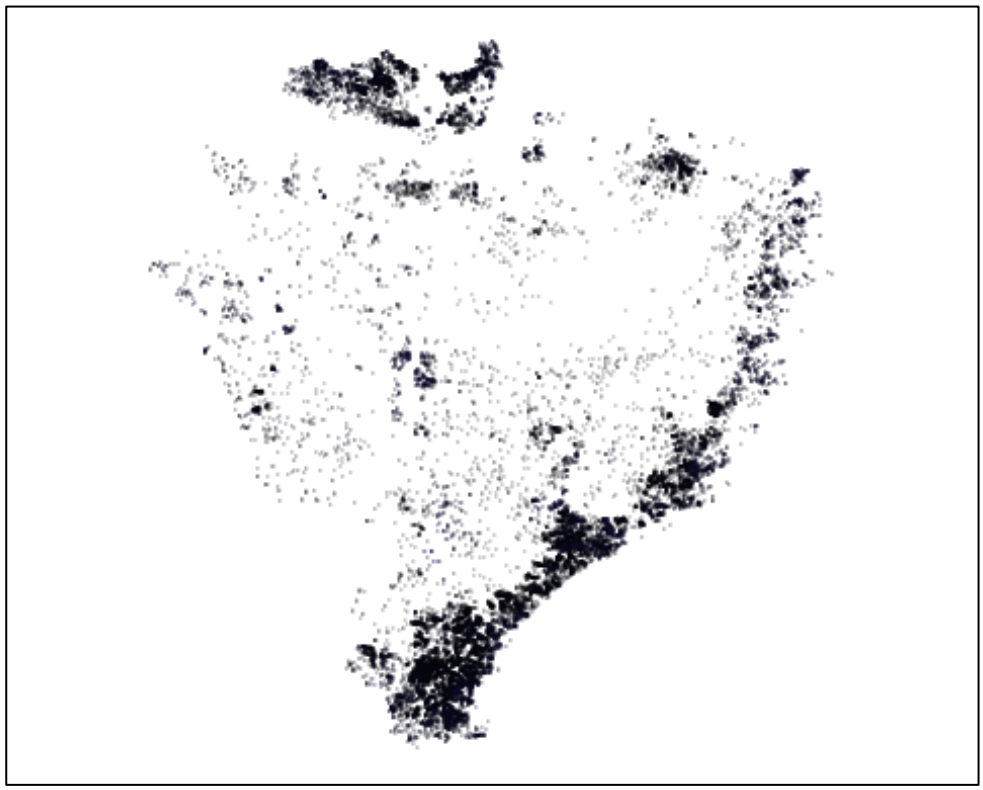


Figure 2-11. Map of the combined relative risks of all risk factors within Hūnua, where grey are lower risk trees and black points are the highest risk trees.

The cumulative relative risk was plotted and the relative area under the curve was 65.0 per cent (Figure 2-12). This reflects the degree to which risk factors are spread across trees. If risks were all focused on just a few trees then the line would run close to the left and top edges of the graph, and the relative area under the curve would be close to 100 per cent. In contrast, if risk factors are randomly scattered across the population, then the line would follow the diagonal line, with an area under the curve of 50 per cent. The shape of this curve sets an upper limit on how likely we are to detect each tree with *P. agathidicida* infested soil, assuming our understanding of the risk factors is accurate.

The random samples, taken together, capture 2.4 per cent of the estimated total risk. For comparison, a random sample of this size would be expected to capture 2.5 per cent of the total risk.

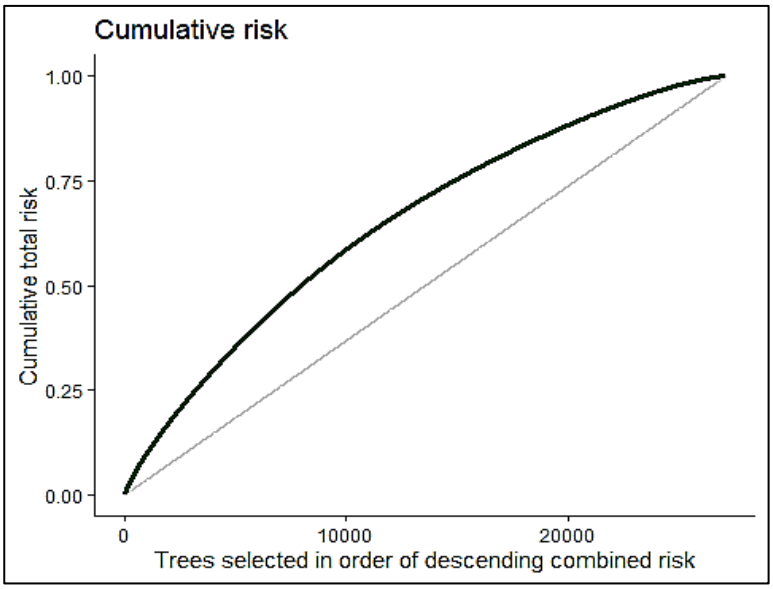


Figure 2-12. Cumulative relative risk for each tree.

The relative contributions of each risk factor are summarised in Figure 2-13 below.

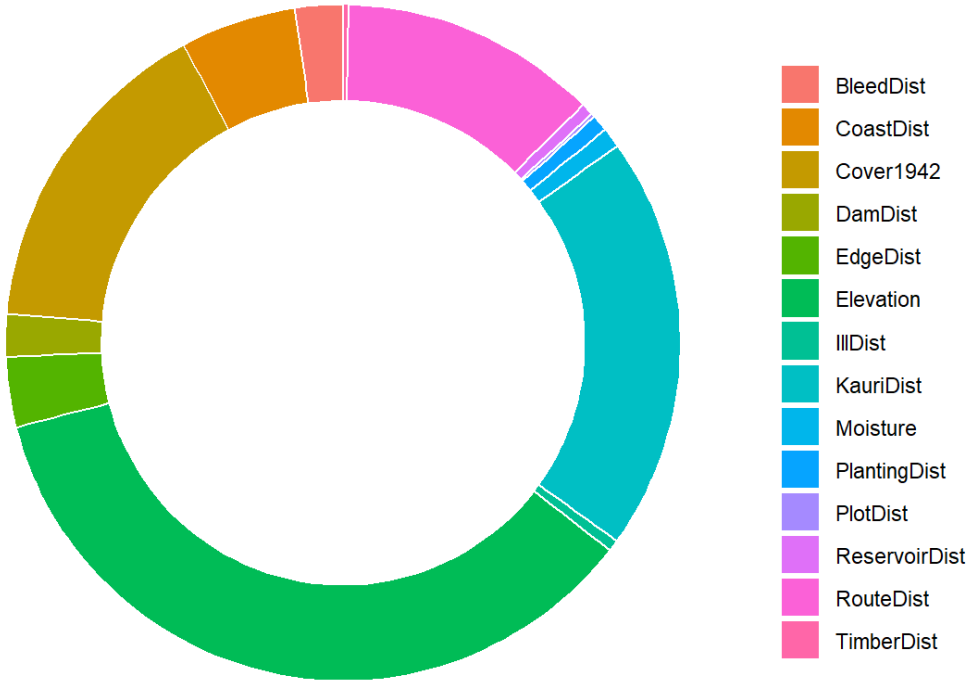


Figure 2-13. The relative contributions of each risk factor to the combined risk calculation.

2.2.9 Risk-based selection of kauri for sampling

We investigated several different ways to select an additional sample of 250 trees based on their risk scores. In all cases we excluded any kauri within 50m of any previously selected tree, including the randomly selected trees.

A total of 5931 trees were ineligible for selection because they were within 50m of a randomly selected tree, leaving 20,565 trees eligible for selection.

Next, we thinned the numbers of remaining trees in the sample frame to avoid oversampling high-risk areas. Where two trees lay within 50m of each other, we removed the one with the lower combined risk value. A total of 6399 trees remained as illustrated in Figure 2-14, with the minimum distance between any two of these trees being 50m. The frequency of distance between trees is illustrated in Figure 2-15 and shows that most kauri were close to other kauri.

Together with the random sample, these trees capture 27.2 per cent of the estimated total risk, the remainder of risk being attributable to trees removed during the thinning process. For comparison, a random sample of this size would be expected to capture 26.0 per cent of the total risk.

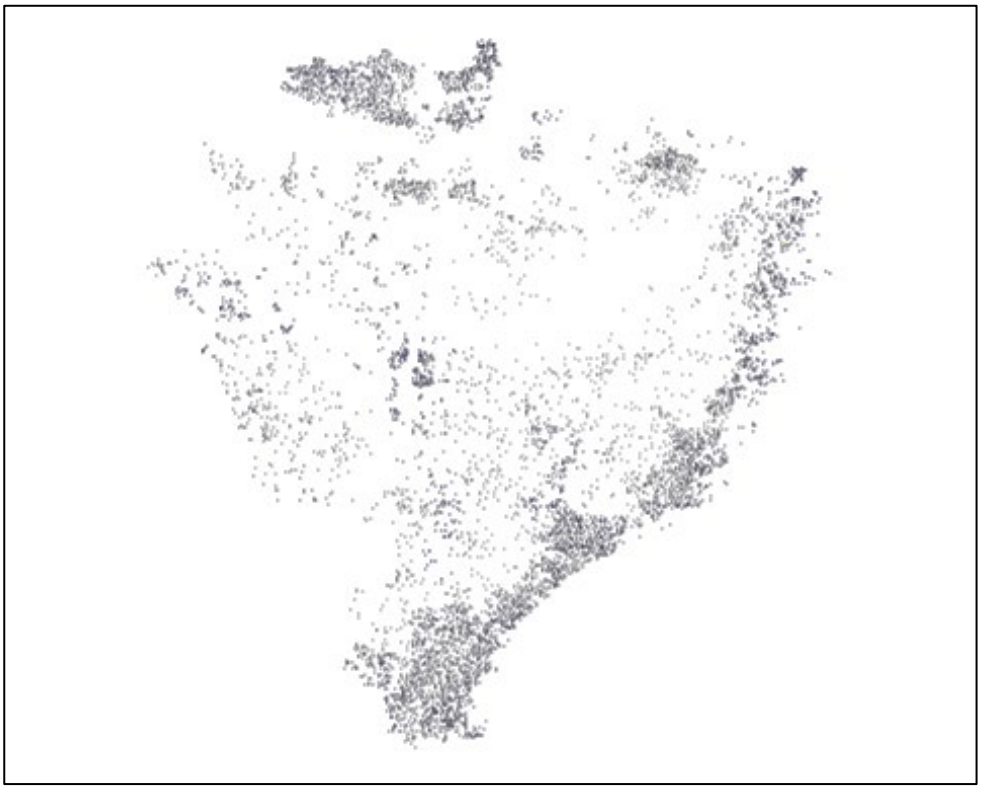


Figure 2-14. Map of trees eligible for risk-based selection after thinning for closely spaced trees (within 50m).

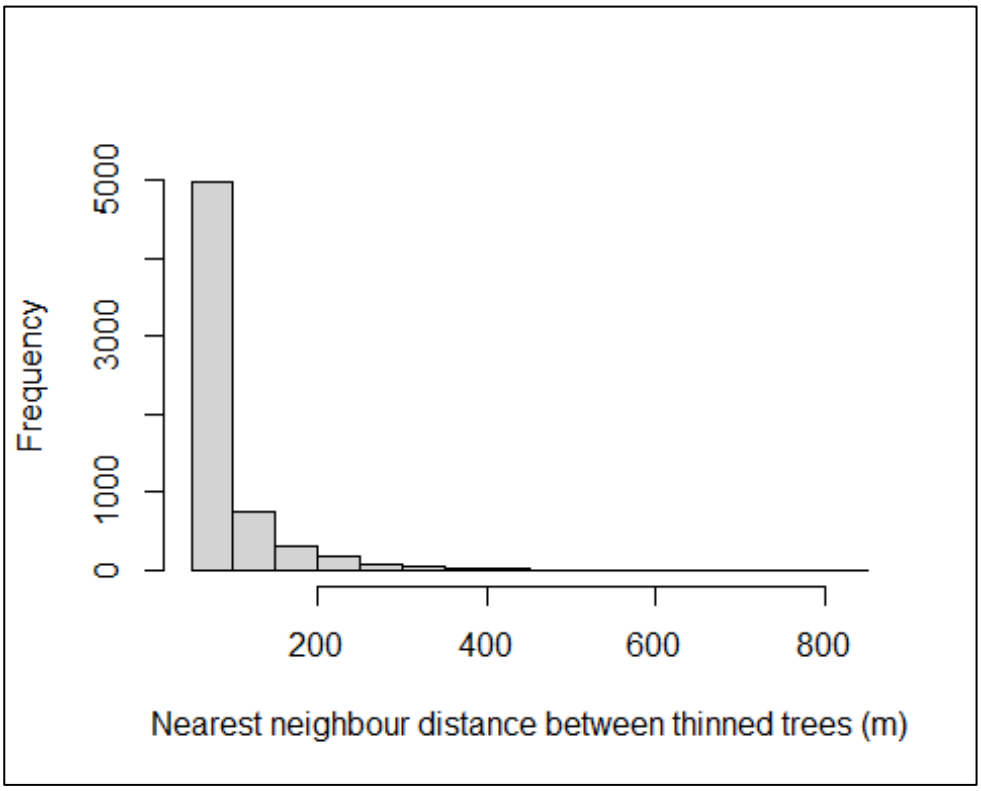


Figure 2-15. Frequency of the distance between kauri trees that were eligible for selection in the risk-based sample.

Our next task was to select the 250 risk-based trees for our reduced sample frame. We considered several approaches before settling on a balanced approach of selecting the five highest risk trees for each individual risk factor and randomly selecting the remaining points from the top 10 per cent of the riskiest trees. Together with the random samples, these trees capture 4.9 per cent of the estimated total risk. For comparison, a random sample would be expected to capture 3.4 per cent of the total risk (an example of this selection is illustrated in Figure 2-16, Figure 2-17, and Figure 2-18.

Details of the alternative approaches are provided in Appendix D.

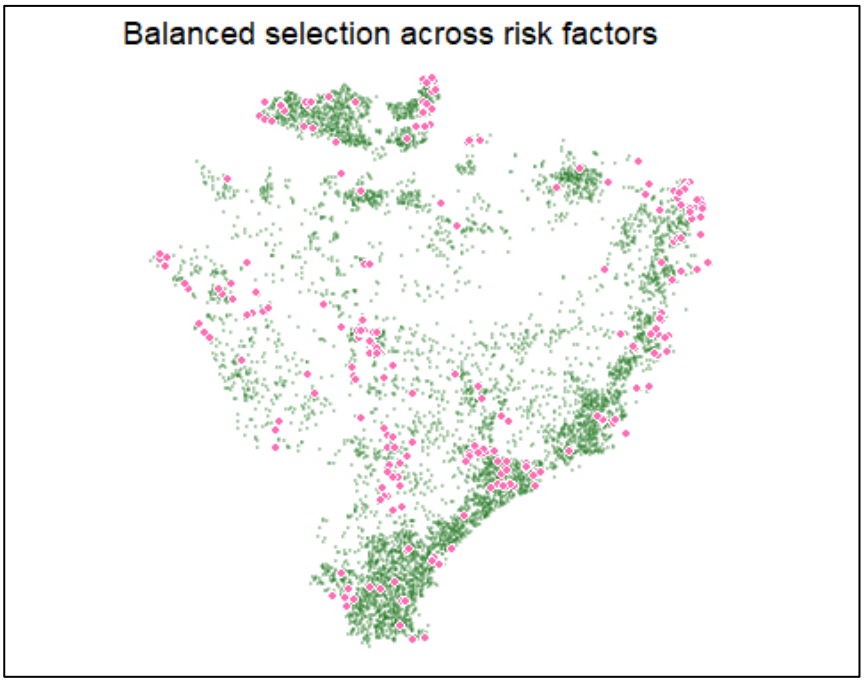


Figure 2-16. Example draw of samples from a balanced risk-based sample selection.

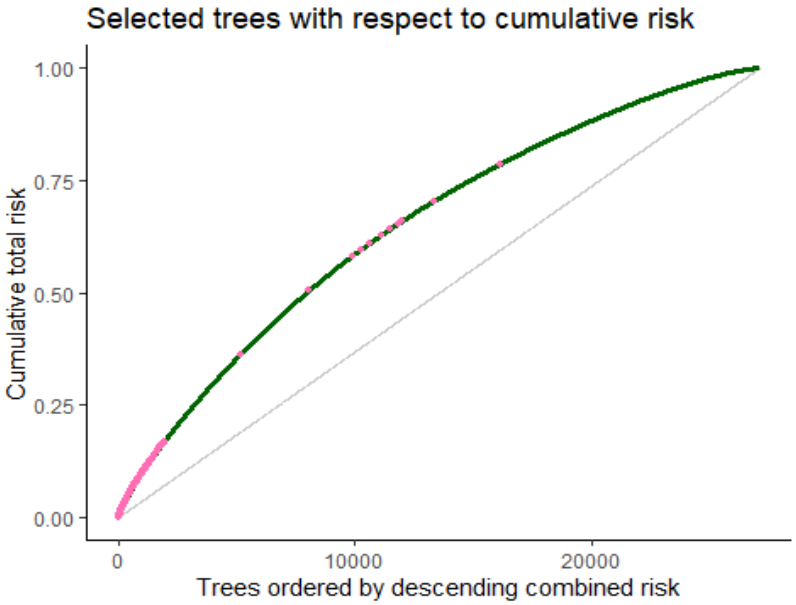


Figure 2-17. Samples selected using a balanced risk-based approach, ordered by highest to lowest combined risk score.

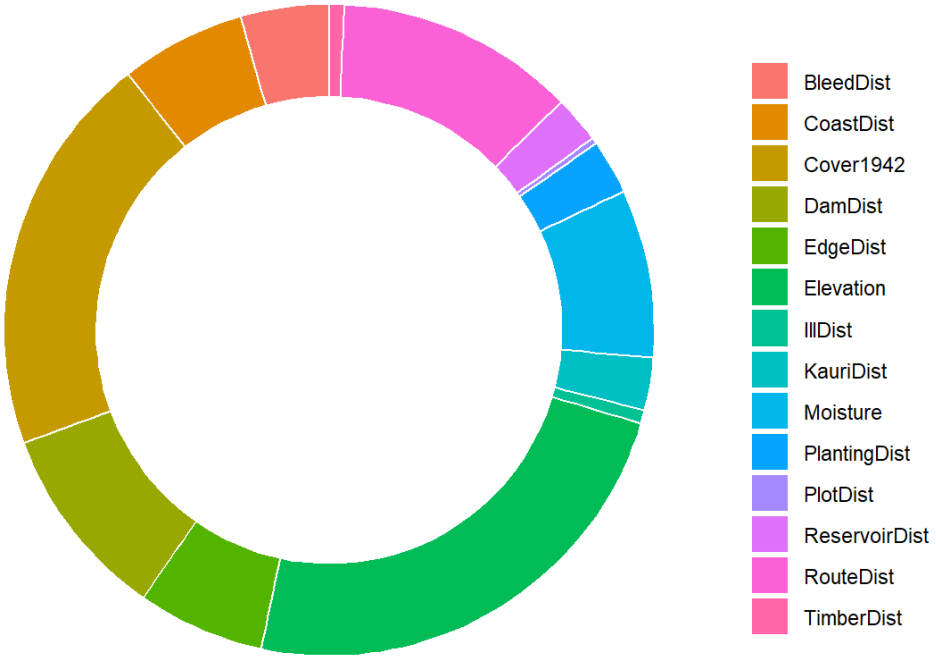


Figure 2-18. Example of risk factors selected from a balanced risk-based approach, showing the relative contribution of each factor to the overall risk profile.

2.2.10 Random and risk-based kauri selected for monitoring

We randomly selected 570 which were then reduced to 551 after host verification using imagery. These random trees form the basis for long-term monitoring. In addition, a further 250 trees were selected as per the balanced risk approach above, and then reduced to 234 after host verification. The working group was provided with the option to force the selection of any specific trees based on perceived risk; two kauri reported as showing ill-thrift near a walkway were then included in the risk-based sample. The working group was also asked if any trees or areas needed to be avoided for cultural reasons, and an accidental- find-of-artefacts-protocol was implemented which would have excluded any selected trees if artefacts were found or if kaitiaki perceived a risk to safety.

Not all of the selected kauri could be sampled in practice. Some were excluded because they were determined to not be kauri, most commonly during validation from aerial imagery. If field crews visited the site and determined it was not a kauri then they were instructed to select a nearby kauri within 50 m for sampling instead. Others were excluded because access was unsafe, or permission to enter private property was not granted. Finally, the crews may have run out of time for sampling the trees.

The sample frame of kauri trees eligible for survey and final numbers of trees sampled are illustrated in Figure 2-19 and 2-20.

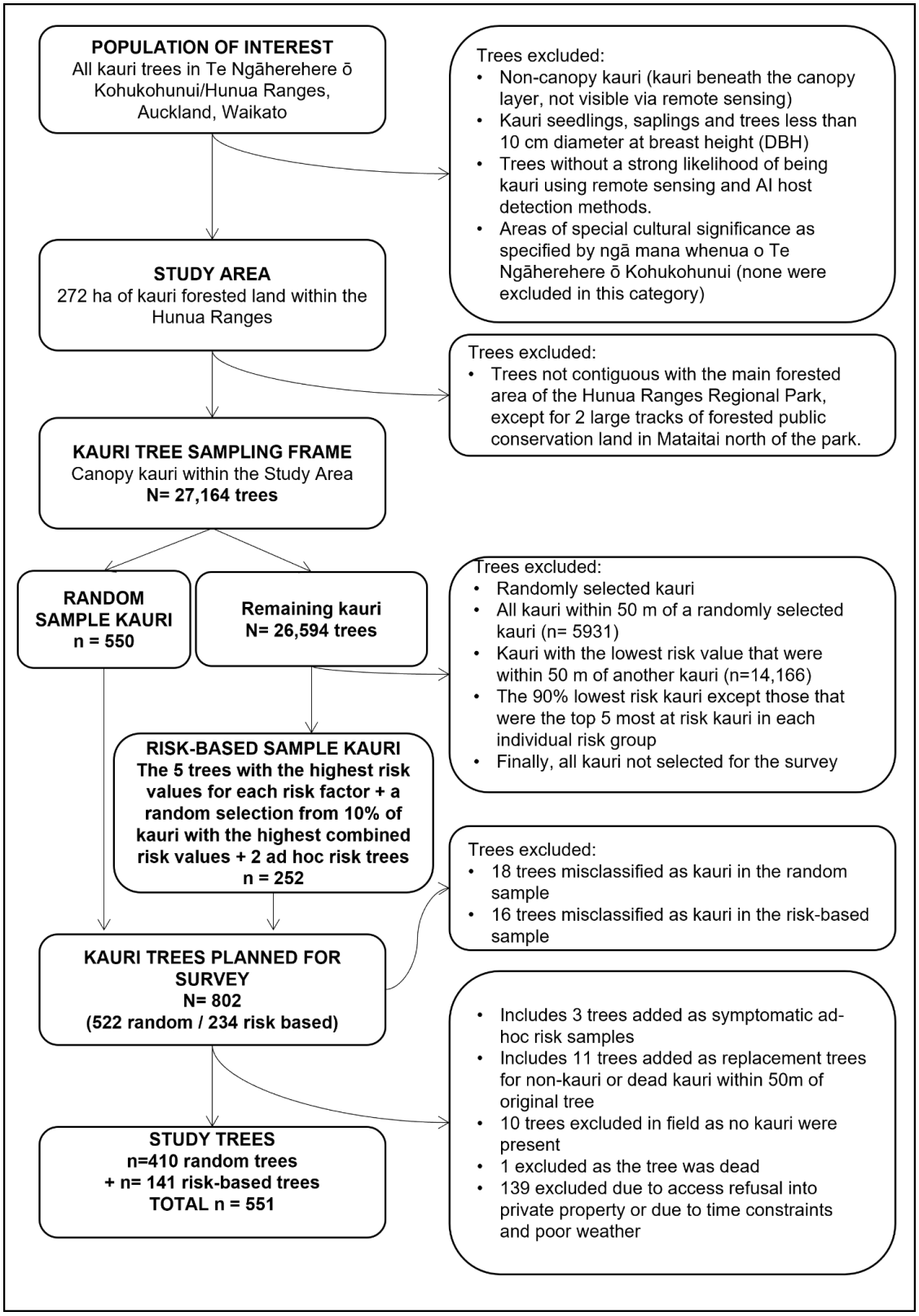


Figure 2-19. Sample frame for selecting kauri showing the transition from the initial population at risk to the final collection of sampled trees.

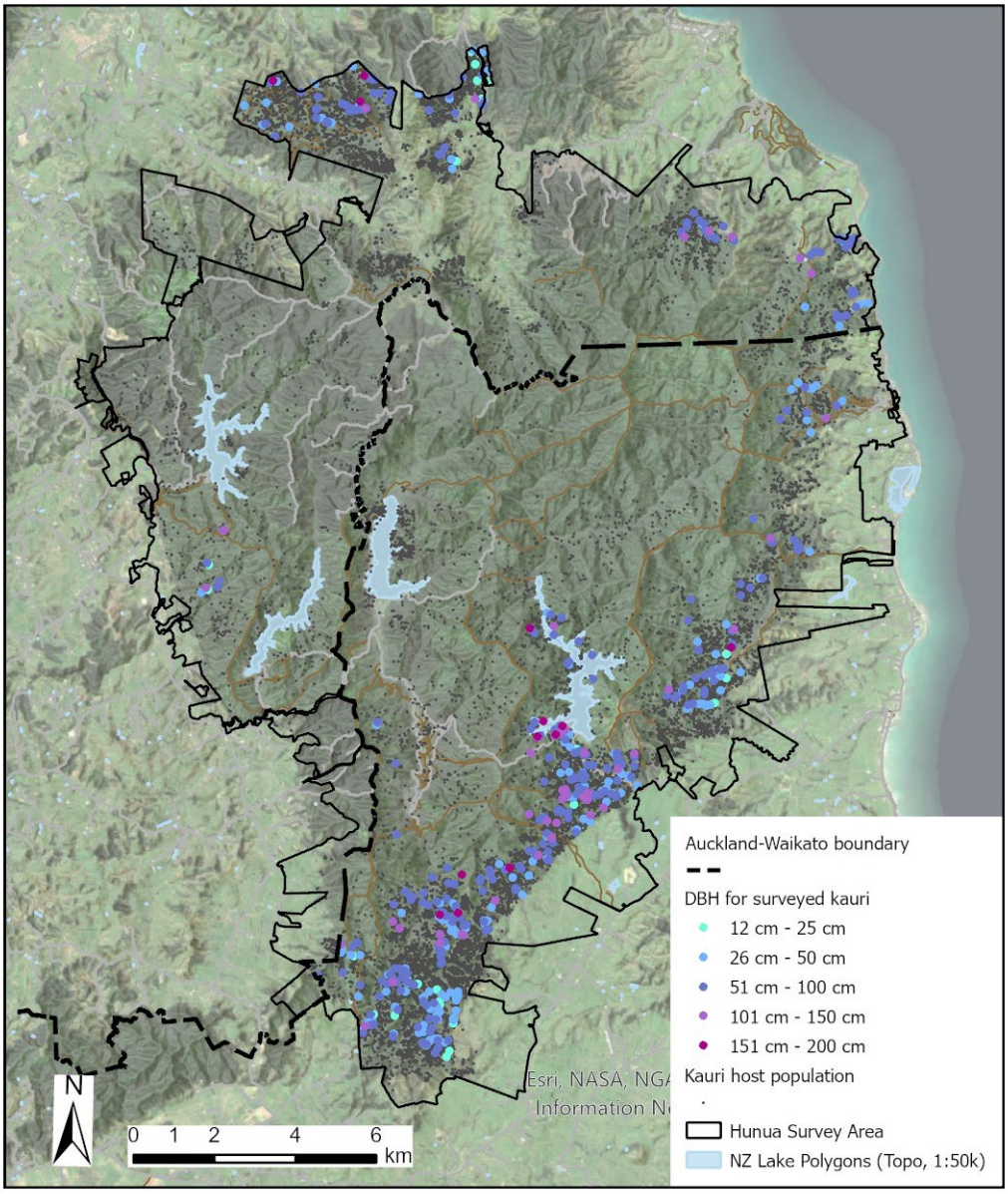


Figure 2-20. Map of sampled kauri from randomly selected and risk-based samples (n=551) stratified by diameter at breast height (DBH).

2.2.11 Monitoring of kauri trees

Baseline kauri tree health, kauri dieback disease symptoms, potential risk factors, ecological impact factors were collected for each tree during monitoring to improve the baseline understanding of the Hūnua forest.

The monitoring form was a revised version of the 2021 Waitākere survey monitoring form (Froud et al., 2022a), with the only significant changes being the removal of a few ecological variables that had proven difficult to measure, the inclusion of a new distance to closest kauri variable, and a revision of the common plants list. In addition, all trees were assessed for host, disease and ecological variables, and soil

samples were collected from all monitored trees, as opposed to the Waitākere survey where ecological variables and soil samples were taken from a subset of sampled trees. The variables are briefly described in the following sections and the monitoring form is in Appendix B.

2.2.12 Investigation Plan development

As part of the co-design process for this study, the working group built an investigation plan. The purpose of the investigation plan was to provide clear guidance for Auckland Council and partners Ngā Iwi Mana Whenua o Te Ngāherehere o Kohukohunui/Hūnua Ranges and Department of Conservation, on how any new detections of *P. agathidicida* would be investigated and communicated in the Hūnua Ranges. The plan was completed in partnership during the design of the survey (i.e. prior to undertaking surveillance). The investigation plan covered awareness, data management (a data agreement was developed between partners), notification of any positive screening tests, the validation process for positive screening tests, an action plan for a confirmed detection (validated test), a communications plan and prompts for a discussion on the welfare of partners in the event of a confirmed detection of *P. agathidicida*. See Figure 2-1.

The investigation plan template and validation process are in Appendix A.

2.2.13 Data collection

Surveys were done by a team of trained surveyors working in small teams for consistency of assessments and health and safety reasons. We targeted different geographical sectors (NW, NE, SW, SE) of the study area each week to minimise the spatial and temporal bias in field assessment and soil collection over the duration of the surveillance programme. We prioritised samples from the regional park and conservation reserves first, followed by private land where access was granted. Field work was suspended during periods of rainy weather as part of the hygiene precautions.

Survey measurements were collected using a monitoring form loaded into ArcGIS Survey123 on waterproof hand-held tablets. Minor adjustments continued to be made to the electronic survey form to improve functionality during field team training at the start of the survey.

The survey was carried out between 30 March and 15 October 2024.

Teams were provided with the GPS coordinates of selected trees and used accurate hand-held field GPS units to locate trees. Where multiple kauri trees were present at GPS points, the closest kauri of >10cm DBH to the GPS coordinate was selected by the ground survey team. Selection of the kauri was based purely on proximity and not on health status.

All monitored trees were tagged with robust aluminium tree tag identifiers to enable future identification and monitoring of the same tree (Figure 2-21). Tree tags were attached using nails at the uphill point of the tree, or north facing on non-sloping land 1.4 m above the ground.

In Figure 2-22 below, Kaimahi Analisa Rawiri (left) and Rangimahora Rawiri (second from left) can be seen passing on kauri survey knowledge to a Department of Conservation field team during a training day.

Figure 2-21. Tree tags used for permanent marking of monitored trees.

Figure 2-22. Passing on kauri survey knowledge during a training day.

2.2.13.1 *P. agathidicida* sites

This study follows the Tiakina Kauri case definition (Stevenson & Froud, 2020) for *P. agathidicida* sites as below:

- A ***P. agathidicida* <u>not detected</u> site** is defined as a point location where the presence of *P. agathidicida* was not detected (from a tree, soil or other substrate), using an approved test at an approved laboratory.
- A ***P. agathidicida* site** is defined as a point location where the presence of *P. agathidicida* has been confirmed (from a tree, soil or other substrate), using an approved test at an approved laboratory. This includes historical *P. agathidicida* detections.

For samples tested in this study, the approved test was soil sampling and bioassay, and the approved laboratory was Plant and Food Research Ltd, Havelock North. In addition, LAMP tests were conducted, and results were also used to assess *P. agathidicida* presence/not detected status.

2.2.13.2 Pathogen freedom calculation

The relevant formulae for detection surveys with randomly selected discrete sample units are shown in the table below. Here, s is the probability of detecting at least one case in a random sample of n units from a population of N total units, where a proportion P^* of the population is infected (prevalence), and the sensitivity of the diagnostic test is p.

Sample type	Sensitivity, s	Design prevalence, P*	Sample size, n
Relatively few units sampled ($n <= 0.1N$)	$1-(1-pP^*)^n$	$\frac{1-(1-s)^{(1/n)}}{p}$	$\lceil\frac{\log(1-s)}{\log(1-pP^*)}\rceil$
Relatively many units sampled ($n > 0.1N$)	$1-\left(1-p\frac{n}{N}\right)^{P^*N}$	$\frac{\log\left((1-s)^{(1/n)}\right)}{\log(1-pn/N)}$	$\lceil\frac{N}{p}\left(1-(1-s)^{1/P^*N}\right)\rceil$
Complete census ($n = N$)	$1-(1-p)^{P^*N}$	$\frac{\log\left((1-s)^{(1/N)}\right)}{\log(1-p)}$	N

For the current survey, the standard soil bioassay test sensitivity is p = 63.2% (95 per cent confidence interval = 42.6 per cent to 88.1 per cent) (Vallee et al., 2022), the sample size is n = 552, and the total population size is estimated to be N = 40,000 trees. Note that the sample size for *P. agathidicida* freedom is one tree larger than the sample size for monitored trees, as one soil sample was collected from a site where the monitoring form failed to load and was not revisited.

The calculations above assume that the samples are taken at random with respect to risk. However, part of our sample was taken specifically from the highest risk trees, so the sensitivity of our sample should be better than that.

If P^* is the proportion of trees infected in the population, then the number of infected trees is P^*N. The probability that tree i in the sample is infected is $P^*N \times R_i / \sum_N R$, and the probability of this sampled tree being infected and that infection being detected is $pP^*NR_i / \sum_N R$. Now the sensitivity of the survey is given by the probability that at least one of the sampled trees is both infected and that infection is detected:

$$s_{risk} = 1 - \prod_i^n \left(1 - pP^*N \frac{R_i}{\sum_N R}\right)$$

Notice that if all trees have equal risk, $R_i / \sum_N R = 1/N$ and this simplifies to $s = 1 - (1 - pP^*)^n$ as in the formula above.

2.2.13.3 Soil sampling

Soil samples were collected from all trees following the same methods used in (Froud et al., 2022a). The surveyors collected a composite sample comprising four sub-samples from within the root zone of the selected kauri, as decided upon in hui with the Operational Group. Individual soil samples were manually manipulated from the outside of the ziplocked bag to ensure samples were homogenised prior to being split into three sub-samples at the BioSense laboratory, following strict hygiene measures to prevent cross-contamination between samples. Of these, one sub-sample was sent to the Plant and Food Research Pathology Laboratory in Havelock North for the standard soil bioassay and morphological ID test, one was sent to Ampersand Laboratory in Palmerston North for the LAMP bioassay molecular test, and the remaining subsample was retained for validation if required. To ensure soil samples were not left in courier depots over the weekend, they were only sent Monday-Wednesday. Samples were stored at room temperature.

2.2.13.4 Soil repatriation

He taonga nō te whenua, me hoki ki te whenua

What is given by the land should return to the land

It was very important to ngā iwi mana whenua o Te Ngāherehere o Kohukohunui that the soils taken during the survey were returned to Papatūānuku (earth mother) at the completion of the survey, if safe to do so. It was agreed prior to the survey, that any soil from *P. agathidicida* positive sites would not be repatriated. All samples were provided with a batch number that indicated the geographical region samples had come from so they could be returned. Tested soils were first autoclaved (pressure and heat treated) to ensure that no pathogens (of any type) remained and then stored until March 2024. The soil was returned to Papatūānuku during a special ceremony by ngā iwi mana whenua o Te Ngāherehere o Kohukohunui, being placed in grass covered reserve land central to the Hūnua Ranges, and well away from kauri (Figure 2-23).

Figure 2-23. Soil repatriation in a small reserve area surrounding small native seedlings with no kauri present.

2.2.13.5 Diagnostic validation plan

As Hūnua had previously been tested for *P. agathidicida* and it was not detected, we developed a validation plan as part of a larger Investigation Plan to confirm pathogen freedom. The Investigation Plan was agreed across all partners. A

templated version of the Investigation Plan is in Appendix A and may be used for similar kauri surveys.

2.2.13.6 Validation process

For the LAMP test three results are possible: positive screening test, questionable screening test and not detected screening test. A questionable screening test is where the test result value lies within the measurement of uncertainty (MU) of a test. The measurement of uncertainty should be incorporated into assessing the results. For example, if the cut off value is Cq 36 and MU is 0.5, test results with Cq values between 35.5 and 36.5 should be interpreted as questionable and need to be further determined (e.g. run a gel to confirm product size is expected). If this is consistent with the expected size, the result can be validated in the same way as a positive screening test for LAMP.

Note:

MU = Square root of [(Average of standard deviation of reproducibility)^2 + (Average of standard deviation of repeatability)^2].

On the receipt of a positive or questionable screening result in an area where validation is required, the following actions are required:

- Request the diagnostic service provider checks sample reception records to ascertain if samples from other areas were being processed at the same time and request processing dates and diagnostic results for those records (anonymous). Check records to rule out any potential mix up of samples, e.g. similar sample submission code.
- Check time to detection for LAMP results to inform questionable results threshold values (i.e. low target concentration in the sample).
- Validation of screening tests can be done using several options (Table 2-3):
    1. start with re-testing any remaining or peeled frozen baits (useful to determine if cross-contamination occurred after baiting)
    2. then re-test remaining soil (useful if cross-contamination occurred during sample splitting and baiting)
    3. if these are inconclusive or the point of cross-contamination is possibly prior to soil splitting, the next step is to collect new samples from the same location and test using morphological testing followed by LAMP testing of peeled baits.

- Collection of new samples:
    1. Do a field investigation of the site to collect standard soil samples (8-point protocol, if appropriate) around the original tree and up to nine other kauri (to account for poor test sensitivity) within 50-100m of the test positive site for additional testing.
    2. The field investigation team should include team members from the partner organisations who are very experienced in PA field sampling.
    3. Store any unused soil until the investigation is completed. If no further positive results are found, this may be used to confirm that the soil does whakapapa to the exact site of collection (using forensic tools such as e-DNA for vegetation, soil chemistry and type, isotope analysis).
- If suspected PA is confirmed detected in a new region or special area:
    1. Send the isolate to MPI Plant Health and Environment Laboratory for confirmation. This involves morphological examination and multi-locus sequence typing. The latter includes sequencing at least two of the taxonomic informative genes (e.g. COX-1, COX-2, HSP90, ND1) from the newly detected isolate and compare with reference sequences from taxonomic ex-holotype isolate (ICMP 17027) to confirm species identification.
    2. Send the isolate to the International Collection of Microorganisms from Plants (ICMP) for long-term preservation and storage.

Table 2-3. Points where cross-contamination may occur, procedures for risk mitigation, and recommended retest options where the options are LAMP and morphological (Morph) + LAMP.

Point of cross-contamination	**Mitigation**	**Retest options for validation**			
		Remaining baits (LAMP)	**Peeled baits if available (LAMP)**	**Remaining soil (Morph + LAMP)**	**New soil sample (Morph + LAMP)**
Field collection					
Trowel used to collect soil	Follow the soil sampling SOP for trowel hygiene.	X	X	X	√
Sample labelling	Carefully label bags and include label photo in data entry form.	X	X	X	√
Sample transport in backpack	Double bag individual samples.	X	X	X	√
Sample transport to lab	Separate batches of samples (from the same location) into separate bags.	X	X	X	√
Sample storage in lab	Check for holes in bags (re-bag). Separate batches of samples (from the same location) into separate bags or bins and ensure storage bins are decontaminated with bleach between batches. Change gloves between batches for all steps.	X	X	X	√
Baiting lab					
Sample splitting	Remove individual samples onto a separate bench for soil splitting. Washdown between samples and denature between batches (avoids spill).	X	X	√	√

Point of cross-contamination	Mitigation	Retest options for validation			
		Remaining baits (LAMP)	Peeled baits if available (LAMP)	Remaining soil (Morph + LAMP)	New soil sample (Morph + LAMP)
Transfer to baiting containers	Remove individual samples onto a separate bench for soil transfer. Use a NEW container or DNA denature washed container for each sample. Washdown between samples and denature between batches (avoids spill)	X	√	√	√
Air drying	Separate containers by batches, apply double sided tape to bench between batches to stop invertebrate movement (also avoids dust/knocking). Include at least two negative control soils in a random location within each batch of samples to detect cross-contamination.	X	√	√	√
Moist incubation	Remove individual samples onto a separate bench for moist incubation spray (avoids splash)	X	√	√	√
Needle extraction	Use ethanol to sterilise forceps and flame until red hot between samples to denature DNA. Replace ethanol between batches.	X	√	√	√
Needle labelling	Double check label. Label is written from lid to base.	X	√	√	√
DNA extraction and testing					
Needle cutting	Use ethanol to sterilise forceps and flame until red hot between samples to denature DNA. Replace	√	√	√	√

Point of cross-contamination	Mitigation	Retest options for validation			
		Remaining baits (LAMP)	Peeled baits if available (LAMP)	Remaining soil (Morph + LAMP)	New soil sample (Morph + LAMP)
	ethanol between batches. Use new section of tissue paper on cutting surface between samples. Denature clean between batches				
Pipette DNA into plate well	Calibrate pipettes three-monthly. Include a weak positive control to detect lower titre target and cross contamination. Typically, this can be x100 higher than the limit of detection.	√	√	√	√
Recording results	Double check sample ID.	√	√	√	√

If both the morphological test and the LAMP test are done in parallel, there are several pairs of results that can arise with differing validation requirements depending on the geographical criteria set for validation (Table 2-4). We developed diagnostic scenarios for validation of screening test results when both LAMP and morphological bioassays are used, stratified by known PA-site informed geographic criteria. See Table 2-4 below.

Table 2-4. Diagnostic scenarios for validation of screening results based on geographic criteria.

		Morphological test			
		Present		**Not detected**	
		Within PA geographic criteria	**Outside PA geographic criteria**	**Within PA geographic criteria**	**Outside PA geographic criteria**
DNA-based LAMP test	**Detected**	Confirmed detection	Positive screening test. New sample validation required.	Confirmed detection	Positive screening test. Validation required.
	Questionable	Confirmed detection	Positive screening test. New sample validation required.	Suspect screening test. Validation required.	Suspect screening test. Validation required.
	Not detected	Confirmed detection	Positive screening test. New sample validation required.	Not detected	Not detected

2.2.13.7 Disease severity variables

Basal or lateral root bleeds consistent with kauri dieback were measured as present, not sure, or absent. Bleed activity was measured following the Horner (2020) methodology of whether the gum is sticky (active), soft but not sticky (semi-active) or hard (not active) and relates to whether the tree is still exuding gum.

Basal bleed height was measured to indicate disease severity, in that it indicates how long a tree may have been infected as the pathogen infects via the roots and

then travels up the trunk over time, remaining at the leading edge (outer/upper edge) of the lesion. This enables future monitoring to determine how fast lesions develop over time. Where more than one bleed was present on the trunk, the highest one was assessed.

Percentage of trunk with basal bleeds was measured as an estimate (in deciles) of the base of the trunk affected by the basal bleed. This gives a crude indication of the diameter of girdling that has occurred through pathogen infection.

Canopy dieback was quantified based on the Dick and Bellgard (2012) 5-scale canopy health score, with an adjustment to include half-points. This was to provide more differentiation particularly between 2-3 and 3-4 canopy scores which is consistent with more recent disease scoring by Horner et al. (2019) (Figure 2-24).

Figure 2-24. Canopy symptom class and severity rating: 1) healthy crown with no visible signs of dieback; 2) canopy thinning; 3) thinning and some branch dieback; 4) severe dieback; 5) dead. (Dick & Bellgard 2012) versus the modified half-point scale.

Kauri canopy and bleed symptoms could be caused by other biotic or abiotic factors and therefore the opinion of a trained observer/surveyor is required to determine if the recorded symptoms are consistent with kauri dieback. The kauri dieback field status was assessed by trained surveyors observing all symptoms, the surroundings of the tree and any other potential causes of symptoms. Field status considers whether the observed symptoms were consistent with kauri

dieback (to meet the final symptomatic criteria of the case definition). Options were non-symptomatic kauri; kauri with ill-thrift (probably not kauri dieback); kauri with possible kauri dieback symptoms; and kauri with severe kauri dieback symptoms.

Canopy colour was assessed from the ground based on all visible canopy and selection was based on the colour of the majority of leaves, rounding down to the healthiest colour if the result was uncertain to enable a change to be detected over time.

Detailed descriptions of disease severity variable measurement are in Appendix B.

2.2.13.8 Symptomatic kauri

The symptomatic kauri prevalence was reported against the Stevenson and Froud (2020) recommended case definition for kauri dieback disease which is updated and summarised in (Froud et al., 2022a). In brief, the case definition for symptomatic vs non-symptomatic trees was met if the symptomatic criteria for kauri dieback (bleeding lesions on the basal trunk, lesions on roots, the presence of canopy thinning, yellowing of the foliage, tree death) were recorded on a kauri tree AND the trained surveyor recorded that these were consistent with possible/probable or severe kauri dieback using the field status assessment variable in the monitoring form (Appendix B).

The surveyors were trained in the variety of basal and lateral root lesion presentations that have been associated with kauri dieback caused by *P. agathidicida.* Trained surveyors only wrote ‘Yes’ if the bleed was typical of kauri dieback bleeds. Further, they were instructed to select ‘Unsure’ when they could not determine whether a basal or lateral root bleed was due to kauri dieback or due to other causes (e.g. physical damage). Both ‘Yes’ and 'Unsure’; were included in the symptomatic criteria component of the algorithm to classify symptomatic kauri. If the field observer stated that symptoms were not consistent with kauri dieback, they were classified as non-symptomatic kauri trees – ill-thrift.

