Appendix A

Monitoring form and detailed methods for study variables

Te puka aroturuki me ngā tikanga whai taipitopito mō te inenga me te tātaitanga o ngā taurangi mātai

A1 Use of monitoring form

Te whakamahinga o te puka aroturuki

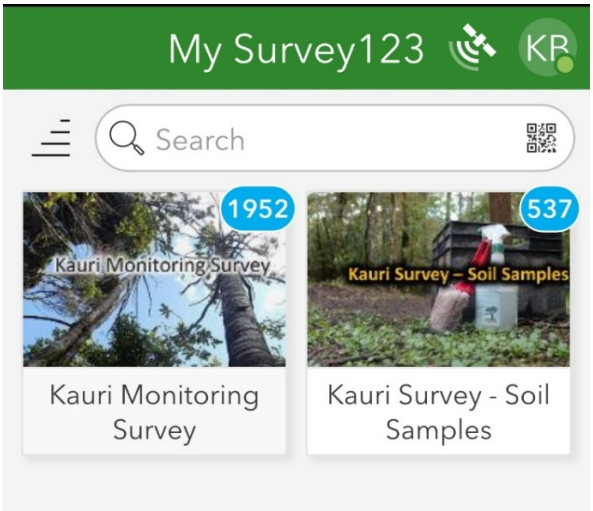
The survey had three form types over the full period of data collection (Table A-1).

From the survey start date of 8/3/2021 through to 23/4/2021, the kauri survey form was completed for all assessed trees. However, following a stop-go point reviewing the time taken to monitor each tree, the sample size was reduced from an original 3500 to 2500 trees on 28 April 2022, which remained within the lower sample size estimate. The number of ecological impact variables assessed per tree were also reduced for all non-soil sample trees following the review (Table A-1).

Table A-1. Survey forms in use during the Waitākere Ranges baseline monitoring survey.

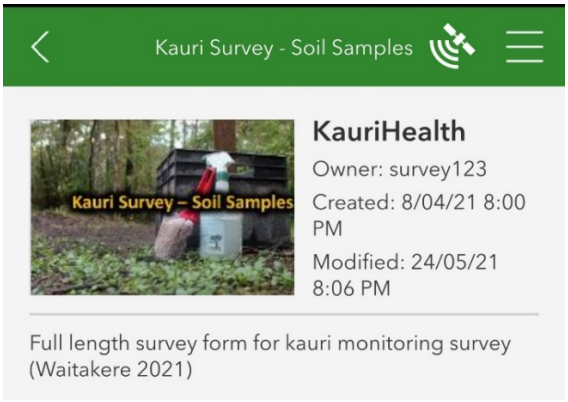
Survey form name	In use period	Usage	Contents
Kauri Monitoring Survey	8/3/2021 to 23/4/2021	Full data collection for all trees	Disease outcomes, potential risk factors, ecological impacts
Kauri Survey – Soil Samples	28/4/2021 to 8/7/2021	Full data collection for soil sample trees only	Disease outcomes, potential risk factors, ecological impacts
Kauri Monitoring Survey	28/4/2021 to 8/7/2021	Partial data collection for non-soil sample trees	Disease outcomes, potential risk factors

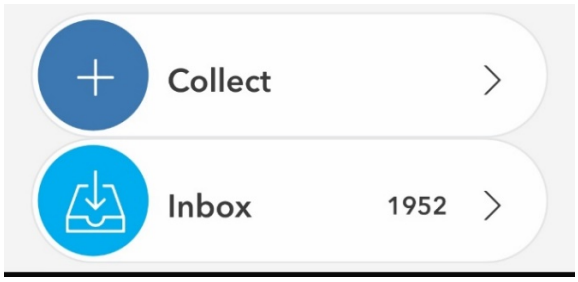
To start the survey, surveyors initially selected the Kauri Monitoring Survey form. After 24 April 2021, they selected either the revised Kauri Monitoring Survey form, or if the Point of Interest (POI) indicated a soil sample was required, the Kauri Survey – Soil Sample survey as below.



The main kauri monitoring survey was used for the majority of trees and collected baseline measurements for potential risk factors and disease outcome variables. The survey entry requirements and measurements for all risk factor and disease outcome variables were replicated in the soil sample survey form. In addition, trees that were selected for soil sampling had additional baseline measurements for ecological impact variables. These additional variables are annotated below as “Soil sample only”.

