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

2021 Waitākere Ranges Kauri Population Health Monitoring Survey

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Chapter 6

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

6.1 Strategy for implementation of the long-term kauri health monitoring framework

Te rautaki hei whakatinana i te anga karioi e aroturuki ana ki te hauora o te kauri

6.1.1 Landscape-scale kauri forest health monitoring

6.1.1.1 Introduction

The long incubation period of kauri dieback disease means that the temporal relationships between kauri health and the impacts of landscape scale mitigation measures such as rāhui and track closures may not show an association with change in disease for many years. Kauri health may get worse before any benefits of interventions are finally seen.

However, it is essential to obtain information on baseline kauri health so any change over time can be monitored and measurement of management intervention efficacy can be attempted. Understanding kauri forest health over time will allow associations with other potential drivers of kauri health to be monitored and assessed, such as changes in land use, management and climate over the long term.

6.1.1.2 Objectives

The key objectives of kauri forest-level health monitoring are:

- To identify the baseline prevalence of stress symptoms in kauri canopies caused by kauri dieback and other causes (e.g., drought) as a measurement of kauri health
- To monitor the change in kauri health over time against the baseline
- To identify kauri trees and kauri forest areas in the landscape that require management interventions based on these baseline and change measurements
- To measure the results of management interventions over time to inform adaptive management.

There are four key requirements to implement kauri forest-level health monitoring which are i) kauri mapping of the host population, ii) development of a stress index for kauri health monitoring, iii) methods to measure efficacy of landscape scale kauri protection interventions and iv) looking at long-term climate impacts on kauri forest health. There is also a development opportunity for mapping and monitoring the health of other native tree canopy species. The four key requirements and the recommended steps for each are described below.

6.1.1.2.1 Kauri population mapping

Building on the methods developed to detect kauri trees in Te Wao Nui ā Tiriwa / the Waitākere Ranges to monitor kauri health at the landscape scale across the wider Tāmaki Makaurau /

Auckland region, it is essential to map the kauri host population at risk in the forest canopy. The following steps are recommended:

1. Using the techniques developed for mapping the kauri population in the Waitākere Ranges, focus on mapping the kauri population in the Hunua Ranges, which contains the most extensive kauri forest in the Auckland Region where kauri dieback has not been found.
2. Build a kauri population map of kauri tree or stand locations defined by remote sensing and mapped for the forested and remnant kauri areas of greater Auckland. Target a minimum positive predictive value of 80% across size classes and disease statuses using existing and recently acquired remote sensing imagery.
3. Collect validation data on host detection and misclassification and undertake a diagnostic test performance evaluation on the sensitivity and specificity of the remote sensing 'test' for detecting kauri of certain characteristics.

6.1.1.2.2 Kauri stress monitoring

To set the baseline prevalence of landscape scale kauri health, methods to differentiate between kauri dieback induced stress vs drought or other canopy stress are needed. These remote sensing parameters can then be used to monitor change in kauri forest health over time. The following steps are recommended:

1. Develop a comprehensive geospatial kauri stress baseline index over the kauri extent layer (from above) for the Auckland region, where each pixel within a raster has a stress index value.
    a. Apply the Meiforth (2020) and Meiforth et al. (2020) developed methods of stress detection to set a geospatial baseline index of landscape scale kauri health based on this imagery.
    b. Build on the Meiforth et al. (2020) proof of concept methods to analyse canopy for stress symptoms in a wider range of kauri ecosystems.
2. Undertake research to assess change in health over time, acquiring repeated remote sensing imagery to provide the first comparison against baseline. With the aim of the research to assess if a change in stress can be detected, how a change would be measured and to recommend an appropriate frequency of assessment of change in kauri forest health (e.g., annually, two-yearly).
3. Undertake research to test if the Waitākere Ranges survey 2021 monitoring dataset can be utilised for disease vs drought stress validation.
    a. Use recently acquired host detection imagery to match monitored trees spatially.
    b. Use stress detection methods and the 2021 symptomatic kauri data to differentiate between kauri dieback induced stress vs drought or other canopy stress
    c. Use stress detection methods to assess any correlation between diseased trees and stressed trees (it is suspected that host stress increases disease).
4. Future research focus on whether localised periodic change in kauri dieback related stress indices can indicate areas of developing disease for early detection and pro-active management especially in disease-free areas.
5. Develop mātauranga Māori indicators as a complementary dataset to provide a future comparative baseline rooted in Te Ao Māori.
6. Repeat tree stress measurements to allow long-term climate impacts to be monitored across the forest.