As canopy dieback and colour of foliage were categorical variables, a cutoff point was selected for each. The level of canopy health score required to be included in the symptomatic criteria was set to a canopy score of 3 or higher after discussion with the field team and I. Horner. This is consistent with being considered symptomatic by Bellgard et al. (2013). Scores from 1-2.5 relate to healthy canopy or some foliage or canopy thinning, whereas scores from 3-5 show signs of branch dieback through to canopy loss and death of the tree. To calculate symptomatic kauri prevalence, trees that scored 5 and were considered dead were excluded. Any

dead trees are reported separately from the baseline prevalence estimate and were not sampled or assessed, as these trees cannot change their disease state in future monitoring, and it is difficult to estimate how long the tree has been dead. The canopy colour score required to be included in the symptomatic kauri group was set to a colour that is more yellow than green and includes yellow-green, copper brown and dead leaves. Trees with a canopy score below 3 or with a canopy colour score below yellow-green were classified as non-symptomatic – healthy or non-symptomatic ill-thrift depending on score and field status. A binary symptomatic kauri and non-symptomatic kauri variable was calculated based on meeting the symptomatic criteria of the case definition, with both symptoms and field status assessed as described in the algorithm in Figure 2-24.

In addition, classes within symptomatic kauri were defined by an epidemiological criteria that incorporated soil sample results, where kauri dieback was 'confirmed' for trees at a *P. agathidicida* site (defined in 2.3.2.3), 'probable' for trees within 50 m of a *P. agathidicida* site, and 'suspect' for trees > 50 m away from a *P. agathidicida* site (Stevenson & Froud, 2020).

Figure 2-24 below shows the decision algorithm for calculating if the symptomatic criteria were met for the symptomatic kauri trees kauri dieback case definition.

The symptomatic criteria were met if:

Basal bleed = 'Yes' or 'Unsure'

OR

Lateral root bleed = ' Yes' or 'Unsure'

OR

Canopy score ≥3

OR

Canopy colour = 'Yellow-Green' or 'Copper Brown'

AND

Kauri dieback field status (approved observer considers symptoms are consistent with kauri dieback) = 'Kauri with possible kauri dieback symptoms' or 'Kauri with severe kauri dieback symptoms'

Figure 2-24. Decision algorithm for symptomatic criteria.

2.2.13.9 Risk factors

Risk factors (both causative and protective) covered host-related variables (e.g. diameter at breast height; DBH), environmental variables (e.g. aspect, elevation, pig damage) and anthropogenic (human modified) variables (e.g. phosphite treatment, track proximity). The full list of variables and the instructions for data collection are included in Appendix B.

2.2.13.10 Ecological and mātauranga informed impact variables

Several long-term ecosystem outcomes were considered for baseline monitoring and future analysis. Full details of measurement are provided in Appendix B.

The revision of the common plants list was done in collaboration with Associate Professor Bruce Burns (University of Auckland) and incorporated mātauranga Māori shared by members of the working group and cross-referenced by Auckland Council Southern Parks staff (Table 2-5). The list was of the 20 most common tree species within the Hūnua kauri forests. Presence of trees from this checklist were recorded within 10m of the monitored tree to provide an indication of species diversity.

Table 2-5. Common kauri forest-associated plant species (scientific and common names) selected for observation.

Scientific name	**Common name**
Astelia trinervia	Kauri grass
Beilschmiedia tarairi	Taraire
Beilschmiedia tawa	Tawa
Brachyglottis kirkii	Kohurangi, Kirk's tree daisy
Broussonetia papyrifera	Aute, paper mulberry
Coprosma lucida	Shining karamū
Dacrydium cupressinum	Rimu
Fuscospora truncata	Tawhairaunui, hard beech
Gahnia xanthocarpa	Māpere, gahnia
Knightia excelsa	Rewarewa
Kunzea robusta	Kānuka
Leucopogon fasciculatus	Mingimingi
Lygodium articulatum	Mangemange
Myrsine australis	Māpou
Pectinopitys ferruginea	Miro
Phyllocladus trichomanoides	Tānekaha
Podocarpus totara var. *totara*	Tōtara
Pseudopanax crassifolius	Horoeka, lancewood
Pterophylla racemosa	Kāmahi
Pterophylla sylvicola	Tōwai

2.2.14 Data analysis

All data analysis was carried out using R Statistical Software (R Core Team, 2020) or ArcGIS® PRO.

2.2.14.1 Descriptive statistics

A descriptive summary of each variable for the monitored trees was calculated to set a baseline for future monitoring.

Histograms and boxplots were used to visualise data distributions and frequencies. Univariable analyses using two by two tables and the Fisher exact test in the epiR package or separate, unmatched, logistic regression procedures were used to determine associations between variables and disease. The level of statistical significance was set at $P \leq 0.05$ and was assessed using the log-likelihood ratio test statistic. Linear regression was used to determine associations between continuous variables and correlations were tested with the Pearson correlation coefficient.

2.2.14.2 Point pattern maps

Point pattern maps were generated using the geographical boundary for the study area to plot two point pattern maps using the R package ggplot2 (Wickham et al., 2016). The first map plotted the point location of all the surveyed kauri trees with points coloured according to their disease status (i.e. symptomatic kauri trees and non-symptomatic (healthy and ill-thrift)) using the case definition. The second map plotted the point location of all the kauri trees from which a soil sample was taken with points coloured according to their pathogen detection status.

2.2.14.3 Relative risk surfaces

A univariate kernel density maps was plotted to show the density of (i) symptomatic kauri trees, (ii) non-symptomatic kauri trees from the randomly selected kauri trees (the risk-based trees were excluded from the analysis) using the spatstat package (Baddeley, 2015). The spatial relative risks for symptomatic kauri after accounting for the varying density of the sampled population were then estimated and plotted. The spatial relative risk represents the ratio of two kernel-estimated densities (i.e. symptomatic vs non-symptomatic) after accounting for variability of the underlying population. These can be used to identify regions with significant elevated spatial risk (Davies et al., 2018). The relative risk is estimated on the natural log scale, such that values > 0 depict areas of elevated risk (log(0) = 1, and therefore log relative risk values > 0 equate to relative risks > 1, that is, increased risk). For these plots, an adaptive smoothing technique was used for the density estimates to provide the flexibility of reduced smoothing in densely occupied areas without compromising the stability of the estimate elsewhere. Where detected, tolerance contours delineating statistically significant risk elevations were drawn at a significance level of 0.1 and 0.05. The plots were created using the R package sparr (Davies and Marshall, 2018) using a pilot bandwidth of 609.1, a Gaussian kernel distribution, and an evaluation grid with dimensions of 128 raster cells in the east-west (150 m) and 128 raster cells in the

north-south (166 m) directions. To calculate the symmetric adaptive relative risk surface range we used the absolute maximum of the range (-7.380591, 1.128512) and therefore set the range symmetrically from 0 at -7.4 to 7.4.

2.2.14.4 Risk factor screening

We did two analyses of risk factors. The first was to visually compare boxplots of the calculated risk factors for Hūnua with those from Waitākere, upon which the Hūnua values were estimated. The second screened the risk factors of the randomly selected trees to test whether they were associated with being symptomatic or not, to try to understand drivers of kauri health and the risk factors for risk-based sample selection. For each tree, potential risk factor variables were either collected during the ground-based survey or derived prior to the survey during the risk-based sample selection as previously described. A univariable screening test (simple logistic regression) for the binary (yes/no) outcome of symptomatic kauri vs non-symptomatic kauri was conducted in R using the 'glm' package (R Core Team, 2020). Distance measurements were rescaled to an appropriate unit to aid interpretation of odds ratios e.g. DBH was rescaled to 10cm units and distance to the closest coast, etc were rescaled to 100m units. The scope of the survey did not include multivariable modelling of risk factors, as our outcome variable was very rare, so a p-value of 0.05 was used to infer significance using the tests described under descriptive statistics. However, all results were provided for future modelling using a more conservative screening p-value of 0.2 to allow for potential confounding variables.

2.3 Results

Ngā hua

2.3.1 Collection of samples

We aimed to survey and collect samples from up to 700 kauri, and the survey team visited a total of 561 points of interest. In one of these sites, the kauri had recently slipped into the gully and a further nine sites did not have a kauri present at the point location. A total of 552 of the 561 point locations visited had a kauri present (or recently present). The positive predictive value for host detection was 98.4 per cent (in that 98.4 per cent of trees classified as kauri by remote sensing, and then manually validated using imagery were kauri). This was much higher than the 2021 Waitākere survey (86 per cent) and indicates that the host detection and manual validation process was significantly improved between the two surveys. Only two of the nine misclassifications of kauri provided the species name of the tree that was found (tanekaha and rimu/rewarewa) so we are unable to generalise on common misclassification species. There were no dead kauri found during the survey and only one tree was inaccessible due to a recent land slip. It was unlikely that dead kauri would be found at our selected tree points as our host detection methods excluded dead and dying trees as they generated too many misclassifications of other tree species, including flowering mānuka or kānuka.

We successfully obtained 551 full survey records and soil bioassay samples. Of these, 410 were random selected trees and 141 were risk-based trees. The reduced number of samples was mainly due to persistent wet weather, reducing the number of days sampling could be done. Samples were collected during two distinct time periods. Most samples (n=518) were collected between 30 March 2023 and 6 July 2023, with an extra 33 collected between 7-15 October. Data cleaning was done and two minor updates to the tree circumference and distance to nearest neighbour tree/kauri tree variables on the monitoring form could be made to improve data collection in the future. Full details of these data errors and recommendations are provided in Appendix C.

The only other data anomaly of note was that one of our surveyed points of interest (DSM771M) was surveyed twice, once in June and again in October and soil samples were collected and tested on both occasions. The reason for the second survey was because the monitoring form data failed to save during the June visit, so the point of interest was not marked as surveyed, even though a sample was collected. The lab results were the same for both samples showing not detected

for both *P. agathidicida* and *P. cinnamomi* for both tests. The October record was retained for analysis.

2.3.2 *P. agathidicida* freedom

There were NO detections of *P. agathidicida* either by the morphological test, or by the LAMP test (Figure 2-25).

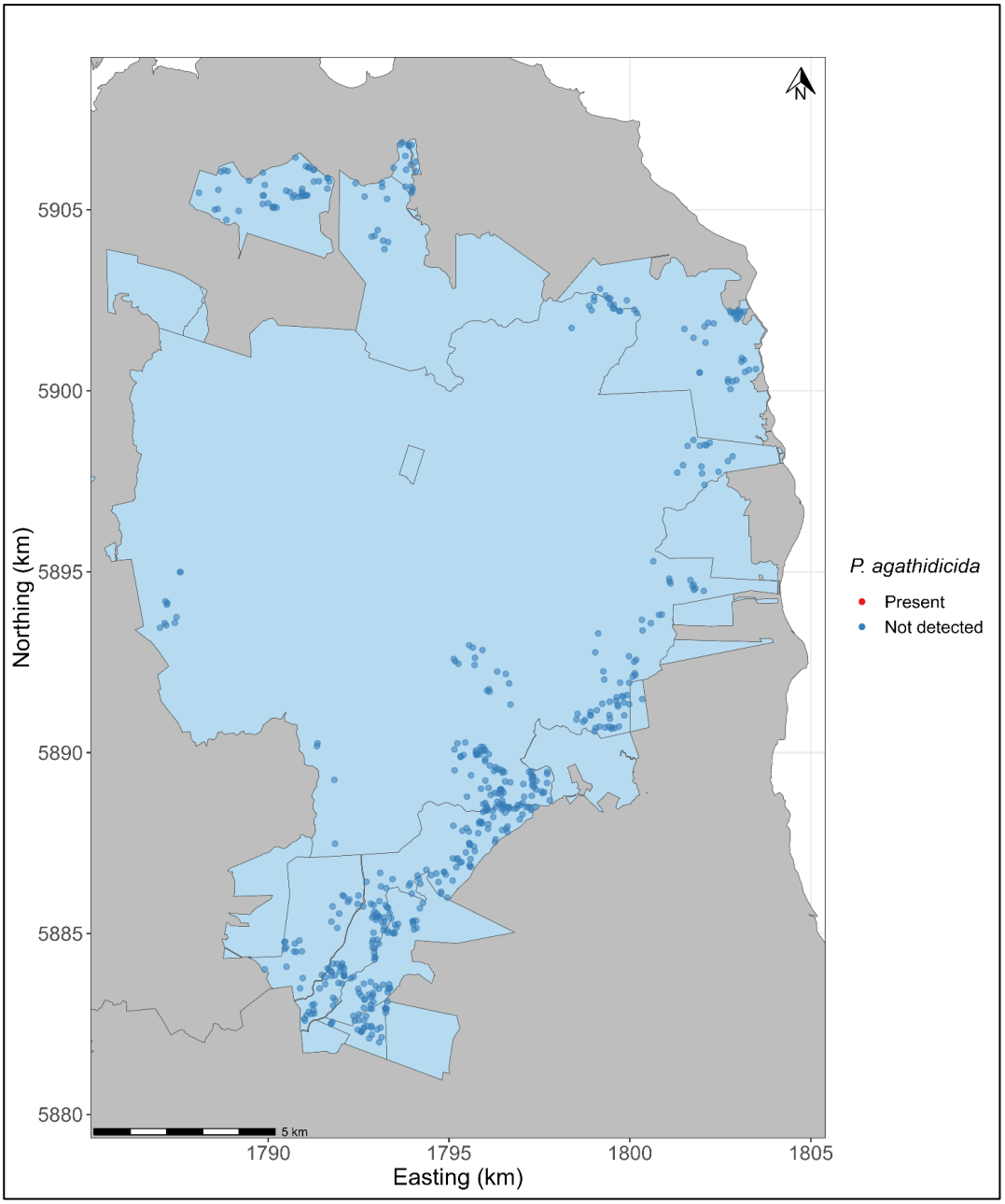


Figure 2-25. Locations where *P. agathidicida* was not detected (n=551, blue), compared to positive detections (n=0).

Given the sample size and design parameters of this study, this means we can be 97 per cent certain that we would have detected *P. agathidicida* if it was present at

a prevalence of 1 per cent or more, i.e. it is not present in association with more than 1 per cent of kauri in Hūnua where:

If P^* = 1 per cent of soil samples were infested with *P. agathidicida*, then the current survey would have s = 97 per cent (CI: 90.5 - 99.2 per cent) probability of detecting *P. agathidicida* in at least one sample.

The results assume that the samples are taken at random with respect to risk. However, part of our sample was taken specifically from the highest risk trees, so the sensitivity of our sample should be better than that. Taking risk into account, the sensitivity of the current survey for a prevalence of 1 per cent of trees infected with *P. agathidicida* was 99.9 per cent. However, this assumes that our characterisation of risk was accurate. If not, then the true sensitivity of the survey will very likely lie between the two extremes of 97 - 99.9 per cent as illustrated in Figure 2-26.

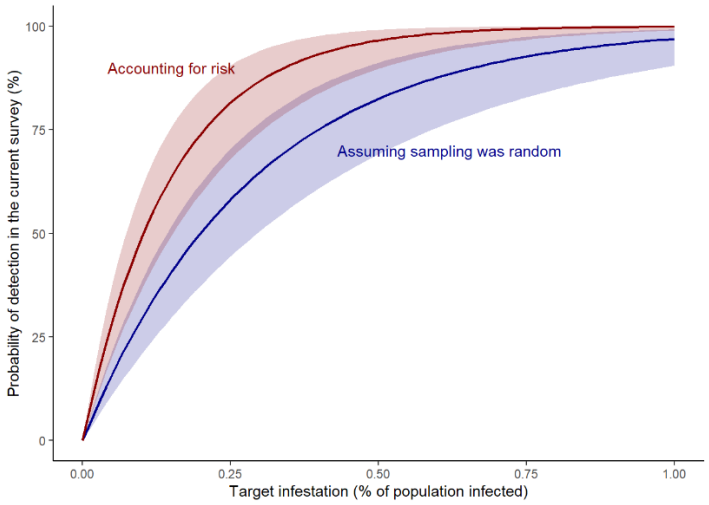


Figure 2-26. Proof of freedom results from the Hūnua survey. Coloured ranges around lines represent the uncertainty arising from the sensitivity of the standard soil bioassay test.

In addition, we also utilised a second test, the LAMP test which we have not yet calculated the **diagnostic sensitivity** test performance parameters for. However, the LAMP test is believed to potentially be more sensitive at detecting *P. agathidicida* as it has high **analytical sensitivity** using a molecular approach. Without knowing the diagnostic sensitivity of LAMP we cannot calculate proof of freedom estimates from the LAMP tests, but it provides additional evidence for our freedom estimates.

In summary, if our characterisation of *P. agathidicida* risk is accurate, we can be 99.9 per cent certain that *P. agathidicida* is not present in association with more

than 1 per cent of Hūnua kauri. If, however, our understanding of *P. agathidicida* risk is so poor that the sampling was effectively random with respect to risk, we can still be 97 per cent confident that we would have detected *P. agathidicida* if it was present in 1 per cent or more Hūnua kauri.

2.3.1 Other *Phytophthora* species

There were 350 detections of *P. cinnamomi* from the 551 soil samples collected (63.5 per cent prevalence) which were spatially distributed evenly across the sample sites (Figure 2-27). This was a higher rate of *P. cinnamomi* than the 53 per cent prevalence of *P. cinnamomi* detected in Waitākere. In addition, there were 23 detections of other *Phytophthora* species (4.2 per cent prevalence), which were unknown to the laboratory and were possibly undescribed *Phytophthora* species. All detected *Phytophthora* species are detailed in Table 2-6.

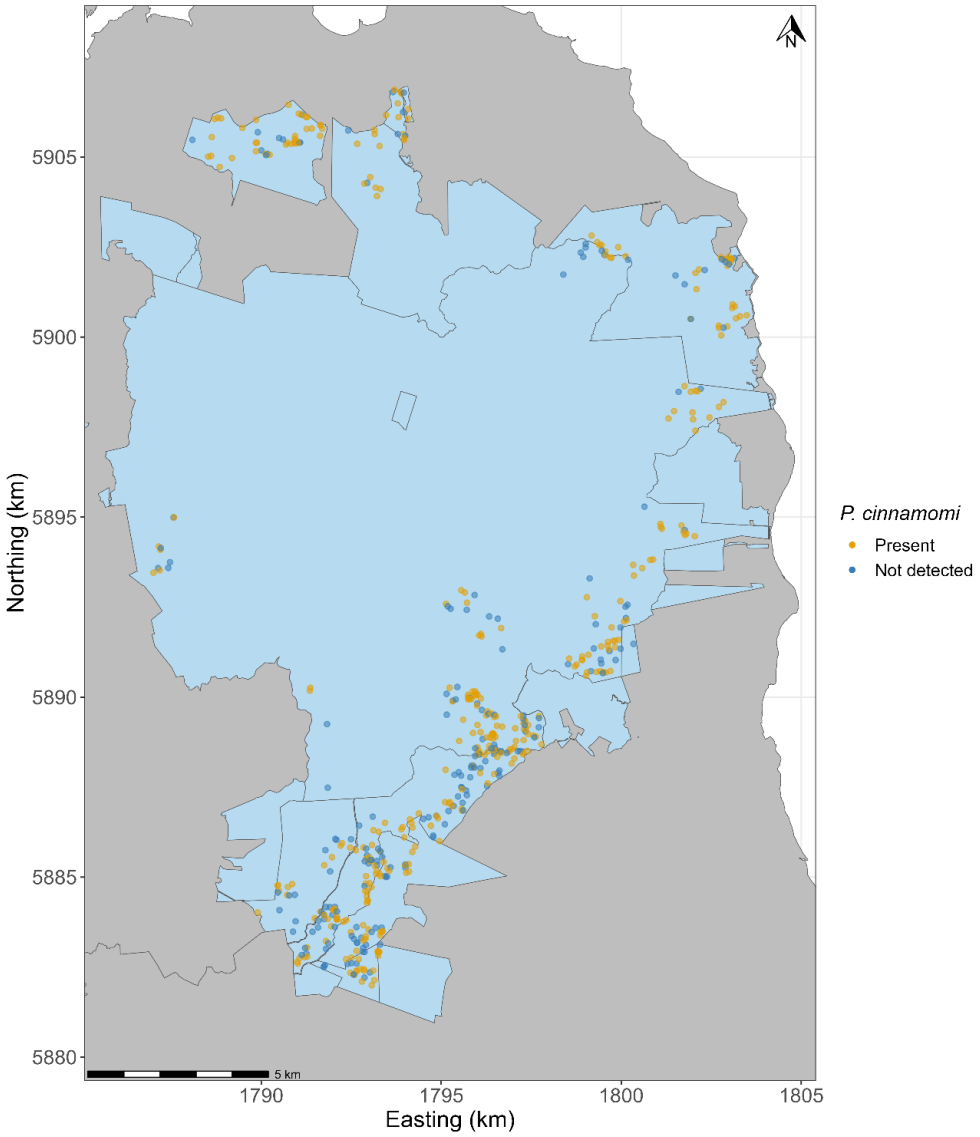


Figure 2-27. Location of kauri soil samples with orange circles indicating the detection of *P. cinnamomi* and blue circles indicating that *P. cinnamomi* was not detected.

Table 2-6. Detection of *Phytophthora* species alone or in combination in the culture bioassay tests from 551 sites where soil samples were collected.

***Phytophthora* species detection**	**Percent of sites**	**Number of sites**
P. cinnamomi only detected	61%	336
P. spp. only detected	1.6%	9
P. cinnamomi and *P.* spp.	2.5%	14
No *Phytophthora* detected	35%	192
Total sites		**551**

2.3.3 Symptomatic kauri prevalence and symptom severity

The majority of trees – 95.1 per cent – surveyed in Hūnua were very healthy. There were only 27 trees classified as symptomatic across the 551 trees that were surveyed, giving a prevalence of symptomatic trees of only 4.9 per cent. The case definition symptom list is not particularly specific to symptoms caused by infection by *P. agathidicida* as all can be caused by other biological or physiological factors. It is important to note that only 11 of these were from the randomly selected tree samples, with the remaining 16 trees coming from the risk-based tree selection, which was informed by an assortment of layers, including trees that had previously been tested due to the appearance of kauri dieback like symptoms, and therefore is likely to be an overestimate of prevalence. Of the symptomatic trees, all were in forest that was assessed as 'cut-over regenerating' where a total of 518 trees were surveyed. There were far fewer areas of mature forest and therefore far fewer samples taken in mature forest (n=30) or other forest types n=3 (plantation, restoration).

The symptomatic kauri prevalence across the study area is shown in Figure 2-28 below.

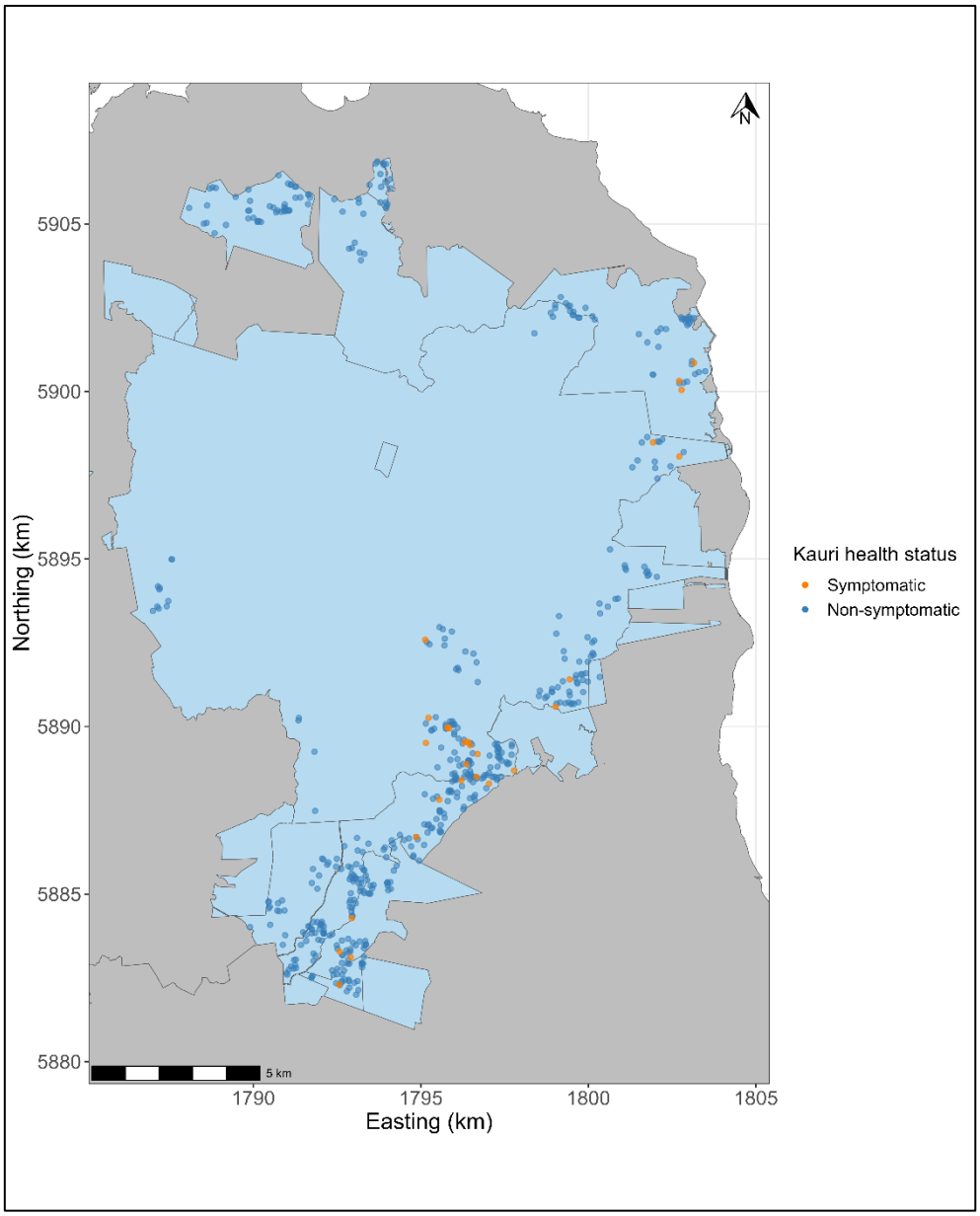


Figure 2-28. The location of surveyed kauri trees with red circles indicating symptomatic kauri and blue circles indicating non-symptomatic kauri.

The spatial relative risk surface for symptomatic kauri (i.e. the ratio of symptomatic kauri to non-symptomatic kauri) assessed only on the randomly selected kauri (n=410), shows a region of elevated symptomatic tree risk at a significance level of 0.1 in the mid-south-eastern area of the Hūnua Ranges around the Mangatangi Reservoir with lower risk in the northern areas (Figure 2-29).

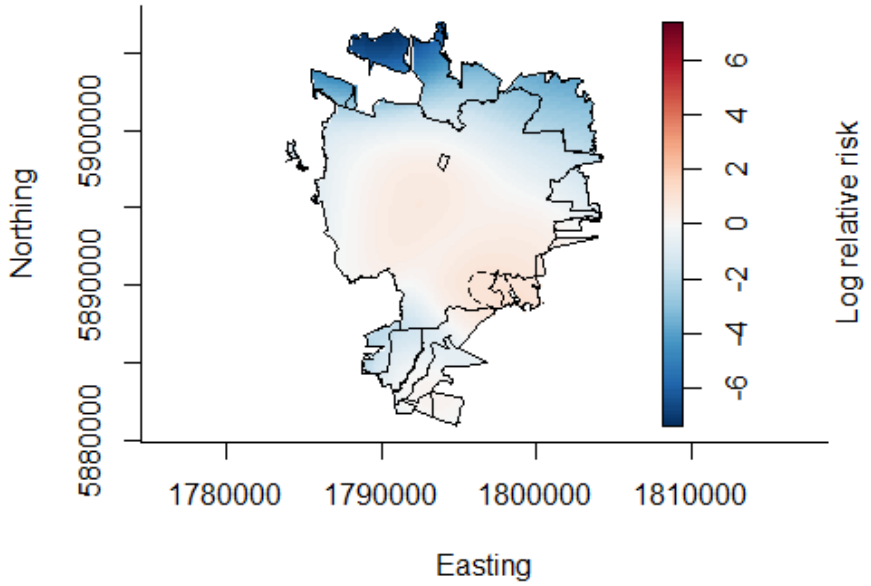


Figure 2-29. Symmetric adaptive log relative risk surfaces.

Symmetric adaptive relative risk surfaces (Davies et al., 2016) were estimated using the randomly selected kauri trees included in the study (n = 410; symptomatic = 11; non-symptomatic = 399) within the study area. The relative risk is estimated on the natural log scale, such that values > 0 depict areas of elevated risk (log(0) = 1, and therefore log relative risk values > 0 equate to relative risks > 1, that is, increased risk). Where detected, tolerance contours delineating statistically significant risk elevations are drawn at significance levels of 0.05 and 0.1. Also note the very low underlying density of kauri in the west-central region of the study area which can be ignored.

The classification of symptomatic kauri against the different classes of the Stevenson and Froud (2020) case definition (using the 2021 Waitākere modified cut-points for classification of either a basal bleed or canopy score of 3 or higher and consistent with kauri dieback assessed by a trained observer) with an epidemiological criteria of 50m from a *P. agathidicida* detection site (point location of a *P. agathidicida* detected test) gives us 27 suspect kauri dieback cases (4.9 per cent prevalence), which we can rule out due to the high confidence in *P. agathidicida* freedom. In addition, there were a further 26 unhealthy kauri observed during the survey, that had mild symptoms that did not meet the case definition.

The kauri dieback field status, which is a classification assigned by trained surveyors in the field to state whether the observed symptoms (basal or lateral root bleeds, canopy scores or canopy colour) are consistent with kauri dieback were also very low. Only three were classified as 'severe dieback' all based on basal bleeds, (hence the low number of symptomatic classified trees) and a further 24 classified as possible dieback. The scores are illustrated in Figure 2-30. The surveyors also assessed the surrounding kauri for symptoms of kauri dieback when entering the monitoring site, and only four sites were recorded as having suspected symptoms of nearby kauri.

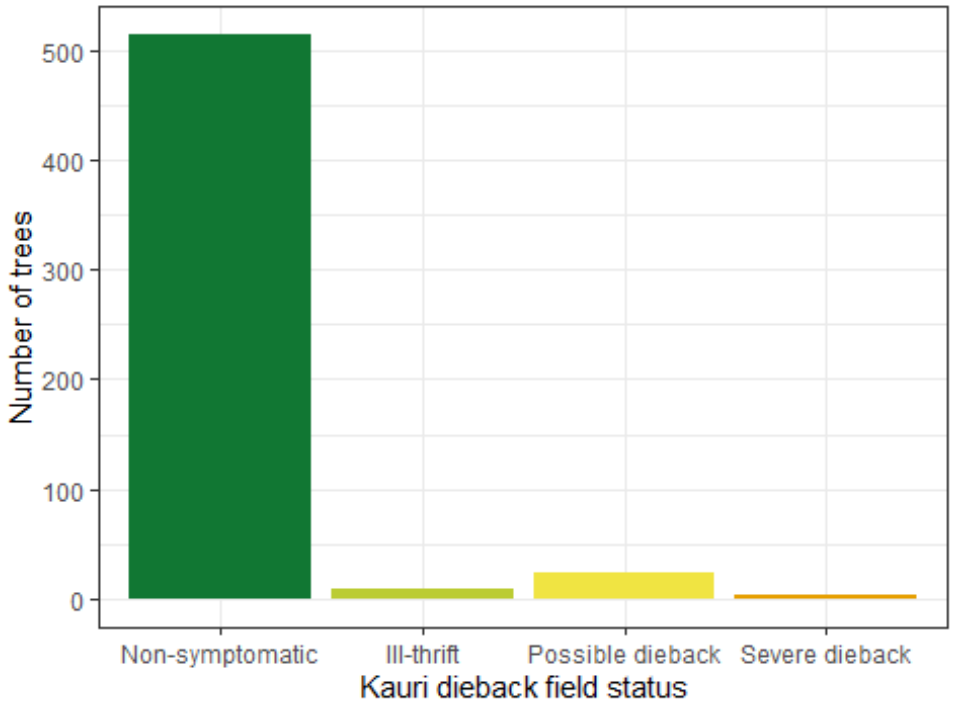


Figure 2-30. Field assessment of whether observed symptoms are consistent with kauri dieback.

Symptomatic kauri was not significantly associated with sites where *P. cinnamomi* was detected (p= 0.541, Fisher's exact test).

2.3.3.1 Basal lesions

Of the 551 trees surveyed, 24 showed basal lesions, however only 16 of these were considered to be consistent with the symptoms of kauri dieback. In addition, 14 trees were assessed as having uncertain basal lesions (where the trained observer was unsure) and only eight of these trees were classified as consistent with symptoms of kauri dieback (Figure 2-31). There were also two trees observed with lateral root lesions, both of which also had basal bleed lesions consistent with kauri dieback symptoms. Of the 38 trees with clear or uncertain basal lesions, the trained observers were asked to assess how active the lesion was. There were 11 active (soft and sticky), 11 semi-active (not sticky, but slightly soft and can dent with fingernail) and 16 were not active (hard and dry – cannot dent with fingernail).

Given the high confidence in *P. agathidicida* freedom in Hūnua, these symptoms are most likely due to other factors.

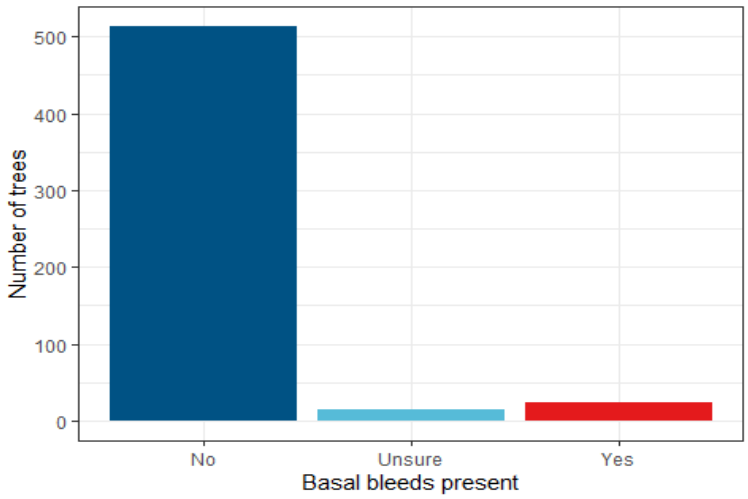


Figure 2-31. Presence of basal bleeds.

2.3.3.2 Canopy health

Most trees, 92 per cent (505/551), had a canopy health score of 2 or less, indicating a healthy crown or only light foliage or canopy thinning (Figure 2-32). A further 30 had scores of 2.5 which is just below the case definition cut-point of 3 for canopy dieback consistent with kauri dieback. A total of 16 trees had canopy scores above 3, and only four of those also had clear basal bleeds. We saw no trees with yellow-green or copper-brown canopies, and only seven were classified as green-yellow with the remaining 544 classified as green, indicating very high canopy health.

Once again, given the high confidence in *P. agathidicida* freedom in Hūnua, these symptoms are most likely due to other factors.

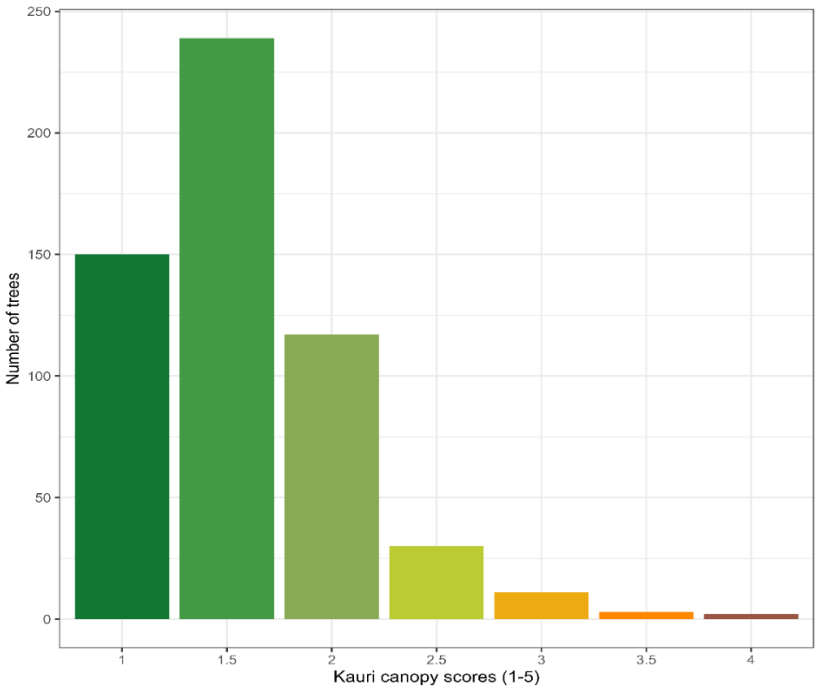


Figure 2-32. Canopy scores from a scale of 1-5 indicating foliage or branch thinning and dieback of the tree crown.

2.3.4 Host-related factors

2.3.4.1 Description of kauri host population

We identified 27,164 kauri trees in the study area using AI-processed aerial stereo imagery. We mapped the density of all AI-estimated kauri within the survey area and found the highest densities of kauri in the southern areas (Figure 2-33).

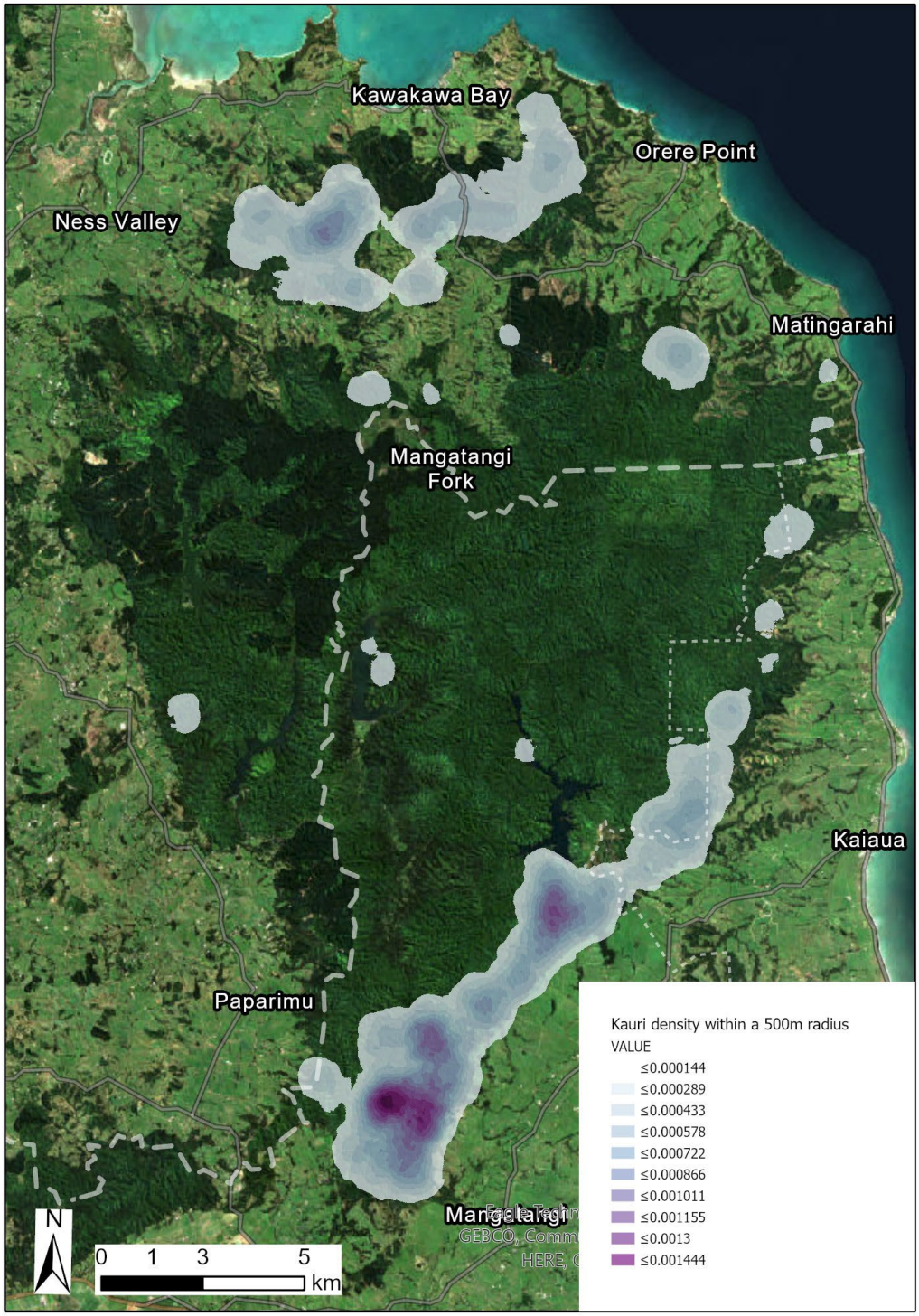


Figure 2-33. Kauri tree density within a 500m radius, showing higher densities in the pink/purple colour range.

2.3.4.2 Kauri tree size and ecological dominance status

Most trees (365/551, 66 per cent) were intermediate in size, in that their circumferences were between 150-450cm. There were only 20 trees (3.6 per cent) in the mature class size with a circumference above 450cm, which were reasonably well spread spatially among the other kauri present (Figure 2-34). The remaining trees (166/551, 30 per cent) were ricker sized (circumference up to 150cm). These are equivalent to DBH (diameter at breast height) of less than 48cm DBH (ricker), between 48 and 143cm DBH (intermediate) and above 143cm DBH (mature). There was quite an interesting pattern in the distribution of DBH across the population, which was left-skewed and a wide range in the DBH of the mature trees, with the smallest tree having a DBH of 12.4cm. The median size was 61cm and the largest was just over 2.5m wide (Figure 2-35). This pattern of tree sizes is not unexpected as the deep learning methods for detection of kauri from imagery is biased towards detecting kauri with a canopy size of greater than 2m (the minimum pixel size), rather than very small trees that have not yet expanded their canopy.

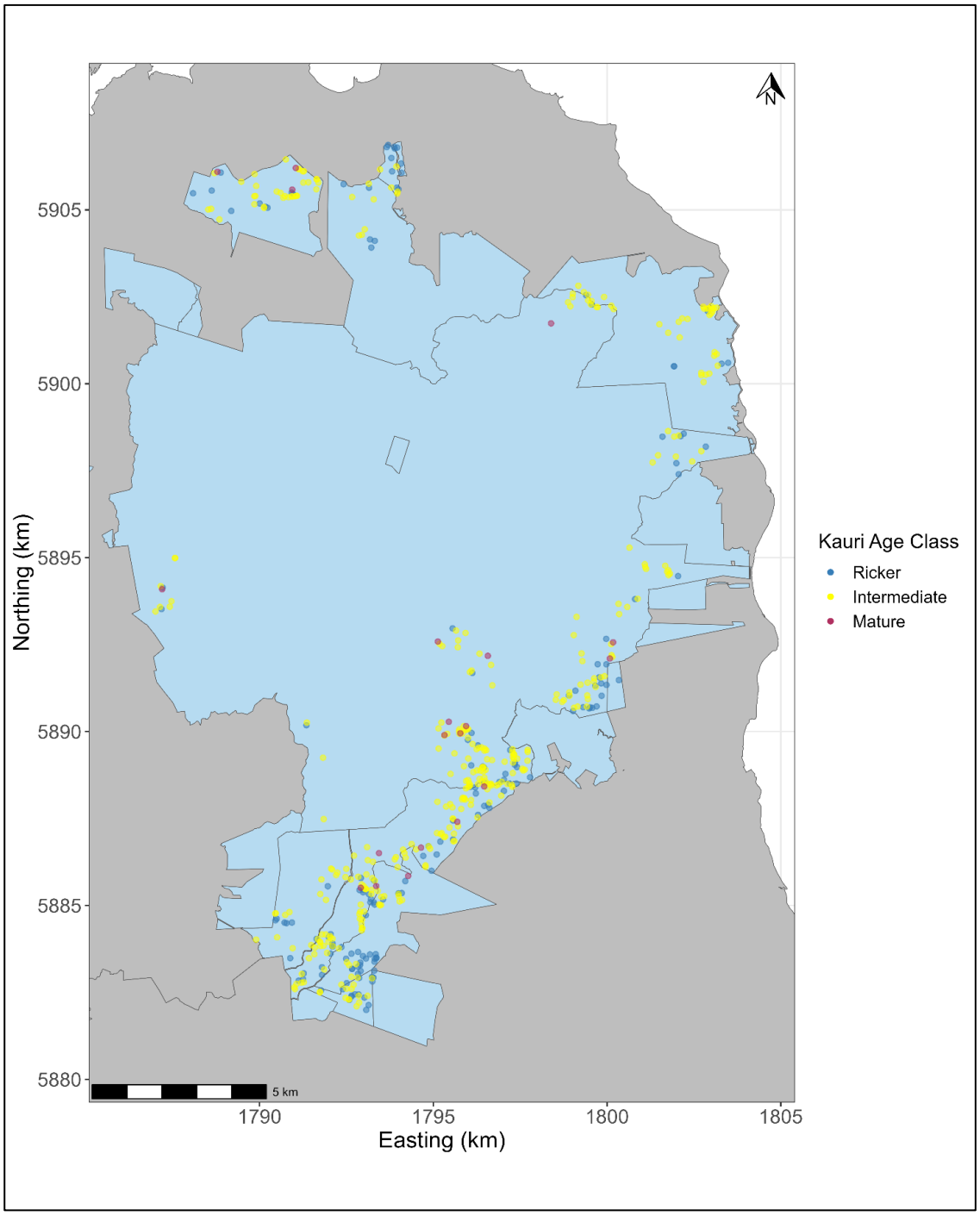


Figure 2-34. Spatial distribution of kauri age classes, from ricker (<48cm DBH), intermediate (48 – 143cm DBH), and mature (>143cm DBH).

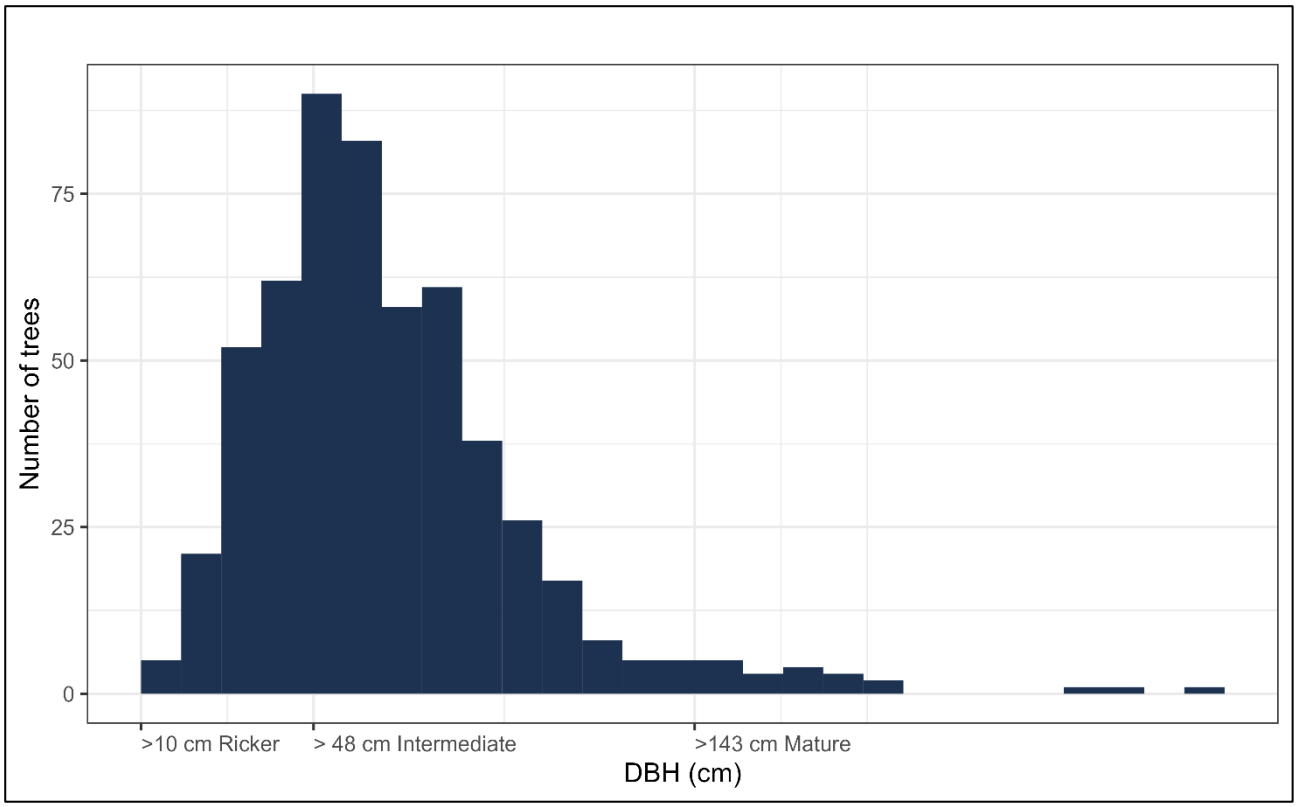


Figure 2-35. Frequency histogram of trees in different size groups (bins set at 10cm), with tick marks indicating where the different age classes start.

We mapped the tree height for kauri crowns as an estimate of mature vs regenerating kauri within the study area and found a mean height of 22m (Std dev. 6.5m) (Figure 2-36). There was a tendency towards larger crown heights to the south (Figure 2-36).

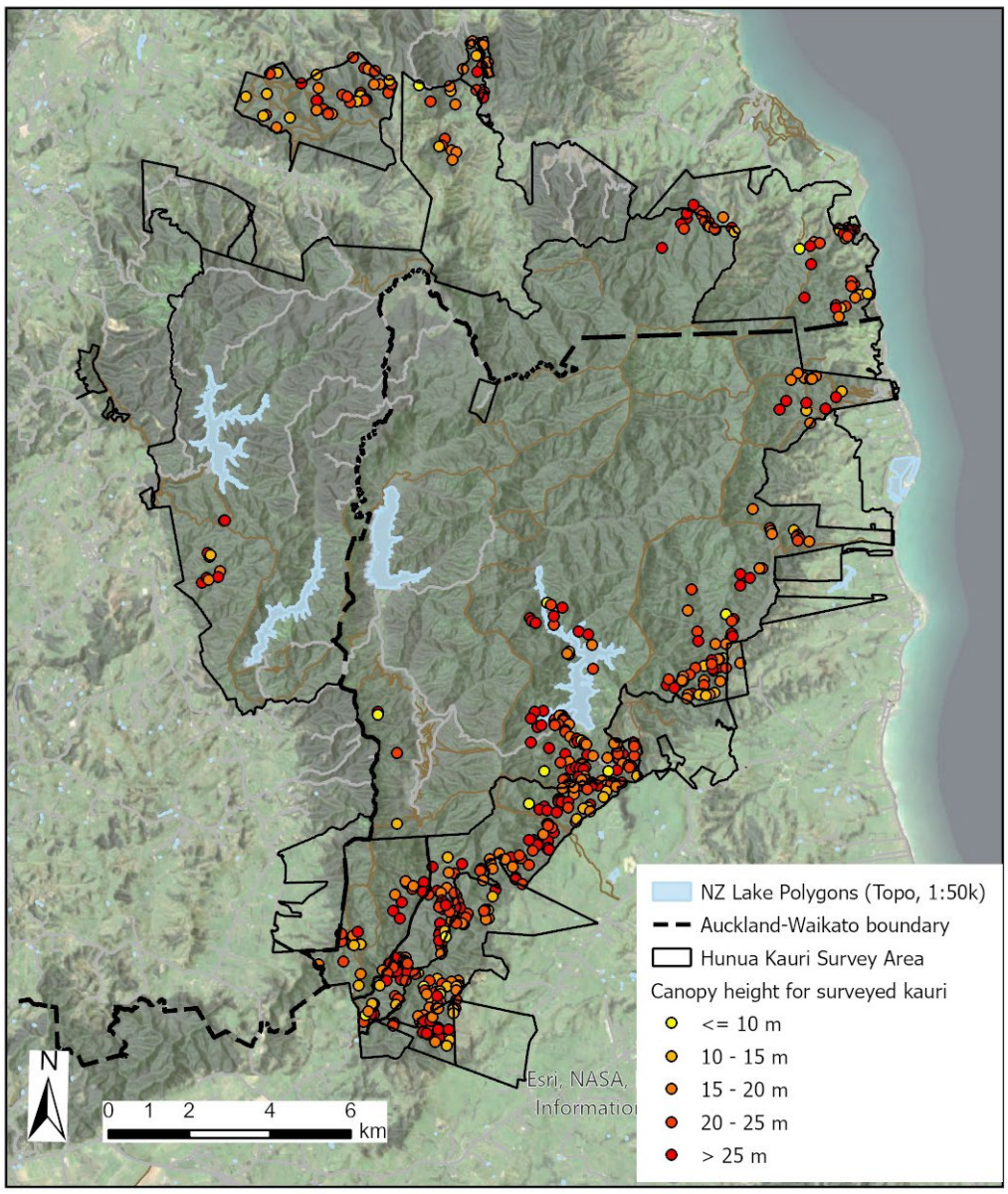


Figure 2-36. Mean canopy height of kauri trees selected for the survey.

2.3.4.2 Kauri seedlings and saplings

The presence of small (<15cm) and established (15 – 1.35m) kauri seedlings and saplings (>1.35m tall and <10cm DBH) within 5m of the surveyed tree was assessed at all 551 of the kauri monitoring sites. We observed seedlings or saplings present at 92.6 per cent of monitored sites (510/551), with only 41 sites (7.4 per cent) with none. Small seedlings were observed at 85 per cent (469/551) of sites, established seedlings were at 51 per cent (282/551) of sites and saplings were observed at 59 per cent (324/551) of sites. A total of 37 per cent (202) of sites had all three size classes

present along with the surveyed kauri tree. Immature kauri seedlings and saplings' presence or absence was not significantly associated with sites where *P. cinnamomi* was detected (p = 0.7379, Fisher's exact test).

2.3.4.4 Climbing vines, epiphytes and epicormic growth

There was an abundance of climbing plants observed on the monitored kauri with 60 per cent (331/551) of trees recording climbing plants. Crown epiphytes were much less abundant than climbing plants, with only 12 per cent of trees (68/551) with epiphytes recorded. This is not surprising given that most trees were smaller trees without fully expanded mature crowns. There were also a few trees that had epicormic growth (13 per cent; 73/551).

2.3.5 Anthropogenic risk factors

2.3.5.1 Forest disturbance

Evidence of disturbance was recorded at 51 per cent of sites (282/551 sites) and some sites had multiple disturbance types. This was much higher than the Waitākere survey (23 per cent). In Hūnua, the highest disturbance category score was human or animal off-track at 34.5 per cent (n=190/551, Table 2-7). In comparison, this was only 2.2 per cent (n=47) in Waitākere, where evidence of disturbance from being nearby a track was the most common at 6.4 per cent (n=136). We also recorded more reports of animal pest control and bait-lines in Hūnua (8.2 per cent) compared to Waitākere. Pest control and bait-lines will have contributed to the human and animal off-track disturbance observations. All other categories of disturbance were infrequent (Table 2-7) or absent (e.g. weed spray, fire).

Table 2-7. Comparison of nearby disturbance evidence between the Hūnua and 2021 Waitākere surveys with the most notable disturbance percentages in bold.

Disturbance type	Number of trees Hūnua 2023 (n = 551)	Percentage of trees Hūnua 2023	Percentage of trees Waitākere 2021 (n = 2140)
Animal pest control or bait-line	45	**8.2%**	1.4%

Disturbance type	Number of trees Hūnua 2023 (n = 551)	Percentage of trees Hūnua 2023	Percentage of trees Waitākere 2021 (n = 2140)
Fallen tree or windthrow	15	2.7%	1.6%
Fungal fruiting bodies	3	0.5%	0.3%
Large, hooved animals (total)	27	**4.9%**	2.1%
Hooved animals	24	4.3%	1.0%
Pig damage to trunk	0	0%	0.3%
Pig wallowing	3	0.5%	0.8%
Human or animal off-track	190	**34.4%**	2.2%
Insect damage to trunk	2	0.4%	0.4%
Invasive weed presence	7	1.3%	0.3%
Poor drainage	2	0.4%	0.0%
Slip or landslide	2	0.4%	0.6%
Soil erosion	7	1.3%	0.4%
Track [a]	42[b]	7.6%	6.4%
Track or road maintenance	12	2.2%	0.9%
Other (all) [b]	69	12.5%	3.0%
Other – road	17	3.1%	0.4%
Other – stream	6	1.1%	0.2%

[a] While track wasn't listed as an option for the Hūnua survey (tracks can be calculated using GIS), 42 records of tracks being a disturbance were noted under 'other'.

[b] If 'other' was recorded by the surveyor, they were asked to provide details and the most common are presented.

2.3.6 Baseline ecological impact factors

2.3.6.1 Closest neighbour species

The closest neighbour tree species and DBH were recorded at all monitoring sites. The DBH of each monitored kauri was compared to the nearest neighbouring tree species to calculate which was the larger and dominant tree. The monitored kauri tree was the dominant tree at 94 per cent (518/551) of sites with only 6 per cent (33) of the monitored kauri trees being smaller than the neighbouring tree and classified as subdominant. The median difference between kauri DBH and the closest neighbour was kauri being 37cm larger (with a minimum of 43 cm smaller and 2.5m larger).

Figure 2-37 below shows tanekaha as the most common neighbouring species at 40 per cent (220/551) with other kauri being the second most common neighbouring species at 21 per cent (113/551). The full list is in Appendix E.

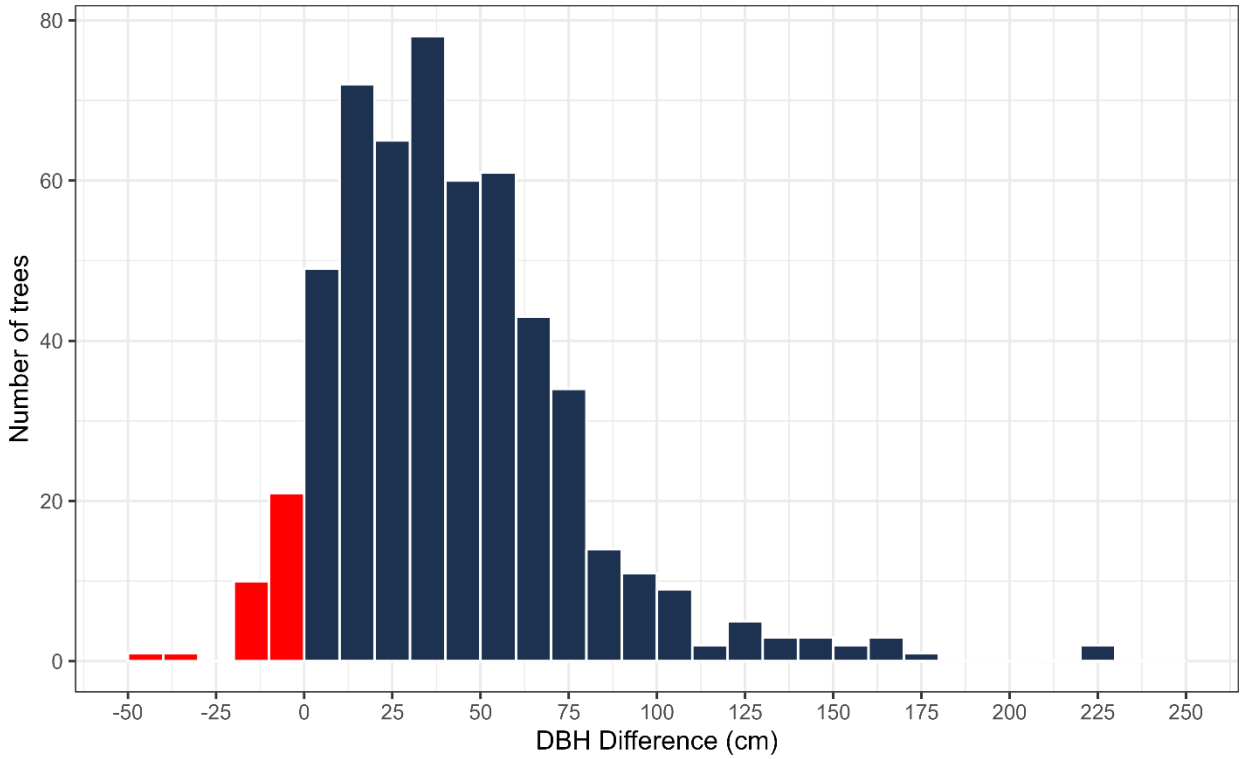


Figure 2-37. Frequency distribution of the difference in DBH between the monitored kauri and the closest neighbouring tree, showing in red where the kauri was sub-dominant (was smaller) and blue where the kauri was dominant (larger).

We also measured the distance to the nearest kauri tree at each site if it was within 10m, and found that in 77 per cent of sites (424/551) there was another kauri present. When the DBH values of these nearby kauri trees, most were smaller than the monitored tree indicating that many of these trees may be sub-canopy sized trees that our remote sensing approach could not detect, or were included in the canopy segmentation of the monitored tree. Some areas had dense ricker stands with multiple kauri within 1m of the monitored tree (Figure 2-38).

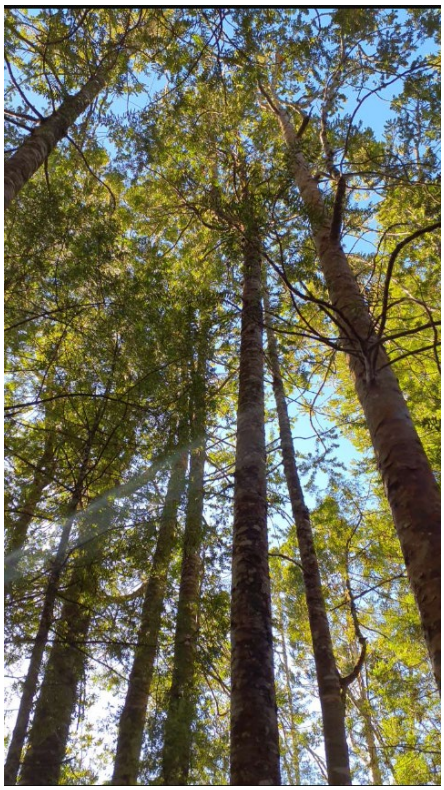


Figure 2-38. Monitored tree in the centre of a dense ricker stand (ref. POI AHS123K).

2.3.6.2 Common species

The most common plant species recorded near monitored kauri in Hūnua was tanekaha at 95 per cent of sites. Kauri grass, shining karamū, rewarewa, mingimingi and horoeka (lancewood) were also very common, observed in over 80 per cent of sites (Table 2-8). We did not observe any Kirk's tree daisy or māpere, and we saw very low levels of aute and taraire near monitored trees during the survey. Tawhairaunui (hard beech) was present at 41 per cent of monitored kauri sites, indicating that 'WF12 – Kauri, podocarp, broadleaved, beech forest' is common across Hūnua despite being a regionally endangered ecosystem type.

Table 2-8. Common kauri forest-associated plant species selected for observation.

Scientific name	Common name	Count	Per cent
Astelia trinervia	Kōkaha, kauri grass	456	**83%**
Beilschmiedia tarairi	Taraire	15	3%
Beilschmiedia tawa	Tawa	145	26%
Brachyglottis kirkii	Kohurangi, Kirk's tree daisy	0	0%
Broussonetia papyrifera	Aute, paper mulberry	4	0.7%
Coprosma lucida	Shining karamū	447	**81%**
Dacrydium cupressinum	Rimu	306	56%
Fuscospora truncata	Tawhairaunui, hard beech	224	41%
Gahnia xanthocarpa	Māpere, gahnia	0	0%
Knightia excelsa	Rewarewa	441	**80%**
Kunzea robusta	Kānuka	236	43%
Leucopogon fasciculatus	Mingimingi	459	**83%**
Lygodium articulatum	Mangemange	354	64%
Myrsine australis	Māpou	394	72%
Pectinopitys ferruginea	Miro	143	26%
Phyllocladus trichomanoides	Tanekaha	523	**95%**
Podocarpus totara	Tōtara	190	35%
Pseudopanax crassifolius	Horoeka, lancewood	445	**81%**
Pterophylla racemosa [a]	Kāmahi	73	13%
Pterophylla sylvicola [a]	Towai	68	12%

[a] *Pterophylla racemosa* and *P. sylvicola* are difficult to distinguish visually; therefore, caution should be taken when comparing the distribution of these two species.

2.3.6.3 Forest floor depth (soil organic layer)

The forest floor depth was measured for the monitored kauri. A mean from the left and right-side forest floor depth measurements per tree was calculated and used as the individual tree forest floor depth value. The population median forest floor depth was 13.5cm (25th percentile 10.5cm; 75th percentile 17.0 m) with a minimum of 2.5cm and maximum of 35.5cm. Forest floor depth was positively correlated with DBH ($p<0.001$, Pearson correlation coefficient), with mature trees having much deeper organic layers than smaller ricker trees (Figure 2-39, Figure 2-40).

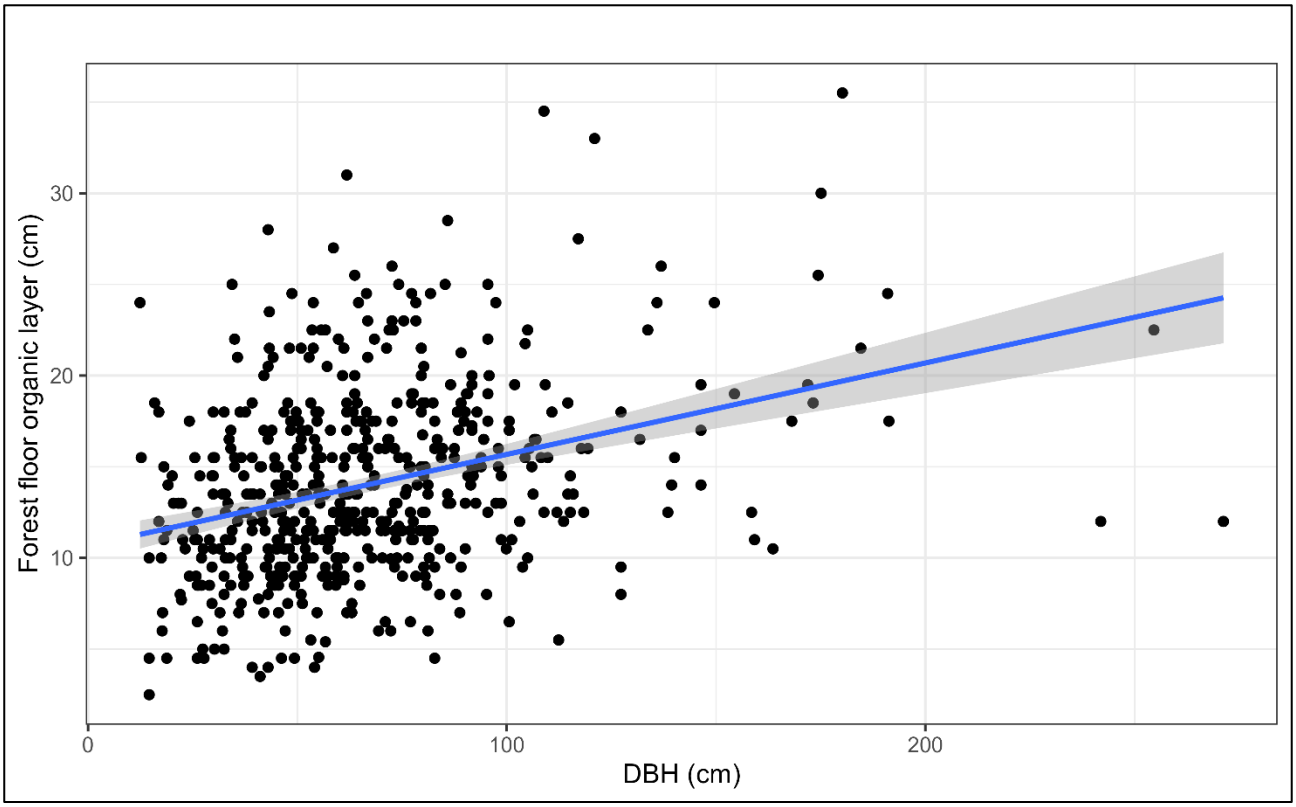


Figure 2-39. Scatter plot showing average forest floor depth (cm) per tree as a function of tree size measured as DBH (cm). Superimposed on this plot is a loess smoothed linear regression line (blue) with 95 per cent confidence intervals (grey shading).

The box plot in Figure 2-40 below shows forest floor depth (cm) per tree as a function of tree size measured as DBH (cm).

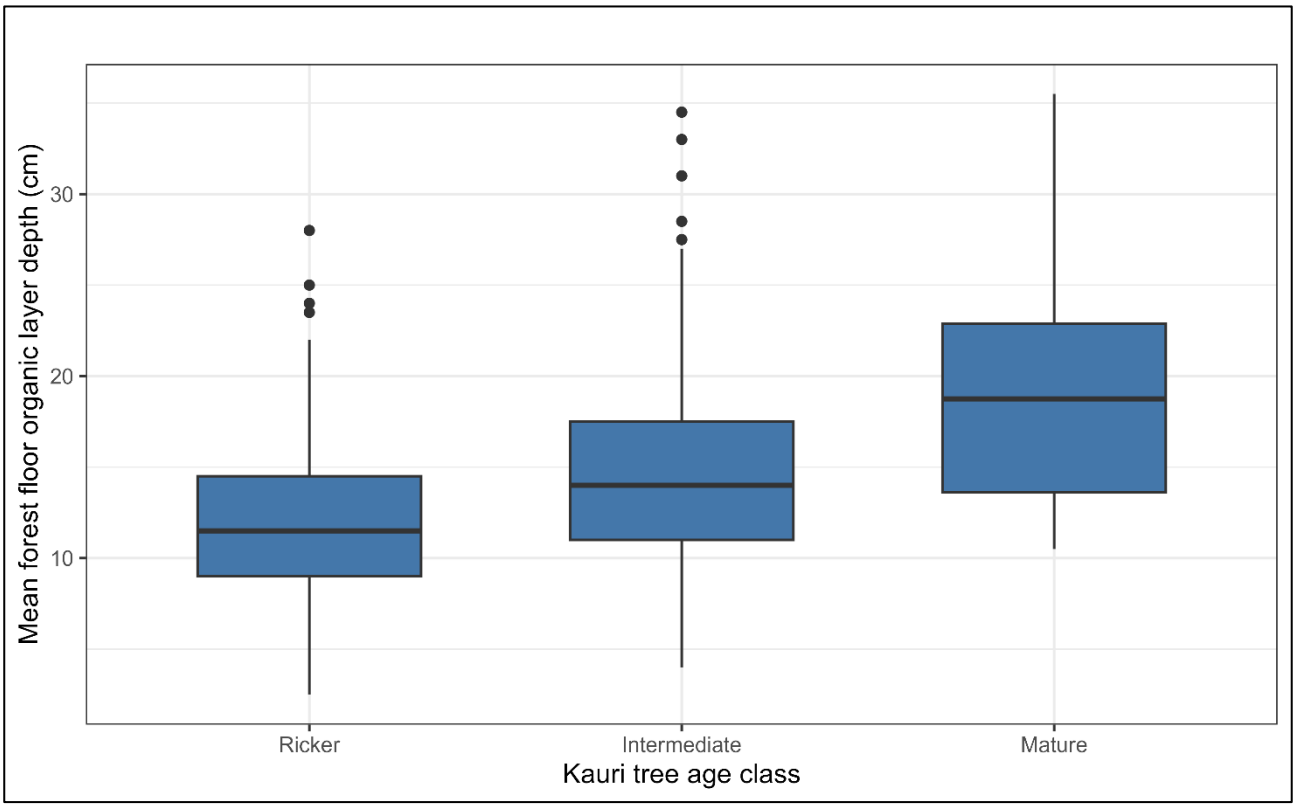


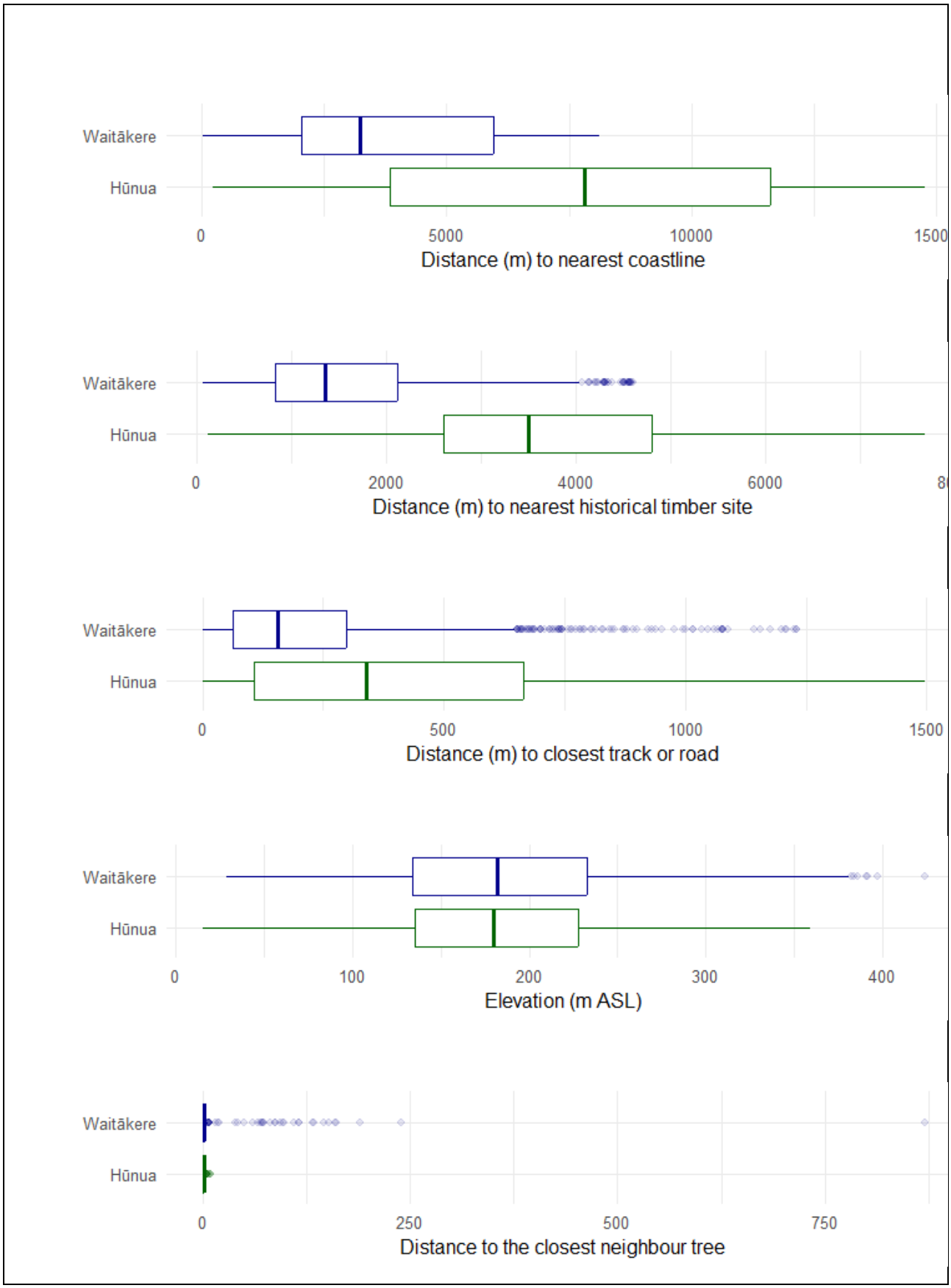
Figure 2-40. Average forest floor depth by monitored kauri age class.

2.3.7 Risk factors

2.3.7.1 Comparison of risk factors

We compared the risk values of the sampled Hūnua trees with those from the 2021 Waitākere survey, as shown in Figure 2-41. The main differences in risk values between Waitākere and Hūnua were that Hūnua had fewer mature age class trees (fewer kauri with large DBH values over 143cm), and Hūnua kauri were further away from the coast, from historical timber sites and from tracks than Waitākere kauri.

Figure 2-41 below depicts box and whisker plots showing the median forest floor depth (cm) per tree, stratified by kauri tree size class from 2127 monitored trees where the size class value was recorded. It shows the median value (horizontal line), interquartile range (within box), maximum and minimum values (excluding outliers, vertical bars) and outliers (dots) for the population.


Waitākere
Hūnua
0
5000
10000
1500
Distance (m) to nearest coastline
Waitākere
Hūnua
0
2000
4000
6000
Distance (m) to nearest historical timber site
Waitākere
Hūnua
0
500
1000
1500
Distance (m) to closest track or road
Waitākere
Hūnua
0
100
200
300
400
Elevation (m ASL)
Waitākere
Hūnua
0
250
500
750
Distance to the closest neighbour tree

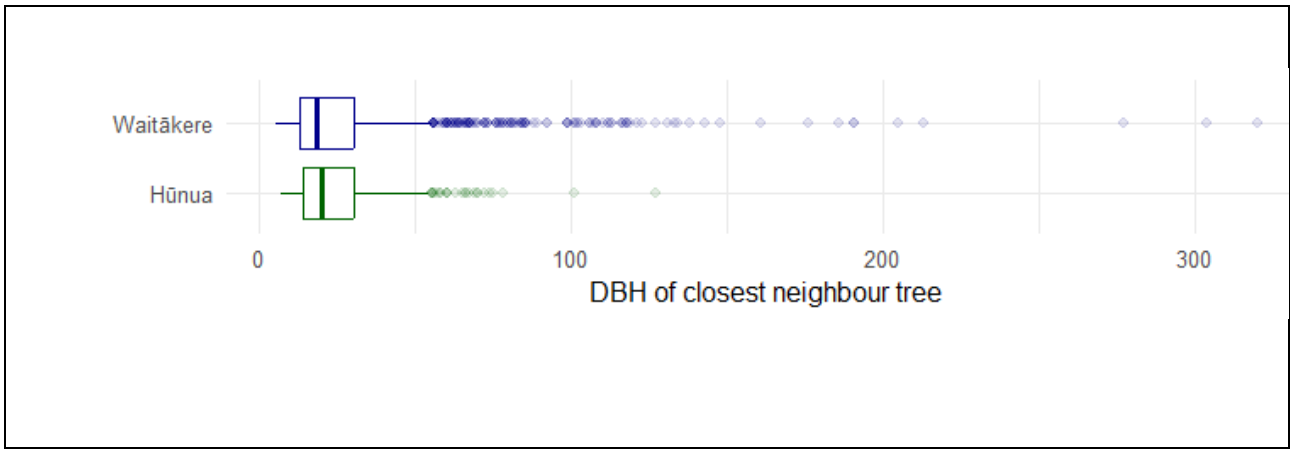


Figure 2-41. Comparison of risk values between 2023 Hūnua kauri monitoring data and 2021 Waitākere Ranges data.

2.3.7.2 Risk factor screening for symptomatic kauri

Before screening the randomly selected trees against the outcome of whether a tree was symptomatic or non-symptomatic, we ran a simple 2 by 2 test to see if there was a difference between random and risk-based samples with the outcome. The results showed a highly significant association ($p<0.001$, Fisher's test) with risk-based samples 4.6 times more likely to be symptomatic (95 per cent CI 2.1; 10.5). This was somewhat driven by the inclusion of distance to previously tested sites, which were typically tested due to ill-thrift symptoms. The spatial distribution of symptomatic trees differed between the randomly selected trees and the risk-based trees in that there were symptomatic trees observed in the north-eastern and central southern area (near Mangatangi Reservoir) of Hūnua from the risk-based trees, but not from the Random selection (Figure 2-42). However, there were fewer random trees monitored in those regions due to a smaller underlying host population. This indicates that our risk-based method for selecting trees was successful in detecting trees that were more likely to be unhealthy.

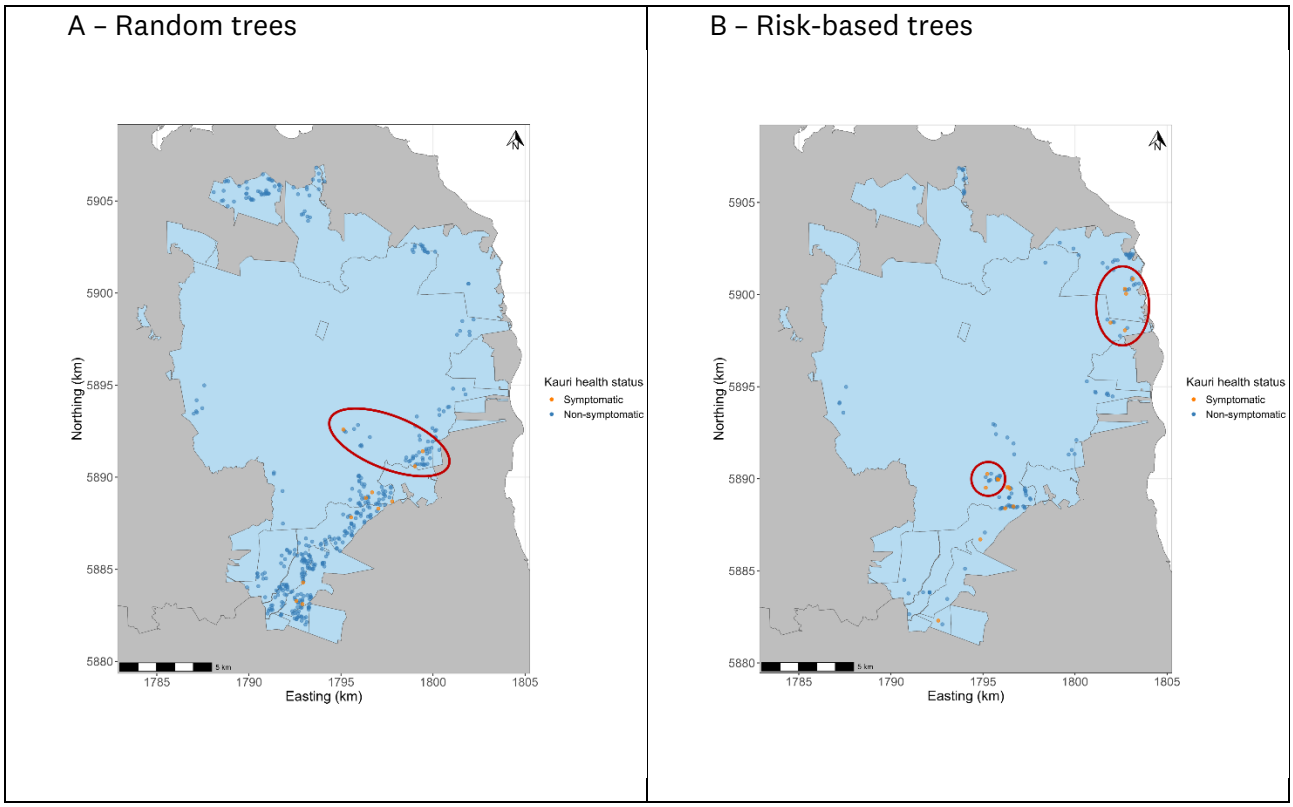


Figure 2-42. Kauri health status by random versus risk selection, with circles indicating differences in symptomatic tree distribution.

Screening of factors that may be associated with kauri health (symptomatic kauri vs non-symptomatic kauri) was then done on data from the 410 randomly selected monitored trees of which only 11 were symptomatic. Only four factors showed a significant association with symptomatic kauri – distance from a water reservoir (p=0.020), human or animal off-track disturbance (p=0.04) and the two *Pterophylla* common plant species – tōwai (*Pterophylla sylvicola)* (p=0.027) and kāmahi (*Pterophylla racemosa)* (p=0.006) (Table 2-8). As only 11 trees were symptomatic, there was insufficient data to assess most factors as they were too rare within the symptomatic group of trees.

Table 2-9 below shows the risk factor screening results for univariate testing of variables for an association with the outcome of symptomatic kauri (vs non-symptomatic) using glm models and a significance of p <0.05. Variable descriptions are provided in Table 2-1 and summary statistics in Appendix D.

Table 2-9. Risk factor screening results for univariate testing of variables for symptomatic vs non-symptomatic kauri.

Variable	Odds Ratio	2.5% CI	97.5% CI	p-value
Size class				
Ricker	Reference			0.60
Intermediate	0.78	0.22	3.08	
Mature	2.75	0.13	20.54	
Pathogens				
Presence of ***P. cinnamomi***	1.64	0.47	7.58	0.469
Presence of Phyt. Other	Insufficient data	NA	NA	NA
Common plants				
Astelia trinervia	0.73	0.18	4.90	0.698
Beilschmiedia tarairi	Insufficient data	NA	NA	NA
Beilschmiedia tawa	0.24	0.01	1.30	0.181
Coprosma lucida	Insufficient data	NA	NA	NA
Dacrydium cupressinum	0.98	0.29	3.44	0.969
Fuscospora truncata	1.91	0.57	6.73	0.292
Knightia excelsa	0.92	0.23	6.15	0.921

Variable	Odds Ratio	2.5% CI	97.5% CI	p-value
Kunzea robusta	0.52	0.11	1.81	0.333
Leucopogon fasciculatus	Insufficient data	NA	NA	NA
Myrsine australis	0.33	0.09	1.10	0.068
Pectinopitys ferruginea	0.62	0.09	2.46	0.548
Phyllocladus trichomanoides	Insufficient data	NA	NA	NA
Podocarpus totara	0.68	0.15	2.39	0.572
Pseudopanax crassifolius	0.92	0.23	6.15	0.921
Pterophylla racemosa	5.56	1.55	19.12	0.006sig.
Pterophylla sylvicola	4.18	1.06	14.37	0.027sig.
Lygodium articulatum	0.56	0.17	1.98	0.346
Broussonetia papyrifera	Insufficient data	NA	NA	NA
Disturbance				
Animal pest control	Insufficient data	NA	NA	NA
Bait line	Insufficient data	NA	NA	NA
Invasive weed	Insufficient data	NA	NA	NA
Fallen tree	Insufficient data	NA	NA	NA

Variable	Odds Ratio	2.5% CI	97.5% CI	p-value
Fungal fruiting bodies	Insufficient data	NA	NA	NA
Hoofed animal	Insufficient data	NA	NA	NA
Human animal off track	3.71	1.10	14.36	0.04 sig.
Insect damage	Insufficient data	NA	NA	NA
Pig wallowing	Insufficient data	NA	NA	NA
Poor drainage	Insufficient data	NA	NA	NA
Road maintenance	Insufficient data	NA	NA	NA
Slip landslide	Insufficient data	NA	NA	NA
Soil erosion	Insufficient data	NA	NA	NA
Track maintenance	Insufficient data	NA	NA	NA
Other	1.38	0.07	7.60	0.764
Host related				
Host origin	Insufficient data	NA	NA	NA
DBH (rescaled to 10 cm)	1.08	0.9	1.24	0.365
Closest neighbour DBH (rescaled to 10 cm)	1.13	0.76	1.50	0.464
Distance closest neighbour	1.15	0.71	1.60	0.503

Variable	Odds Ratio	2.5% CI	97.5% CI	p-value
Distance closest Kauri	1.03	0.80	1.28	0.827
Closest kauri DBH (rescaled to 10 cm)	1.08	0.82	1.32	0.545
Elevation (rescaled to 100 m)	1.07	0.35	3.16	0.905
Kauri distance (a measure of kauri density) (rescaled to 100 m)	0.60	0.02	5.07	0.704
Coast distance (rescaled to 100 m)	1.00	0.98	1.02	0.965
Edge distance (rescaled to 100 m)	0.98	0.83	1.14	0.822
Moisture	Insufficient data	NA	NA	NA
Previously Ill distance (rescaled to 100 m)	0.97	0.88	1.03	0.497
Bleed distance (rescaled to 100 m)	0.98	0.96	1.01	0.209
Route distance (rescaled to 100 m)	0.93	0.75	1.10	0.424
Timber distance (rescaled to 100 m)	1.03	0.99	1.07	0.112
Dam distance (rescaled to 100 m)	0.96	0.88	1.04	0.306
Reservoir distance (rescaled to 100 m)	0.97	0.95	0.99	0.020sig.
Vegetation Plots distance (rescaled to 100 m)	0.99	0.96	1.01	0.254
Planting distance (rescaled to 100 m)	0.97	0.94	1.00	0.086

Variable	Odds Ratio	2.5% CI	97.5% CI	p-value
Stream distance (rescaled to 100 m)	1.01	0.99	1.02	0.179

[sig.] Significant at $p<0.05$

The four significant factors can be interpreted as indicators of risk that require further multivariate modelling. Interpretation of their odds ratios and confidence intervals demonstrating the effect of one unit difference from the average value of the variable are:

- Distance to reservoir: The odds of symptomatic kauri was 0.97 times (3 per cent) less for each 100m increase in distance away, i.e. symptom prevalence was higher closer to reservoirs.
- Human or animal off-track disturbance: The odds of symptomatic kauri was 3.7 times higher for kauri trees with human or animal off-track disturbance recorded during the survey, i.e. symptom prevalence was higher when off-track disturbance was present.
- Kāmahi and tōwai common plants: The odds of symptomatic kauri was 4.2 or 5.6 times higher for kauri trees that had either *Pterophylla sylvicola* or *Pterophylla racemosa* recorded nearby during the survey, i.e. symptom prevalence was higher when kāmahi or tōwai were present.

Risk factor screening results for univariate testing of variables for an association with the outcome of symptomatic kauri (vs non-symptomatic) using glm models and a significance of $p<0.05$. Variable descriptions are provided in Table 2-1 or Appendix D.

There was a reduction in the risk of being symptomatic in association with increasing distance from a water reservoir, indicating that reservoirs increase the risk of poor kauri health, possibly due to historic disturbance or changes in soil moisture (see Table 2-9). There was a significant increase in the risk of poor kauri health in association with the presence of human or animal off-track disturbance, which may be related to root damage. For common plants, there was a higher risk of being symptomatic in association with the presence of the two *Pterophylla* species (Table 2-9). Kāmahi and tōwai are known to be involved in the gap-phase regeneration of broadleaf forest, taking over from tree ferns after the loss of a large canopy tree (Dawson, 1988, Silvester, 1964). The presence of kāmahi and tōwai may be indicators of historical habitat disturbance as they were less palatable to goats which were abundant in the Mangatangi area following historic logging (Silvester, 1964). Of note was finding no association between the presence of *P. cinnamomi* ($p=0.47$) and symptomatic kauri (Table 2-9), which is consistent with our Waitākere findings.

2.4 Discussion

Te matapaki

This study had three key objectives, with the primary objective being to assess pathogen freedom from *P. agathidicida* in Hūnua. We also aimed screen risk factors for symptomatic kauri to inform management to enhance kauri health and to assess baseline kauri and ecosystem health in Hūnua.

Our key finding from this study is that we are between 97-99.9 per cent certain that, if *P. agathidicida* was present in the Hūnua study area and was infecting 1 per cent or more kauri trees, we have taken enough samples to have detected it. Therefore, we consider it almost certainly absent.