6.1.1.2.3 Landscape scale kauri protection efficacy

To measure the efficacy of kauri protection measures over time (e.g., track closures, track upgrades, hygiene stations and phosphite treatments) the following actions are recommended:

1. Collate temporal and geospatial (time and place) data for all future kauri dieback mitigations. For example, hygiene stations are expected to protect forest that is contained within a specific track network. Geospatial layers need to be developed to show areas that are and are not protected by specific mitigations and for how long.
2. Wherever possible, collate historical geospatial and temporal data for kauri protection interventions (track upgrades, closures, rāhui, phosphite areas, pig control areas etc).
3. This data will eventually be able to be used to analyse kauri protection efficacy by modelling change in landscape-scale kauri health where interventions have and have not been applied long term.
4. Fully measuring efficacy of rāhui or other Māori cultural protection measures necessitates the development of mātauranga Māori indicators to supplement and corroborate other measures.

6.1.1.2.4 Long-term climate impacts on kauri forest health

It is reasonable to expect that the change in climate over the last 30-50 years may be contributing to 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). It is recommended that:

1. Botanical epidemiological modelling of climate and kauri dieback are considered using the landscape prevalence of kauri health, knowledge of soil moisture effects (Macinnis-Ng et al., 2013) and the biology of *P. agathidicida.*
2. Climate data are acquired for monitored kauri forests at suitable spatial and temporal scales in conjunction with stress index measurements.
3. Climate data are used to inform the stress index with a view to classifying between disease and drought.

6.1.1.2.5 Mapping and monitoring other tree species at the landscape scale

Outside the scope of this work is the opportunity to utilise the baseline remote sensing data to characterise other forest canopy species within Tāmaki Makaurau that are currently at risk (e.g., from climate change, or *Myrtaceae* species such as pōhutukawa and rātā, susceptible to myrtle rust) or become at risk in future biosecurity events and to assess full forest health.

6.1.2 Implementation of tree-level kauri dieback disease monitoring

6.1.2.1 Introduction

The 2021 Waitākere Ranges survey aimed to refine the methods to set baseline disease and pathogen prevalence values and collect risk factor and ecological impact data. Building on the successful completion of the 2021 Waitākere Ranges survey, baseline tree-level monitoring needs to be extended to other kauri areas within Tāmaki Makaurau. In addition, repeated monitoring of areas with baseline prevalence values to measure incidence (the number of new symptomatic trees developing over time) is required for adaptive management of kauri dieback and to investigate efficacy of management measures.

6.1.2.2 Objectives

The key objectives of tree-level kauri dieback monitoring are:

- To set the baseline kauri host population at risk across Tāmaki Makaurau
- To undertake randomised ground-based monitoring studies in kauri dominant forest areas across Tāmaki Makaurau to:
    - set baseline symptomatic kauri prevalence
    - describe kauri, symptomatic kauri (consistent with kauri dieback) and *P. agathidicida* spatially
    - describe the severity of kauri dieback
    - monitor change in disease incidence (new cases) and disease severity (basal bleed and canopy health scores) over time
- To collect tree-level kauri dieback risk factor and ecological impact data from high priority representative kauri dominant forests within Tāmaki Makaurau
- To use the baseline prevalence and repeated monitoring incidence measurements to inform, prioritise and investigate efficacy of management measures.