There is a growing body of evidence that historical disturbances are likely introduction pathways for *P. agathidicida* (Froud et al. 2022). A benefit of our study design is that we also used randomly selected kauri to monitor for *P. agathidicida* and kauri health, so even if our risk factors were not accurate, we would still have 97% confidence in our non-detection.

Samples were taken over a broad time period from 30 March 2023 to 6 July 2023, with an extra 33 collected between 7-15 October 2023. While there is currently no evidence that sampling at different times of the year can affect test accuracy, we should be cautious. It is considered reasonable that if *P. agathidicida* is present in the soil sample, then the test will detect it in the laboratory. However, it is possible that the concentration of *P. agathidicida* in the soil differs during the year as it does in other *Phytophthora* species (e.g. Riddell et al. 2020) and therefore, there may be a lower or higher chance of *P. agathidicida* inclusion in the soil samples taken in the field at different times of the year.

Another potential concern was the lack of sampling from some privately owned properties contiguous to the main forested area. These sites have an unquantified *P. agathidicida* status; however, trees on the immediate boundaries of these properties all returned 'not detected' results and there is no reason to believe that properties where access was denied differ significantly from neighbouring properties that were sampled. One of the reasons given by landowners for refusing access for sampling was to protect the forest from the potential introduction of *P. agathidicida* from the surveyors, which indicates a high awareness of potential risk and a level of risk mitigation on those properties.

Our confidence in the non-detection of *P. agathidicida* is reinforced by the high analytical sensitivity of the molecular diagnostic test (LAMP; Winkworth et al, 2020). However, without knowing the diagnostic sensitivity of LAMP we are unable to calculate proof of freedom estimates for this test. It is strongly recommended that the diagnostic sensitivity and specificity for the LAMP test are determined. The sample size required for undertaking this type of analysis is approximately 800 samples from a known infected forest. This would be an expensive undertaking; however, if this or another sensitive and replicable tool was developed, tested, and approved, this could mean only one test is required to prove freedom in the future, resulting in a cost saving to the wider kauri lands community.

The proof of freedom calculations used in this study alongside the diagnostic sensitivity of the standard soil bioassay test can be applied to other forests in kauri lands. Further validation of the risk factors from the Waitākere survey (Froud et al., 2022a) and those developed for Hūnua and other forests would help improve our freedom estimates. There would be value in validating these risk factors in forests where *P. agathidicida* has been previously detected but not yet well described spatially.

There were very few symptomatic kauri observed during the survey with a very low prevalence of only 4.9 per cent. When we looked at the relative risk of being symptomatic versus non-symptomatic based on the underlying host population density, we found that the area around the Mangatangi Dam had a slightly significant ($p = 0.1$) increased risk. Signs of stress in these kauri may be due to competition or root disturbance from other factors, including the severe weather events of January and early February (Anniversary Day floods and Cyclone Gabrielle) in 2023. This is consistent with both our risk factors screening analysis and with the observation of symptomatic kauri in Waitākere near disturbed sites.

The vast majority of Hūnua kauri were very healthy, with over 95 per cent of them showing no or very limited signs of ill-health. Almost all trees had healthy green canopies and very few had basal lesions, with only three trees having symptoms that looked consistent with severe kauri dieback. Given our high confidence in *P. agathidicida* freedom, it is most likely that other factors have contributed to the poor health of these three trees. There had been some severe weather events in the Hūnua Ranges leading up to the study resulting in landslips in the area which may have contributed to some of the ill-health. Likewise, the extensive rainfall in Auckland during the spring and summer of 2022/2023 likely contributed to the healthy green canopy of kauri in Hūnua. The area with an elevated risk of unhealthy kauri was near the Mangatangi Dam. We know from the 2021 Waitākere study that

kauri health was poorer in areas close to historical disturbances which is consistent with these results. This is of interest for future management of the forest, as trees in poor condition are more likely to be vulnerable to *P. agathidicida* if it is introduced into Hūnua, as we saw in other host pathogen systems (Martin, 2008).

As we found with the Waitākere survey, there was no association between the detection of *P. cinnamomi* and symptomatic kauri adding to the evidence that *P. cinnamomi* is not a significant pathogen of kauri trees at present in the Auckland Region. More research on co-infection and impacts of future climates may be helpful to fully understand the risks of *P. cinnamomi* to forests in Tāmaki Makaurau.

Most trees in our sample were intermediate in size with a median DBH of 61cm which was similar to the Waitākere trees (median of 66 cm). However, there were fewer mature trees in Hūnua (3.6 per cent) than Waitākere (10 per cent). The dominance of small-intermediate sized trees is consistent with kauri forest that is regenerating from logging in the late 1800s and early 1900s (i.e. 100-120-year-old trees transitioning from ricker to intermediate size classes; (Bergin & Steward, 2004). Our results also reflect the use of remote sensing to detect our sample frame with taller (larger) canopy trees more likely to be included.

We found a very high rate of 92.6 per cent of sites with seedlings or saplings present beneath the monitored trees, indicating a healthy population with good recruitment. This was a much higher rate than 55 per cent of sites observed in the 2021 Waitākere survey; however, it was dominated by young seedlings (85 per cent of sites). In addition to the lack of *P. agathidicida* pressure on seedling survival, the increased kauri recruitment in Hūnua may have been promoted by the wetter weather conditions leading up to this survey compared to Waitākere which had suffered several years of dry weather prior to the 2021 survey. As we found with the Waitākere survey, there was no association between the detection of *P. cinnamomi* and the presence of kauri seedlings and saplings, giving further evidence that *P. cinnamomi* is not a significant pathogen of kauri seedlings.

We recorded a high level of human or animal off-track disturbance during the survey; 34.5 per cent of monitored kauri showed signs of such disturbance which was much higher than the 2.2 per cent in Waitākere. While some of this variation may be due to team differences between the two studies, there are some potentially contributing factors relating to off-track disturbance sign at Hūnua. For example, we recorded higher animal pest control and bait-lines in Hūnua (8.2 per cent) compared to Waitākere, which will have contributed to the human and animal off-track disturbance observations. A large-scale pest control operation was completed just before our survey began, which is likely to have contributed to the observed

disturbance. Pest management in Hūnua is often undertaken aerially to reduce ground-based disturbance; this may be more important in the future to avoid the introduction and spread of *P. agathidicida*. In addition, the Waitākere survey was restricted to regional park lands which had been under a rāhui and controlled area notices since 2017, so very few people entered the forest away from open tracks, whereas the Hūnua survey included private land. It was also much wetter during the Hūnua survey, so off-track disturbance may have been more visible. Regardless, it is important to be aware of the heightened risk of off-track disturbance in Hūnua which may provide an important spread pathway if *P. agathidicida* is introduced in the future.

As expected with kauri being a keystone species, we found that kauri were the dominant sized trees in 94 per cent of our monitoring sites. We also found that 77 per cent of trees had another kauri tree (over 10cm DBH) within 10m, most of which were smaller than the monitored tree, indicating that many of these trees may be sub-canopy sized trees that our remote sensing approach could not detect or were included in the canopy segmentation of the monitored tree. In addition, some areas had dense ricker stands with multiple kauri within 1m of the monitored tree, indicating that our population estimates may have underestimated the population of kauri at canopy height. Once the total population size is more than a few thousand, this number does not affect the sample size calculations, so our likely underestimate of the kauri population does not change or invalidate our results.

We also obtained baseline forest floor organic layer data and found that the combined mean for Hūnua was similar to Waitākere in that the median values were close at 13.5cm and 16.5cm depth respectively and were strongly correlated to kauri age class with much deeper forest floor layers in the larger mature trees. The was a difference in the upper values with the 75th percentile for Hūnua at 17cm compared to 23cm in Waitākere, reflecting the larger number of mature trees in Waitākere. Change in forest floor depth is classified as a potential impact from kauri dieback as significantly less leaf litter depth was recorded in areas of Waitākere with *P. agathidicida* (Froud et al., 2022b);these Hūnua leaf litter depth values set a baseline for future testing if *P. agathidicida* is introduced.

It was useful to look at the risk values of the sampled Hūnua trees in comparison to those from the Waitākere survey. These were the factors that were associated with a higher probability of *P. agathidicida* detection in Waitākere (Froud et al., 2022b) and were used to predict high-risk areas for monitoring in Hūnua. We noted that Hūnua had fewer mature age class trees (with large DBH values), and that trees sampled in Hūnua were further away from the coast, from historical timber sites and from

tracks across both the randomly selected and risk-based trees. This raises the hypothesis that the absence of *P. agathidicida* from Hūnua may in part be due to differences in historic and recent risk profiles.

The screening for associations between symptomatic kauri and our risk factors mostly showed no increased risk or had such low numbers of symptomatic kauri that no association could be assessed, consistent with a much lower rate of symptomatic kauri in Hūnua than observed in Waitākere. However, we did find three interesting associations of increased risk of symptomatic kauri being closer to a water reservoir, where there was evidence of human or animal off-track use, or in the presence of two common plant species (kāmahi and tōwai) that are indicators of heavily grazed (by goats) regenerating forest. We suspect that, as we found in the Waitākere survey, poor kauri health is associated with disturbance and regeneration.

2.5 Conclusion

Te whakatau

This study found no evidence of *P. agathidicida* in the Hūnua ranges and the extent of testing give us between 97 per cent and 99.9 per cent confidence it is absent from the Hūnua study area. This confidence is extremely important for informing ongoing forest management between all partners and landowners in Hūnua. We have successfully built a risk profile for Hūnua identifying the areas of highest future introduction or detection risk. Knowing that the risk of *P. agathidicida* introduction via risk pathways is an ongoing threat, partners can target its spread/introduction prevention and protected areas strategies around our identified high-risk areas. Maintaining *P. agathidicida* freedom from the kauri population within Hūnua is of great importance both regionally and nationally for the ongoing survival of kauri. Future monitoring can be targeted at areas of higher risk that were not accessible in 2023.

We have set a baseline of kauri health which can be used for ongoing monitoring that considers the risk of *P. agathidicida* introduction and the detection of other potential impacts on kauri. As of 2023, we have identified most kauri within Hūnua as healthy; however, there is a higher risk of poor kauri health in association with disturbance, particularly around the Mangatangi Dam. We found extensive animal and human off-track disturbance in the forest which indicates potential for *P. agathidicida* introduction and risk of spreading, and kauri root disturbance that could affect kauri health and vulnerability.

As we move towards a less stable environmental future with climate change, it will be important to maintain *P. agathidicida* freedom, reduce spread of other non-indigenous pathogens such as *P. cinnamomi,* and continue monitoring and manage kauri health as it is a keystone species and an indicator of forest health in this unique habitat. Ngā Iwi Mana Whenua o Kohukohunui support ongoing monitoring, cleaning stations, pest control and would support exploring other initiatives to ensure the Hūnua Ranges remain free of *P. agathidicida*.

Section 3: Methods for stream monitoring for cultural and environmental health in kauri forest areas of Te Ngāherehere o Kohukohunui / Hūnua Ranges in the Auckland region

Ngā tikanga aroturuki i te roma e pā ana ki te ora ā-ahurea, ā-taiao hoki i ngā wāhi uru kauri o Te Ngāherehere o Kohukohunui i te rohe o Tāmaki Makaurau

3.1 Introduction

Te whakataki

This stream baiting study aimed, firstly to gather additional evidence to understand whether Te Ngāherehere o Kohukohunui / Hūnua Ranges is free of *Phytophthora agathidicida*, the causal agent of kauri dieback disease, and secondly to collect data for mana whenua on the environmental and cultural health of the streams. We aimed to do this by trialling a new tool that pairs stream baiting with LAMP diagnostic testing. This test is relatively new but has been successful in detecting *P. agathidicida* in streams where *P. agathidicida* is known to be present in the nearby kauri population. The sensitivity and specificity of the LAMP test has not been evaluated, so we used it alongside the soil-based morphological testing for greater certainty.

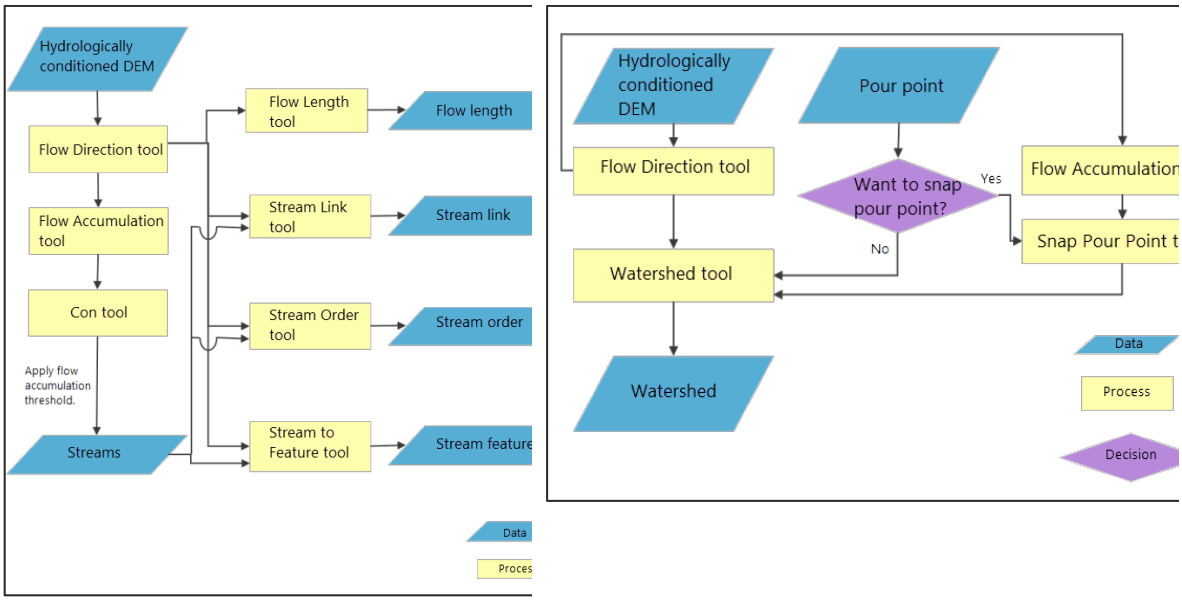
3.2 Method to identify stream sub-catchments

We located the sampling locations for the stream baiting by:

a. calculating a permanent stream layer
b. delineating sub-catchments
c. selecting and combining sub-catchments for the sampling
d. manually placing the locations for the stream baiting along the streams.

3.2.1 A: Calculating permanent streams

We calculated the permanent streams with ArcPro, according to a workflow that is documented by ESRI as 'Stream network and characteristics' (see Figure 3-1 (a)).



(a) (b)

Figure 3-1. a). Stream network and characteristics flowchart. (b) Watershed delineation flowchart. (b) Source: https://pro.arcgis.com/en/pro-app/latest/tool-reference/spatial-analyst/deriving-runoff-characteristics.html

The input DEM was created as a combination of the 1m LiDAR based height models from Auckland Council and Waikato Council. The threshold for a permanent stream was set as a 5ha watershed area in the flow accumulation raster to match the permanent stream layer calculated for the rest of Auckland. We calculated the stream order calculated and added it as an attribute to the layer. We deleted the area of reservoirs extended by a 50m buffer from the stream layer.

B. Sub-catchment delineation

We took the sub-catchments in the Auckland Council part of the Hūnua Ranges from the Freshwater Management Tool (FWMT) which was implemented by Morphum Environmental and is documented here: https://www.knowledgeauckland.org.nz/publications/freshwater-management-tool-report-1-baseline-data-inputs/

Our goal was to replicate the method for the sub-catchment delineation used in the FWMT In the Hūnua Ranges. The calculation of sub-catchments with ArcPro followed a workflow documented on the ESRI webpage as 'Watershed delineation' (Figure 3-1 (b)). According to the method used in the FWMT, the input DTM was

resampled to 2m and filled, using the ArcPro 'Fill' tool. Pour points mark the outlet of a watershed. They were automatically generated at the start and the end of each stream section (see stream delineation described under (a). Small streams under 20m were deleted so they did not result in a sub-catchment delineation. The area of reservoirs, extended by a 10m buffer, were clipped out of the resulting sub-catchment areas. Figure 3-2 shows the final sub-catchments for the Hūnua Ranges.

C. Selection of sub-catchments

A two-step process was used to select sub-catchments for the stream baiting. In the first, we calculated the combined path distance of all kauri multiplied within a 100m buffer to the permanent streams. This value was multiplied by the combined risk value for each tree. The highest resulting values marked the initial selection of 23 sub-catchments that were of interest for the stream baiting.

The equation to calculate the combined risk of a stream (RiskDist100mStream) was based on the distance (SumDistTree) and risk factor (SumRiskTree) of kauri trees within a 100m buffer:

$$RiskDist100mStream = e^{-4.6*SumDistTree/100} * SumRiskTree$$

In a second step, we combined the pre-selected sub-catchments and adjusted them to match the extent of the Ministry for the Environment watershed delineation 3rd order (Ministry for the Environment, 2010). We chose a final selection of 11 combined sub-catchments to inform the selection of stream baiting locations (see Figure 3-2).

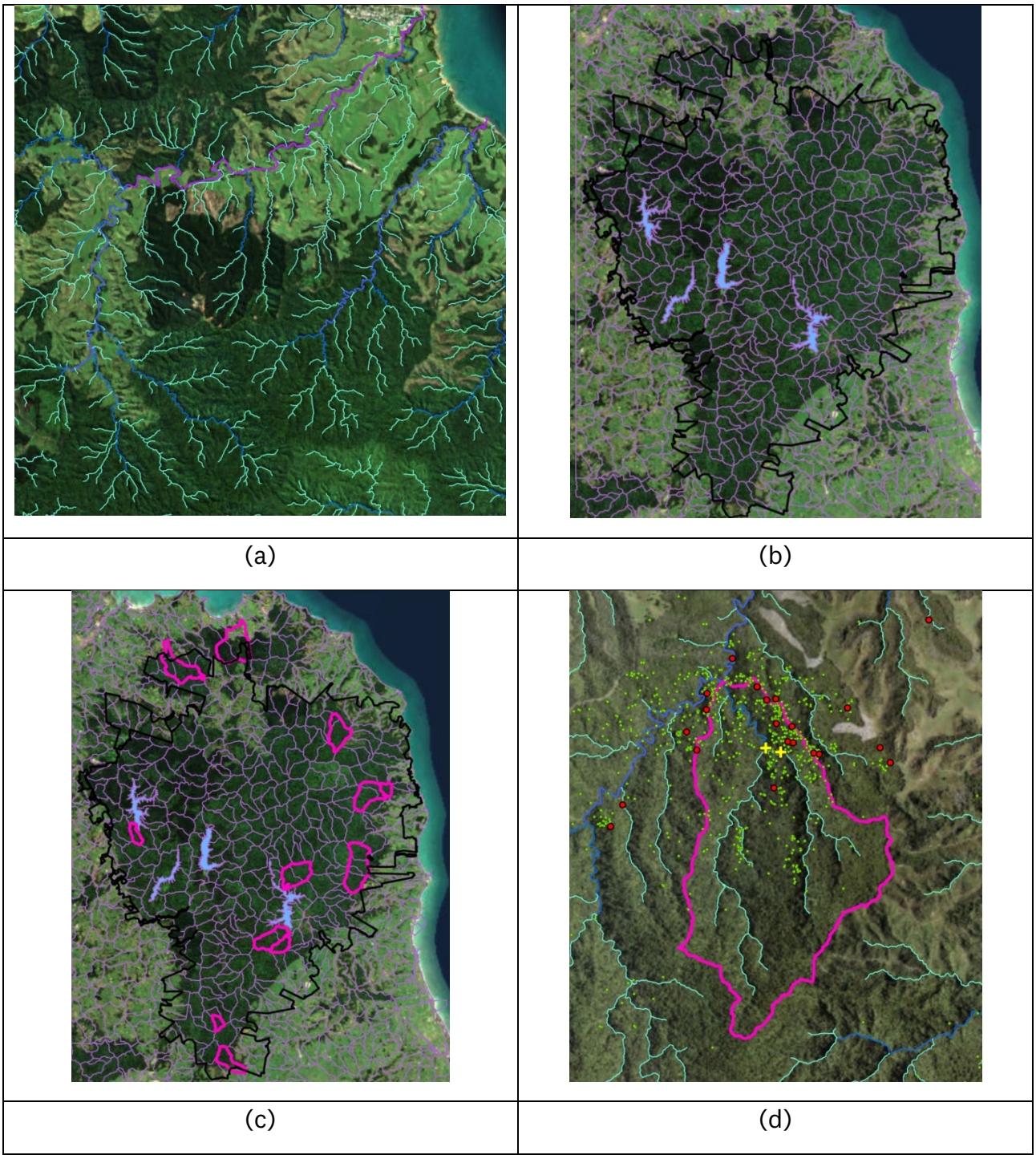


Figure 3-2. Catchment selection for stream baiting.

Figure 3-2 above shows:

a. Calculated permanent streams with a drainage area larger than 5ha, coloured according to their stream order.

b. Sub-catchments for the Hūnua Ranges.

c. Final selection of 11 combined sub-catchments for the stream baiting.

d. Stream baiting locations (yellow cross) manually placed along permanent streams (blue lines) within a combined selected watershed area (pink polygon) that contains both kauri baseline trees (green) and selected kauri trees for the soil sampling (red points). (Background: NZ Imagery, ESRI Living Atlas)

D. Manual placement of locations for the stream baiting

We manually placed 20 locations for the stream baiting along the permanent streams for the selected combined sub-catchments (Figure 3-3) following these criteria:

- number of kauri locations in the upper watershed area
- distance to kauri locations
- accessibility via tracks and roads
- terrain not too steep
- distance to stream junctions
- locations for kauri soil samples within that watershed.

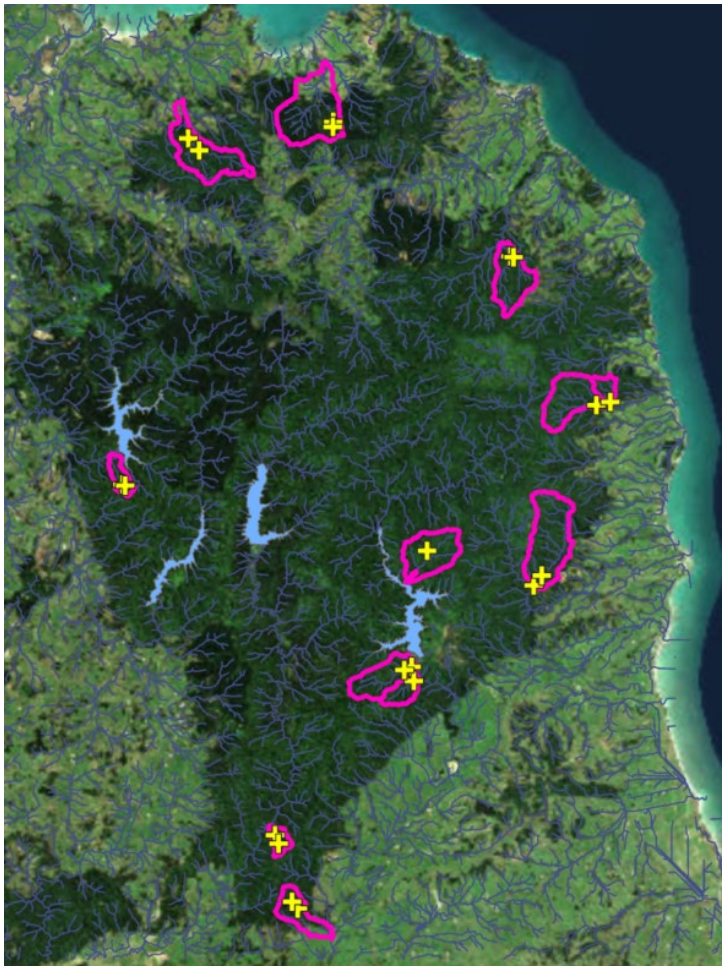


Figure 3-3. Overview map of 11 selected, combined sub-catchments (pink polygons) and 20 manually placed sampling locations for the stream baiting.

3.2.4 Selecting catchments for stream sampling

We wanted to select 20 catchments for stream sampling to detect *P. agathidicida*. Such sampling requires level 1 or 2 (small to medium) streams. We measured the distance from every tree to the nearest level 1 or 2 stream and applied a declining risk function to that distance (as is described above for other distance risk factors). Based on discussion with Richard Winkworth (Massey University), we assumed that the likelihood of *P. agathidicida* zoospores entering a waterway would decline by 99 per cent after b = 200m.

For each tree, the stream distance risk factor was multiplied by the combined risk from other factors. Note that other factors were summed because they were assumed to be independent alternatives contributing to risk – a tree or site could be risky because of one factor **or** another. However, for the stream risk we multiply

because the likelihood of *P. agathidicida* entering the waterway depends on the riskiness of trees **and** their proximity to a stream.

Finally, we aggregated the results by catchment to sum the stream risk factors across all kauri trees present in each catchment, with the summed relative risks and locations shown in Table 3-1 and Figure 3-4.

Table 3-1. Top 20 aggregated sum of stream risk factors across all kauri trees present in each catchment.

Catchment ID	Water risk	Priority
14	617.6784	1
94	394.1591	2
10	315.5736	3
70	261.9229	4
34	253.7150	5
55	247.9554	6
200	246.3457	7
91	237.5419	8
82	221.6701	9
145	192.5045	10
81	173.5234	11
49	159.0116	12
193	155.9842	13
58	146.2809	14
117	145.8061	15
47	143.5450	16
97	141.3751	17
80	136.5115	18
57	135.9418	19
19	133.7539	20

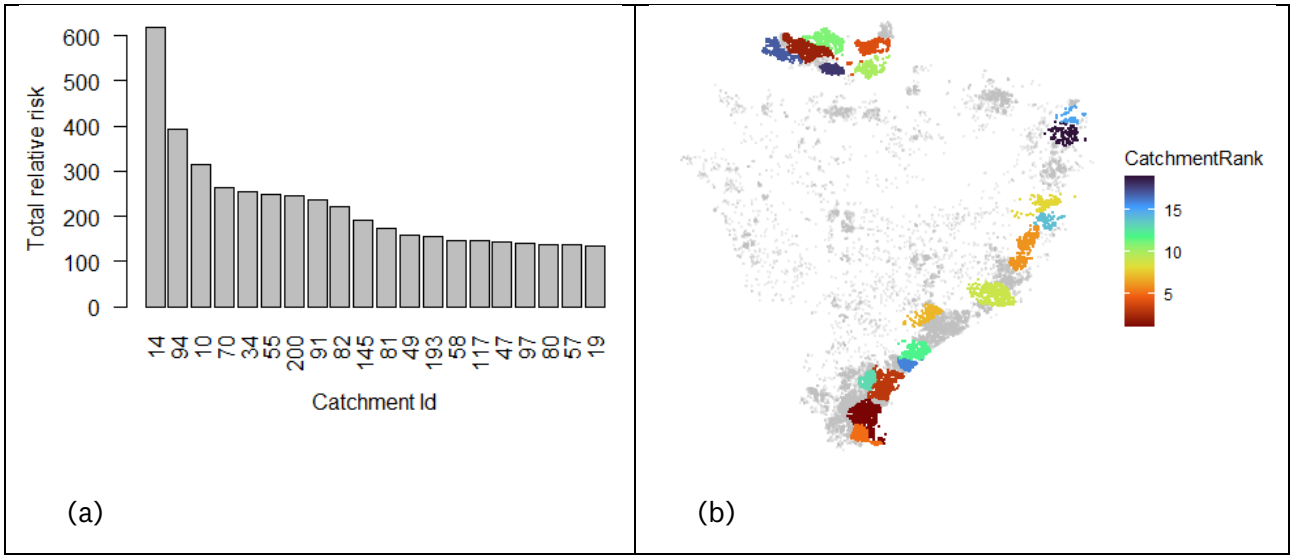


Figure 3-4. (a). Highest priority stream sub-catchments for sampling based on the total relative risk; (b). Location of the top 20 stream sub-catchments prioritised for sampling.

3.2.5 Development of the monitoring form

As with the main survey, the stream monitoring form was co-designed with members of the working group.

3.2.5.1 Standard ecological monitoring

We developed some standard stream ecological monitoring variables, informed by Edward Sides, Freshwater Ecologist, Boffa Miskell, which included:

- stream width in metres measured to one decimal point (e.g. 1.3m) at cassette deployment point using a laser measure
- stream depth estimated mid-stream at point of cassette deployment
- stream substrate, based on the predominant composition of the stream bed at the point of cassette deployment.
- estimated stream velocity by leaning over the stream at the point above the cassette and dropping a leaf onto the water surface, counting in seconds how long it takes for the leaf to travel 1m.

In addition, we assessed the common plants list from the main survey monitoring form, selecting all tree species from the list that are visually present within 10m of the stream.

3.2.5.2 Cultural health indicators

The cultural health indicators section of the monitoring form were only for kaitiaki to complete. These fields were developed by our mana whenua partners including Ngāti Tamaoho, Ngāi Tai ki Tāmaki, Ngaati Whanaunga, Ngāti Paoa, Ngāti Tamaterā, Ngāti Te Ata Waiohua. These indicators are their intellectual property and are for their use. They were informed by Tipa and Teirney (2006).

3.2.6 Field survey data collection and analysis

3.2.6.1 Stream bait deployment

Surveyors were provided with the following instructions:

- Bait deployment can only occur during typical weather conditions, including rainy periods. Using MetService or similar, use the 7-14 day forecast to avoid extreme rainfall situations for the 14-day duration of bait placement, avoiding both drought (no rain forecast at all) and excessive rain (extreme rain watch or warnings).
- All monitoring must abide by tikanga put in place by Ngā Mana Whenua o Te Ngāherehere o Kohukohunui / Hūnua Ranges.
- Once at the pre-determined stream bait deployment point, assess the site for the optimum deployment position following these decision criteria:
    - The stream is permanent with running water (sites have been preselected to maximise this). If the deployment point is not a running stream, then move up to 200m down the catchment to the nearest point where a stream is present. If no stream is found (e.g. it is a tomo), do not deploy the bait.
    - Select a point in the steam that is a 'run', defined as stretches of river with a uniform current, an unbroken surface and moderate depth and water flow. This is as opposed to pools (deep, slow-flowing stretches of river with a smooth surface, often on the outside of bends) or riffles (short, steep sections of river with fast-flowing, shallow water with a rapid broken flow). If the flow rate is very rapid, select a spot on the edge of a pool where the water is slower up to 200m downstream or up to 200m upstream, as long as kauri are visibly present upstream.
- Once the deployment position has been selected, tag the closest tree (of any species) using a robust aluminium tree tag with a unique identifier, so that the exact position can be returned to in the future.

- As per the methods developed by Randall (2011), place 10 fresh cedar needles into plastic bait cassettes, and deploy the stream baiting cassette at a depth of 30cm, securely anchored to the stream bank. Leave for two weeks.
- Conduct the stream baiting stream assessment and cultural health survey via the supplied Survey123 monitoring form (Kauri Stream Baiting Hūnua 2023 – Deployment form). All variables must be collected in full.

3.2.6.2 Stream bait recovery

Bait cassettes were sealed in individual plastic zip-lock bags and stored at 4°C until they were sent to Massey University, Palmerston North. The samples were not chilled during transport.

Samples were then tested using the LAMP test protocol (Winkworth et al., 2020).

3.3 Results

No *P. agathidicida* was detected from the stream bait samples. Survey data was collected for each of the monitoring form variables and data was provided to mana whenua for cultural assessment.

We developed a simplified monitoring form based on the Tipa and Teirney (2006) cultural health indicators. Permission to access and utilise this form may be sought by Ngāti Tamaoho.

Kaitiaki successfully collected ecological and cultural health indicator data for mana whenua.

3.4 Conclusion

There was no *P. agathidicida* detected from the stream baits. While we do not know the diagnostic sensitivity of this new test, it was reassuring that these results were consistent with the soil sampling from Hūnua and it provides further evidence towards the conclusion that Hūnua is free of *P. agathidicida*.

Mana whenua valued the opportunity to exercise manaakitanga, and for kaitiaki to participate in assessing stream health using sight, smell, sound and feel, to inform future assessments from the baseline indicators. There is potential for future use of the baseline stream health methods for ongoing kauri health monitoring.

Section 4: Future steps for the long-term strategy for monitoring kauri health in the Auckland region

Ngā mahi o anamata e pā ana ki te rautaki karioi hei

aroturuki ki te hauora o te kauri i Tāmaki Makaurau

4.1 Introduction

Te whakataki

We have now completed long-term monitoring in two highly valued kauri forests within Tāmaki Makaurau and have built a wider picture of the distribution, epidemiology and impact of *P. agathidicida* within the region that can help inform the strategic direction for kauri forest management.

A science plan for prioritising research of *P. agathidicida* infection in kauri was drafted in 2018. The context of the surveillance, detection, diagnostics and pathways theme was a fundamental uncertainty of whether *P. agathidicida* was discreet or ubiquitous (Kauri Dieback Strategic Science Advisory Group, 2018). It was stated that:

> 'There are competing paradigms of "an ubiquitous pathogen, present in all areas" versus "active spread and areas currently pathogen free" – knowing this will inform how we manage the pathogen(s) and disease it causes, i.e., pathway management or forest health management?' (Kauri Dieback Strategic Science Advisory Group, 2018)

P. agathidicida is believed to be an introduced rather than native pathogen (Weir et al., 2015; Winkworth et al, 2021). It sits within Clade 5 of the genus *Phytophthora* which has host and geographic associations that suggest 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).

P. agathidicida is most likely discrete rather than ubiquitous within kauri lands. This is based on results from the Hūnua survey where *P. agathidicida* was absent, and from the 2021 Waitākere survey where *P. agathidicida* was found in discrete areas and was not detected in the central area of kauri forest (Froud et al., 2022a).

There is further evidence of both a significant association between *P. agathidicida* and symptomatic kauri (Froud et al., 2022a), and that *P. agathidicida* is more pathogenic on kauri than any other New Zealand *Phytophthora* species (Horner and Hough, 2014; Nari Williams, Ngā Rākau Taketake (NRT) presentation, May 2024). This indicates that kauri and *P. agathidicida* did not co-evolve over millennia. If they had, there would be evidence of genetic resistance as there is with other common New Zealand *Phytophthora* detected from kauri roots; however, this has not been demonstrated (Herewini 2017). This reinforces our knowledge that *P.*

agathidicida is a highly pathogenic introduced infectious agent with kauri as the primary host.

Adding to this, NRT research into the host range of *P. agathidicida* has shown that while other common tree species in kauri forests can harbour *P. agathidicida* in a laboratory setting, they appear to be very poor hosts in indigenous forest systems, especially in comparison to kauri (Ian Horner, NRT presentation Feb 2024). In the field, the detection of *P. agathidicida* in non-kauri hosts was rare and petered out within a short distance from an infected kauri (Ian Horner, NRT presentation Feb 2024). This indicates a limitation for natural spread within kauri forest between stands of kauri. In contrast, we now have additional evidence that *P. cinnamomi*, also believed to be an introduced *Phytophthora*, is evenly and extensively distributed within New Zealand kauri forests (Reference). The contrast between the spread and abundance of *P. cinnamomi* compared with *P. agathidicida* within kauri forest may be due to a much wider host range as suggested by Studholme et al. (2016). When considering these soil-borne pathogens as infectious agents, the big difference is that *P. agathidicida* appears to be spatially restricted by the proximity to other susceptible hosts, whereas *P. cinnamomi* is not restricted and disperses between multiple plant species.

4.2 Kauri ora management recommendations

To infect an area, *Phytophthora agathidicida* needs an introduction event, which, at a landscape-scale, appears to rely on spread via human or animal vectoring of contaminated soil. This is evidenced by the spread patterns in the Waitākere Ranges where, over time, extensive localised spread has occurred in highly disturbed and well used areas around introduction foci (e.g. Piha, Cascades Kauri, Huia). Current interventions of isolation using movement controls, maintaining dry-foot track standards in kauri areas, installing and maintaining hygiene stations and implementing mammalian pest management to reduce transmission, will help not only in areas where *P. agathidicida* is known to be present but also will provide good biosecurity for areas where introduction has not yet occurred or has not yet been detected.

Kauri appear to be more prone to poor health in places that have been disturbed and these kauri may be more vulnerable to disease in the event of *P. agathidicida* introduction. As we observed in Waitākere, the detection of *P. agathidicida* was strongly associated with historical and contemporary disturbance events, and in those places, kauri are in poor health and many are dying. Therefore, for long-term kauri ora

(good health), it is essential to minimise forest disturbance around kauri and, where *P. agathidicida* is not yet present, to maintain pathogen freedom. Restricting the localised spread of *P. agathidicida* following introduction between isolated kauri stands and between stream sub-catchment management units will help minimise the burden of disease and localised loss of kauri. This will be particularly important where large stands of kauri are regenerating, as the opportunity for transmission between roots is high, and trees are vulnerable due to succession competition (Ogden et al., 1987).

4.3 Recommended advances for long-term kauri ora (health) monitoring

4.3.1 Collaborative monitoring approach

Using a working group that includes iwi partners and other land managers to co-design, deliver, interpret the results of the survey was a particular strength of this study, and is highly recommended for future similar projects across the kauri lands. In addition to meeting the principles of Te Tiriti by supporting kaitiakitanga, this collaborative approach allowed for knowledge sharing between operational group partners and resulted in matauranga-informed methodologies and practices. The inclusion of kaimahi in fieldwork benefitted the survey work, and provided training that we hope will provide a long-term benefit our iwi partners. An example of a change in practice brought by our partnership was the addition of a soil repatriation ceremony. Typically, soils are disposed of after testing as contaminated waste. The operational group agreed that repatriation of the soils (bringing the soil back to Hūnua) safely was an appropriate alternative to disposal that was more in-line with tikanga. Soil that tested negative for *P. agathidicida* was heat treated, then returned to an area of the forest without kauri as an additional precaution.

We recommend building off our collaborative operational team approach for all future kauri monitoring, within and beyond the Auckland region.

4.3.1 Kauri forest-level health monitoring

Monitoring current kauri health is essential to track any change over time and measure how well our interventions are working. Long-term health monitoring will also help us determine how other factors affect kauri health, such as land use, environmental management and climate change.

To measure forest level kauri health we need:

4.1.1 kauri mapping of the host population

4.1.2 measurements of baseline kauri health and kauri health change detection methods

4.1.3 geospatial data to represent kauri protection interventions (rasters of protected area)

4.1.4 collaboration with climatology researchers to investigate long-term climate impacts on kauri forest health.

4.3.2 Kauri population mapping

We built on and improved the methods developed to detect kauri trees in the Waitākere Ranges for the Hūnua survey. This survey was more efficient due to improved AI and machine learning tools. Analysis of high-resolution aerial imagery across key kauri forested areas will be required to obtain the baseline population outside Waitākere and Hūnua and this may need better validation of false positive identifications of kauri. For example, there were issues picked up in our initial review process with flowering kānuka being misclassified as dead kauri in Hūnua. Our technique was subsequently refined to address this issue.

4.3.3 Kauri stress monitoring and change detection

To set the baseline prevalence of landscape scale kauri health, we need methods to differentiate between kauri dieback induced stress vs drought or other canopy stress. These remote sensing parameters can then be used to monitor change in kauri forest health over time. This work is being progressed in a parallel project and is showing promising results. In brief:

- Future surveys of kauri health can include the automatic detection of canopy symptoms of decline with remote sensing data. Two methods are most promising: Optical indices and deep learning. For the optical indices, the best results so far could be reached with high resolution data from satellite (e.g. WorldView) or plane (e.g. HiRAMS). The data should include at least a red and NIR band with a maximum pixel size of 2m for a crown-based analysis. Optical indices do not distinguish between species and therefore need a prior identification and segmentation of kauri crowns, including dead/dying trees as the target crown locations for the object-based analysis.
- The deep learning analysis requires at least 3-band imagery (red, green, blue) with a higher spatial resolution, ideally 7.5cm. Deep learning analysis

offers the potential to combine kauri identification with symptom detection. However, this method still needs improvement with a sufficient training set for aerial imagery with different resolutions. There are two documents in preparation: Kauri change detection by Jane Meiforth (Auckland Council) and an article on deep learning for kauri/species identification from Jan Schindler (Manaaki Whenua Landcare Research).

4.3.4 Landscape scale kauri protection efficacy

Continuing from our recommendations in the Waitākere report, we recommend the following actions to measure the efficacy of kauri protection measures over time (e.g., track closures, track upgrades, hygiene stations and phosphite treatments):

- Collate temporal and geospatial (time and place) data for all future kauri dieback mitigations. The temporal data is required to assess how long mitigations have been in place. Geospatial layers need to be developed to show areas that are and are not protected by specific mitigations. This could be characterised in the same manner as risks are for risk-based sample selection, either at a raster level or tree level. The risk factors addressed by each mitigation should be identified, and their impacts could be modelled by applying a scale factor (between 0 and 1) to those risk factors, and potentially including a distance of effect range to indicate how far from the mitigation the protective effect would reach.
- Where possible, collate historical geospatial and temporal data for kauri protection interventions (e.g. track upgrades, closures, rāhui, phosphite areas, pig control areas) in the same manner as described above.
- These data will eventually be usable in analysing kauri protection efficacy by modelling change in landscape-scale kauri health where a range of interventions have and have not been applied, while also accounting for known geospatial risk.
- Fully measuring efficacy of rāhui or other Māori cultural protection measures necessitates the development of mātauranga Māori indicators to supplement and corroborate other measures.

4.3.5 Long-term climate impacts on kauri forest health

As we stated in the Waitākere report, it remains reasonable to expect that the change in climate over the last 30-50 years may be contributing to the development and severity of kauri dieback disease (Homet et al., 2019, Aguayo et al., 2014). Extreme weather events such as drought and flooding affecting soil moisture levels may favour the pathogen and disadvantage the kauri host (Homet et al., 2019, Macinnis-Ng et al.,

2013) leading to more disease. The three recommendations made in the Waitākere report remain important for trying to understand the impacts of climate change and kauri health with and without *P. agathidicida.*

- Climate data are acquired for monitored kauri forests at suitable spatial and temporal scales in conjunction with stress index measurements.
- Climate data are used to inform the stress index with a view to classifying between disease and drought.
- Modelling of long-term climate data using the landscape baseline prevalence of kauri stress and change over time, knowledge of soil moisture effects (Macinnis-Ng et al., 2013) and in the presence or absence of *P. agathidicida.* It may take many years to acquire sufficient data to determine the impact of climate change, but baseline data should be collected as often as possible to enable future analysis.

The first recommendation has proven difficult at the local level; however, nationally-available data may be used in the future across kauri lands. The placement and maintenance of weather stations within kauri forests is not feasible. Kauri health change detection has progressed in 2023/2024 and may ultimately be able to distinguish between disease and drought based on surveillance data.

Lastly, it will take a multidisciplinary research programme to model climate and kauri stress, and this has not progressed in New Zealand at this stage. All three recommendations are national level objectives.

4.4 Implementation of tree-level kauri health monitoring

The 2021 Waitākere survey refined the methods to set baseline pathogen prevalence values and kauri health data. We now have this data for 761 randomly selected sites across Waitākere Ranges Regional Park, and 410 randomly selected sites in Hūnua. There are two recommended next steps:

- Roll out baseline tree level pathogen and kauri health monitoring to the remaining significant kauri forests within Tāmaki Makaurau.
- Plan for repeated monitoring of Waitākere Ranges Regional Park, initially, and then for other areas with baseline prevalence values (e.g. Hūnua) to measure incidence (the number of new symptomatic trees developing over time). This will provide the data for adaptive management of kauri health and investigate the efficacy of management interventions.

4.5 Implementation of pathogen freedom surveillance

Site-level *P. agathidicida* pathogen freedom surveillance is aimed at early detection in areas previously thought to be free of the pathogen (including high-value areas). This will inform protection areas, ongoing pathogen spread prevention, and the investigation and management of new outbreaks.

We applied a hybrid 75 per cent baseline (random) samples and 25 per cent freedom (risk-based) surveillance approach to the Hūnua survey. This addressed both the objectives of setting a baseline for ongoing kauri health monitoring (random) and those of estimating freedom from the pathogen.

From a practical management perspective, the aim of freedom surveillance is to provide robust evidence to support protection areas and identify where forest access could be provided safely to maximise the amenity value to Auckland communities.

The Hūnua survey developed the key steps to implementing a risk-based freedom survey, including risk maps/profiles for individual trees (Figure 2-11), sample selection and sample size calculations (Section 2.2.10). These methods have been further refined by Tiakina Kauri and DOC, building significantly on the progress made during the Hūnua survey (with the assistance of Jane Meiforth, John Kean and Karyn Froud) and can be directly applied to additional forests within Tāmaki Makaurau where the objective is proof of freedom.

We recommend that the next round of kauri monitoring in Hūnua includes the 410 random trees (for kauri health assessment) along with a new selection of risk-based trees. In making the new risk-based selection, the combined risk value of all previously sampled trees should be discounted by multiplying by a factor <1 that reflects the residual risk that those trees might be infected, despite previously testing negative. The discount parameter should therefore reflect the sensitivity of the previously applied test (to account for false negatives) as well as the time since the test was administered (to account for the possibility of new infection). If the action of sampling trees was thought to pose some risk of infection, then this should be included too. However, test sensitivity is moderately high, current data suggest *P. agathidicida* spreads and infects slowly, and strict hygiene practices were adopted during sampling. Therefore, most or all previously surveyed risk trees would provide relatively little new information if re-sampled. The risk discounting factor could also apply to nearby trees, weakening with distance in the same way that many of the other risk factors are modelled. In summary, previous

sampling should inform ongoing risk-based surveys to reflect which trees and stands would contribute the most to proof of freedom.

Frequency of freedom surveillance will be objective and risk-dependent, but we estimate it to be approximately five-yearly. However, it may be appropriate to extend that period for repeated baseline monitoring in a forest free of *P. agathidicida*. Only new risk-based kauri would be monitored in five years, and kauri health could be monitored approximately 10-yearly if the forest remains free of *P. agathidicida*.

4.6 Conclusions

The repeated monitoring of sites, particularly those with *P. agathidicida* infection, will aid in our understanding of disease latency, symptom development and recovery of infected kauri.

Working alongside Ngā Iwi Mana Whenua to design, deliver, and interpret monitoring strengthens the survey and has been an integral part of this work. Together, the operational group has created a collaborative working system that is respectful and successful. We jointly recommend future kauri ora surveys continue to take this approach.

The confidence in *P. agathidicida* freedom within Hūnua, coupled with better understanding of the limited host reservoirs of the pathogen, is a big step forward in how we think about long-term management of *P. agathidicida*. We will continue to focus on reducing long-distance spread opportunities by managing pathways of possible introduction.

The implementation of the long-term monitoring framework has advanced significantly in the last two years with developments in freedom surveillance design and kauri health change detection methods.

4.6.1 Conclusions of Ngā iwi mana whenua o Te Ngāherehere o Kohukohunui

The repatriation of soil taken for sampling highlighted the process and the collaboration between DOC, Ngā iwi mana whenua o Te Ngāherehere o Kohukohunui and Auckland Council. This demonstrated the combining of mātauranga Māori and western science and the willingness of people working together to achieve a successful outcome.

Ngā iwi mana whenua o Te Ngāherehere o Kohukohunui advocate for rāhui should signs of *P. agathidicida* be detected and iwi with interests to be contacted as soon as practicably possible.

Iwi must be enabled to maintain their cultural connections to te ngāherehere and over time, each iwi with the support of their treaty partner must be able to harvest the necessary rākau for carved waka and ancestral whare.

References

Ngā tohutoro

Aguayo J, Elegbede F, Husson C, Saintonge FX, Marçais B, 2014. Modeling climate impact on an emerging disease, the *Phytophthora alni*-induced alder decline. *Global Change Biology* **20**, 3209-21.

Ahmed M, 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**, 217-29.

Auckland Council, 2023. Tūtangi Ora (Historic Heritage Information) – data accessed on the 14.02.2023. Website: https://www.aucklandcouncil.govt.nz/arts-culture-heritage/heritage/Pages/search-cultural-heritage-inventory.aspx.

Baddeley A, 2015. Analysing replicated point patterns in spatstat. *Cran Vignettes* **35**, 38.

Barrett S, Whittle P, Mengersen K, Stoklosa R, 2010. Biosecurity threats: the design of surveillance systems, based on power and risk. *Environmental and ecological statistics* **17**, 503-19.

Barton I, 2002. Report on the refurbishing and re-measurement of the kauri planting trial – Moumoukai Valley. Tane's Tree Trust.

Beever RE, Waipara NW, Ramsfield TD, Dick MA, Horner IJ, 2009. Kauri (*Agathis australis*) under threat from *Phytophthora*? *Phytophthoras in forests and natural ecosystems* **74**, 74-85.

Bellgard S, Padamsee M, Probst C, Lebel T, Williams S, 2016. Visualizing the early infection of *Agathis australis* by *Phytophthora agathidicida*, using microscopy and fluorescent in situ hybridization. *Forest Pathology* **46**, 622-31.

Bellgard S, Weir BS, Pennycook SR*, et al.*, 2013. Specialist *Phytophthora* research: biology, pathology, ecology and detection of PTA. *Final report for the Kauri Dieback Joint Agency Response MPI Contract 11927*, Pp. 104.

Bergin D, Steward G, 2004. Kauri: Ecology, establishment, growth and management. New Zealand Indigenous Tree Bulletin No, 2. *Forest Research, Rotorua, New Zealand*.

Bhopal RS, 2016. *Concepts of epidemiology: integrating the ideas, theories, principles, and methods of epidemiology*. Oxford University Press.

Black A, Dickie I, 2016. Independent review of the state of kauri dieback knowledge. *Report prepared for the Kauri Dieback Programme*, Pp. 79.

Bradshaw R, Bellgard S, Black A*, et al.*, 2020. *Phytophthora agathidicida*: research progress, cultural perspectives and knowledge gaps in the control and management of kauri dieback in New Zealand. *Plant Pathology* **69**, 3-16.

Brunk H, Holstein JE, Williams F, 1968. The Teacher's Corner: A Comparison of Binomial Approximations to the Hypergeometric Distribution. *The American Statistician* **22**, 24-6.

Cogger N, Froud K, Vallee E, Phiri B, 2016. Kauri dieback disease epidemiology scoping exercise. *A report prepared for the Kauri Dieback Programme Planning and Intelligence Team*, 16 pp.

Davies TM, Marshall JC, Hazelton ML, 2018. Tutorial on kernel estimation of continuous spatial and spatiotemporal relative risk. *Statistics in Medicine* **37**, 1191-221.

Dawson J, 1988. *Forest vines to snow tussocks: the story of New Zealand plants*.

Dick M, Bellgard SE, 2012. Soil survey method for *Phytophthora* taxon *Agathis*. *Report prepared for the Ministry of Agriculture and Forestry on behalf of Kauri Dieback Joint Agency* Version 2.1, modified by A.J. Beauchamp, Department of Conservation, Pp. 13.

Diehr P, Martin DC, Koepsell T, Cheadle A, Psaty BM, Wagner EH, 1995. Optimal survey design for community intervention evaluations: cohort or cross-sectional? *Journal of Clinical Epidemiology* **48**, 1461-72.

Dohoo IR, Martin W, Stryhn H, 2009. *Veterinary epidemiologic research*. Charlottetown, P.E.I., Canada.: University of Prince Edward Island.

Dosli, 1942. NZ Department of Survey and Land Information (DOSLI). New Zealand topographical map 1:63,360, sheet 48 “Mangatawhiri”. . *N.Z. Lands and Survey (publisher) Wellington. Sourced via the Auckland University Geodata Hub:*

Dosli, 1946. NZ Department of Survey and Land Information (DOSLI). New Zealand topographical map 1:63,360, sheet 360 “Ponui”. . *N.Z. Lands and Survey (publisher) Wellington. Sourced via the Auckland University Geodata Hub:*

Ecroyd C, 1982. Biological flora of New Zealand 8. *Agathis australis* (D. Don) Lindl. (Araucariaceae) Kauri. *New Zealand Journal of Botany* **20**, 17-36.

Erueti B, Tassell-Matamua N, Pomare P*, et al.*, 2023. 'Pūrākau o te Ngahere': Indigenous Māori Interpretations, Expressions and Connection to Taonga Species and Biosecurity Issues. *Knowledge Cultures* **11**, 34-54.

Froud K, 2020. Kauri dieback building knowledge: Review of operational research undertaken by the Kauri Dieback Programme from January 2009 to June 2020 and related research for biology, surveillance, vectors, control, and decision support. *A report prepared for MPI and the Kauri Dieback Programme by Biosecurity Research Limited.* Biosecurity New Zealand Technical Paper No. 2020/09, Pp. 97.

Froud K, Chew YC, Kean J*, et al.*, 2022a. 2021 Waitākere Ranges kauri population health monitoring survey. *Auckland Council technical report, TR2022/8.*, Pp. 265.

Froud K, Han J, Compton C*, et al.*, 2022b. Multivariable analysis of risk factors associated with symptomatic kauri and detection of *P. agathidicida* in the Waitākere Ranges. In: Froud K, ed. *2021 Waitākere Ranges kauri population health monitoring survey.* Auckland: Auckland Council, 58-84.

Gadgil PD, 1974. *Phytophthora heveae, a pathogen of kauri*. New Zealand Forest Service.

Haine D, Dohoo I, Dufour S, 2018. Selection and misclassification biases in longitudinal studies. *Frontiers in Veterinary Science* **5**.

Herewini, E. (2017). *Development of an in vitro assay to screen Agathis australis (kauri) for resistance to Phytophthora agathidicida: a thesis presented in partial fulfilment of the requirements for the degree of Master of Science at Massey University, Manawatū, New Zealand* (Doctoral dissertation, Massey University).

Hill L, Waipara M, Stanley R, Hammon C, 2017. Kauri Dieback Report 2017: An investigation into the distribution of kauri dieback, and implications for its future management, within the Waitākere Ranges Regional Park. *A report on the 2015/2016 kauri dieback surveys and management within the Waitākere Ranges Regional Park by Auckland Council* Version 2: Update June 2017, 40 pp.

Hill L, Wii N, Fraider F, 2014. Groundtruthing survey for kauri dieback on Aotea/Great Barrier Island 2014: Report of findings of Kauri Dieback on Great Barrier Island. *A report prepared for the Kauri Dieback Programme Planning and Intelligence Team*, Pp. 21.

Homet P, González M, Matías L*, et al.*, 2019. Exploring interactive effects of climate change and exotic pathogens on *Quercus suber* performance: Damage caused by *Phytophthora cinnamomi* varies across contrasting scenarios of soil moisture. *Agricultural and Forest Meteorology* **276**, 107605.

Horner I, Arnet M, 2020. Phosphite large tree treatment trials: brief report, April 2020. *A confidential report prepared for MPI by Plant and Food Research SPTS No. 19316*, Pp. 7.

Horner I, Barton M, Hill L*, et al.*, 2019. Kauri Rescue™: A citizen science programme evaluating kauri dieback controls. *In: Bradshaw, R.E. and Horner, I.J. (Eds.) Abstract Proceedings from the New Zealand Plant Protection Society Phytophthora Symposium, 12 August 2019, Auckland, New Zealand*, Pg 14.

Horner, I.J. and Hough, E.G., 2014. Pathogenicity of four *Phytophthora* species on kauri in vitro and glasshouse trials. *New Zealand Plant Protection*, *67*, pp.54-59.

Horner I, Hough E, Horner M, 2017. Phosphite for control of kauri dieback: final report, July 2017. *A confidential report prepared for the Ministry for Primary Industries by Plant and Food Research SPTS No. 17682*, Pp. 48.

Jamieson A, 2012a. Aerial Survey of Kauri Dieback on Aotea/Great Barrier Island. Contract 15483 – Trial Survey. . *Report prepared for the Ministry for Primary Industries by Wild Earth Media Ltd.* .

Jamieson A, 2012b. Summary report: Aerial survey of kauri dieback in the Waitākere Ranges. *Report prepared for Auckland Council by Wild Earth Media Ltd.*

Jamieson A, 2014a. Aerial survey for kauri dieback at Hauturu Little Barrier Island. *Report prepared for Auckland Council*, Pp. 25.

Jamieson A, 2014b. Aerial survey for kauri dieback at Waiheke and Ponui Islands. *Report prepared for Auckland Council by Wild Earth Media Ltd.*

Jamieson A, 2014c. Aerial survey for kauri dieback on Kawau Island. *Report prepared for the Kauri Dieback Programme*, Pp. 7.

Jamieson A, 2017. Aerial survey for kauri dieback in the Hūnua Ranges and Awhitu Peninsula. *Report prepared for Auckland Council by Wild Earth Media Ltd.*, Pp. 9.

Jamieson A, Bassett I, Hill L*, et al.*, 2014. Aerial surveillance to detect kauri dieback in New Zealand. *New Zealand Plant Protection* **67**, 60-5.

Jamieson A, Hill L, Waipara M, Craw J, 2012. Survey of kauri dieback in the Hūnua Ranges and environs. *Report prepared with Auckland Council and Wild Earth Media Ltd*.

Kauri Dieback Strategic Science Advisory Group, 2018. Kauri dieback science plan. *Science plan prepared for the Kauri dieback programme by the Kauri Dieback Strategic Science Advisory Group* **www.kauridieback.co.nz/media/1865/kauri-dieback-science-plan-2018.pdf**, Pp. 31.

Killick, S. A., 2022. The physiological effects of *Phytophthora agathidicida* infection in kauri (*Agathis australis*) (Doctoral dissertation, ResearchSpace@ Auckland).

Lambert S, Waipara N, Black A, Mark-Shadbolt M, Wood W, 2018. Indigenous biosecurity: Māori responses to kauri dieback and myrtle rust in Aotearoa New Zealand. In. *The Human Dimensions of Forest and Tree Health.* Springer, 109-37.

Macinnis-Ng, C. and Schwendenmann, L., 2015. Litterfall, carbon and nitrogen cycling in a southern hemisphere conifer forest dominated by kauri (Agathis australis) during drought. *Plant Ecology*, *216*, pp.247-262.

Macinnis-Ng C, Schwendenmann L, Clearwater M. Radial variation of sap flow of kauri (*Agathis australis*) during wet and dry summers. *Proceedings of the IX International Workshop on Sap Flow 991*, *2013*, 205-13.

Manaaki Whenua Landcare Research, 2020. Manaaki Whenua Landcare Research Land Cover Database version 5.0, Mainland, New Zealand. Accessed in January 2023 via the LRIS portal: https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/.

Martin W, 2008. Linking causal concepts, study design, analysis and inference in support of one epidemiology for population health. *Preventive Veterinary Medicine* **86**, 270-88.

Mcardle BH, 1990. When are rare species not there? *Oikos* **57**, 276-7.

Meiforth JJ, 2020. Stress detection in New Zealand kauri canopies with WorldView-2 Satellite and LiDAR data. *Remote Sensing* **12 (12)**.

Meiforth JJ, Buddenbaum H, Hill J, Shepherd J, 2020. Monitoring of canopy stress symptoms in New Zealand kauri trees analysed with AISA hyperspectral data. *Remote Sensing* **12(6)**.

Ministry for the Environment, 2010. Dataset; River Environment classification New Zealand, Watershed delineation 3rd order. Data modified 04. Oct. 2010; accessed on the 11th of October 2023. Website: https://data.mfe.govt.nz/layer/52370-river-environment-classification-catchment-order-3-2010/.

Newhook FJ, 1972. Hūnua Ranges Management Plan. – Appendix L "Report on Hūnua Ranges". Auckland University.

O'connor K, 2023. Historical data of infrastructure and aerial images in the Hūnua Ranges; Provided in KML and tif format to Auckland Council in January 2023.

Ogden J, Wardle GM, 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**, 231-42.

Randall S, 2011. *Fishing of Phytophthora: A yearlong investigation into the diversity of Phytophthora species in the Waitākere Ranges, Auckland, NZ*: A Thesis at ResearchSpace@ Auckland University.

Reed JM, 1996. Using statistical probability to increase confidence of inferring species extinction. *Conservation biology* **10**, 1283-5.

Riddell, C.E., Dun, H.F., Elliot, M., Armstrong, A.C., Clark, M., Forster, J., Hedley, P.E. and Green, S., 2020. Detection and spread of *Phytophthora austrocedri* within infected Juniperus communis woodland and diversity of co-associated *Phytophthoras* as revealed by metabarcoding. *Forest Pathology*, *50*(3), p.e12602.

Ryder JM, Waipara NW, Burns BR, 2016. What is the host range of *Phytophthora agathidicida* in New Zealand? *New Zealand Plant Protection* **69**, 320.

Silvester W, 1964. Forest regeneration problems in the Hūnua Range, Auckland.

Singers NJ, Osborne B, Lovegrove T*, et al.*, 2017. *Indigenous terrestrial and wetland ecosystems of Auckland*. Auckland Council, Te Kaunihera o Tāmaki Makaurau.

Stevenson M, Froud K, 2020. Recommended case definition and design of a baseline monitoring methodology for kauri dieback. *A report for the Ministry for Primary Industries on behalf of the Kauri Dieback Programme*, 41 pp.

Studholme D, Mcdougal R, Sambles C*, et al.*, 2016. Genome sequences of six *Phytophthora* species associated with forests in New Zealand. *Genomics data* **7**, 54-6.

Tipa G, Teirney LD, 2006. *Using the cultural health index: how to assess the health of streams and waterways*. Ministry for the Environment, Manatū Mō Te Taiao.

Tronsmo AM, Collinge DB, Djurle A, Munk L, Yuen J, Tronsmo A, 2020. *Plant Pathology and Plant Diseases*. CABI.

Vallee E, Froud K, Kean J, Chew YC, Heuer C, Tolich L, 2022. Estimation of the diagnostic sensitivity and specificity of kauri dieback visual assessment and *Phytophthora agathidicida* soil baiting, culturing and morphological identification using Bayesian latent class analysis. In: Froud K, ed. *2021 Waitākere Ranges kauri population health monitoring survey.* Auckland: Auckland Council, 85-111.

Venette RC, Moon RD, Hutchison WD, 2002. Strategies and statistics of sampling for rare individuals. *Annual Review of Entomology* **47**, 143-74.

Waipara N, Hill S, Hill L, Hough E, Horner I, 2013. Surveillance methods to determine tree health, distribution of kauri dieback disease and associated pathogens. *New Zealand Plant Protection* **66**, 235-41.

Weir BS, Paderes EP, Anand N*, et al.*, 2015. A taxonomic revision of *Phytophthora* Clade 5 including two new species, *Phytophthora agathidicida* and *P. cocois*. *Phytotaxa* **205**, 21-38.

Wickham H, Chang W, Wickham MH, 2016. Package 'ggplot2'. *Create elegant data visualisations using the grammar of graphics. Version* **2**, 1-189.

Winkworth RC, Nelson BC, Bellgard SE, Probst CM, Mclenachan PA, Lockhart PJ, 2020. A LAMP at the end of the tunnel: A rapid, field deployable assay for the kauri dieback pathogen, *Phytophthora agathidicida*. *PLoS ONE* **15**, e0224007.

Wyse, S.V., Burns, B.R. and Wright, S.D., 2014. Distinctive vegetation communities are associated with the long-lived conifer *Agathis australis* (New Zealand kauri, A raucariaceae) in New Zealand rainforests. *Austral ecology*, *39*(4), pp.388-400.

Appendix A: Investigation Plan Template

Kauri Health Survey

Phytophthora agathidicida

Investigation plan

TEMPLATE

17 July, 2024

Authors

Karyn Froud, Biosecurity Research

Yue Chin Chew, Auckland Council

Reviewers

Alastair Jamieson, Auckland Council

Miranda Bennett, Auckland Council

Lisa Tolich, Auckland Council

Suliana Teasdale, Department of Conservation

Tony Beauchamp, Department of Conservation

Wellcome Ho, Ministry of Primary Industries

Lauren Waller, Ministry of Primary Industries

Organism Name	*Phytophthora agathidicida* Causal agent of kauri dieback disease
Lead Agency	
Partnership Hapu / Iwi	
Partnership Agency	
Other agencies	

Version control

Version	Date	Updated by	Details	Comment

Introduction

1.1 Purpose

The purpose of this document is to provide for clear guidance for land managers and partners, including Councils, ngā mana whenua, and Department of Conservation, to plan how new detections of *Phytophthora agathidicida* (PA) will be investigated and communicated. The structure of this plan has been completed in partnership when designing the 2023 Hunua Ranges Kauri Health Survey (i.e. prior to undertaking surveillance), and may now be used as a template for similar work.

Note that this investigation plan notes the difference between a positive screening test and a confirmed detection of PA. A test result (indicating presence of PA) provides a piece of evidence towards assessing whether a detection of the organism is confirmed.

A glossary of key terms is included in section 0. The validation section may be used for a range of scenarios (examples provided in Appendix A).

1.2 Scope

1.2.1 In scope

Covering period of time we receive results back, up to survey report release. Short-term actions we may need to deal with positive detections.

1.2.2 Out of scope

Long-term management of sites. Note that these are in scope for discussion at the Operations Group meetings, but are outside the scope of the Investigation Plan.

Investigation Plan

1.3 Awareness of Planned Surveillance

Who should be aware of surveillance activities:

Prompts:

List agencies that need to be aware of surveillance including within the lead agency, mana whenua partners, supporting agencies, private land-owners, communities.

Include any private property landowners as a heads up, prior to contact about land access

Think about consequences, the most likely one is an interview in the media of someone saying "I didn't even know they were doing surveillance!" in relation to any results or issues (e.g. trampers observing people breaking the rules by going off-track, when it is our surveyors, or following the detection of artefacts) due to the project. Who would these people be?

How will you raise awareness:

Prompts:

Describe the key awareness messages amongst key stakeholders including communities and the most suitable means (for your contexts) to communicate these prior to surveillance.

While key messages should be consistent across partners, their context will differ with different world views and agency responsibilities. This should be discussed in the comms plan to enable different views to be communicated.

1.4 Data Management

How should surveillance data and test results be managed:

Prompts:

- *Describe any data sharing agreements between agencies that are involved in the surveillance including the lead agency, mana whenua partners, supporting agencies, community groups.*
- *If no agreements exist, describe how test result data and confirmed detection data will be managed.*
- *How PFR and Ampersand manage results data – will it go to BioSense as the client or to AC/Working Group directly. What confidentiality provisions are in place within contracts?*

1.5 Notification of Positive Screening Test Results

Prompts:

- *Describe the process for reporting positive screening test results for P. agathidicida from the diagnostics service provider to the lead agency, including contact names and details.*
- *Describe the process (e.g. phone calls, email, urgent online hui) and timeframes for the lead agency to notify partners and key stakeholders of a positive (unvalidated) screening test result.*
- *Describe how you will ensure confidentiality is maintained when reporting results, including with field team contractors, labs and operations group. I.e. what is the risk of leakage of a suspect test result before validation occurs? Don't go too wide with your notification, just partners.*

- *Detail who, within and external to the lead agency, will be informed during validation. Include how often and at what points in the investigation they should be updated.*
- *Does anyone else need to know?I.e. who will be really upset to find out that we are validating a positive test (through a leak to the media or via social channels) without them being informed? What will that do to the trust relationship?*
- *Describe how awareness of this process will be maintained to ensure effective and timely sharing of notifications.*

1.5.1 Not detected results

Who needs to be notified, and when?

1.5.2 Positive screening results

Who are suspect detected results are to be sent to, and who will be responsible for informing partners?

A pre-designed email to the set group for notification is provided in Appendix 1.

1.6 Validation of screening test results for a confirmed detection

This plan notes the difference between a screening test result and a confirmed detection of PA. A positive screening test (indicating presence of PA) provides a piece of evidence towards validating whether a detection of the organism is confirmed.

Prompts:

- *Describe the process (e.g. phone calls, email, urgent online hui) and timeframes for the lead agency to notify partners and key stakeholders of the progress of validation for a positive screening test.*
- *Describe expectations for validating results, including timeframes to complete validation.*
- *Ensure confidentiality is maintained when validating results.*
- *Describe the funding mechanism for validation of diagnostic results.*

1.6.1 Screening test background

Observing symptoms of disease on kauri trees gives an indication of the presence of PA, the causal pathogen of kauri dieback, however the symptoms are not unique and can be caused by other biotic and abiotic factors. It is also possible to have PA present in the soil or kauri roots prior to the development of symptoms. To confirm the detection of PA we currently have two MPI approved screening tests, a DNA-based LAMP bioassay and culture-based Morphological bioassay.

Screening tests are used to give an indication if the pathogen is present and the two tests have different characteristics that together can help to confirm presence of the pathogen, alongside epidemiological criteria.

When screening for a pathogen, it is useful to have a test with high sensitivity, which will find most of the sites where the pathogen is present (true positives) but may also identify sites where the pathogen is not present (false positives). In contrast, a test with high specificity will correctly identify sites as true positives but may miss sites where the pathogen is present (false negatives). When screening for PA, the

LAMP test has an assumed high sensitivity, but a risk of false positives (Table 9). The morphological test for PA has known high specificity, but a risk of false negatives (Table 10) (Froud et al., 2022). Therefore, a validation process is required to confirm detection of PA when using these tests. NOTE: At present we haven't quantified the diagnostic sensitivity or specificity of the LAMP test, so can't accurately estimate how many false negatives it will have, but we can guess that it will be less than the morphological test.
The LAMP test performs well and there are no known issues with cross-reactions or misidentification (confusion with other *Phytophthora* species in NZ), however, due to the very high analytical sensitivity of the test to detect the DNA of PA, there is a risk of cross-contamination. This means there is a (low) risk that a positive result may be from a different sample. MPI's PHEL (Plant Health and Environment Laboratory) has worked with test providers to identify cross-contamination risk points during the diagnostic test process (Table 2-2. Points where cross-contamination may occur, procedures for risk mitigation, and recommended retest options) and approved test providers have implemented measures to minimise this risk. In addition, extra steps can be taken during surveillance and sample collection to address cross-contamination (Table 2-2. Points where cross-contamination may occur, procedures for risk mitigation, and recommended retest options). A recent review of soil sampling procedures has identified a change that may improve the sensitivity of the morphological test by modifying where soil is collected around the tree (4 x cardinal points and 4 x risk-based points around the tree base). This is now the standard soil sampling procedure.

Table A1. Table showing the result options for the DNA-based LAMP test compared to the true status of the pathogen in the field. The main risk with this test is a False Positive result

		DNA based LAMP test		
		Detected	Questionable	Not detected
True Pathogen status	Present	Detected	Suspect positive Result is uncertain due to low titre of pathogen in sample.	FALSE negative Sample did not collect the pathogen.
	Absent	FALSE positive Result is positive due to possible cross-contamination.	FALSE suspect positive Result is uncertain due to possible cross-contamination.	Not detected

Table A2. Table showing the result options for the morphological test compared to the true status of the pathogen in the field. The main risk with this test is a False Negative result.

		Morphological test	
		Present	Not detected
True Pathogen status	Present	Detected	**Possible** False negative Sample did not collect enough pathogen
	Absent	**Unlikely** False positive Cultured pathogen is misidentified.	Not detected

1.6.2 Geographical criteria for validation

Proximity to previous PA detections (many of which were via the morphological bioassay test) and an estimate of the prevalence of PA in an area that is to be surveyed can inform the effort required for screening test validation. For example, the consequence of a false positive may be very low in an area where PA is widely known and distributed, compared to an area where it is unknown.
Several decisions are required for setting the requirement for screening test validation (Table 11). A decision is required between partners to identify specific survey sites or areas that require screening test validation (see validation process below). In addition, a geographical distance beyond which screening test validation is required needs to be agreed. This may be in the form of a set distance (e.g. 300m) or between spatially based management units (e.g. water catchments or stream sub-catchments). An indication on the conditions for validation is also required, in that, is validation only required for the first instance, for instances or will this be reviewed at a certain point during surveillance (e.g. if more than 3 stream sub-catchments have confirmed PA detections, the validation requirement for the survey will be reviewed).

Table A3. Screening test validation requirements and conditions.

Screening test validation required	Geographic details	Validation conditions
Specific sites/areas	• *Describe the geographical locations or areas that require validation of positive or questionable screening test results (e.g., areas perceived as high consequence, where a PA detection is unexpected).*	
Geographical distance or spatial management units	• *Describe the geographical distance or spatial management areas beyond which validation of positive or questionable screening test results are required (e.g. beyond a 250m radius from a known PA site, or screening test positives in stream sub-catchments that are not contiguous with stream sub-catchments that contain a known PA site).*	

1.6.3 Validation process

- *Describe the process for validating positive screening test results for* P. agathidicida *with the diagnostics service provider.* * Completed below.
- *Describe the process for validating questionable, positive or negative screening test results when DNA and morphological tests return different results. *Completed below.*

It is recommended that the DNA-based LAMP test is used to screen samples and the morphological test is used as part of the process to validate samples. Some surveys may choose to use both tests in parallel.
For the LAMP test three results are possible, positive screening test, questionable screening test and not detected screening test. A questionable screening test is where the test result value lies within the measurement of uncertainty (MU) of a test. The measurement of uncertainty should be incorporated into assessing the results. For example, if the cut off value is Cq 36 and MU is 0.5, test results with Cq values between 35.5 and 36.5 should be interpreted as questionable and need to be further determined (e.g. run a gel to confirm product size is expected) if this is consistent with the expected size, the result can be validated in the same way as a positive screening test for LAMP.
Note: MU = Square root of [(Average of standard deviation of reproducibility)^2 + (Average of standard deviation of repeatability)^2].

On the receipt of a positive or questionable screening result in an area where validation is required the following actions are required:

- Request the diagnostic service provider checks sample reception records to ascertain if samples from other areas were being processed at the same time and request processing dates and diagnostic results for those records (anonymous) and check records to rule out any potential mix up of samples, e.g. similar sample submission code.

- Check time to detection for LAMP results to inform questionable results threshold values (i.e., low target concentration in the sample)
- Validation of screening tests can be undertaken using several options (Table 2-2. Points where cross-contamination may occur, procedures for risk mitigation, and recommended retest options):
    1. start with re-testing any remaining or peeled frozen baits (useful to determine if cross-contamination occurred after baiting),
    2. then re-test remaining soil (useful if cross-contamination occurred during sample splitting and baiting).
    3. If these are inconclusive or the point of cross-contamination is possibly prior to soil splitting, the next step is to collect new samples from the same location and test using morphological testing followed by LAMP testing of peeled baits.
- Collection of new samples:
    1. undertake a field investigation of the site to collect standard soil samples (8-point protocol) around the original tree and up to 9 other kauri (to account for poor test sensitivity) within 50-100 m of the test positive site for additional testing.
    2. the field investigation team should include team members from the partner organisations that are very experienced in PA field sampling.
    3. Store any unused soil until the investigation is completed. If no further positive results are found, this may be used to confirm that the soil does Whakapapa to the exact site of collection (using forensic tools such as e-DNA for vegetation, soil chemistry and type, isotope analysis).
- If suspected PA is confirmed detected in a new region or special area:
    1. Send the isolate to MPI Plant Health and Environment Laboratory for confirmation. Confirmation technique involves morphological examination and multi-locus sequence typing. The latter includes sequencing at least two of the taxonomic informative genes (e.g. COX-1, COX-2, HSP90, ND1) from the newly detected isolate and compare with reference sequences from taxonomic ex-holotype isolate (ICMP 17027) to confirm species identification.
    2. Send the isolate to the International Collection of Microorganisms from Plants (ICMP) for long term preservation and storage.

Table A4. Table of points in the soil sample and DNA-based LAMP test process where cross-contamination may occur, procedures for risk mitigation and recommended retest options. Where the options are LAMP (retesting using LAMP for remaining frozen LAMP baits and frozen peeled baits from morphological testing) and Morph + LAMP (morphological tests undertaken in series with LAMP test by peeling baits from the morphological test substrate and sending frozen baits for LAMP testing).

Point of cross-contamination	Mitigation	Retest options for validation			
		Remaining baits (LAMP)	Peeled baits if available (LAMP)	Remaining soil (Morph + LAMP)	New soil sample (Morph + LAMP)
Field collection					
Trowel used to collect soil	Follow the soil sampling SOP for trowel hygiene.	X	X	X	√
Sample labelling	Carefully label bags and include label photo in data entry form.	X	X	X	√
Sample transport in backpack	Double bag individual samples.	X	X	X	√
Sample transport to lab	Separate batches of samples (from the same location) into separate bags.	X	X	X	√
Sample storage in lab	Check for holes in bags (re-bag). Separate batches of samples (from the same location) into separate bags or bins and ensure storage bins are decontaminated with bleach between batches. Change gloves between batches for all steps.	X	X	X	√
Baiting lab					
Sample splitting	Remove individual samples onto a separate bench for soil splitting. Washdown between samples and denature between batches (avoids spill).	X	X	√	√
Transfer to baiting containers	Remove individual samples onto a separate bench for soil transfer. Use a NEW container or DNA denature washed container for each sample. Washdown between samples and denature between batches (avoids spill)	X	√	√	√
Air drying	Separate containers by batches, apply double sided tape to bench between batches to stop invertebrate movement (also avoids dust/knocking). Include at least 2 negative control soils in a random location within each batch of	X	√	√	√

	samples to detect cross contamination.				
Moist incubation	Remove individual samples onto a separate bench for moist incubation spray (avoids splash)	X	√	√	√
Needle extraction	Use ethanol to sterilise forceps and flame until red hot between samples to denature DNA. Replace ethanol between batches.	X	√	√	√
Needle labelling	Double check label. Label is written from lid to base.	X	√	√	√
DNA extraction and testing					
Needle cutting	Use ethanol to sterilise forceps and flame until red hot between samples to denature DNA. Replace ethanol between batches. Use new section of tissue paper on cutting surface between samples. Denature clean between batches	√	√	√	√
Pipette DNA into plate well	Calibrate pipettes 3 monthly. Include a weak positive control to detect lower titre target and cross contamination. Typically, this can be x100 higher than the limit of detection.	√	√	√	√
Recording results	Double check sample ID.	√	√	√	√

If both the morphological test and the LAMP test are undertaken in parallel, there are several pairs of results that can arise with differing validation requirements depending on the geographical criteria set for validation (Table 13).

Table A5. Diagnostic scenarios for validation of screening test results when both LAMP and Morphological bioassays are used, stratified by known PA-site informed geographic criteria.

		Morphological test			
		Present		**Not detected**	
		Within PA geographic criteria	***Outside PA geographic criteria***	***Within PA geographic criteria***	***Outside PA geographic criteria***
DNA-based LAMP test	**Detected**	Confirmed detection	Positive screening test. New sample validation required.	Confirmed detection	Positive screening test. Validation required.
	Questionable	Confirmed detection	Positive screening test. New sample validation required.	Suspect screening test. Validation required.	Suspect screening test. Validation required.
	Not detected	Confirmed detection	Positive screening test. New sample validation required.	Not detected	Not detected

Action Plan for a Confirmed Detection

Prompts:

Describe the type of urgent actions that may be undertaken and their objectives (e.g. track closures, site investigation to understand introduction pathways (incorporated in the additional sample collection) including tracing of planted kauri, adjustment of forest management plans (weed/pest control operations, planned maintenance), treatment etc.)

Prepare a range of options for ongoing management of the area based on possible detection scenarios. Include a list of all current management tools and when they may apply or be extended if already in place.

Prepare key messages and comms material for public awareness for all possible detection scenarios.

Discuss the timeframes that urgent measures will apply to, compared to ongoing management.

Identify general principles to apply, regardless of location

Describe the process (e.g. phone calls, email, urgent online hui) and timeframes for the lead agency to agree with partners (and key stakeholders if required) to implement the action plan. Describe the approval process.

Detail who has the authority to approve funding and resources to implement the actions.

Consider and socialise with partners and community that the survey will continue as planned (with some additional risk mitigation around order of collection from low to high risk). You want to avoid disruption and knee-jerk reactions of "everything has to stop" as the survey information will inform what you are actually dealing with (i.e. 1 tree, 1 sub-catchment vs >1 tree, >1 sub-catchment, multi foci). That additional information (from the random samples) is essential to plan management of the forest.

1.6.4 Contaminated soil management

Confirmed detection notification follows similar process to positive screening test notification with additional reach above working group members.

Expect to hold urgent **confirmed detection meeting** within 1-3 working days as above.

Comms process examples and prompts:

- Operations group partners set key messages
- These are drafted into a media release(s) by partners (can be multiple, but must be coordinated to go at the same time with consistent key messages)
- Other partners are provided with draft to check (this is important and must include the specific names of participating mana whenua, not some generic term)
- Also check media release prompt materials (e.g. Facebook notifications) and links to story.
- Assign spokespersons from partners to provide their world view context around the key messages.
- Decide in advance whether the survey will continue in the background while an investigation or validation process is undertaken.
- Soil repatriation can be batched and stored until the final results are available prior to repatriation.
- Basal trunk or root lesion samples were acceptable to determine infection of PA during validation.

1.6.5 If confirmed on Auckland Council-managed Parkland

Example process of notification

1. Survey Ops Group to be informed of confirmed positive result
2. Project Manager to inform the following parties via an internal e-mail (i.e. Head of Natural Environment Delivery, Environmental Services Group Manager, Southern Regional Parks Principal Ranger, Regional Parks Manager etc).
3. Ops Group members to inform specific people in their respective organisations (as detailed below)
4. Activation of communications plan with AC Parkland scenario pathway
    - Inform Elected Members
    - Inform partners (WRC, MPI) and ngā mana whenua without representation outside Ops Group with suggested wording
    - Media release; social media? – (think through scenarios in terms of timeframes. Continuation of survey)
    - Etc.

Review survey workplan to make sure risk is mitigated (i.e. do not go from high-risk sites to low-risk sites)

Short-term measures (to address immediate risk (typically: movement control, delimiting surveillance, tracing, organism management). Detail to be developed at short-term measures meeting prior to confirmation of detection.

Consider movement control for risk area (urgent track closures).

Develop delimitation plan for the risk site to determine extent of the 'outbreak', also consider prioritising collection and processing of soil samples for this area that are part of the survey area to gain additional information.

Management toolbox	Scenarios			
	1 tree with P.a.	**> 1 tree, 1 stream subcatchment**	**>1 tree, > 1 stream subcatchment, all contiguous**	**>1 tree, >1 stream subcatchment, multiple foci**
Cultural protocols				
Track closures				
Change in park work activities				
Biosecurity Act requirements				
NPMP obligations				
Soil management				

1.6.6 If found on Department of Conservation PCL

Example process of notification

1. Activation of communications plan with DOC scenario pathway
2. A phone call to the Auckland Operations Manager
3. An e-mail to the following parties (*complete with project DOC contacts if relevant*).

4. An email sent to partners (ngā mana whenua) – this may be for DOC to progress
5. Support DOC with media release

1.6.7 If found on private land

Example process of notification

1. Activation of communications plan with private land scenario pathway
2. An internal e-mail to the following parties (e.g. Plant Pathogens Manager, Head of Natural Environment Delivery, Environmental Services Group Manager, Southern Regional Parks Senior Conservation Ranger, Southern Regional Parks Principal Ranger, Regional Parks Manager etc).
3. An email sent to partners (ngā mana whenua, DOC, WRC) with suggested wording.
4. A letter to the property landowners.
5. Provision of kauri dieback management plan.
6. Media release; think through scenarios in terms of timeframes and continuation of survey. *Note: it is important to bear in mind the Privacy Act when publicly discussing results from private property testing. Do not release the address or any identifying information.*

Communications Plan

Prompts:

Describe communication plan for a confirmed PA detection following validation of a positive screening test result.

Detail how and at what point a confirmed detection of P. agathidicida will be communicated to the wider community. Consider key messages for a draft comms plan.

Assign media spokespersons for the survey period, and agree how consistent information and messaging will be maintained, while allowing differences in worldview across Partners spokespersons.

Consider preparing key messages should information be made public prior to the planned communication (e.g. prior to a confirmed detection).

Welfare

Prompts:

Be mentally and physically prepared that we might find it. How do we prepare for this?

- *Consider how to provide support for mana whenua as there may be feelings related to kaitiakitanga where they have lost physical ownership and ability to manage risk through land seizures etc.*
- *For forest managers, it may be upsetting due to all the efforts put in over the years to keep the forest kauri dieback free.*
- *For private landowners: Think of the potential consequences of detection on private land or land contiguous to private land and the human tendency to feel blame. How will you support landowner welfare? e.g. Rural Trust support, prepared key messages on pathways etc.*
- *Socialisation/pre-warning?*
- *For the public and wider region.*

References

Glossary of Key Terms

Note: additional definitions can be added as required.

Baseline surveillance	The first comprehensive measurement of symptomatic tree prevalence, pathogen prevalence and impact variables in a population. A baseline is set so that future measurements can be compared against it to detect a change over time.
Case definition	The consistent criteria by which the health condition of an individual tree is included as a 'case' in a disease outbreak or study.
Delimiting surveillance	Surveys designed to determine the extent and distribution of a new biosecurity risk outbreak or incursion.
Disease	A dynamic development of abnormal life processes due to a pathogen or abiotic disorder, lasting long enough to cause vital disturbances in the life of the host, possibly leading to its death.
Ill-thrift	Ill-thrift describes plants that fail to thrive. It can refer to kauri trees that are not healthy, but their poor health is caused either by other biotic or abiotic causes, or very early infection by *P. agathidicida* causing kauri dieback, where conclusive symptoms are not yet apparent.
Incidence	The number of new cases of disease (i.e., trees that meet the case definition) in a defined population over a defined period of time. *NOTE: This should not be confused with incidence as defined in plant pathology, as the number of diseased/symptomatic individuals within a defined population at a point in time. This is much closer to the epidemiological definition of prevalence (Madden et al., 2007).*
Incubation period	The time between an individual (tree) being infected by a pathogen and when symptoms become visible (also referred to as the asymptomatic period).
Latency / Latent period	The time period between an individual (tree) being infected by a pathogen and when the pathogen has completed its lifecycle and becomes infectious, in that it releases reproductive structures (e.g., zoospores) and can infect other trees. Note that the pathogen can spread prior to the host tree becoming symptomatic (during the incubation period).
Long term management	Management of an unwanted organism or biosecurity risk organism that has established in New Zealand and is not suitable for eradication. Long term management may include slowing of spread, pest or disease management and local elimination.
Misclassification bias	A type of measurement error where a study unit (e.g., kauri tree) is classified into the wrong group e.g., being classified as diseased when healthy. Or when an imperfect test is used to detect a pathogen and the pathogen is classified as absent when it is present. Misclassification can bias estimates of disease or pathogen prevalence or measures of association between variables.
Monitoring	Repeated surveys to determine changes in the frequency and distribution of a disease over time.

Pathogen	An infectious agent that causes disease in a host. In plants, this includes oomycetes, fungi, viruses, virus-like organisms, bacteria, and nematodes.
Prevalence	The number of individuals in a defined population having a specified outcome at a given point in time. Where the outcome may be presence of a pathogen (pathogen prevalence) or meeting the case definition for diseased (disease prevalence). *NOTE: This should not be confused with prevalence as defined in plant pathology, as the count of geographical sampling units where disease is present (e.g., fields, plots, regions, countries) divided by the number assessed.*
Risk factors	Any factor or variable that is associated with either an increase or decrease in disease prevalence or pathogen prevalence.
Sensitivity (Se)	This is the diagnostic sensitivity of a test. Proportion of trees with the disease that will test positive: $\frac{True\ positives}{True\ positives + False\ negatives}$ Where false negatives are trees that test negative but do have disease. Highly sensitive tests can be used to rule out disease because they will have few or no false negatives. Less sensitive tests such as the soil bioassay may fail to detect *P. agathidicida* even when it is present. Typically, if a test has high sensitivity, it will have lower specificity (i.e., you will find almost all cases of disease (high Se), but you will also call lots of things diseased that are not (low Sp). *NOTE: Diagnostic sensitivity should not be confused with analytical sensitivity which is the lowest level of target agent that can be measured accurately by the test.*
Specificity (Sp)	This is the diagnostic specificity of a test. Proportion of healthy trees that will test negative: $\frac{True\ negatives}{True\ negatives + False\ positives}$ Where false positives are trees that test positive but do not have disease. Highly specific tests will have very few or no false positives e.g., if we detect *P. agathidicida* in a soil sample using culture and sequencing it is almost certain that *P. agathidicida* is present. Typically, if a test has high specificity, it will have lower sensitivity (i.e., the cases you find are truly diseased, but you will miss quite a few cases of disease). *NOTE: Diagnostic specificity should not be confused with analytical specificity, which is similar, but is concerned with performance around excluding non-target species and cross-reactions (false positives) in laboratory testing.*

Surveillance	Surveillance is the systematic ongoing collection, collation and analysis of information related to health (plant health in this case) and causal agents and the timely dissemination of that information to those who need to know so that action can be taken.
Symptoms/ symptomatic	Physiological or structural changes in a plant that indicate the presence of disease by reaction of the host, e.g., canker, leaf spot, wilt, lesion, dieback.

Endorsement

Authors

Name and position:
Signature:

Date:

Name and position:
Signature:

Date:

Reviewers

Name and position:
Signature:

Date:

Approval

Name and position:
Signature:

Date:

Programme leads

Name and position:
Signature:

Date:

Appendix 1: Positive screening test draft email

To:	All members of the Operations Group
CC:	
Subject:	[Area] kauri health survey: Notification of a SUSPECT positive screening test for *Phytophthora agathidicida* the causal agent of kauri dieback
Body text:	Kia ora koutou, As part of our [area] kauri health survey we have been undertaking screening tests to indicate if *Phytophthora*

	agathidicida (PA) the causal agent (pathogen) of kauri dieback disease may be present. In some situations, the test may pick up something even though PA isn't actually there. This is called a false positive result and while we have put in place measures to reduce the risk of a false positive result, we need to do more work to rule it out. We call this work the validation process and expect it to take several weeks as we may need to review laboratory information, retest, revisit the original sample site, collect additional samples and confirm the diagnosis. This suspect result should remain confidential within the [area] kauri health survey partners during the validation process as there is uncertainty about whether PA has been detected at this stage. Updates will be sent whenever key information is received by the investigation team, at a minimum this will be a [fortnightly /alternative agreed timeframe] update during the regular Operations Group hui. If the screening test is validated as positive for PA then this will be notified to you immediately and our agreed investigation plan process for a positive detection will be followed. For further information please contact: Name (email address) Ngā mihi,
Signature:	

Appendix B. Monitoring form guidelines

Te Ngāherehere O Kohukohunui / Hūnua Ranges
2023 Kauri Population Health Monitoring Survey

Survey Manual for Field Staff

Background

This survey aims to assess approximately 500 random and 200 risk-based kauri which have been selected for monitoring across Te Ngāherehere o Kohukohunui / the Hūnua Ranges. The random kauri are being assessed as part of a cross-sectional epidemiological study, i.e. we have randomly selected trees to understand health in the population, and better understand the risk factors associated with disease. This will help us adapt our management interventions accordingly in the future. Monitoring the same trees over time will also help us understand changes in tree health over time.

The Hūnua Ranges are highly significant in that we have not detected *Phytophthora agathidicida* (causal agent of kauri dieback disease) to date. It is the largest tract of forest in the Auckland Region that still maintains this status. By going into these special places, we do pose a phytosanitary risk to these kauri, and so you must take all care that your gear and equipment which have been acquired and issued to you specifically for the Hūnua Kauri Survey do not get used in any other context or purpose.

The primary aim of the survey is to detect *P. agathidicida* if it is present in the Hūnua Ranges. As such, we are taking soil samples at all points. You may come across kauri you suspect are exhibiting symptoms of kauri dieback disease, in which case please take an additional soil sample for testing.