There are several key steps required to implement kauri tree-level disease monitoring across Tāmaki Makaurau. These include site selection, considering additions to the unit of interest, kauri mapping, sample size calculations, refinements to field monitoring, analysis of monitoring results and calculation of incidence risk, and additional exploration of risk factors and plot monitoring. The recommended steps are described below.

6.1.2.3 Recommended steps

6.1.2.3.1 Site selection

Priority sites for future baseline monitoring need to be selected in partnership with mana whenua.

6.1.2.3.2 Units of interest and host population at risk

The recommended unit of interest is individual kauri trees that have a diameter at breast height (DBH) of greater than 10 cm and tree height of greater than 15 m. These parameters were tested in the 2021 Waitākere Ranges survey and were concluded to be an appropriate representation of kauri for the purposes of constructing a sample frame using remote sensing to detect the host population at risk. As remote sensing techniques are further refined, it may be possible that shorter ricker trees within dense stands in immature forest areas can be detected. If this technology is validated by Manaaki Whenua – Landcare Research, then shorter trees that are greater than 10 cm DBH could be included in the sample frame for selection and monitoring. This will be particularly useful in areas that have large stands of immature kauri trees that could be represented in baseline monitoring.

6.1.2.3.3 Kauri mapping

To monitor change in symptomatic kauri prevalence over time, it is essential to map the kauri host population at risk in the forest canopy so a sample frame can be built for random selection of monitored trees. It is recommended to:

1. Set the baseline kauri host population at risk using remote sensing as described in section 6.1.1.2.1 (Kauri population mapping).
2. It is recommended that the kauri extent layer is confined to trees >15 m in mature or regenerating forest (i.e., kauri dominant forest) at this stage, due to methodological constraints.
3. If <15 m canopy kauri can be detected in the future (through other research) then it could be added to the kauri extent layer, and smaller trees could be incorporated into future monitoring rounds.

6.1.2.3.4 Field monitoring

The methods deployed during the 2021 Waitākere Ranges survey are recommended for future studies, with the following minor modifications.

1. Mātauranga Māori indicators should be developed to monitor individual trees (using the same trees) noting that this data would form a separate iwi-held but complementary database.
2. It takes two people one hour on average to sample individual trees (including access time), therefore the sample size can be confirmed prior to the start of monitoring. Overall sample time may be reduced if the host detection accuracy can be improved. Analysis of GPS tracklogs from the surveyors will also allow the most efficient trails between trees to be plotted to aid efficient navigation to trees and reduce forest disturbance during repeated surveys.
3. In the future, the minimum sample size should be the starting sample, and if time and resources allow additional samples can be added (through the same random selection process).
4. Observer training, data validation and checking for missing values or inconsistencies should be conducted in real time during a specified training and pre-testing period prior to the start of the main survey.
5. A revised monitoring form has been drafted based on the survey results and excludes variables that were difficult to measure consistently in the field (e.g., new growth flush and seed cones). It should also include distance to closest kauri tree (>10 DBH) to assist understanding the risk and rate of spread (S. Green, Forest Research, United Kingdom, pers. comm.).
6. New tests with known sensitivity and specificity can be incorporated into future monitoring and compared with existing data based on calculated true prevalence values (refer to Chapter 4).

6.1.2.3.5 Sample size

The frequency of potential risk factors (how common they are) and their effect sizes (calculated in the 2021 Waitākere Ranges survey, Chapter 3) informs the future calculation of sample sizes. As does the estimated symptomatic kauri or *P. agathidicida* prevalence of the forests to be monitored and the known sensitivity and specificity parameters of the *P. agathidicida* tests (Chapter 4).

The recommended sample size for future monitoring surveys (both repeated and baseline in new areas) should be based on these criteria:

1. The sensitivity and specificity (Se/Sp) of the visual assessment test and the soil bioassay test, along with the combined Se/Sp if both tests are interpreted in series (refer to Chapter 4).
2. Whether sites will be assessed for baseline disease and *P. agathidicida* prevalence only, or if risk factor analysis is required.
3. Future surveys should consider use of DNA-based testing such as LAMP, qPCR or meta-barcoding, however the sensitivity and specificity parameters should be known in advance or calculated on first use. Note: LAMP testing (Winkworth et al., 2020) and diagnostic test evaluation was planned during the 2021 Waitākere Ranges survey, but was not possible due to sample loss caused by a COVID-19 lockdown part-way through baiting.
4. If the forest ecosystems are very different to the Waitākere Ranges Regional Park, such as the Hunua Ranges and Hauraki Gulf Islands. In these cases collection and analysis of risk factors are recommended to find different contributors to disease or pathogen risk. The factors that are different between forests are of the most interest and their estimated prevalence will inform sample size requirements.
5. Prior estimates of symptomatic kauri prevalence informed by land managers and mana whenua.

6.1.2.3.6 Analysis of monitoring results

The baseline prevalence methods and the R-code to analyse and visualise the results (for *P. agathidicida* sites and for symptomatic kauri trees consistent with kauri dieback) has been developed for future monitoring.

Analysis of incidence risk for repeated monitoring methods are as follows:

Baseline symptomatic kauri prevalence for each survey period is calculated by dividing the number of trees that met the symptomatic kauri criteria by the total number of trees selected in the survey period (Equation 1).

$$\text{Prevalence} = \frac{\text{Symptomatic kauri}}{(\text{Symptomatic kauri} + \text{Not Symptomatic kauri})} \qquad \textbf{Equation 1}$$

Because spontaneous or treatment assisted recovery is not known to occur, the incidence risk (also referred to as cumulative incidence) is calculated by counting the number of new cases of diseased trees (incident cases) that were not diseased (i.e., healthy or ill-thrift) at the start of the period and dividing that number by the number of trees initially at risk (Equation 2). If recovery is found to occur in the future, then that can be incorporated into the calculation as those trees return to the at-risk group when no longer diseased.

$$\text{Incidence risk} = \frac{\text{Number of new symptomatic kauri (incident cases)}}{\text{Number of trees initially at risk}}$$ **Equation 2**

Incidence risk can be compared between management areas such as stream sub-catchments where sufficient samples are available.

6.1.2.3.7 Additional monitoring and exploration of risk factors

The results of the multivariable modelling showed associations with several risk factors both for *P. agathidicida* and symptomatic kauri prevalence. The strongest relationship for symptomatic kauri was distance from *P. agathidicida* sites, confirming the known causal relationship with *P. agathidicida* and kauri dieback. Results from the prevalence study showed that observed disease is likely to be multifactorial and that while *P. agathidicida* is necessary to cause kauri dieback, it is not sufficient to cause disease without other contributing factors. We also found that symptoms consistent with kauri dieback were observed in areas where *P. agathidicida* was not detected. Further research is required to find other causal explanations for these symptoms and to refine the case definition to exclude misclassification of stressed trees from other causes.

Due to the cross-sectional study design (i.e., the dataset only provides information about symptom or pathogen status at a single point in time) in some instances it is not possible to infer a temporal and therefore potentially causal relationship for associated variables. The intent of a cross-sectional study is to describe disease and risk factors in space and time to generate and test hypotheses on associations and discuss what the causal relationship may be to inform possible management interventions. Interventions are easier for anthropogenic risk factors than for non-modifiable environmental risk factors. Therefore, each associated variable (both strongly associated and of note variables) will need to be assessed to decide what, if any, further management or research could be taken based on the evidence. For example:

1. Can the risk factor be managed in any way?
2. Is the association strong?
3. How frequent is the risk factor within the kauri tree population?
4. Is pro-active management of the risk factor warranted to reduce risk?
5. Is further research required to understand the causal relationship of the risk factor?
6. What risk factors were suggested, but not able to be measured?