The GPS coordinates of these trees will be provided to survey teams, along with physical and digital maps of the points. Teams will conduct the survey using the tablet-based data capture app Survey123, which can be downloaded from Google Play Store or the iOS App Store. Teams also have access to the Field Maps app, which will allow you to display different layers (e.g. topo, baitlines, streams) and may help you navigate to your point in the field.

> You will be working in designated zones with the codes as follows. Ensure that you are working only in zones you have been directed to work in for the day. Do not access private property unless permission has been given.

There will also be a small pilot study centered around stream baiting and cultural health monitoring which will be detailed in a separate document.

Kauri hygiene

Kauri dieback is a soil-borne disease that can spread through movement of contaminated soil or water. Hygiene protocols must be followed to limit the human-assisted spread of Kauri dieback. The Standard Operating Procedures for Kauri

Dieback must be followed at all times. A personal phytosanitary kit (including a spray bottle of Sterigene and a brush) must be carried at all times during the survey.

You will be operating under the Hūnua Ranges Controlled Area Notice for Kauri Dieback. Ensure that you are adhering to the highest hygiene standards at all times.

You will be issued with new gear and equipment that must only be used in the Hūnua Ranges for the duration of this project.

Plan your day and work operations to carry out low risk work first then to higher risk work. For example, you should aim to work in dry areas before wet or muddy areas.

Footwear and equipment must be cleaned:

- At the start and end of each day. Arrive on site with soil-free vehicles, gear and footwear.
- At all fixed phytosanitary stations along the track network.
- Every time the surveyor exits or enters the track network.
- Before entering and after exiting a kauri hygiene area (kauri stands).
- Before entering and after exiting a zone.

Cleaning of footwear and equipment is carried out by removal of all soil and debris using the brush and then applying Sterigene.

Before leaving the forested area, remove all loose dirt. Then when back at your depot, wash your gear and equipment on a hard surface away from areas of bush, and make sure wastewater drains away from other vehicles and equipment. Make sure there is no visible soil left and spray with Sterigene.

Hygiene within and between samples:

- Boots should be cleaned between all pre-selected sampling points to remove all mud and organic material, and sprayed with 2% Sterigene.
- Clothing that gets muddy should not be worn between pre-selected sites. Clothing can be cleaned in 50 ml concentrated Sterigene per wash without adding additional detergents.
- Knees and other parts of the body that can get muddy while taking samples need to be cleaned between pre-selected sites.
- Sterigene should be carried during all site investigations and tree selection. Sterigene should be applied to boots at the place where symptomology or vegetation types indicate you are moving from potentially contaminated sites to

those that are potentially not contaminated at each site and definitely before re-entering a public track or route.

- The water used for washing equipment should be from a treated water source instead of from a natural stream. No soil or equipment should be washed in or into water courses.
- Equipment used to dig hole should be cleaned of visible soil, sprayed with methylated spirits and be dry before using it to sample additional sites.
- All contaminated paper towels and other materials used on site should be bagged and disposed of in a sanitary manner
- Any chilly bins and cleaning equipment used should be maintained clean and clear of soil

Other points to note

1. If a member of the public approaches you and asks what you are doing, please say that you are working on an Environmental Services project for Auckland Council. Feel free to provide them with the kauri@aucklandcouncil.govt.nz email address or the Council hotline 09 301 0101. We will look to provide you with a letter with these details on them.
2. The Regional Park duty supervisor pager number for emergencies is 086 899 344. The sense check before dialing this out of hours should always be "can it wait until morning?" but if you need any immediate assistance from our staff or need to involve emergency services then please make the call (after dialling 111).

Gear Check

Make sure you have all these items before you head into the bush.

Personal safety and navigation:	**Tree survey equipment:**
GPS	Tablet
PLB/InReach	Hammer
Physical maps	Nails
First aid kit and personal medication	Tree tags

Proper clothing and waterproofs

Leaf litter rod probes

Compass

DBH tape

Kauri hygiene kit:

Sterigene

Cleaning brush

Carabiners and paracord (to hang equipment up)

Soil sample kit:

Trowel

Methylated spirits, DNA decontaminant and cleaning equipment

Zip-lock bags

Sharpies

Kauri Health Survey and Sampling Protocol

Approximately 500 individual kauri will be randomly selected for monitoring across the entire Hūnua Ranges forested area. Another approximately 200 individual kauri will be selected using a risk-based approach in the same area. These coordinates will be provided to survey teams, along with maps and access points from tracks.

All monitoring must abide by tikanga put in place by ngā mana whenua o Te Ngāherehere o Kohukohunui / Hūnua Ranges.

<u>If you come across a large dead tree, please take a photo and GPS it.</u>

Once at the pre-determined kauri point, tag the tree using a robust aluminium tree tag with a unique identifier and conduct the kauri health survey via the supplied Survey123 monitoring form.

All variables must be collected in full regardless of disease status.

Collect a soil sample at all trees.

If the selected tree is not a kauri, note this on the monitoring form. Do not take a soil sample. Move to the closest kauri tree (regardless of its health status), which will be the re-assigned tree. Tag that tree instead and conduct the kauri health survey.

If the selected tree is a dead kauri, note this on the monitoring form and also take a soil sample. There will not be a tree tag ID attached to this tree. Move to the closest kauri tree (regardless of its health status), which will be the re-assigned tree. Tag that tree instead and conduct the kauri health survey.

The current sample size for soil sampling is 700 + a contingency of approx. 50 extra samples to account for preselected sites that are associated with dead trees or other reasons that may result in inability to survey or sample the tree.

All the samples should be placed in plastic zip lock bags which is then labelled with the kauri point, tree tag ID and soil sample ID number (generated by the app) e.g.

AHS123K 6241 20230604 130245

Where AHS refers to Auckland Council Hūnua Ranges Regional Park South; K flagging that this was a Risk-based soil sample (rather than M for Random); 6241 to the tree tag ID and 20230604 130245 to the soil sample ID.

If sampling a dead tree, replace the tree tag ID with the letters ‘dd’. The text on the bag should now look like this:

AHS123K dd 20230604 130245

After each sample has been collected the trowel must be cleaned. This involves the thorough removal of all soil and debris then applying methylated spirits. Allow the trowel a few seconds to dry before placing back in its bag.

As these samples will also undergo DNA-based analysis, there are additional protocols you must abide by, which you will be briefed about. These are essential to reduce the risk of cross-contamination.

Clean the survey equipment (e.g. leaf litter probe, DBH tape) used.

Survey and soil sampling equipment must also be cleaned at the start and end of each day as per the hygiene protocol.

Notes:

Examine the overall topography and the tree canopy symptomology. If the site is flat and the trees exceed ricker-size, and there are live kauri stands or groups, then root

material may well be widely and uniformly distributed. If it is potentially wet or water-logged then root material may be on the upper mounds. You are aiming to sample where there is root material if at all possible. At the most likely site gently remove the upper unbound leaf litter from the site until roots are seen. Examine the roots to see if they are kauri and have the characteristic nodules. If they are kauri then examine them to see if they are alive or dead. Live roots may have white 1mm long growing tips, and the outer root will not separate from the inner root if pulled. Dead roots will separate. If sampling in old growth kauri forest the top of the leaf litter may well be over 20 cm above the soil. It is wise to have a probe to establish how far down you need to go to get soil. Take some dead roots from the upper surface, and then gently expose the area down to soil. Take organic material from 5 cm above soil level and soil from the upper region.

If the trees are rickers, you may have kauri feeder roots on the surface or you may have to dig and look at the material in the hole.

The survey requires notes and photographs of the trunk and the canopy. Not all symptomatic trees develop lesions, and not all lesions are caused by PA. Photos of lesions without a shot of the canopy can make assessment of a not-detected result and further sampling more difficult and will lead to increased costs.

The leaf colour of kauri and their natural leaf loss (actually they shed small bunches of leaves) change naturally with the dryness of the environment, so it is important that you take notes on anything that you see that you cannot adequately represent in the data collected or the photographs.

Variability in distribution of kauri, of symptomatic kauri, in the terrain and in the thickness of the understory means that surveyors will need to be flexible and to make some instant decisions about the suitability of sampling points.

Sampling generally targets live trees (with root material) and very newly dead trees (with bark showing the remains of PA type lesions).

Accidental Discovery Protocol

Please abide by the following rules as specified in the Auckland Unitary Plan:

http://unitaryplan.aucklandcouncil.govt.nz/Images/Auckland%20Unitary%20Plan%20Operative/Chapter%20E%20Auckland-wide/1.%20Natural%20Resources/E11%20Land%20disturbance%20-%20Regional.pdf

E11.6.1. Accidental discovery rule

(1) Despite any other rule in this Plan permitting earthworks or land disturbance or any activity associated with earthworks or land disturbance, in the event of discovery of sensitive material which is not expressly provided for by any resource consent or other statutory authority, the standards and procedures set out in this rule must apply.

(2) For the purpose of this rule, 'sensitive material' means:

a. human remains and kōiwi;

b. an archaeological site;

c. a Māori cultural artefact/taonga tuturu;

d. a protected New Zealand object as defined in the Protected Objects Act 1975 (including any fossil or sub-fossil);

e. evidence of contaminated land (such as discolouration, vapours, asbestos, separate phase hydrocarbons, landfill material or significant odour); or

f. a lava cave greater than 1m in diameter on any axis.

(3) On discovery of any sensitive material, the owner of the site or the consent holder must take the following steps:

Cease works and secure the area

a. immediately cease all works within 20m of any part of the discovery, including shutting down all earth disturbing machinery and stopping all earth moving activities, and in the case of evidence of contaminated land apply controls to minimise discharge of contaminants into the environment;

b. secure the area of the discovery, including a sufficient buffer area to ensure that all sensitive material remains undisturbed;

Inform relevant authorities and parties

c. inform the following parties immediately of the discovery:

i. the New Zealand Police if the discovery is of human remains or kōiwi;

ii. the Council in all cases;

iii. Heritage New Zealand Pouhere Taonga if the discovery is an archaeological site, Māori cultural artefact, human remains or kōiwi; and

iv. Mana Whenua if the discovery is an archaeological site, Māori cultural artefact, or kōiwi.

Wait for and enable inspection of the site

d. wait for and enable the site to be inspected by the relevant authority or agency:

i. if the discovery is human remains or kōiwi the New Zealand Police are required to investigate the human remains to determine whether they are those of a missing person or are a crime scene. The remainder of this process will not apply until the New Zealand Police confirm that they have no further interest in the discovery; or

ii. if the discovery is of sensitive material, other than evidence of contaminants, a site inspection for the purpose of initial assessment and response will be arranged by the Council in consultation with Heritage New Zealand Pouhere Taonga and appropriate Mana Whenua representatives; or

iii. if the discovery is evidence of contaminants, a suitably qualified and experienced person is required to complete an initial assessment and provide information to the Council on the assessment and response.

e. following site inspection and consultation with all relevant parties (including the owner and consent holder), the Council will determine the area within which work must cease, and any changes to controls on discharges of contaminants, until the requirements of step E11.6.1(3)(f) are met;

Recommencement of work

f. work within the area determined by the Council at step E11.6.1(3)(e) must not recommence until all of the following requirements, so far as relevant to the discovery, have been met:

i. Heritage New Zealand has confirmed that an archaeological authority has been approved for the work or that none is required;

ii. any required notification under the Protected Objects Act 1975 has been made to the Ministry for Culture and Heritage;

iii. the requirements of Section E30 Contaminated land and/or the National Environmental Standards for Assessing and Managing Contaminants in Soil to Protect Human Health 2011 have been met;

iv. any material of scientific or educational importance has been recorded and if appropriate recovered and preserved;

v. if the discovery is a lava cave as outlined in E11.6.1(2)(f) above and if the site is assessed to be regionally significant, reasonable measures have been taken to minimise adverse effects of the works on the scientific values of the site; an

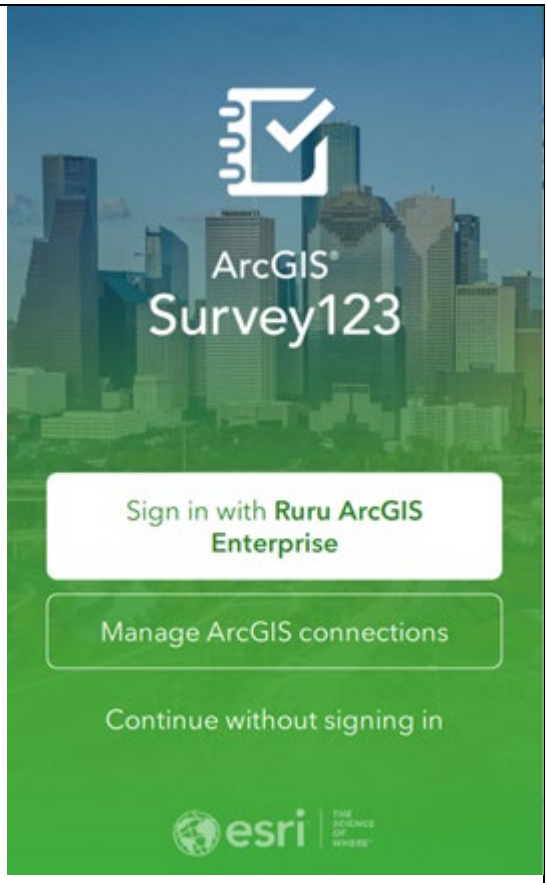
vi. where the site is of Māori origin and an authority from Heritage New Zealand Pouhere Taonga is not required the Council will confirm, in consultation with Mana Whenua, that

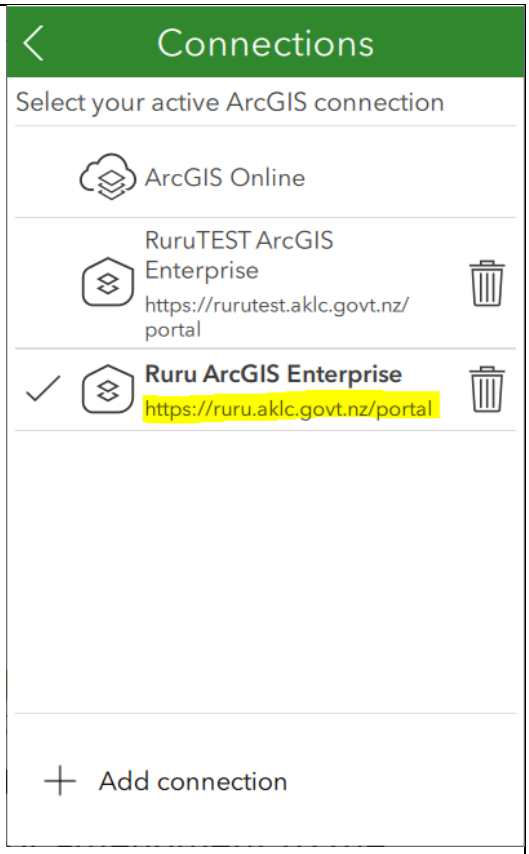
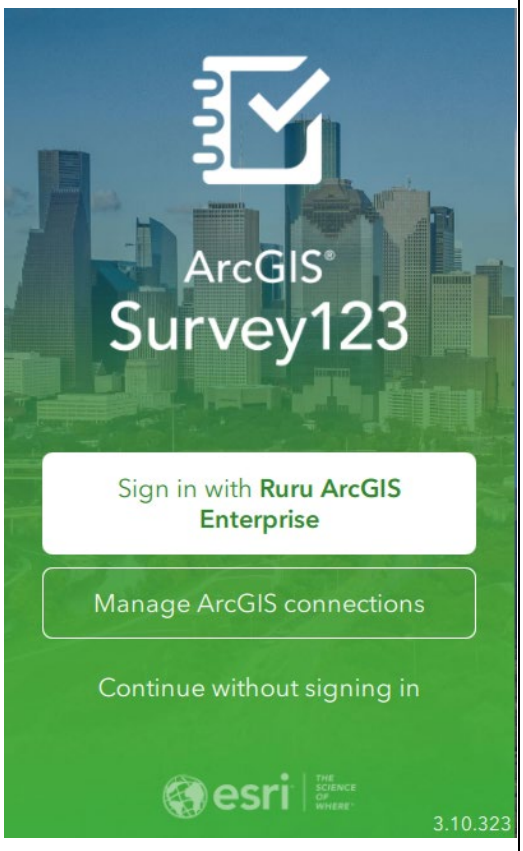
- any kōiwi have either been retained where discovered or removed in accordance with the appropriate tikanga; and
- any agreed revisions to the planned works to be/have been made in order to address adverse effects on Māori cultural values

vii. resource consent has been granted for any alteration or amendment to the earthworks or land disturbance that may be necessary to avoid the sensitive materials and that is not otherwise permitted under the Plan or allowed by any existing resource consent; and

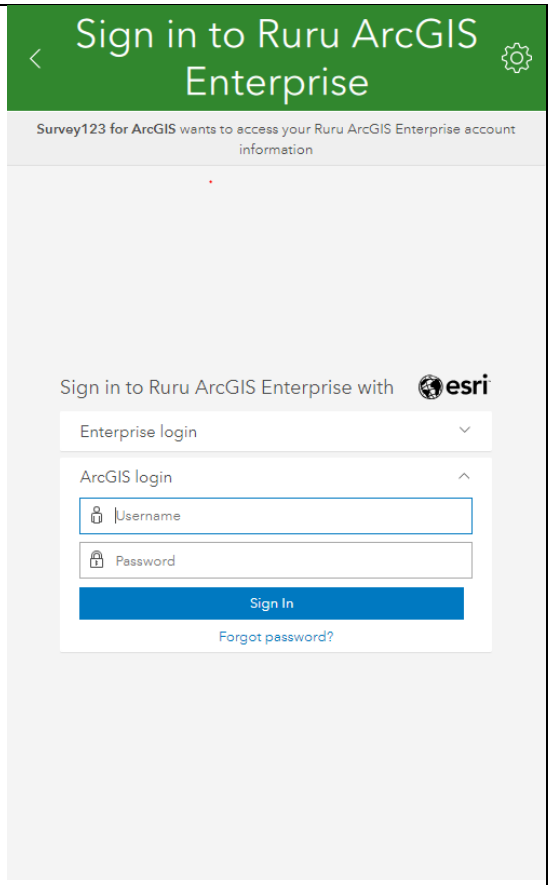
viii. that there are no requirements in the case of archaeological sites that are not of Māori origin and are not covered by the Heritage New Zealand Pouhere Taonga Act 2014.

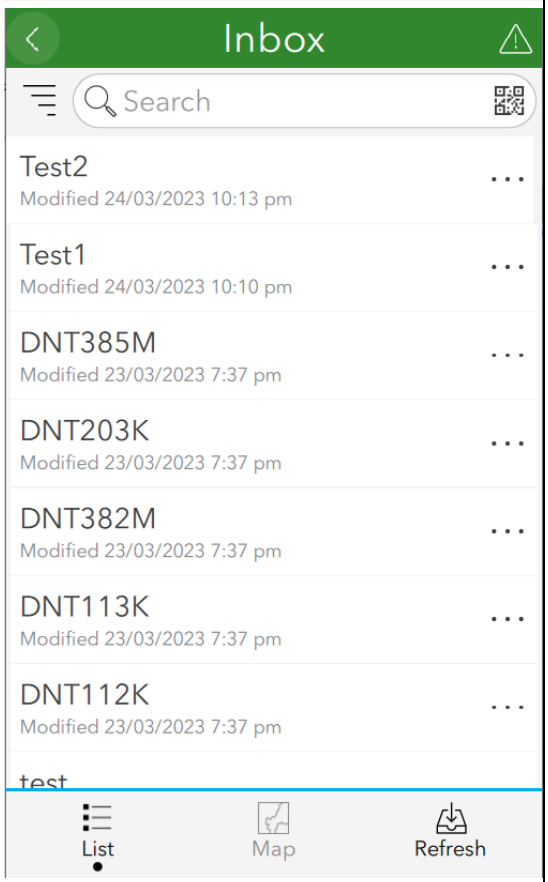
Setting up the Monitoring Form in Survey123

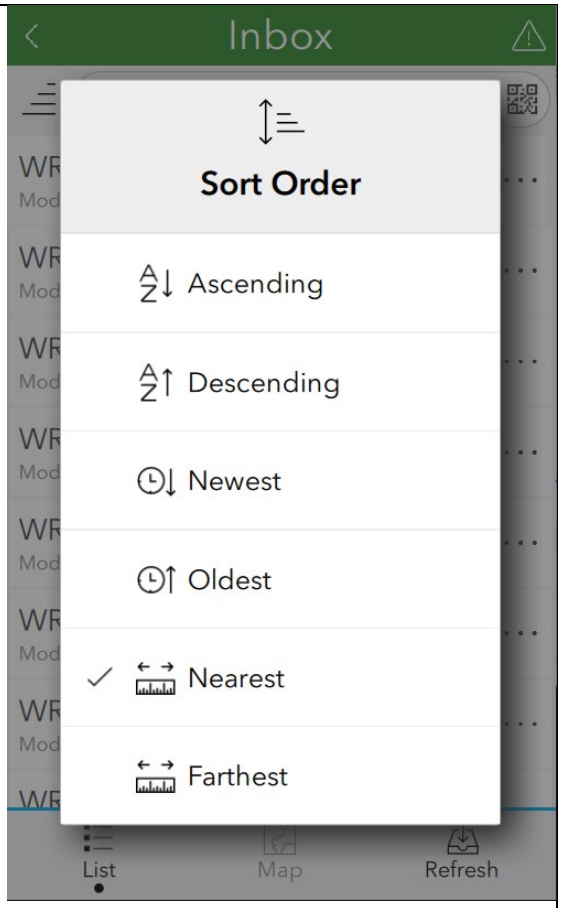
1. To download the form, first you will have to log in to the right portal. When you open the app, you should see this screen. Tap on 'Manage ArcGIS connections'.	

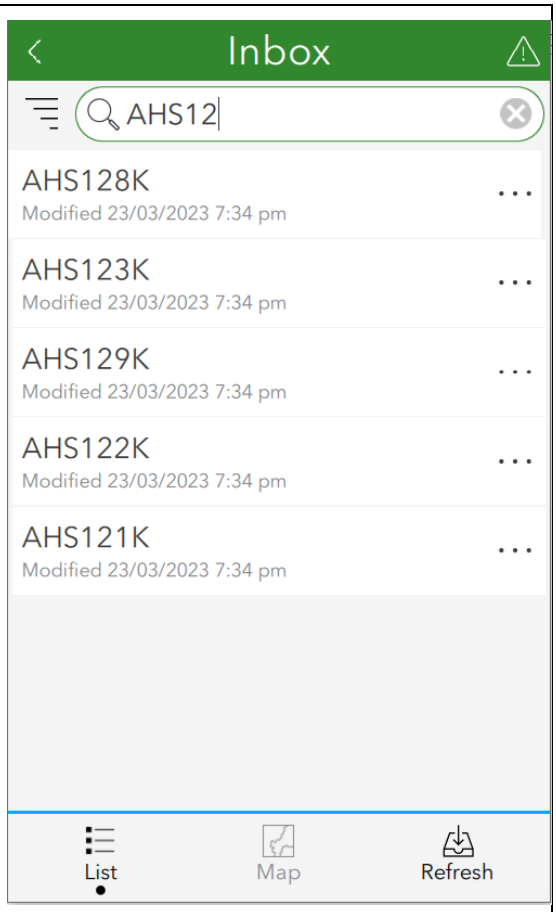
2. Tap ‘Add connection’. 3. Type in **https://ruru.aklc.govt.nz/portal** and tap ‘Add’. 4. Then make sure the right one is selected – ‘Ruru ArcGIS Enterprise’.	
5. Go back to the main screen. You should now see this. 6. Tap on ‘Sign in with Ruru ArcGIS Enterprise’.	

7. Within Survey123, sign in to Ruru ArcGIS Enterprise with the provided username and password. This screen should come up. Make sure you tap on ‘ArcGIS login’ NOT ‘Enterprise login’.
8. Tap on the circle with your initials at the top right, and then select ‘Download Surveys’. Tap on ‘Kauri Monitoring Survey Hūnua 2023’ to download it.
9. You will now have the survey saved to your device. Tap on it, and then tap ‘Inbox’ and ‘Refresh’. You will now see a list of the points of interest stored in there, or a map.

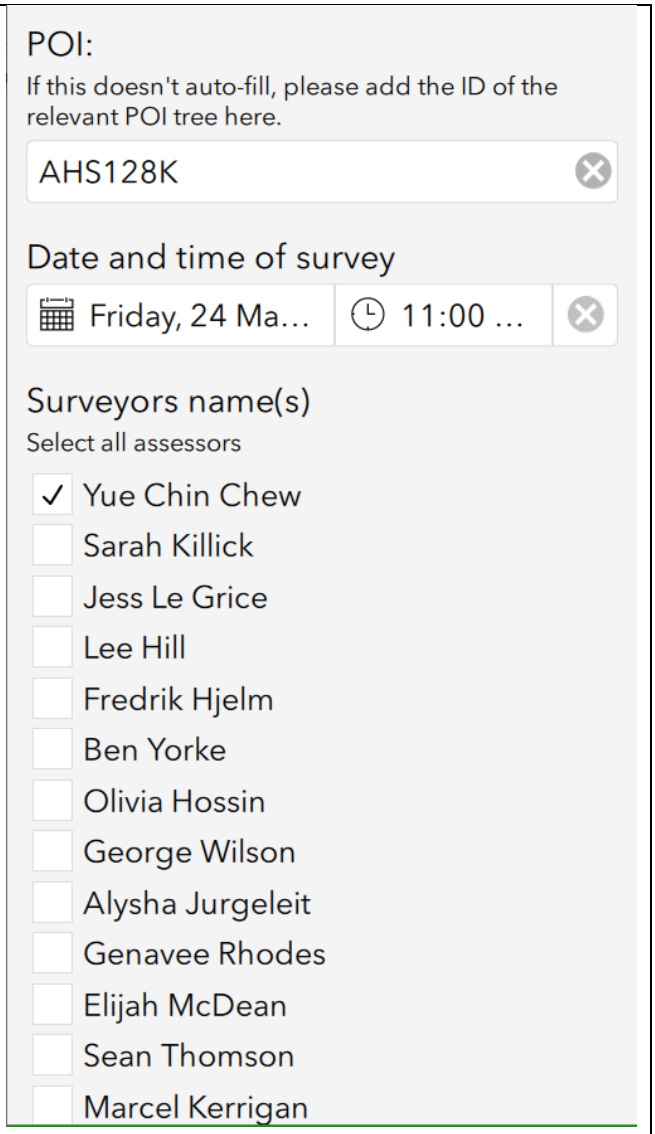


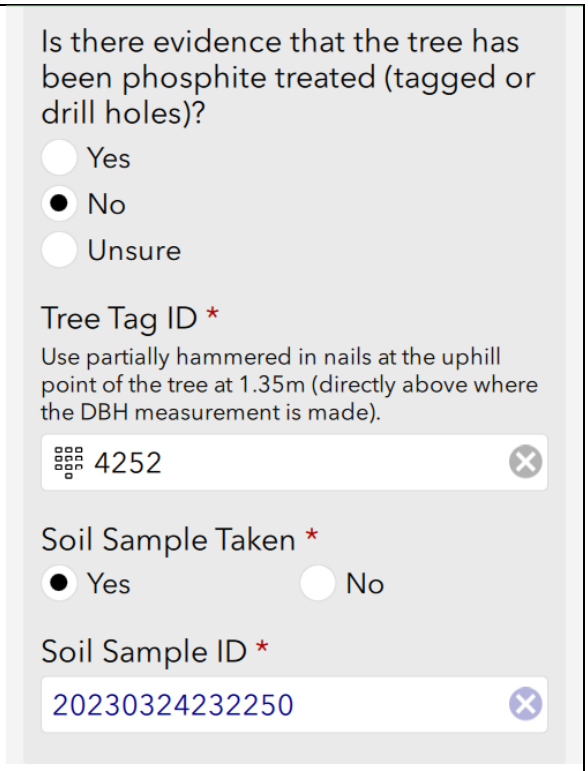
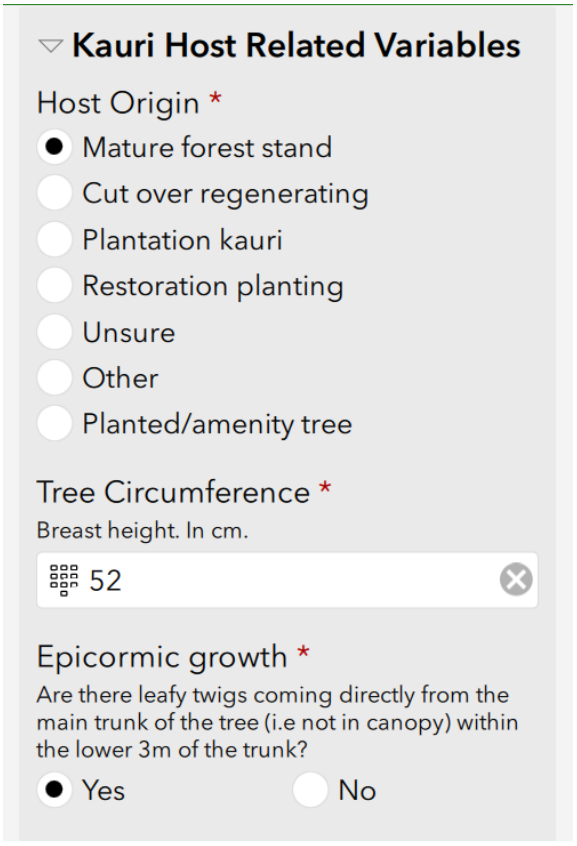


10. Use either the search function to find the POI ID, or tap on ‘Sort Order’ to sort the points by distance from your location.	

11. Tap on the point you are about to survey and commence the survey.	

Using the Monitoring Form

Site and Surveyor Info These should mostly auto-fill. You will have to tap on the date for it to auto-fill. Tap on your name and all surveyors present.	

Is there evidence that the tree has been phosphite treated?: Look for consistently spaced streaks around the trunk, at a consistent height. **Tree tag ID:** Write the tag number in the box and take a photo of the tree tag. **Soil sample taken:** You must take a sample at ALL selected trees. **Soil sample ID:** This will auto-populate. It is in the date/time format YYYYMMDDHHMMSS. Make sure you write the ID clearly and accurately on the bag. It must be 14 numbers long.	
Kauri host-related info **Host origin:** If known, select the host origin type from the list, or select unsure if you do not know. **Circumference at breast height(cm):** Measure this at 135cm above the ground on the uphill side. Please see Appendix 1 “standard points of DBH measurement” for non-standard shaped trees. **Epicormic growth:** are there leafy twigs coming directly from the main trunk of the tree? The leaves on these are often reddish-brown.	

Presence of seedlings >15cm tall: based on a radius of 5m centered on the monitored tree, are there any kauri seedlings visible within 5m of the trunk?

Presence of seedlings between 15cm and 135cm tall: based on radius of 5m centered on the monitored tree, are there any kauri seedlings visible within 5m of the trunk?

Count of saplings between 135cm tall and <10cm DBH: Note our minimum is a height measure but our maximum is a DBH measure.
Based on radius of 5m centered on the monitored tree, are there any kauri saplings visible within 5m of the trunk? Count them.

Disease-related info

Canopy health: 1-5 scale (see Appendix 3).
1 = Healthy crown
2 = Foliage/canopy thinning
3 = Some branch dieback
4 = Severe dieback
5 = Dead

Presence of seedlings less than 15cm tall *

Based on 5m radius centred on the monitored tree are any kauri seedlings visible within 5m of the trunk?

- Yes
- No

Presence of seedlings between 15cm and 1.35m tall *

Are any established kauri seedlings visible within 5m of the trunk of the monitored tree?

- Yes
- No

Count of saplings between 1.35m tall and less than 10cm DBH *

Are any kauri saplings visible within 5m of the trunk of the monitored tree?

- 0
- 1 to 5
- 6 to 10
- >10

Disease Related Variables

Canopy Health *

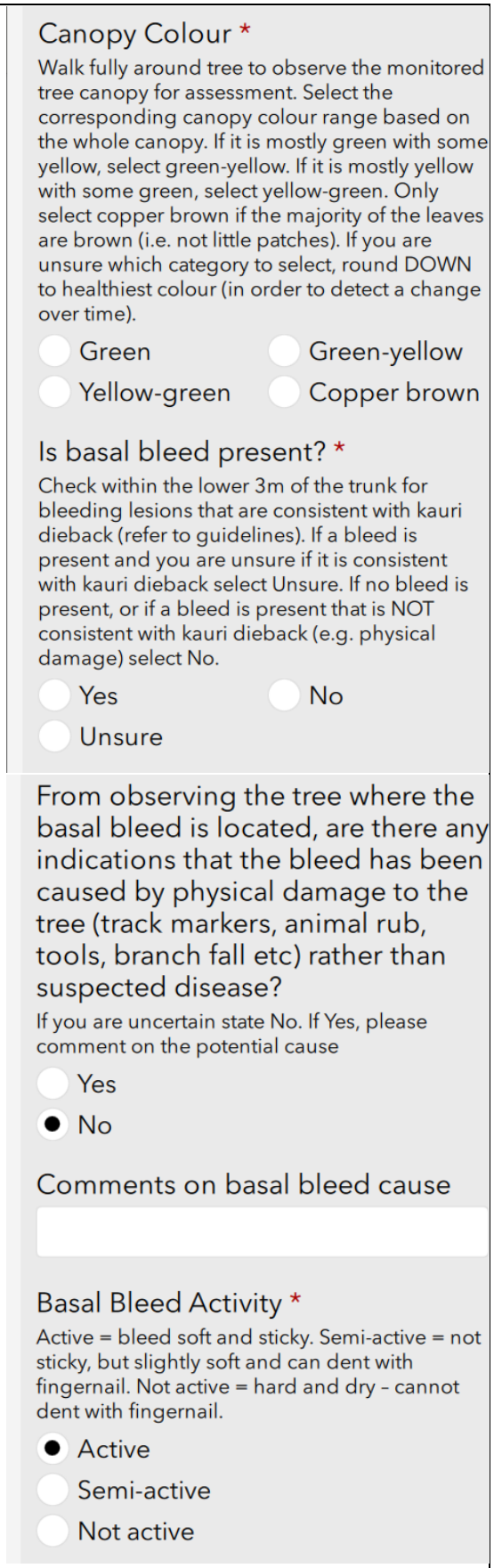
Walk fully around tree to observe the monitored tree canopy for assessment. Select the corresponding canopy health score based on the guidelines below based on the whole canopy. If you are unsure which category to select, round DOWN to healthiest scale (in order to detect a change over time).

- 1 (Healthy crown - no visible signs of dieback)
- 1.5
- 2 (Foliage/canopy thinning)
- 2.5
- 3 (Some branch dieback)
- 3.5
- 4 (Severe dieback)
- 4.5
- 5 (Dead)

Canopy colour: Walk fully around tree to observe the monitored tree canopy for assessment. Select the corresponding canopy colour range based on the whole canopy.

Base bleed present: Note not all basal lesions are related to pathogen presence (could be mechanical damage or not suspicious). If you are unsure, state Unsure and take an image.

Base bleed activity: Active bleeds are very sticky, and inactive bleeds are hard and cannot be dented.

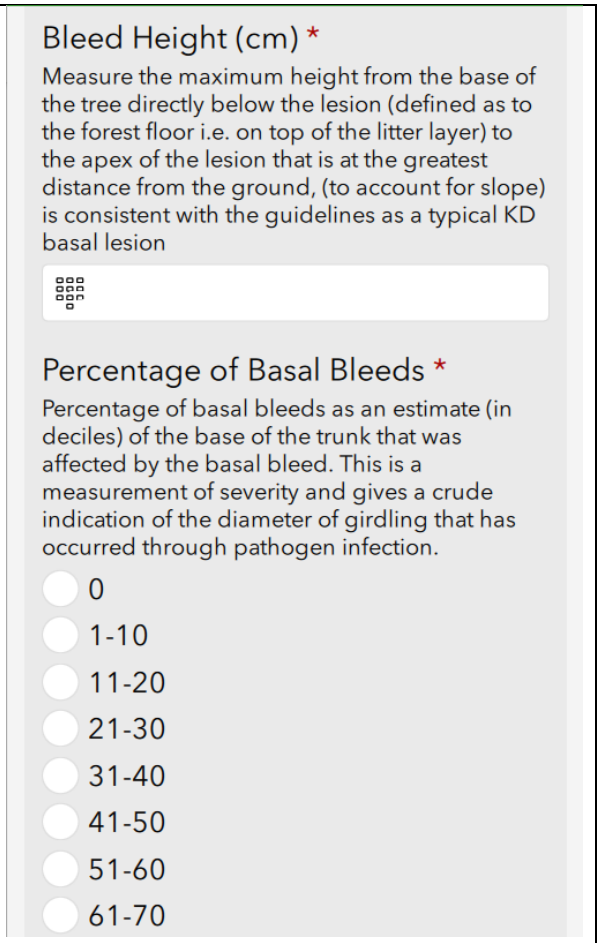


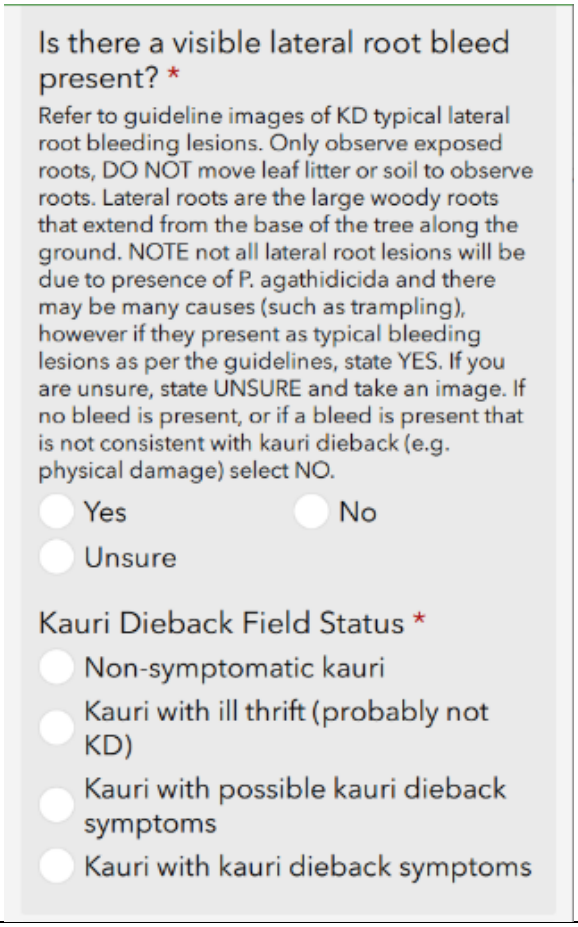
Base bleed height (cm): Measure the maximum height from the forest floor to the apex of the bleed, directly below the bleed itself.

Percentage of basal bleeds: Estimate the percentage of basal bleeds around the base of the trunk.

Is there a visible lateral root bleed present: Only observe exposed roots, DO NOT move leaf litter or soil to observe roots. Lateral roots are the large woody roots that extend from the base of the tree along the ground. If you are unsure, state UNSURE and take an image.
Lateral root bleed activity: same scale as basal bleed activity

Is the bleed due to a physical cause?: yes or no – if uncertain, state no.





Kauri dieback field status: From the expressed symptoms, please provide a first assessment. It is the trained observer's opportunity to state whether the symptoms observed are consistent or inconsistent with kauri dieback based on their expert opinion. If they are unsure then they should state possible KD. **Evidence of disturbance:** If yes, tick the checklist (you can select multiple options). **Stock fencing?:** yes/no/not applicable. Only answer Yes or No if you are aware that the	Was there evidence of disturbance? * ● Yes ○ No Type of Disturbance ✓ Animal pest control ☐ Bait-line ☐ Evidence of weed spray ☐ Fallen tree ☐ Fire ☐ Fungal fruiting bodies ☐ Hoofed animal disturbance ☐ Human or animal off track ✓ Insect damage to trunk ☐ Invasive weed presence ☐ Mowing around tree base ☐ Pig damage to tree trunk/base ✓ Pig wallowing ☐ Poor drainage at tree base ☐ Possum browse ☐ Road maintenance ☐ Slip/landslide ☐ Track maintenance ☐ Windthrow ☐ Other Please provide more details on the disturbance if necessary: Is the site fenced off from stock? * Only answer Yes or No if you are aware that the whole site has stock excluded by fencing, if you are in a large forest and do not know what the boundaries are like, answer NA ○ Yes ○ No ○ NA Please include photos of any evidence of disturbance at the end of this form if they require confirmation/ID or if not in the above list.

whole site has stock excluded by fencing, if you are in a large forest and do not know what the boundaries are like, answer NA

Ecology info

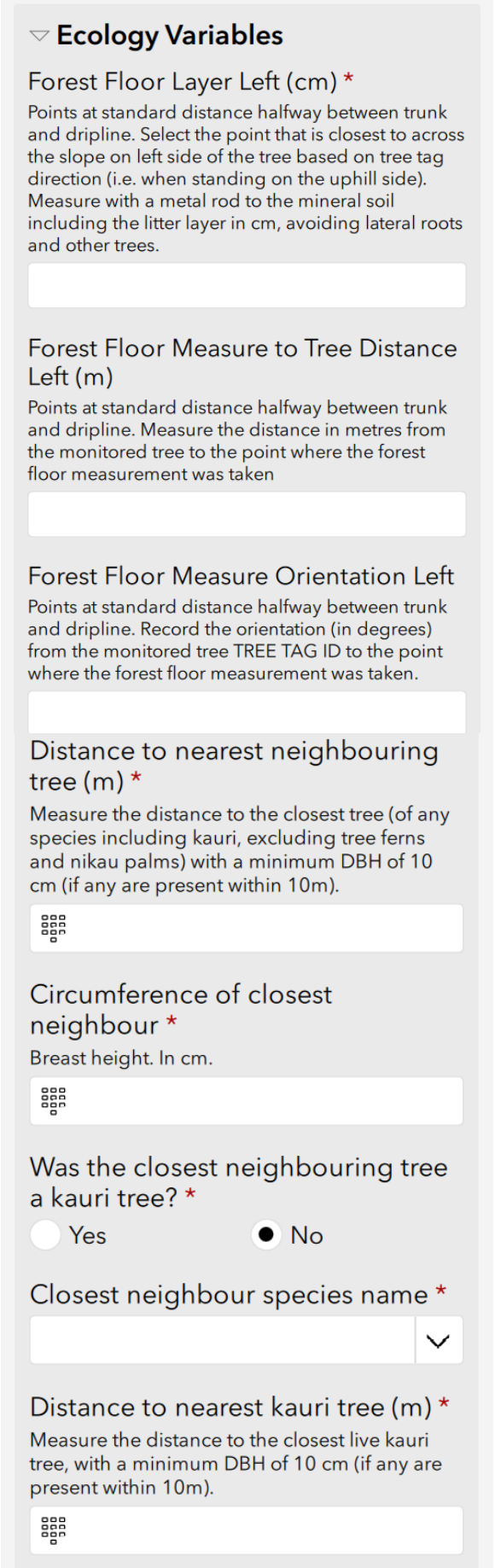
Forest floor layer left/right (cm): Select a point that is halfway between trunk and dripline, closest to across the slope on left/right side of the tree based on tree tag direction (i.e. when standing on the uphill side). Measure with a metal rod to the mineral soil including the litter layer in cm, avoiding lateral roots and other trees.

Forest floor measure to tree distance left/right (m): Measure the distance in m from the monitored tree to the point where the forest floor measurement was taken.

Forest floor measure orientation left/right (degrees): Record the orientation (in degrees) from the monitored tree TREE TAG ID to the point where the forest floor measurement was taken. It should be 90 for the left measure and 270 for the right measure.

Distance to nearest neighbouring tree (m): Measure the distance to the closest tree (of any species including kauri, excluding tree ferns and nikau palms) with a minimum DBH of 10 cm (if any are present within 10m). This indicates if there is a subordinate or dominant tree in the space.