An example of the latter is pig disturbance. It will be useful to work with ecologists to design a way to collect pig density data for future studies. For example, while we included a monitoring form variable asking if the roots had been disturbed around the monitored tree, this missed the field observation of significant pig sign in some areas of the Waitākere Ranges. One option for measuring this would be to record way-points for every pig sign while navigating to the monitored tree and convert that into a spatial pig-sign density value per management area (e.g., stream sub-catchments), which has been undertaken in earlier studies (Auckland Council, 2010). Collection of pig faeces for laboratory analysis could also be included in field monitoring (e.g., DNA fingerprinting of individuals).

In addition to adding mātauranga Māori indicators to repeated cross-sectional ground monitoring surveys, there is an opportunity for iwi to develop mātauranga Māori indicators that require more frequent or seasonal measurement to monitor individual indicators (e.g., birds) around monitored kauri trees (potentially using a subset of the same trees) noting that this data would also form a separate iwi-held but complementary database.

A mixed-model approach of tree-level and plot-based kauri dieback monitoring was initially proposed, however, due to time and economic constraints, plot-based sampling was not included in the 2021 Waitākere Ranges survey. The advantage of tree-level monitoring was that we could quantify prevalence of *P. agathidicida* and symptomatic kauri across the forest, undertake diagnostic test evaluation and generate hypotheses about risk factors across the entire study region. This made the method more cost-efficient. The Kauri Protection Agency has indicated it may fund plot-based sampling and these results will indicate if it would be useful to extend into Tāmaki Makaurau. If this is not undertaken, then consideration of the value and costs of intensive field plot surveys for the Auckland region should be explored to support ecological impact assessment which is more suited to a plot-based approach. A potential methodology to build on existing data from the prevalence and risk factor surveys would be to apply a forestry plot-based methodology using the central point of the monitored kauri tree to centre a 20 m x 20 m plot. Where monitored plots that contain kauri already exist in the Waitākere Ranges, it is recommended to force their selection during sample selection, so that historical records can be included. These intensive survey plots would provide evidence of ecological change over time which will give a finer understanding of ecosystem impacts such as kauri loss in the forest.

6.1.3 Implementation of pathogen freedom and disease freedom surveillance

6.1.3.1 Introduction

Site-level *P. agathidicida* pathogen freedom and tree-level kauri dieback disease freedom surveillance is aimed at early detection of *P. agathidicida* in areas previously thought to be free of the pathogen (including high value areas), and early detection of kauri dieback in high value areas previously known to have *P. agathidicida* present but not exhibiting significant disease. This will inform protection areas, ongoing pathogen spread prevention, and the investigation and management of new outbreaks.

Freedom surveillance will be useful in three scenarios where:

1. *P. agathidicida* has not been detected and symptomatic kauri trees are absent or rare
2. Symptomatic kauri trees are present but *P. agathidicida* has not been detected from sampling
3. *P. agathidicida* has been detected, but kauri dieback is absent or rare

The key questions that were identified based on these three scenarios were:

- Where are kauri present and absent in the forest area?
- Where is *P. agathidicida* present and where is it absent and how certain can we be about this?
- Where are symptomatic trees and non-symptomatic trees?
- What would risk-informed buffer zones look like?
- Where should vector management be applied (human and animal)?

An example would be the south-east area of the Waitākere Ranges Regional Park where symptomatic kauri trees consistent with kauri dieback were recorded but *P. agathidicida* was not detected. Questions that are raised by this result are:

- What management decisions could be made in this area?
- How could pathogen freedom surveillance support these decisions?
- Should protection from *P. agathidicida* spread into this area be attempted?
- Are trees that are exposed to other component causes of disease (risk factors) more vulnerable to the introduction of a severe pathogen like *P. agathidicida*?
- Could this area be restricted for access other than for pest control and increased pig culling and/or exclusion?
- Would pathogen freedom be needed to continue support for ongoing restrictions, and how often (burden of proof for public support of interventions)?
- Would pathogen freedom surveillance be deployed for early detection of *P. agathidicida* into the area so rapid treatment could be applied to contain spread?