Circumference of closest neighbouring tree (cm): Measure the circumference of the

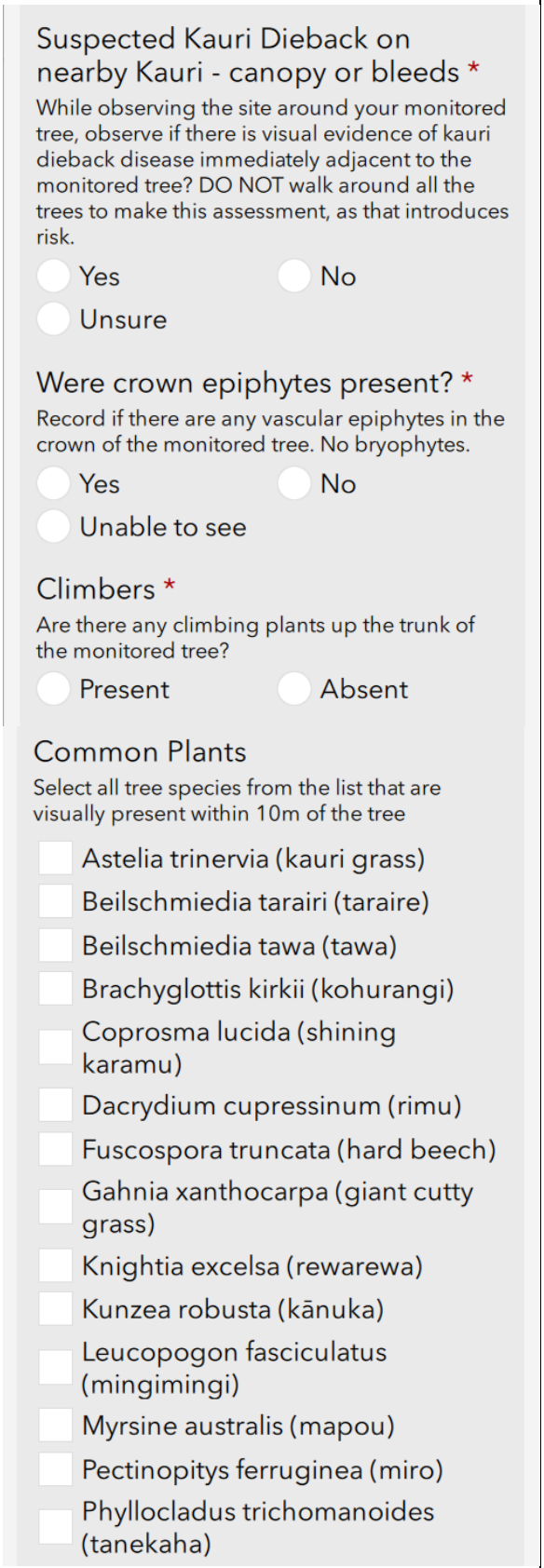


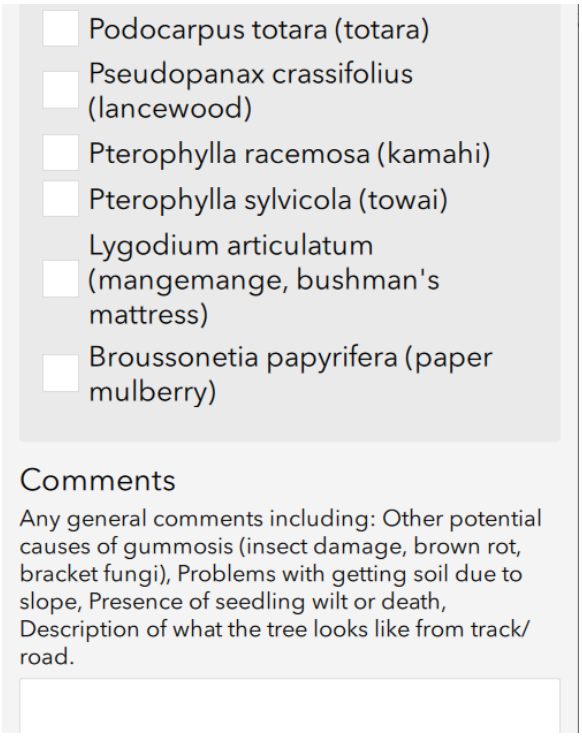
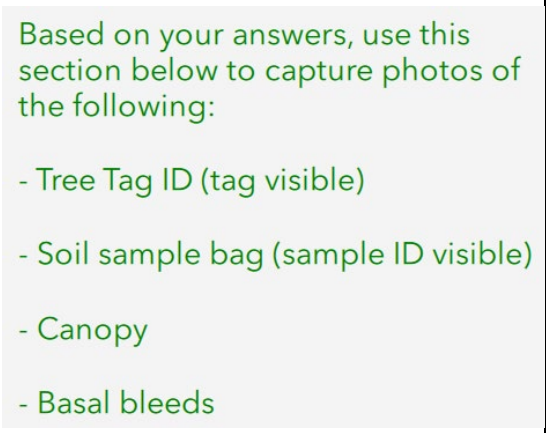
closest neighbouring tree. The DBH will auto-calculate.
DBH of closest neighbouring tree (cm): must be a tree above 10cm DBH. See Appendix 2 for how to measure DBH.
If the closest neighbouring tree is not a kauri, add:
Closest neighbour species name: This is a list of all our flora. Please search for the name of the tree (e.g. rimu or *Dacrydium cupressinum*). Take photo of leaves if unsure.
Circumference of closest neighbour (cm).
Distance to nearest kauri tree (m): with a minimum DBH of 10cm, if any are present within 10m.
and
Circumference of closest kauri (cm).

Suspected kauri dieback on nearby kauri – canopy or bleeds: is there visual evidence of canopy dieback or basal bleeds/lesions in other kauri immediately adjacent to the monitored tree?
Presence of crown epiphytes: are there any plants in the crown of the monitored tree? Yes/no/not able to see.

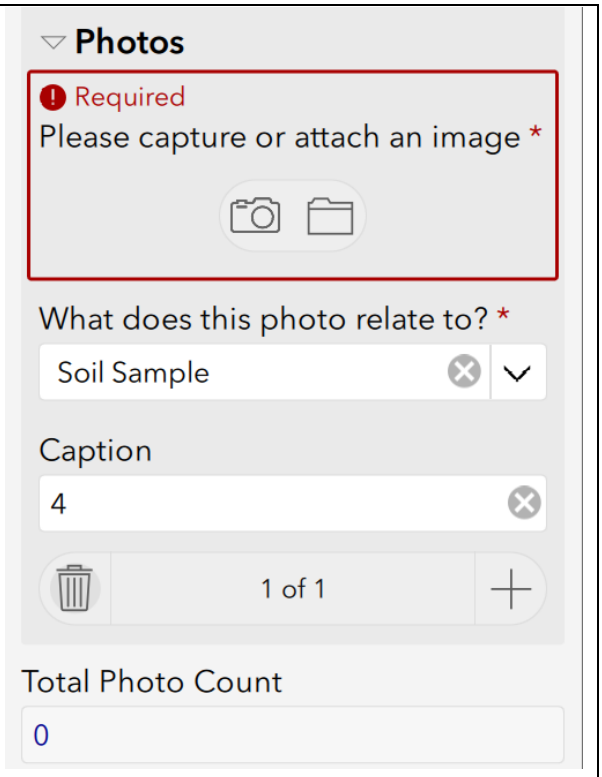
Presence of climbers: are there any climbing plants up the trunk of the monitored tree? Present/absent/unsure.

Common plants: select all of the plant species present in the checklist within 10m radius of the tree. In general, look for plants above 1.35m, but if you see it, tick it.



Any general comments.	
Photos: These are highly important especially to help us match data. It is a slightly finicky section, so please check you are submitting the right photos. **You must take at least 3 photos** (canopy, soil sample bag and tree tag ID) in order to be able to submit the form. **Soil sample:** Make sure the information written on the bag of the POI ID, the soil sample ID and tree tag ID information is	

clearly **LEGIBLE**. You can include the number of points sampled (4 or 8) in the caption. **Tree tag photo:** Check to see this is clear and not a blurry photo. **Canopy photo:** take this from the best view of unobstructed canopy. Note the orientation from the tree in degrees and distance from the tree in cm. **Please also take photos of your GPS, other identifiers if present, basal bleeds if present.** If you see evidence of disturbance or neighbouring species that are difficult to identify, you may take photos of these too.	

Data and Sample Management Protocol

Soil sample handling:

1. The soil samples must be stored in a cool (10-25°C), dark place until dispatch. The samples are to be double-bagged (i.e. two big bags with 20-40 samples in) and couriered in boxes via overnight post. They should only be sent on Mon, Tues, and Wed to avoid prolonged time in courier vans or facilities. Batches of samples should ideally be between 20-40 bags at a time for ease of processing at the lab.
2. Ensure the kauri point, tree tag ID and soil sample ID are marked clearly on the outside of each ziplock bag for the lab to read, with the same label on waterproof paper inside the bag. Each box must have the list of these codes enclosed, and an accompanying excel spreadsheet sent to Auckland Council on the day of couriering.
3. Please send the boxes to:

Dr Ian Horner
Plant & Food Research Hawkes Bay
Cnr Crosses and St Georges Roads
Havelock North, 4130
New Zealand

There will be separate instructions specifically for the LAMP assay analysis.

Data download and storage:

1. There is a risk of damage and loss of the electronic devices being used. Therefore a data download is required at the end of each day.
2. A download of the Waypoint and Track GPX files must be carried out every week, and shared with Auckland Council at regular intervals (e.g. every fortnight).
3. All data recorded via the kauri health survey form on the tablets are to be submitted as soon as possible, i.e. after each form has been filled in, but at least by the end of each day.
4. Any data saved on external hard drives should always be stored safe and secure and in a separate location to the other devices.

Using the GPS

START OF DAY

At the start of the day turn the GPS on at the top of the device. It takes a few minutes for the device to acquire satellites.

TRACK LOG

Once the device has acquired satellites, at the start of the day, turn on the track log:

1. Press the ‘MENU’ button twice to go to the main menu.
2. Use the arrow key pad to move over to the ‘Setup’ box and press the ‘ENTER’ button.
3. Use the arrow key pad to move over to the ‘Tracks’ box and press the ‘ENTER’ button.
4. Use the arrow key pad to move over to the ‘Track Log’ box and press the ‘ENTER’ button.
5. Use the arrow key pad to move over to the ‘Record, Show on Map’ and press the ‘ENTER’ button.
6. The ‘Track Log’ box should change to reflect this.
7. Press the ‘QUIT’ button twice to go to the main menu.

At the end of the day when out of the field and back at vehicle, save the track log for the day:

1. Press the ‘MENU’ button twice to go to the main menu.
2. Use the arrow key pad to move over to the ‘Track Manager’ box and press the ‘ENTER’ button.
3. Use the arrow key pad to move over to the ‘Save Track’ box and press the ‘ENTER’ button.
4. The track will be assigned a name related to the date which is sufficient for identification later.
5. Use the arrow key pad to move over to the ‘Done’ box and press the ‘ENTER’ button.
6. You will be asked if you would like to clear current track data. Use the arrow key pad to move over to the ‘Yes’ box and press the ‘ENTER’ button.

7. Press the ‘QUIT’ button to leave the Track menu page.

The track log should now be turned off for the day:

1. Press the ‘MENU’ button twice to go to the main menu.
2. Use the arrow key pad to move over to the ‘Setup’ box and press the ‘ENTER’ button.
3. Use the arrow key pad to move over to the ‘Tracks’ box and press the ‘ENTER’ button.
4. Use the arrow key pad to move over to the ‘Track Log’ box and press the ‘ENTER’ button.
5. Use the arrow key pad to move over to the ‘Do Not Record’ and press the ‘ENTER’ button.
6. The ‘Track Log’ box should change to reflect this.
7. Press the ‘QUIT’ button twice to go to the main menu.

LOCATING THE POINT OF INTEREST

The locations of the points of interest will already be stored on the GPS. To help locate the area:

1. Press the ‘FIND’ button.
2. Use the arrow key pad to move over to the ‘Waypoint’ box and press the ‘ENTER’ button.

3a. If the site is shown on the list use the arrow key pad to move onto the site and press the ‘ENTER’

button. The screen should then change to show the point on a map. Press the ‘ENTER’ button again and the navigation assistant should begin

3b. If the site is not listed on the waypoint screen then press the ‘MENU’ button, move on to the ‘spell

search’ box and press the ‘ENTER’ button. Use the arrow key pad and the ‘ENTER’ button to type in SITE and move to the ‘done’ box and press ‘ENTER’. This should bring up all on the areas of interest. Then just follow point 3a above.

4. To turn navigation off, press the ‘FIND’ button, use the arrow key pad to move to ‘Stop Navigation’ and press the ‘ENTER’ button.

RECORDING A LOCATION

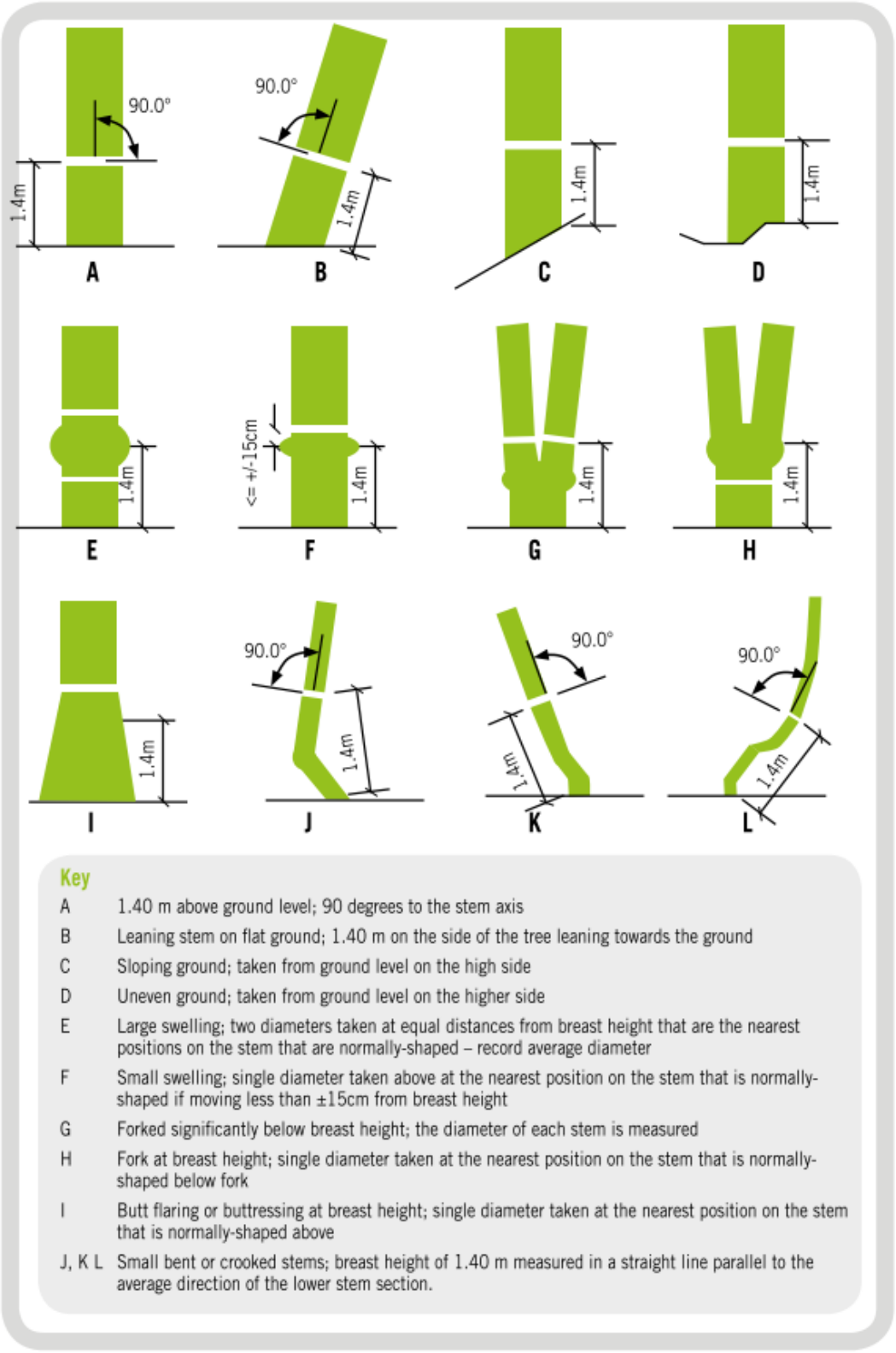
When ready to enter a Kauri location:

1. Hold the GPS close to the tree and press the ‘MARK’ button.
2. Edit the waypoint ID. E.g. for the POI ID AHS123K, enter ‘AHS123K’. This will help us track the waypoints in case any data goes missing.
3. Once you have recorded the Eastings and Northings on the survey form, use the arrow key pad to move down to the ‘Done’ box on the bottom right of the screen and press the ‘ENTER’ button.

Standard points of circumference measurement

Use 1.35m, not 1.4m.

Figure 6: Standard points of DBH measurement



Key

A	1.40 m above ground level; 90 degrees to the stem axis
B	Leaning stem on flat ground; 1.40 m on the side of the tree leaning towards the ground
C	Sloping ground; taken from ground level on the high side
D	Uneven ground; taken from ground level on the higher side
E	Large swelling; two diameters taken at equal distances from breast height that are the nearest positions on the stem that are normally-shaped – record average diameter
F	Small swelling; single diameter taken above at the nearest position on the stem that is normally-shaped if moving less than ±15cm from breast height
G	Forked significantly below breast height; the diameter of each stem is measured
H	Fork at breast height; single diameter taken at the nearest position on the stem that is normally-shaped below fork
I	Butt flaring or buttressing at breast height; single diameter taken at the nearest position on the stem that is normally-shaped above
J, K L	Small bent or crooked stems; breast height of 1.40 m measured in a straight line parallel to the average direction of the lower stem section.

Canopy health scoring

Canopy scores

1 = Healthy crown – no visible signs of dieback
2 = Foliage/canopy thinning
3 = Some branch dieback
4 = Severe dieback
5 = Dead

Appendix C. Recommended updates to the monitoring form

There were two variables that required data cleaning, which could be avoided in the future by minor updates to the monitoring form.

Tree circumference* (Breast height. In cm.)

There were some values which were entered with one decimal place. In this survey, none of them appeared to be incorrect data, but it is unnecessary to include a decimal point where the measurement is in cm.

> **Recommendation:** Minor change to remove the decimal point from the number pad if feasible.

Distance to nearest neighbouring tree (m)* (measure the distance to the closest tree of any species including kauri, excluding tree ferns and nikau palms) with a minimum DBH of 10cm (if any are present within 1 m).

The use of m to measure this variable seems to be an issue with data entry. There were 10 observations that were outliers, exceeding the 'within 10m from the tree' instruction, ranging from 13m (which could be correct) to 145m which is clearly an error. The canopy photos from the field can be used to infer if these values are incorrect. By looking at the canopy photo for the PPU734M observation, it is clear that the neighbouring tanekaha tree is much closer than 65m and is within one metre, so was cleaned to 0.65 m (Figure A-0-1). The same process was conducted for the other 10 outliers. For one observation – DSV593M – it was difficult to determine where the decimal place should be, with a value of 97m; was it measured in cm and should 0.97m or is the decimal in the wrong place making it 9.7m? On inspection of the canopy photo, this remained uncertain, but it was a large tree so 9.7m seemed more likely. To assess this, we reviewed other canopy photos that were close to 1m and close to 9m. The image was a much closer match to a similar sized tree which was 9m from its nearest neighbour and 9.7m was selected (Figure A-0-2).

> **Recommendation:** Apply data value restrictions to the monitoring form with a warning for values entered greater than 10m and rejection of values greater than 15m. In addition, reinforce with surveyors during training that this measurement is in metres.

Figure A1: Canopy photo of observation POIs: PPU734M; DSM645M and DSM661M, all ricker sized trees, showing the proximity of the nearest neighbouring tree was 0.65m rather than 65m; 0.13m rather than 13m and 1.45m rather than 145m.

Figure A2. Canopy photo of observation POIs: DSV593M and AHE307M showing the similarity between the two large trees and a 9-10m distance to their nearest neighbours..

Appendix D. Risk-based monitoring points selection details

Descriptive summary of risk factors

The tree-based data and risk attributes are summarised below.

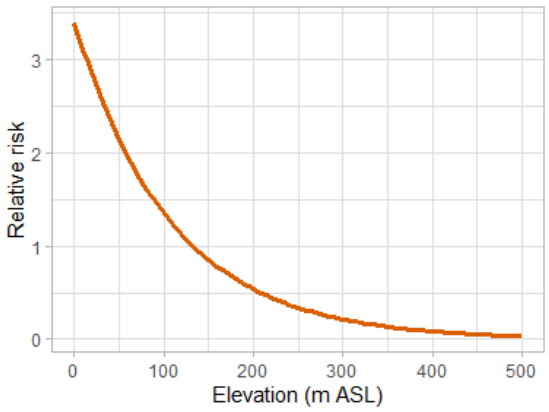
Variable	mean	Sd	min	1st quartile	median	3rd quartile	max
Elevation	187.64	62.38	14.05	142.29	182.65	228.29	596.23
KauriDist	63.96	81.66	8.39	24.89	36.56	63.41	1154.05
CoastDist	8091.02	3846.54	77.10	4337.80	8070.88	11839.00	16489
EdgeDist	544.29	437.54	0.00	186.97	449.36	800.82	2850.38
Cover1942	0.21	0.36	0.00	0.00	0.00	0.20	1.00
Moisture	959.48	69942.43	0.08	8.30	16.19	33.52	9602480
IllDist	1320.17	1236.90	1.10	514.58	876.50	1743.73	7576.42
BleedDist	3671.84	2330.89	1.00	1722.65	3500.40	5603.98	9196.86
RouteDist	459.80	349.14	0.00	163.51	386.88	704.68	1738.07
TimberDist	3514.05	1792.56	29.75	2174.69	3442.85	4719.54	8316.95
DamDist	1953.21	976.61	0.00	1318.76	1913.97	2491.96	6612.47
ReservoirDist	5513.48	3125.97	3.39	2455.10	6060.85	8062.20	12364.50
PlotDist	3375.44	2579.53	14.63	1201.16	2332.05	5787.77	9572.33
PlantingDist	7510.38	5503.60	51.84	3373.08	5284.32	11684.25	19684.40

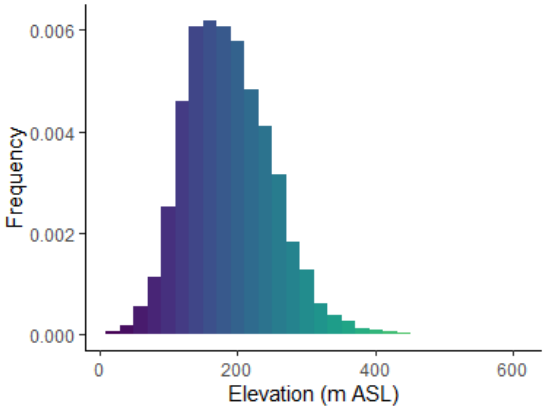
Elevation

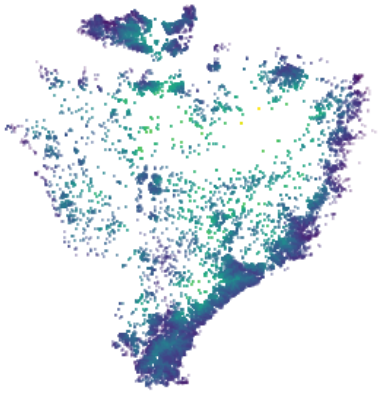
Justification: Waitākere survey indicated less risk as elevation increases.

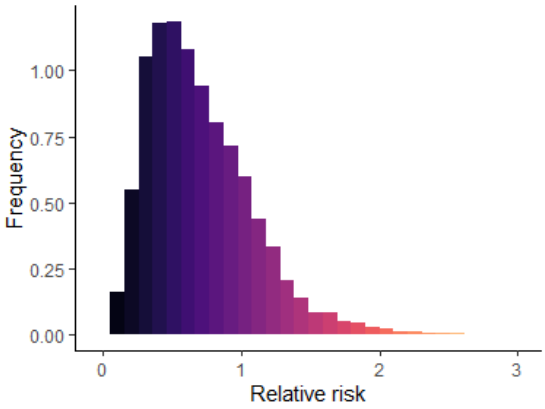
Elevation

Range = 500
Weight = 3.4









Details of the highest risk trees according to Elevation, randomly ordered where the risk value is equal

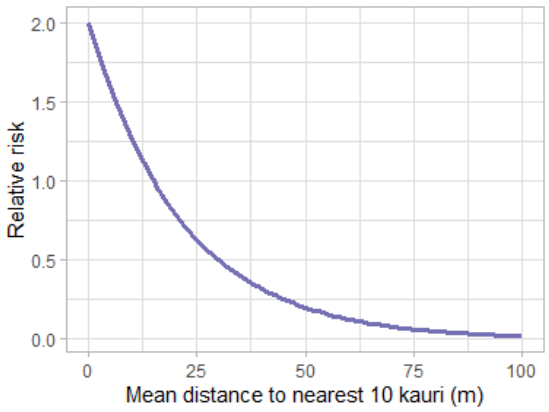
TreeId	Northing	Easting	Elevation	Risk value
2011	5901140	1803531	14.0500	2.987735
1080	5902191	1803150	15.1130	2.958658
11014	5900962	1803517	17.5529	2.892985
10356	5902020	1802996	18.1045	2.878341
10849	5901363	1803373	18.2054	2.875670
517	5901368	1803441	18.7284	2.861867
10255	5902168	1803140	18.8733	2.858054
10887	5901297	1803416	19.8401	2.832746
10281	5902133	1803094	20.2834	2.821216
10320	5902075	1803035	20.7385	2.809429
10315	5902079	1803038	21.1719	2.798249
10256	5902168	1803074	21.3127	2.794627
11664	5898445	1803872	21.4251	2.791739
392	5901979	1802949	21.4490	2.791125
2551	5902214	1803133	21.7279	2.783972
10237	5902189	1803131	22.7091	2.758954
2556	5902210	1803134	22.9567	2.752677
10216	5902211	1803044	23.0215	2.751036
10326	5902072	1802989	24.5368	2.712951
10313	5902090	1803045	24.9266	2.703239

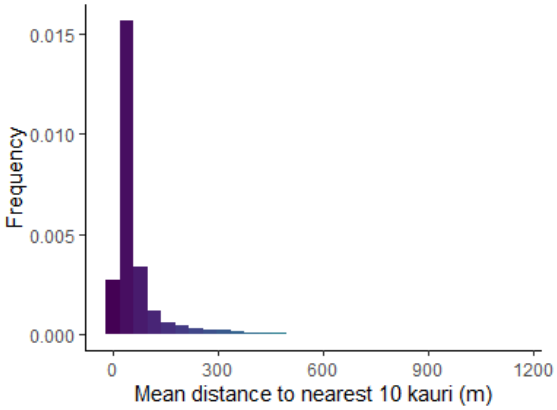
Mean distance to nearest 10 kauri

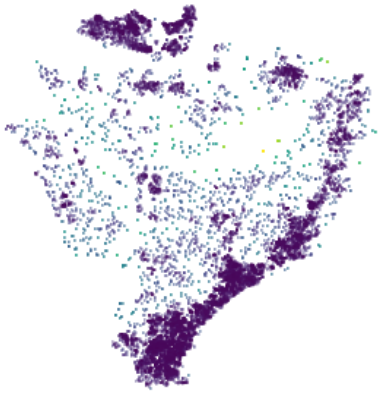
Justification: Transmission between trees is highest when trees are close together.

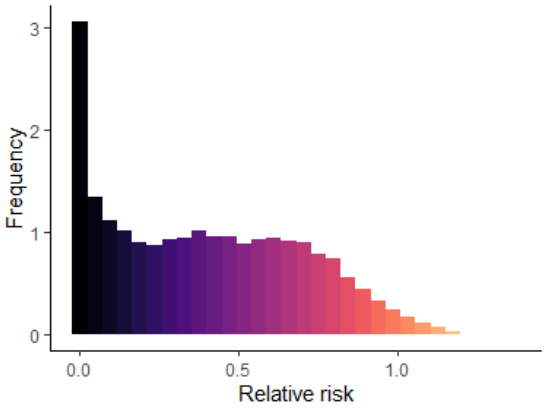
KauriDist

Range = 100
Weight = 2









Details of the highest risk trees according to KauriDist, randomly ordered where the risk value is equal

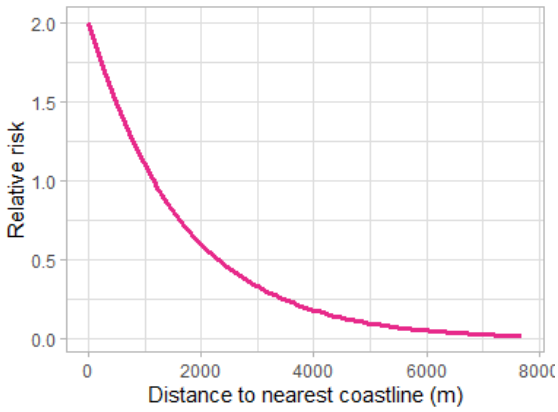
TreeId	Northing	Easting	KauriDist	Risk value
24094	5883474	1793063	8.389456	1.359657
24101	5883471	1793065	8.681748	1.341498
5918	5883834	1792104	8.917642	1.327020
5914	5883835	1792099	9.079164	1.317197
5897	5883839	1792100	9.212556	1.309139
5929	5883828	1792103	9.479595	1.293156
24085	5883478	1793064	9.548974	1.289036
24103	5883469	1793068	9.569109	1.287842
24106	5883468	1793061	9.694322	1.280446
5946	5883824	1792103	9.730681	1.278306
5898	5883839	1792109	9.754853	1.276885
5937	5883827	1792110	9.892323	1.268836
24105	5883470	1793057	9.977702	1.263863
5954	5883819	1792104	10.099236	1.256817
5901	5883838	1792094	10.117409	1.255767
13072	5894139	1787213	10.275923	1.246644
5915	5883835	1792113	10.404811	1.239274
5798	5883894	1792086	10.507996	1.233406
5805	5883889	1792089	10.592888	1.228599
24083	5883479	1793071	10.692171	1.223000

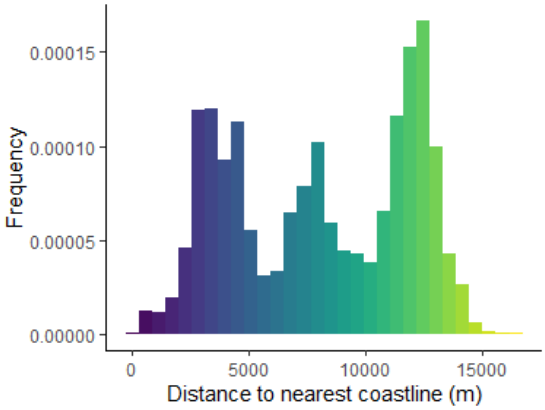
Distance to nearest coastline

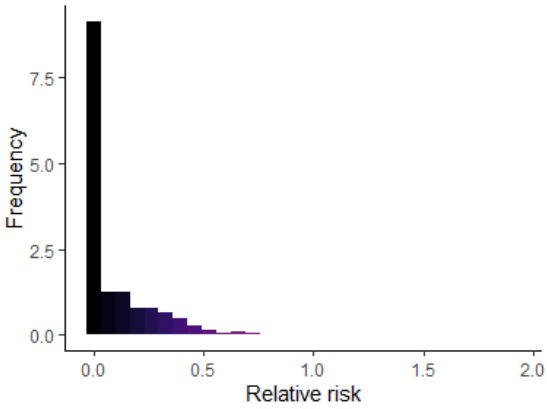
Justification: Waitākere survey indicated less risk as distance from the coast increases.

CoastDist

Range = 7700
Weight = 2





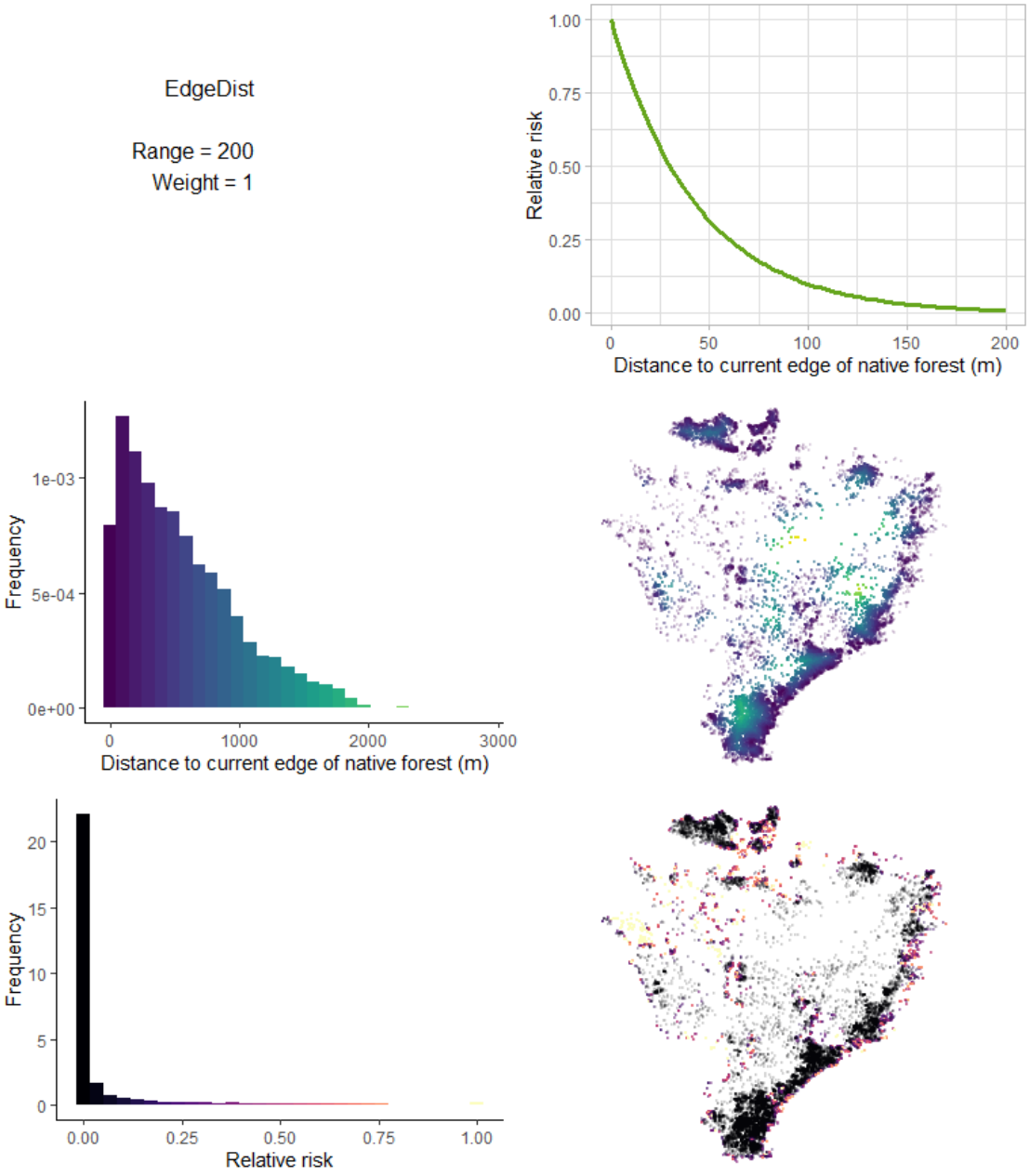


Details of the highest risk trees according to CoastDist, randomly ordered where the risk value is equal

TreeId	Northing	Easting	CoastDist	Risk value
2011	5901140	1803531	77.1038	1.909965
11014	5900962	1803517	114.9480	1.867269
517	5901368	1803441	204.0830	1.770439
1080	5902191	1803150	210.7060	1.763448
11084	5900603	1803485	213.2140	1.760808
2551	5902214	1803133	214.2940	1.759672
2556	5902210	1803134	216.2080	1.757661
10237	5902189	1803131	228.2540	1.745058
10255	5902168	1803140	230.8680	1.742335
11088	5900594	1803461	232.8800	1.740242
10887	5901297	1803416	235.7330	1.737278
10849	5901363	1803373	273.2400	1.698784
10974	5901070	1803334	276.6320	1.695345
10953	5901100	1803329	278.6490	1.693304
26699	5901038	1803329	284.8030	1.687090
10256	5902168	1803074	288.1890	1.683681
10281	5902133	1803094	288.4670	1.683401
26700	5901039	1803324	289.6640	1.682198
10216	5902211	1803044	295.1610	1.676683
11664	5898445	1803872	298.4020	1.673439

Distance to current edge of native forest

Justification: Proximity to the forest edge may increase disturbance and risk of *P. agathidicida* colonisation.



Details of the highest risk trees according to EdgeDist, randomly ordered where the risk value is equal.

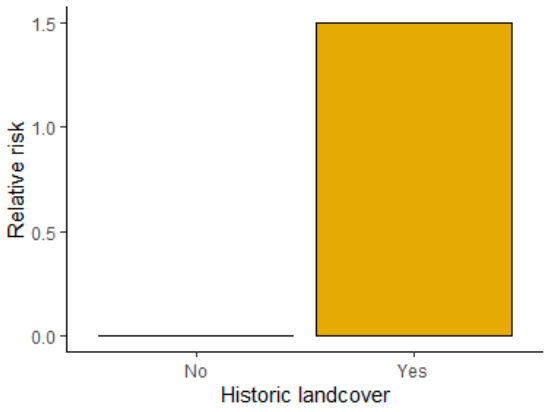
TreeId	Northing	Easting	EdgeDist	Risk value
2215	5889865	1790547	0	1
11778	5898153	1785525	0	1
11341	5899825	1803090	0	1
10790	5901446	1788952	0	1
10890	5901295	1787605	0	1
783	5899840	1802951	0	1
2632	5899411	1802669	0	1
7180	5905756	1793632	0	1
16842	5889174	1797839	0	1
10876	5901321	1789028	0	1
11063	5900777	1792320	0	1
8386	5905198	1792608	0	1
2176	5897198	1786089	0	1
11434	5899476	1802144	0	1
22084	5884417	1790069	0	1
11759	5898193	1786300	0	1
10780	5901465	1788939	0	1
11506	5899210	1785057	0	1
1060	5897259	1786359	0	1
26759	5895683	1785616	0	1

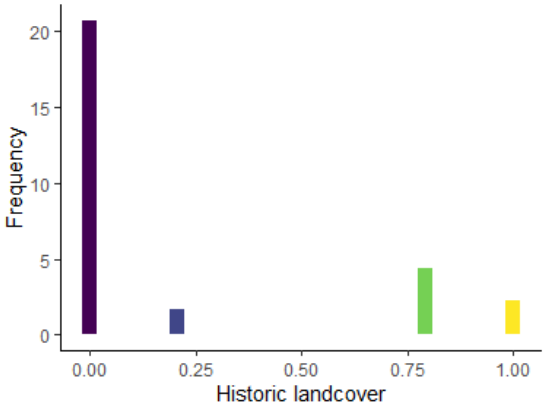
Historic landcover

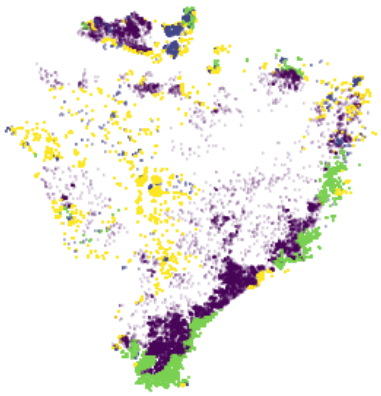
Justification: Indicates historical disturbance.

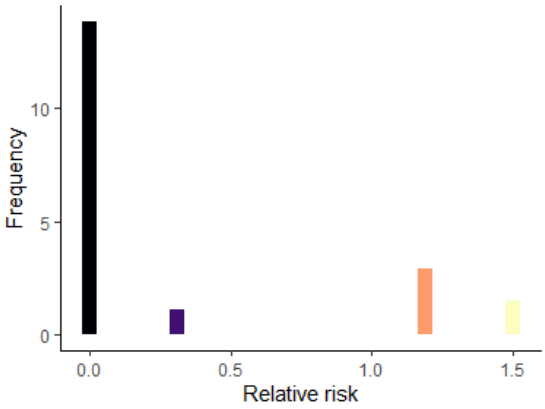
Cover1942

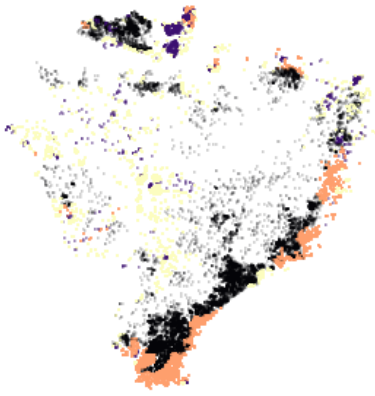
Range = 0
Weight = 1.5









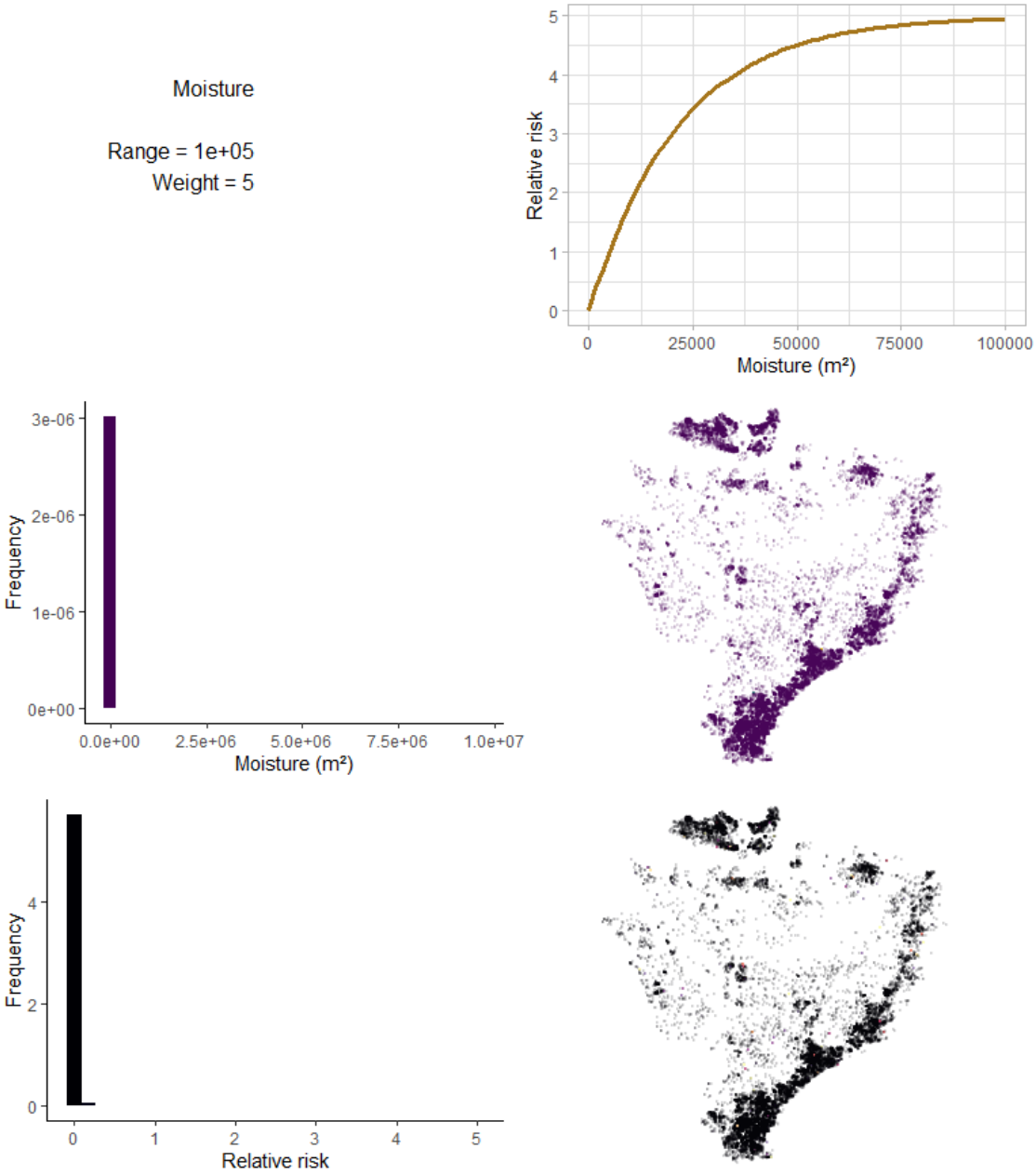


Details of the highest risk trees according to Cover1942, randomly ordered where the risk value is equa**l.**

TreeId	Northing	Easting	Cover1942	Risk value
11365	5899727	1802688	1	1.5
18187	5888316	1791959	1	1.5
17268	5888904	1797789	1	1.5
13828	5892612	1791735	1	1.5
10965	5901081	1802741	1	1.5
1052	5892503	1789678	1	1.5
12109	5897088	1790447	1	1.5
1194	5894414	1791729	1	1.5
11781	5898146	1786591	1	1.5
26607	5902832	1795071	1	1.5
7450	5905641	1793433	1	1.5
15505	5890472	1791792	1	1.5
11596	5898679	1784301	1	1.5
91	5895290	1791342	1	1.5
11671	5898437	1791521	1	1.5
7084	5905799	1788579	1	1.5
11370	5899714	1790564	1	1.5
7336	5905690	1793447	1	1.5
6327	5881609	1793569	1	1.5
9477	5903999	1792378	1	1.5

Moisture

Justification: *P. agathidicida* dispersal may be facilitated by ground and surface water flow.