6.1.3.2 Objectives

The ultimate aim of freedom surveillance from a practical management perspective 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.

Freedom surveys build on knowledge from the higher levels of the long-term monitoring framework. They rely on kauri mapping of the host population from the kauri forest level monitoring, and understanding the baseline disease and pathogen prevalence, and risk factors of selected areas from tree-level baseline prevalence monitoring. The key development steps required to implement risk-based freedom surveys include sample selection and sample size calculations and development of risk maps in kauri dieback-free areas.

It is recommended that baseline tree-level disease and pathogen prevalence and risk factor monitoring is conducted in selected sites first and then freedom surveillance is implemented in forests where no disease and/or *P. agathidicida* is detected. Where disease or *P. agathidicida* is detected, then repeated monitoring for incidence is required rather than freedom surveillance. Frequency of monitoring or freedom surveillance will be objective dependant but is estimated to be approximately five yearly.

The development areas and the recommended steps for sample size and selection and risk maps are described below.

6.1.3.3 Recommended steps

6.1.3.3.1 Sample selection and sample size

For kauri dieback, risk-map based freedom surveillance trees for inclusion in surveillance change over time. This is based on the value of the information that they contribute to understanding disease freedom. The risk factors identified from the tree-level cross-sectional observational study will help to identify the trees most susceptible to becoming infected in areas thought to be free of the disease. Sampling would initially focus on these trees, but because we believe kauri dieback spreads and develops slowly over many years, these trees would provide relatively little new information if re-sampled the following year. Therefore, the model for risk of infection will also incorporate the sampling history of individual trees (and stands, if disease is found to cluster) to identify those that contribute the most to proof of freedom.

The diagnostic test performance evaluation has provided estimates of the sensitivity and specificity of visual assessment and the soil sampling bioassay. These parameters, along with results of prevalence surveys for disease and pathogen, along with risk factor frequencies are used to calculate the sample size required to be 95% confident that *P. agathidicida* would be detected if it was present at a set design prevalence such as 5%.

The parameters can be used to estimate the prevalence level of *P. agathidicida* above which there would be 95% confidence of detection in an area that has been surveyed using the soil sampling bioassay test. A real example from an area of the Waitākere Ranges Regional Park where symptomatic kauri were recorded, but no *P. agathidicida* was detected during the 2021 survey can be used to illustrate sample size calculations using the soil sampling bioassay sensitivity value and the AusVet Epitools calculator (https://epitools.ausvet.com.au/herdsensfive) (Figure 6-1). There were an estimated 12,680 kauri trees in the polygon depicted in Figure 8 which were at least 500 m from any known *P. agathidicida* site, of which 125 were soil sampled. Using the Se parameters of the soil sampling bioassay test, we can be 95% confident that *P. agathidicida* was not present at a prevalence of 3.8% or 90% confident that *P. agathidicida* was not present at a prevalence of 2.9%. Note that this assumes random, representative sampling in a study designed for detecting freedom, and where the distribution of positives would be homogenous.

Figure 6-1. Map showing point locations of 125 soil samples collected from an area (inside the polygon) of the Waitākere Ranges Regional Park containing an estimated 12,680 kauri trees where *P. agathidicida* was not detected during the 2021 Waitākere Ranges survey.

6.1.3.3.2 Kauri host and risk maps for sample selection

To undertake risk-based disease or pathogen freedom surveillance, two types of maps are required. Firstly, the host population at risk needs to be mapped. Then, a series of risk map layers should be overlaid onto the host map. The risk maps show the spatial distribution of the risk factors identified in Chapter 3 (refer to Appendix G as an example from the Waitākere Survey). The spatial distribution of risk factors would be collected from field survey or GIS data during ground-based baseline prevalence monitoring. Future research under Ngā Rākau Taketake could inform additional risks and improve selection of sample sites.