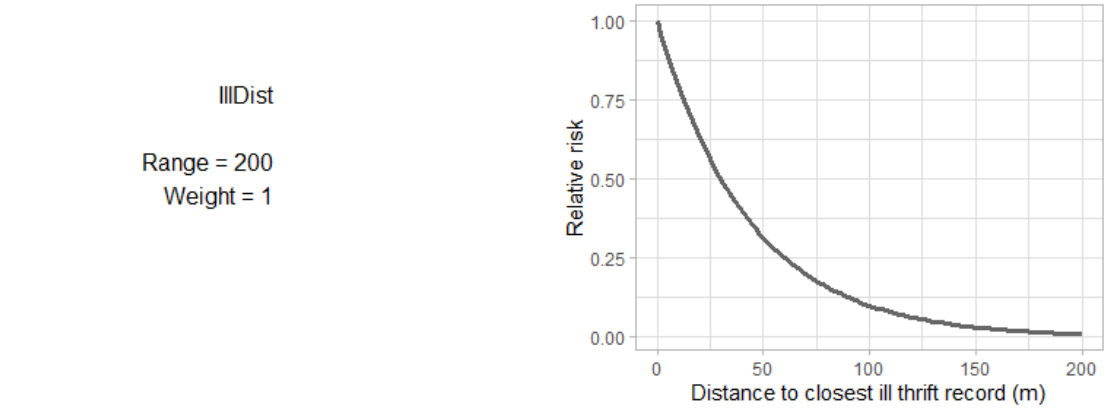


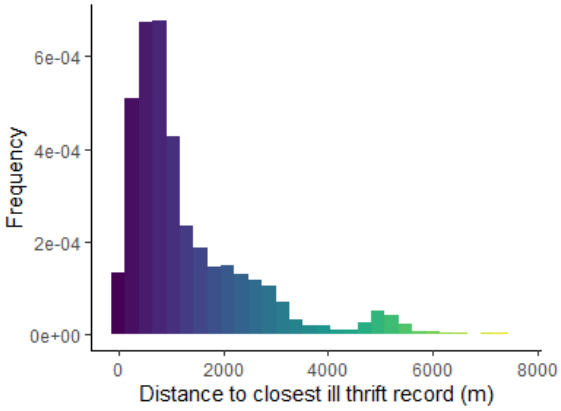
Details of the highest risk trees according to Moisture , randomly ordered where the risk value is equal

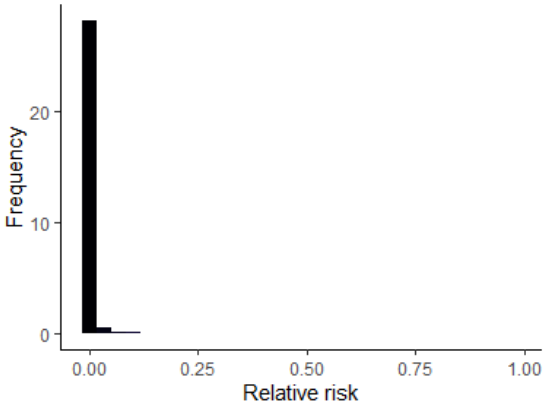
TreeId	Northing	Easting	Moisture	Risk value
2076	5904769	1793855	1002580.0	5.000000
761	5889577	1796604	9602480.0	5.000000
18827	5887317	1792546	1524780.0	5.000000
1945	5904142	1793093	920985.0	5.000000
18177	5888329	1792179	1443330.0	5.000000
19409	5886411	1792697	5762730.0	5.000000
11742	5898232	1800044	729150.0	5.000000
27294	5881619	1793724	411983.0	5.000000
10386	5901950	1798376	324687.0	4.999998
164	5897125	1802534	276185.0	4.999985
26070	5882102	1792796	248200.0	4.999945
26036	5882129	1792776	224648.0	4.999837
11210	5900223	1794818	195560.0	4.999380
2097	5896189	1802207	184546.0	4.998971
3378	5889535	1796308	180121.0	4.998739
397	5893458	1794770	153936.0	4.995796
8645	5905055	1789887	118305.0	4.978347
12621	5895136	1786086	111588.0	4.970507
3040	5892101	1800080	110776.0	4.969385
1376	5901652	1791927	89601.7	4.918914

Distance to closest ill-thrift record

Justification: Ill-thrift (suggested by soil samples being taken, or direct observation during AC helicopter survey) may indicate *P. agathidicida* presence.





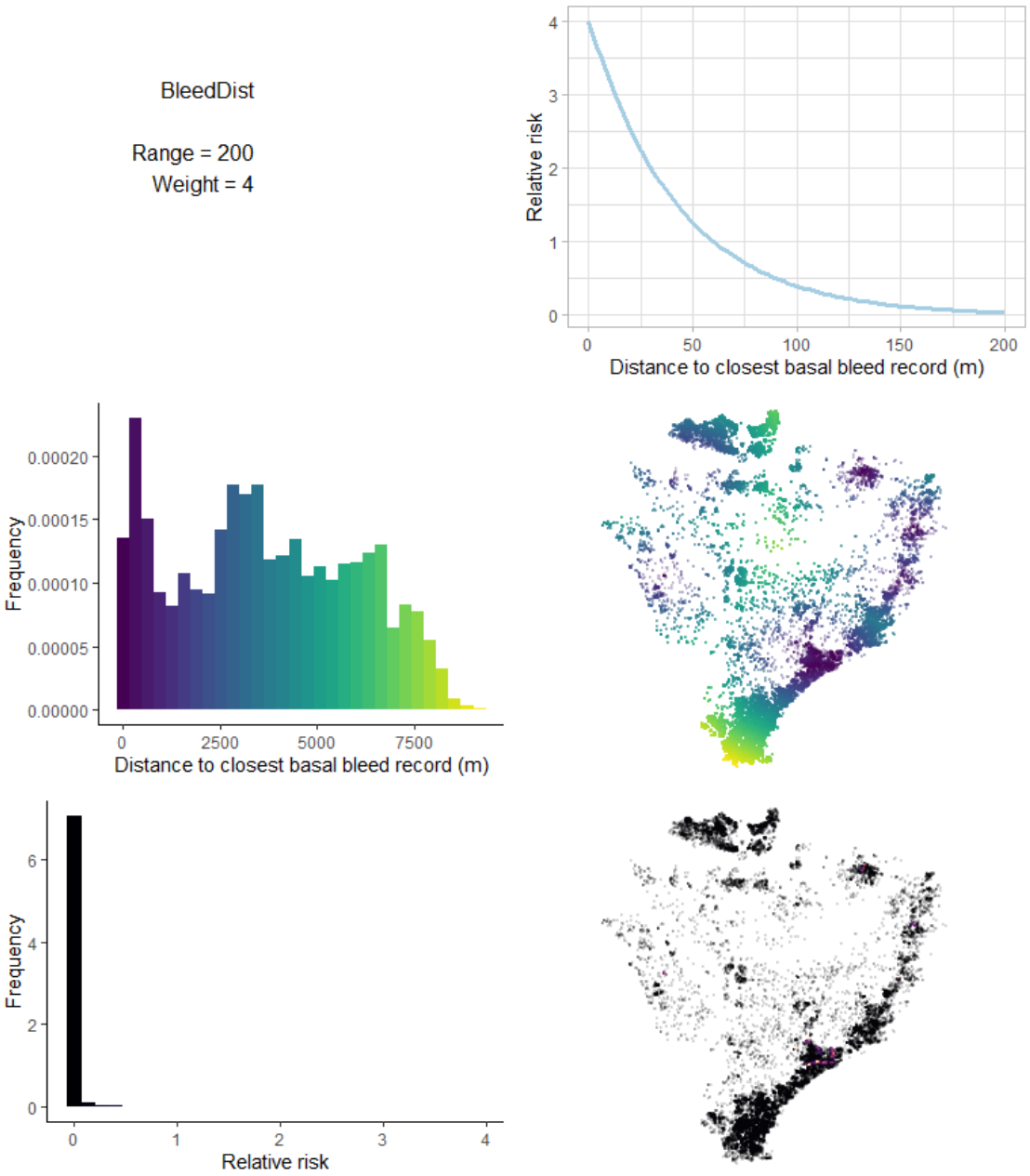


Details of the highest risk trees according to IllDist, randomly ordered where the risk value is equal.

TreeId	Northing	Easting	IllDist	Risk value
14665	5891321	1799660	1.09658	0.9750941
2795	5894092	1787200	1.56490	0.9646473
16374	5889490	1797281	2.05716	0.9537872
12554	5895287	1800645	2.06795	0.9535505
2726	5894990	1787567	2.24057	0.9497722
18938	5887081	1795107	2.27733	0.9489695
12552	5895293	1800648	2.41647	0.9459375
12546	5895303	1800659	2.55034	0.9430294
15920	5889979	1795815	3.16569	0.9297767
2798	5894085	1787198	4.66299	0.8983022
5861	5883851	1792121	5.20905	0.8870906
2727	5894990	1787575	5.82353	0.8746415
3498	5889266	1797313	5.84316	0.8742467
7123	5905783	1791263	5.90493	0.8730055
26830	5893278	1799135	6.45148	0.8621000
2694	5896085	1801177	6.70318	0.8571236
5888	5883840	1792120	6.96479	0.8519818
3135	5891320	1799654	7.05243	0.8502661
3500	5889265	1797305	7.23735	0.8466575
18080	5888425	1797260	7.58765	0.8398635

Distance to closest basal bleed record

Justification: Basal bleeds may indicate *P. agathidicida* infection.



Details of the highest risk trees according to BleedDist, randomly ordered where the risk value is equal

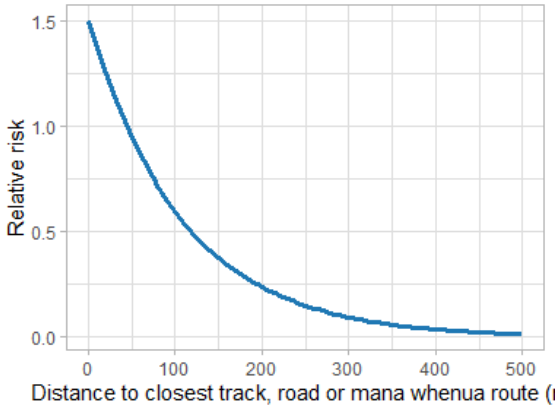
TreeId	Northing	Easting	BleedDist	Risk value
12819	5894676	1801125	1.00020	3.909032
26969	5888575	1796395	1.41421	3.871986
3294	5889976	1795792	1.43976	3.869711
705	5890053	1795888	1.61645	3.854017
16671	5889349	1797327	2.83217	3.747746
16810	5889204	1796549	2.84566	3.746583
3499	5889267	1797322	2.87772	3.743821
18150	5888365	1795941	3.01040	3.732414
16769	5889239	1797321	3.50750	3.689983
2734	5894979	1787565	3.87858	3.658624
3479	5889392	1797274	4.02175	3.646596
16939	5889091	1797347	4.03935	3.645120
17888	5888533	1796484	4.36771	3.617695
16334	5889512	1795154	4.59691	3.598674
17855	5888551	1796462	4.75911	3.585274
3478	5889399	1797277	5.09954	3.557311
954	5889107	1797337	5.32701	3.538749
3670	5888505	1796577	5.41533	3.531567
17800	5888578	1796401	5.67016	3.510929
2740	5894947	1787554	6.11172	3.475453

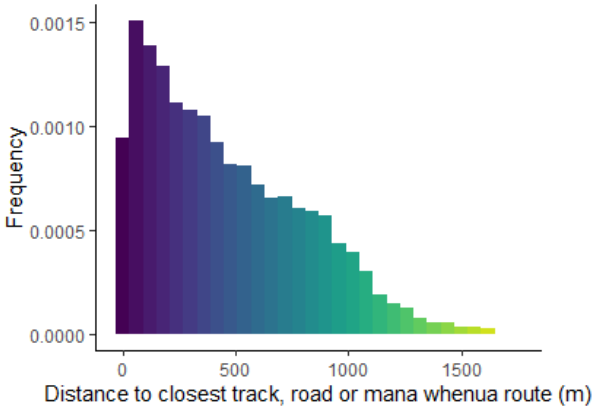
Distance to closest track, road or mana whenua route

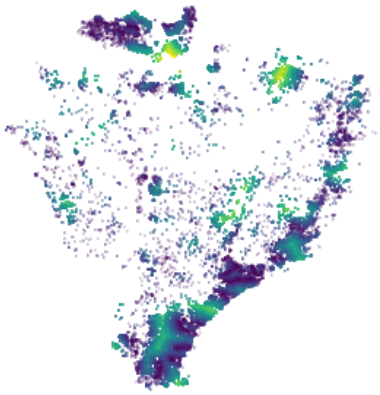
Justification: Waitākere survey indicated increased risk of *P. agathidicida* presence close to roads and tracks.

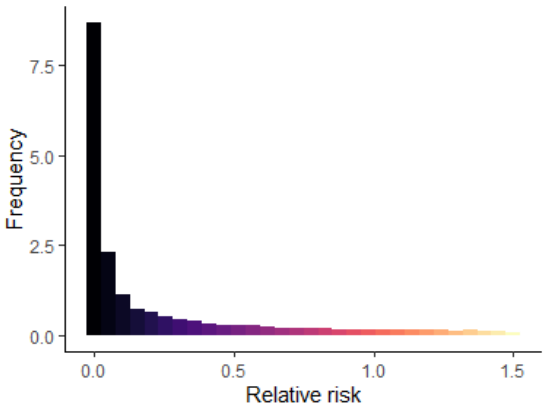
RouteDist

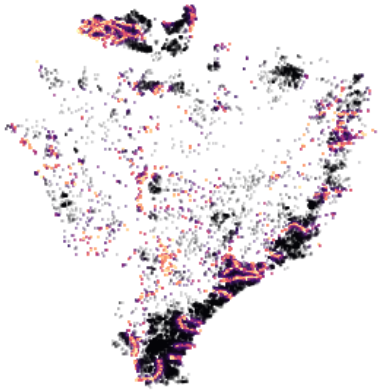
Range = 500
Weight = 1.5









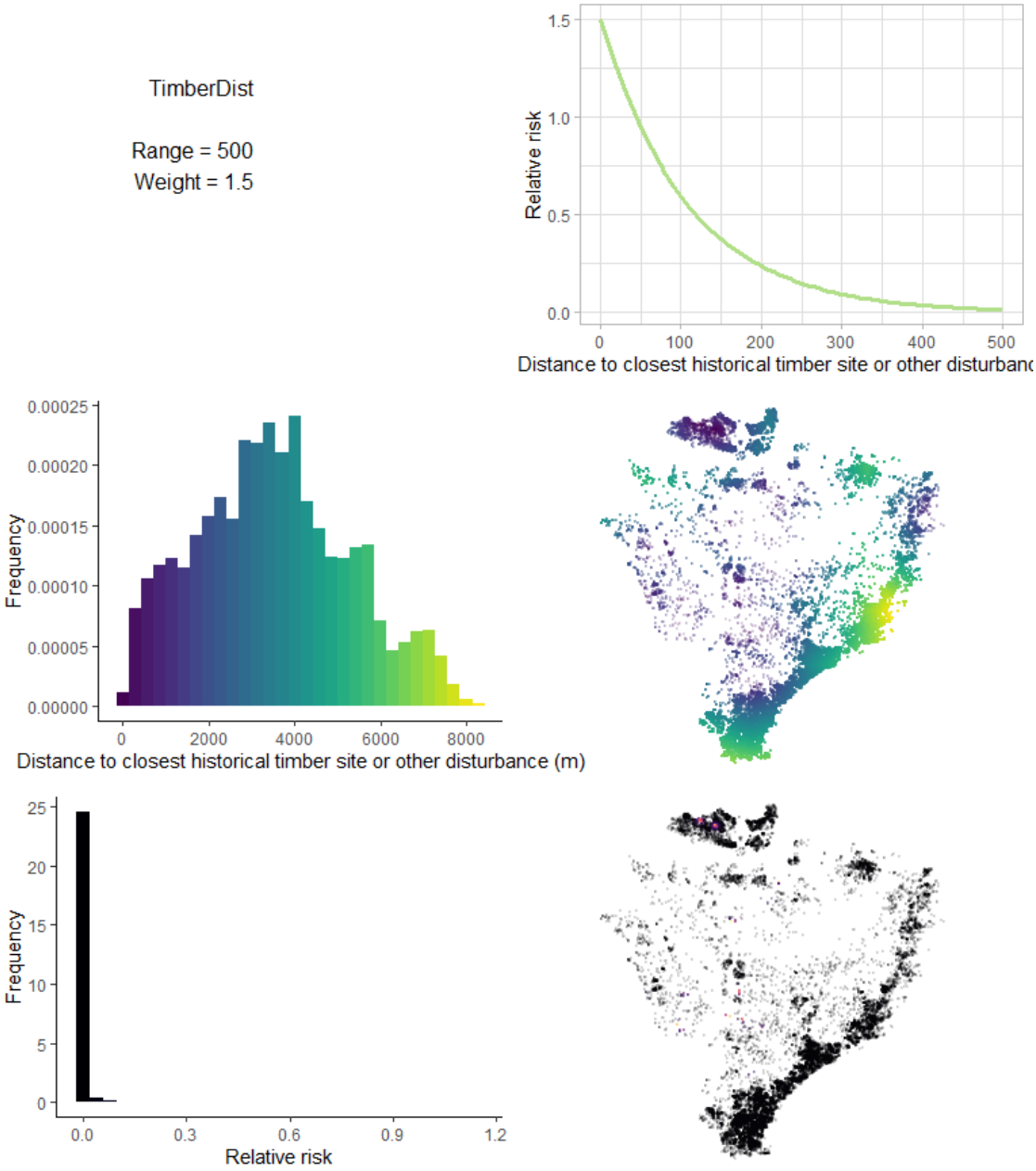


Details of the highest risk trees according to RouteDist , randomly ordered where the risk value is equal

TreeId	Northing	Easting	RouteDist	Risk value
628	5905785	1789248	0	1.5
18705	5887558	1791251	0	1.5
7815	5905507	1790704	0	1.5
8171	5905312	1790025	0	1.5
7184	5905751	1789217	0	1.5
12513	5895368	1785886	0	1.5
1654	5905403	1791055	0	1.5
8949	5904709	1789095	0	1.5
26938	5889225	1797320	0	1.5
8444	5905164	1787850	0	1.5
2095	5905535	1790897	0	1.5
8977	5904640	1788859	0	1.5
8165	5905317	1789072	0	1.5
18079	5888429	1796039	0	1.5
18696	5887569	1795735	0	1.5
6151	5883187	1793022	0	1.5
8028	5905401	1791060	0	1.5
24615	5883196	1792961	0	1.5
17000	5889041	1797686	0	1.5
17055	5889004	1795883	0	1.5

Distance to closest historical timber site or other disturbance

Justification: Waitākere survey indicated increased risk of *P. agathidicida* presence close to known historical disturbance sites.



Details of the highest risk trees according to TimberDist , randomly ordered where the risk value is equal

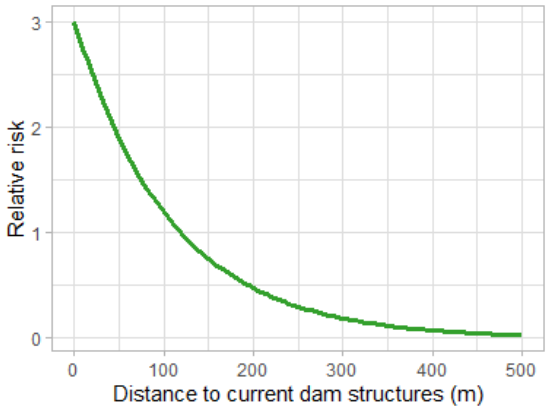
TreeId	Northing	Easting	TimberDist	Risk value
11671	5898437	1791521	29.7501	1.1408393
11669	5898440	1791515	31.2922	1.1247681
7279	5905713	1789668	31.6227	1.1213533
7308	5905700	1789675	32.8991	1.1082624
698	5901250	1794285	33.9649	1.0974486
7245	5905726	1789660	35.6323	1.0807421
14503	5891536	1791414	37.1799	1.0654636
15017	5890948	1788378	39.3541	1.0443633
8133	5905344	1790576	48.1278	0.9633768
8136	5905345	1790597	48.9123	0.9564488
7331	5905692	1789661	49.6355	0.9501062
7304	5905706	1789653	49.6863	0.9496623
2403	5905346	1790606	53.2896	0.9186967
2400	5905352	1790601	58.2095	0.8780407
2401	5905351	1790606	58.6725	0.8743086
2402	5905349	1790613	59.6626	0.8663807
26446	5905732	1789745	61.5349	0.8515850
26527	5905360	1790586	62.4666	0.8443167
26526	5905362	1790588	65.2789	0.8227517
7132	5905778	1789680	65.4885	0.8211667

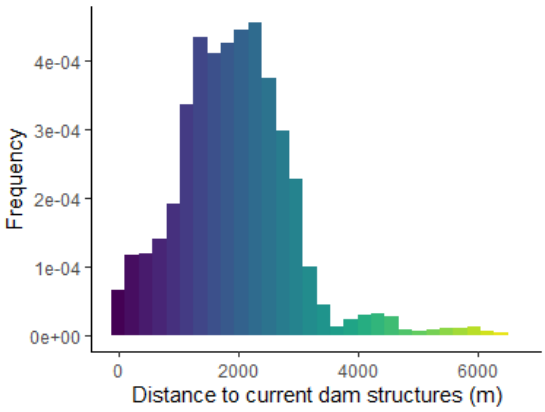
Distance to current dam structures

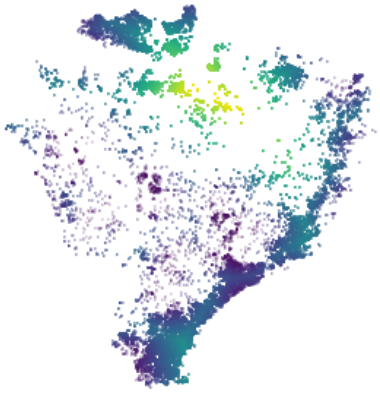
Justification: Waitākere survey indicated increased risk of *P. agathidicida* presence close to known historical disturbance sites.

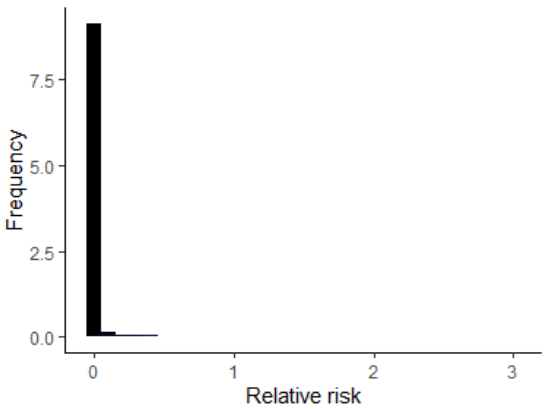
DamDist

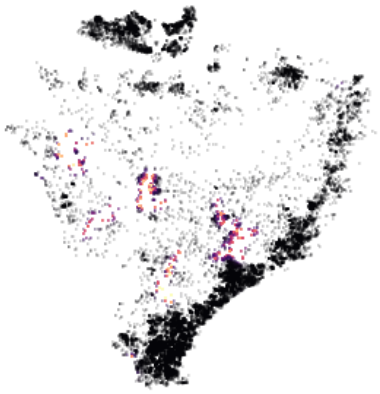
Range = 500
Weight = 3









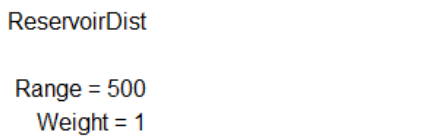


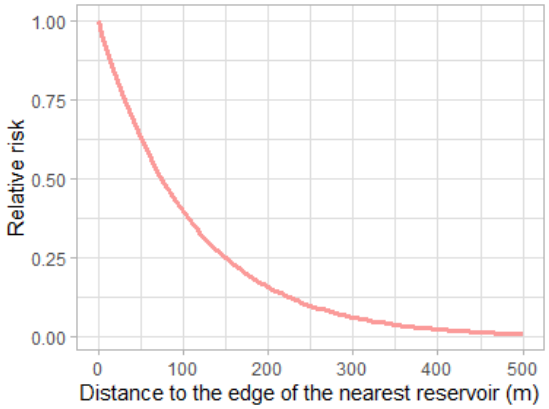
Details of the highest risk trees according to DamDist , randomly ordered where the risk value is equal

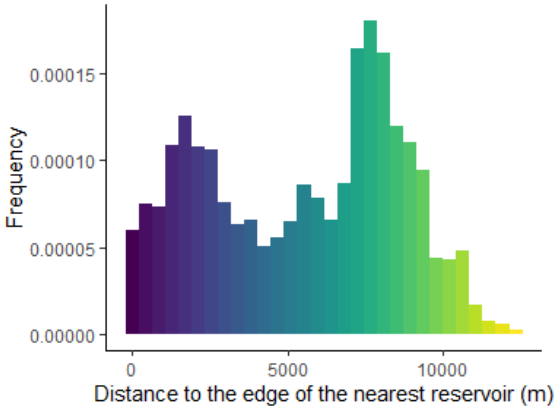
TreeId	Northing	Easting	DamDist	Risk value
18827	5887317	1792546	0.00000	3.000000
16496	5889440	1792835	0.00000	3.000000
18431	5887981	1792224	0.00000	3.000000
18834	5887294	1792545	0.00000	3.000000
18464	5887939	1792384	0.00000	3.000000
409	5887935	1792382	0.00000	3.000000
17340	5888858	1792739	0.00000	3.000000
18720	5887511	1792854	0.00000	3.000000
1189	5896283	1787553	3.39392	2.907775
12750	5894845	1791759	4.04481	2.890415
12778	5894781	1791741	5.48351	2.852409
12855	5894591	1791713	5.49298	2.852161
12760	5894819	1791739	5.70912	2.846495
12769	5894803	1791708	5.74825	2.845470
12146	5896855	1786862	5.87325	2.842200
12753	5894840	1791759	7.01564	2.812485
1970	5889275	1792671	9.08300	2.759498
2742	5894888	1791711	10.38630	2.726608
16734	5889277	1792670	11.14930	2.707535
12944	5894461	1791781	11.24980	2.705033

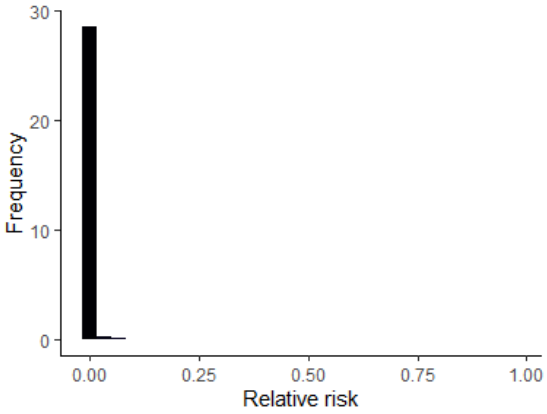
Distance to the edge of the nearest reservoir

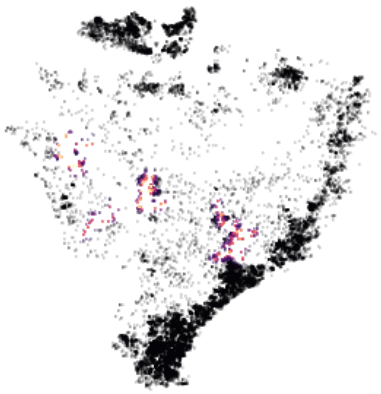
Justification: Waitākere survey indicated increased risk of *P. agathidicida* presence close to known historical disturbance sites.









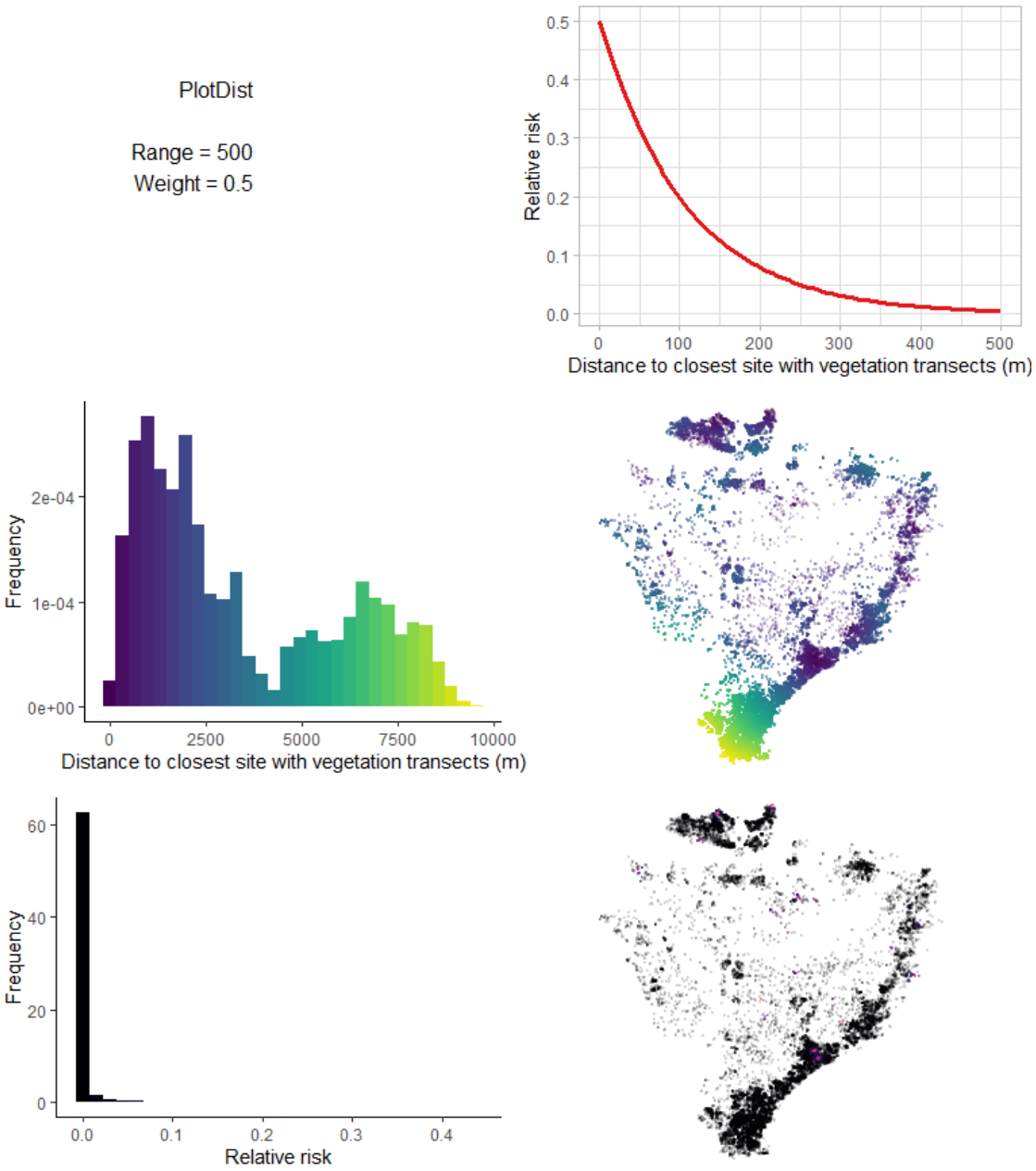


Details of the highest risk trees according to ReservoirDist , randomly ordered where the risk value is equal

TreeId	Northing	Easting	ReservoirDist	Risk value
1189	5896283	1787553	3.39392	0.9692584
12750	5894845	1791759	4.04481	0.9634716
12778	5894781	1791741	5.48351	0.9508031
12855	5894591	1791713	5.49298	0.9507203
12760	5894819	1791739	5.70912	0.9488316
12769	5894803	1791708	5.74825	0.9484901
12146	5896855	1786862	5.87325	0.9474000
12753	5894840	1791759	7.01564	0.9374950
2742	5894888	1791711	10.38630	0.9088693
12944	5894461	1791781	11.24980	0.9016777
12478	5895451	1791551	12.54760	0.8909759
3254	5890280	1795448	13.27270	0.8850520
12481	5895446	1791547	14.16940	0.8777807
2741	5894894	1791709	14.89110	0.8719719
12736	5894883	1791767	15.00000	0.8710987
12618	5895148	1791349	15.31020	0.8686163
14332	5891812	1796410	15.56580	0.8665761
13385	5893505	1791150	15.69290	0.8655634
12489	5895437	1791546	16.09320	0.8623816
12775	5894787	1791710	16.15810	0.8618668

Distance to closest site with vegetation transects

Justification: Visits to transects could have introduced *P. agathidicida* to the area.

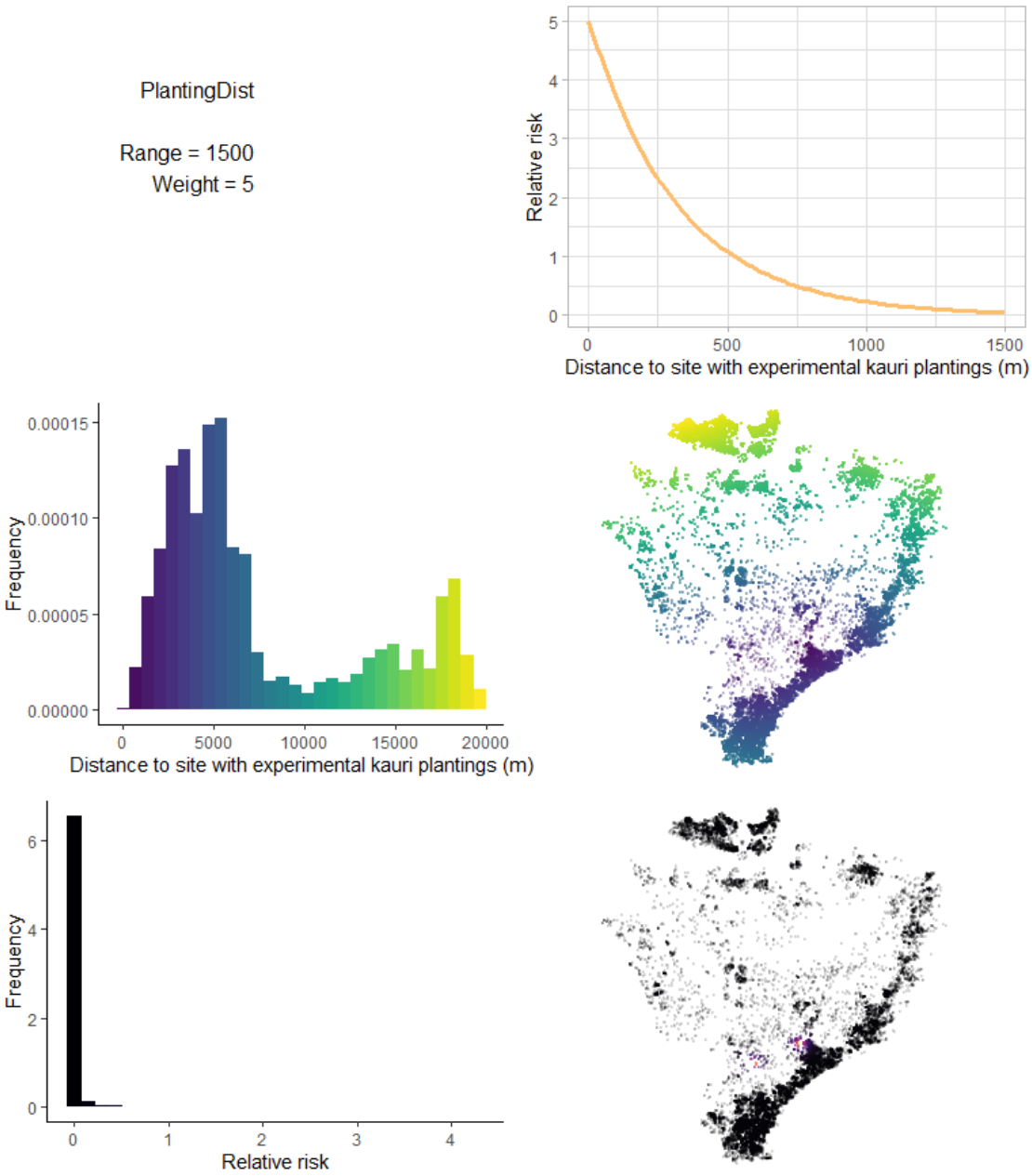


Details of the highest risk trees according to PlotDist , randomly ordered where the risk value is equal

TreeId	Northing	Easting	PlotDist	Risk value
17080	5888993	1796427	14.6260	0.4370506
17136	5888965	1796426	14.7665	0.4364860
17095	5888987	1796439	14.8086	0.4363170
6342	5906772	1793981	20.9761	0.4122492
18004	5888480	1796645	22.5845	0.4061939
17114	5888973	1796408	23.7069	0.4020211
320	5888470	1796641	24.3990	0.3994695
17112	5888981	1796451	24.8733	0.3977301
6341	5906776	1794022	26.3455	0.3923795
17140	5888963	1796410	26.4424	0.3920299
683	5892608	1793255	27.2173	0.3892450
17974	5888499	1796663	27.9834	0.3865112
18056	5888447	1796665	32.2761	0.3715443
3560	5888989	1796400	32.8364	0.3696340
17107	5888979	1796460	34.2908	0.3647210
6338	5906804	1794017	35.0036	0.3623371
18025	5888466	1796630	37.1261	0.3553304
17062	5889003	1796454	37.4158	0.3543846
17135	5888965	1796459	37.8903	0.3528409
3561	5888987	1796394	39.2336	0.3485072

Distance to site with experimental kauri plantings

Justification: Experimental plantings could have introduced *P. agathidicida* to the area.



Details of the highest risk trees according to PlantingDist , randomly ordered where the risk value is equal

TreeId	Northing	Easting	PlantingDist	Risk value
15996	5889935	1795403	51.8376	4.265116
3305	5889900	1795323	69.1427	4.044671
3306	5889883	1795317	77.6360	3.940684
1131	5888418	1792826	136.4540	3.290301
18086	5888420	1792828	137.8690	3.276054
18089	5888418	1792832	142.2650	3.232186
16118	5889794	1795289	146.5490	3.190000
18034	5888457	1792853	154.6490	3.111737
15950	5889956	1795254	177.7930	2.898537
15966	5889943	1795199	236.9270	2.417809
2016	5889945	1795589	247.6000	2.339954
16212	5889675	1795329	251.1980	2.314277
16021	5889915	1795609	267.3210	2.202633
3304	5889925	1795626	286.1270	2.079197
3303	5889926	1795630	291.5010	2.045212
16072	5889859	1795638	303.4150	1.971836
16049	5889883	1795649	309.0050	1.938322
15712	5890159	1795322	314.1110	1.908207
15699	5890167	1795311	325.7870	1.841090
16036	5889894	1795665	326.4680	1.837249

Alternative methods for selecting the highest risk trees for monitoring

Method 1: Selecting the highest risk trees

This method simply selects the 250 trees with the highest combined risk value from the thinned data set.

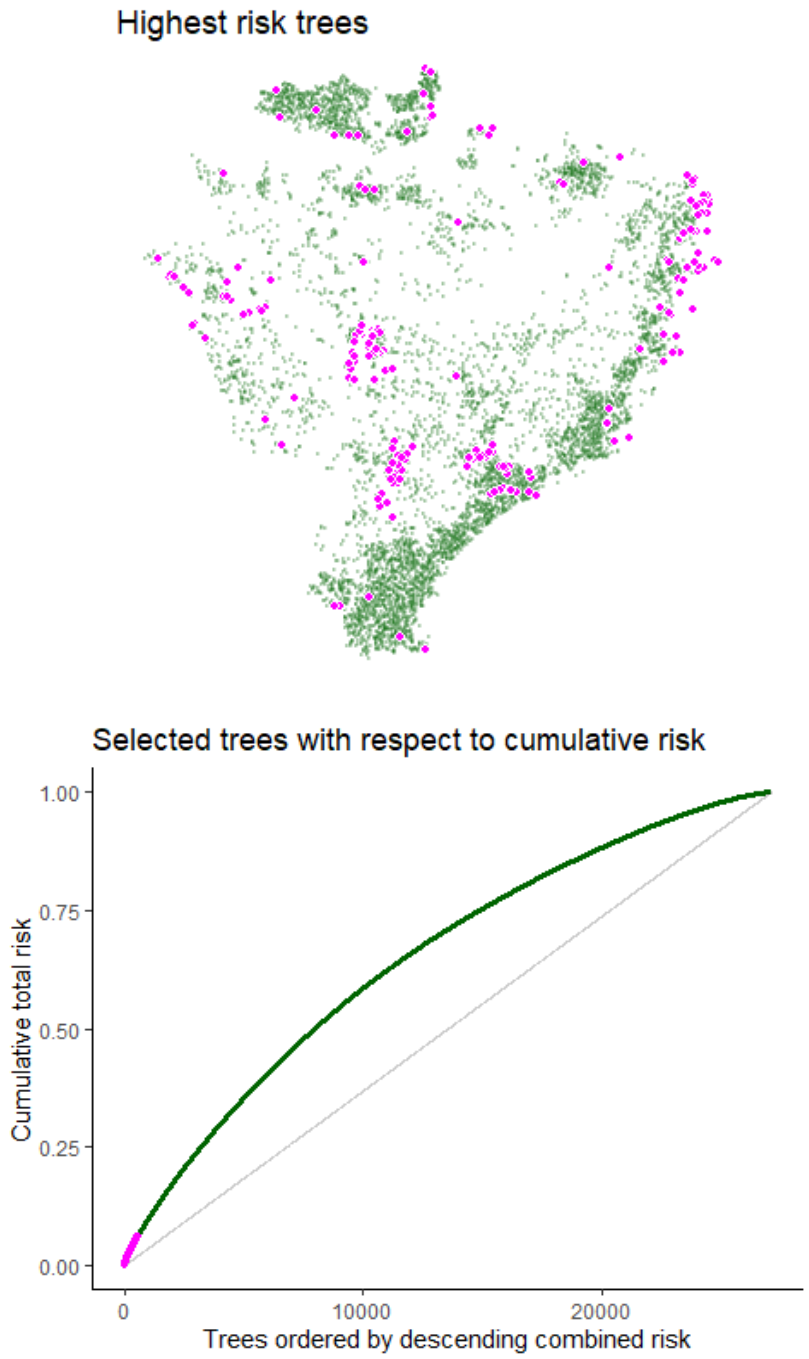
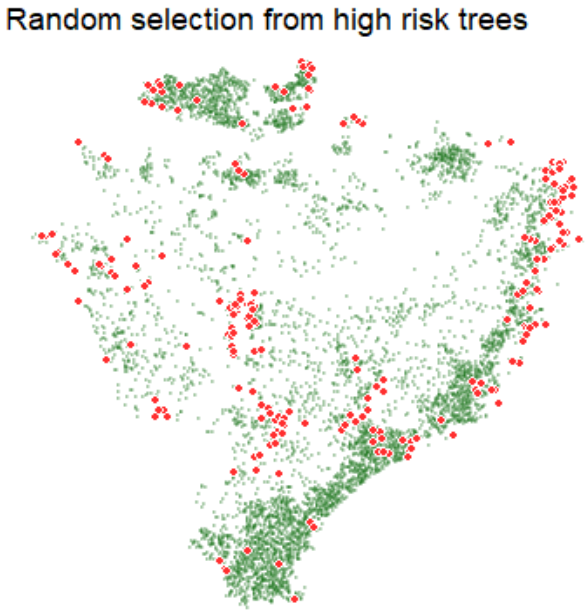


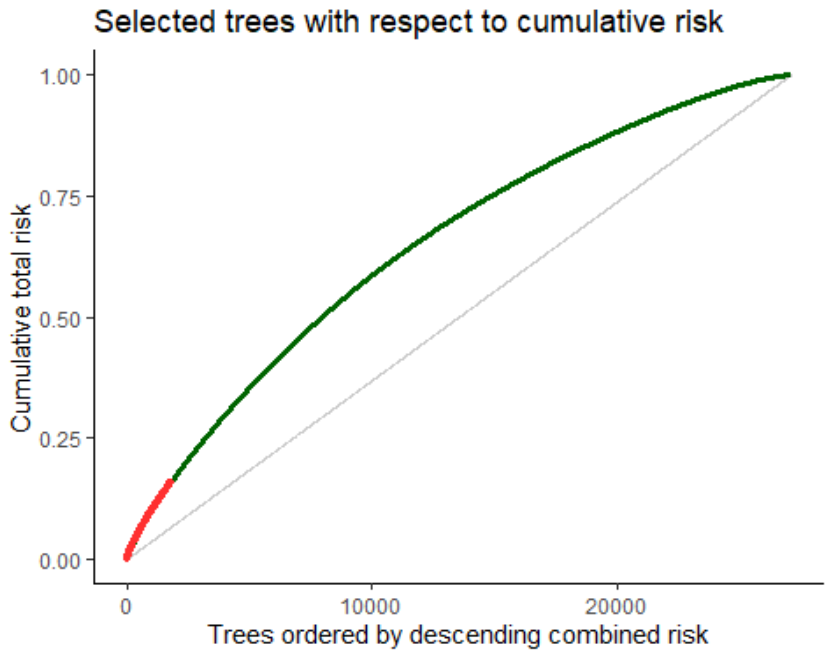
Figure A3. Relative contribution to overall risk in highest risk trees

Together with the random sample, these trees capture 5.4 per cent of the estimated total risk. For comparison, a random sample of that size would be expected to capture 3.4 per cent of the total risk.

Method 2: Selecting randomly from high-risk trees

This method selects 250 trees randomly from the 10 per cent of thinned trees with the highest combined risk scores. One such random selection is shown below.





Together with the random samples, these trees capture 4.7 per cent of the estimated total risk. For comparison, a random sample of the same size would be expected to capture 3.4 per cent of the total risk.

Appendix E. Detailed results from the monitoring survey

Table A6. Closest neighbour species from 551 monitored kauri tree sites.

Species	Common names	Count of sites
Phyllocladus trichomanoides	Tanekaha	220
Agathis australis	Kauri	113
Fuscospora truncata	Hard beech, Hututawhai	44
Knightia excelsa	Rewarewa	42
Kunzea robusta	Kanuka	33
Beilschmiedia tawa	Tawa	12
Pectinopitys ferruginea	Miro	11
Olearia rani	Heketara	10
Dacrydium cupressinum	Rimu	10
Pseudopanax crassifolius	Horoeka, Lancewood	9
Kunzea amathicola	Kanuka	6
Myrsine australis	Red mapou	5
Hedycarya arborea	Porokaiwhiri, Pigeonwood	4
Nestegis cunninghamii	Black maire, Maire	3
Didymocheton spectabilis	Kohekohe	3
Podocarpus totara	Totara	3
Pterophylla sylvicola	Towai	3
Nestegis lanceolata	White maire, Maire	3
Fuscospora solandri	Black beech, Tawhairauriki	2
Pterophylla racemosa	Kāmahi	2
Leucopogon fasciculatus	Mingimingi	2
Elaeocarpus dentatus	Hinau	1

Species	Common names	Count of sites
Dacrycarpus dacrydioides	Kahikatea	1
Melicytus ramiflorus	Mahoe	1
Melicytus lanceolatus	Narrow-leaved mahoe	1
Alectryon excelsus	New Zealand ash, Titoki	1
Rhopalostylis sapida	Nikau	1
Metrosideros robusta	Northern rata	1
Beilschmiedia tarairi	Taraire	1
Not recorded/unknown		3

Find out more: kauri@aucklandcouncil.govt.nz

or visit knowledgeauckland.org.nz and aucklandcouncil.govt.nz

Auckland Council
Te Kaunihera o Tāmaki Makaurau