An example of predicted probability maps for the Waitākere Ranges were constructed from the multivariable modelling (Chapter 3) and give an indication of what the risk maps may look like for other areas. The predicted probability in Figures 5 and 6 indicates the chance of a representative kauri having each outcome (disease or *P. agathidicida*) if there was a tree with DBH of 80 cm and the distance to the closest neighbouring tree of 2 m for both models and with tanekaha nearby for the *P. agathidicida* model only. These figures should be used as illustrations only as the model predicted probability does not consider any bias, such as the weighted sampling in a pre-known kauri dieback prevalent area at the early stage of sampling (only in the disease map), thus the maps may over- or under-represent the reality.

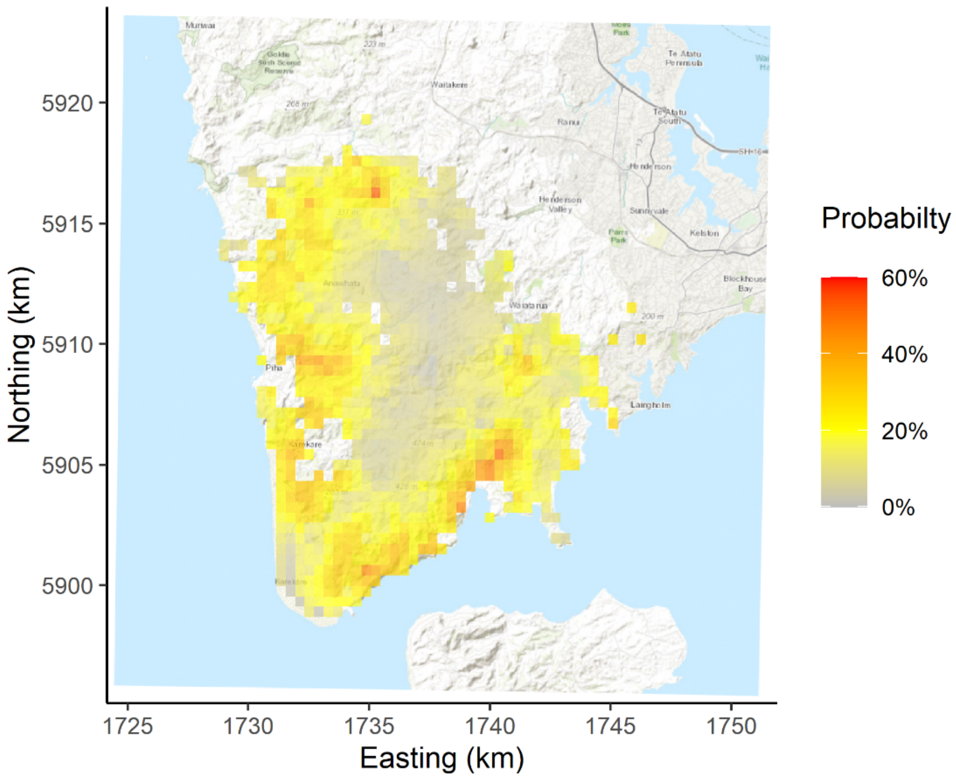

Figure 6-2. Predicted probability of symptomatic kauri presence for a representative kauri across the Waitākere Ranges study area.

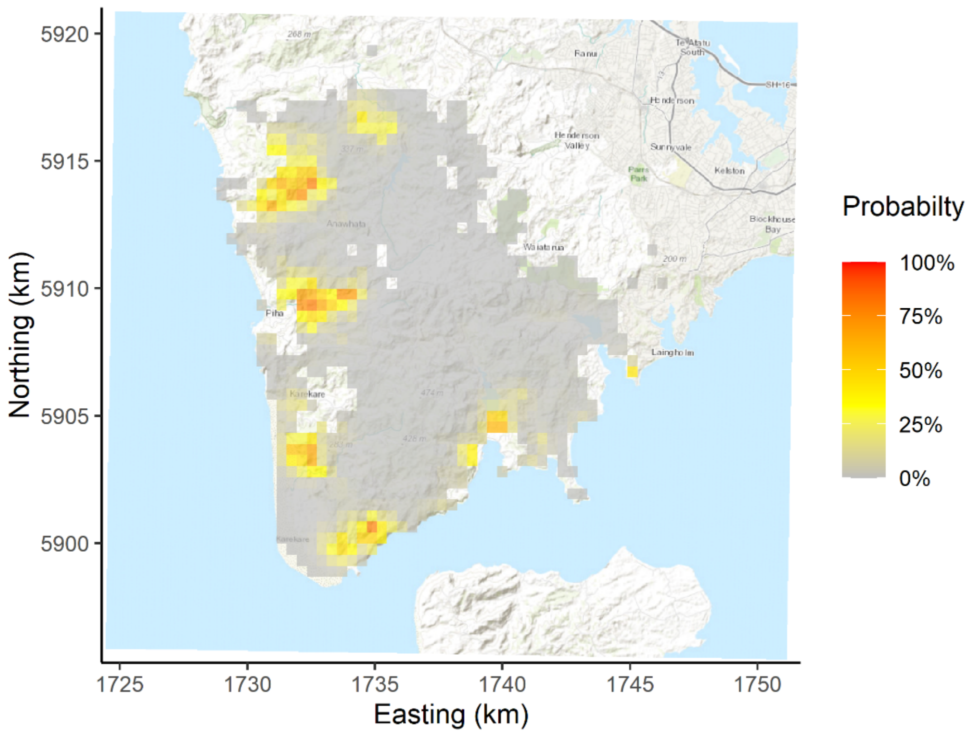

Figure 6-3. Predicted probability of *P. agathidicida* detection for a representative kauri across the Waitākere Ranges study area.

Prevalence ratios inform the surveillance effort and location (high risk sites) and the test performance parameters (sensitivity and specificity) inform the sample size. Samples are taken at the highest risk sites and the results support absence from pathogen or disease at lower risk sites without the cost of surveying them. In the future the kauri health stress index may also contribute to the risk map, identifying areas of higher disease risk.

As an extra step, forest maps should be assessed to see if the host population kauri map and the high-risk areas fully overlap or if the high-risk areas form discrete areas within the extent of kauri forest. Where they are discrete it is most efficient to undertake risk-based freedom surveys. However, where they fully (or mostly) overlap then it is better to undertake repeated prevalence monitoring as there are no target areas of risk to base freedom surveys on. Both use a randomisation of samples across either the host population surface (prevalence survey) or the relative risk surface (freedom survey).

A potential limitation of extrapolating the symptomatic kauri and *P. agathidicida* risk models from the 2021 Waitākere Ranges survey to other areas is if forests have different spread mechanisms. In that, the model may not apply to an area where *P. agathidicida* is absent as it is driven by within forest spread variables that may not be relevant. For example, earthworks introducing *P. agathidicida* vs pigs spreading *P. agathidicida* within the forest. Therefore, the baseline *P. agathidicida* site prevalence and the symptomatic kauri trees consistent with kauri dieback prevalence needs to be known in advance.

6.1.4 Conclusion

Finally, the results of the 2021 Waitākere Ranges survey have moved our understanding of both the presence of *P. agathidicida* in the forest and role it plays in the distribution of symptomatic trees. We have new information on factors associated with higher prevalence which we can apply to new areas to inform risk-based monitoring and we have an estimate of the diagnostic test parameters for our tests, which allow us to estimate the sample size for future surveys. We have also proven the value of using remote sensing to build a kauri extent map as the anchor to build our surveillance designs.

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