Upon selection of the correct form, the surveyor could open the inbox and be guided to the nearest tree to their GPS position. If the tree was not an assigned POI, for example when the original POI was found to not be a kauri and the surveyor had to collect survey information on a replacement tree, the surveyor could open a new observation by selecting ‘Collect’.





When opening the 'Inbox', all of the GPS points of the selected nearby trees are shown if 'Map' view is opened. This function of Survey123 did not work all the time, as the map disappeared outside areas with no mobile data reception. When this occurred, the accuracy of locating the preselected POI may have been affected as surveyors had to use a hand-held GPS with no aerial photos of the site to guide them to the specific tree.

It is recommended that all hand-held units are capable of pre-loading all sites and maps, if possible, to enable flexibility of operational deployment into different areas depending on conditions (e.g., potential for rain and terrain constraints).

Areas were assigned to each team for survey based on an achievable planned route through the forest for the day (using large A0 maps and smaller A4 booklets of more detailed topographical maps of each area) and the preloaded GPS points on the surveyors' hand-held GPS unit. The planned route was based on prior knowledge of areas to be visited from experienced BioSense staff, in that if there is known kauri dieback in an area, those trees would be visited later in the day to minimise transmission of *P. agathidicida* to non-symptomatic or unknown disease status areas. Note the existing disease data were not released to the survey teams to avoid biasing their search effort. The route planning also took account of existing tracks and bait lines to guide the most efficient route to the selected tree and minimise time off track.

A2 Survey information

Ngā pārongo mō te rangahau

Question 1: Survey name

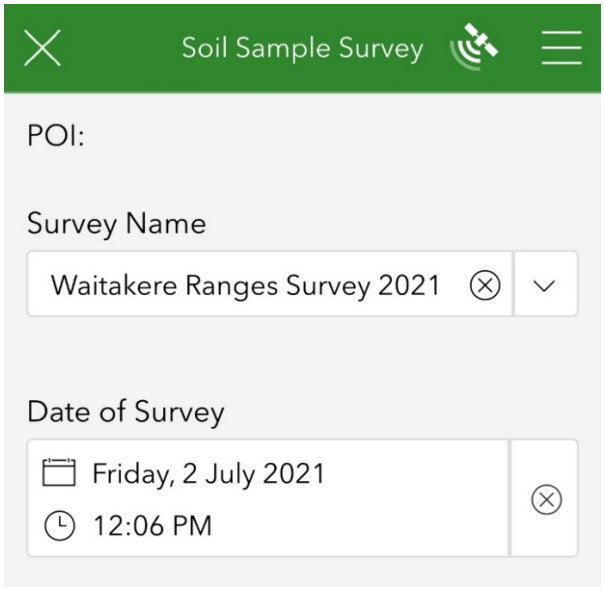
Question 2: Date and time of survey

Prevalence study; Risk factors study

This survey was recorded as ‘Waitākere Ranges Survey 2021’. The date and time variable sets the date component of ‘time and place’ for future comparison of sampled trees. In addition, we were interested to understand if a pattern could be detected in some variables over the five-month survey period (e.g., if canopy colour, new flush foliage and female cones changed over the survey period of 8 March 2021 to 8 July 2021 and also if there was a difference in foliage and colour detection at different times of the day).

The ‘Survey Name’ box is a drop-down of all active surveys that the team are undertaking (typically just a single survey, but some team members may be undertaking multiple surveys in the same area). The date and time should auto-populate when a new POI is selected. Note for

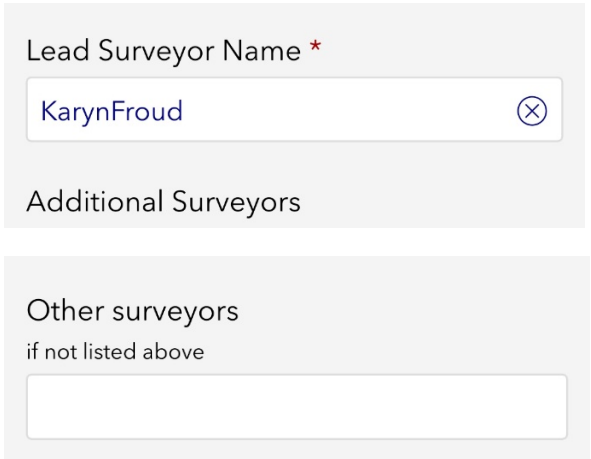
future surveys, the date and time need to be checked prior to the survey to make sure they are correct and set to 24-hour time to avoid an AM/PM error (some records were 12 hours ahead of actual time and were later amended in the data cleaning process).



Question 3: Lead and support surveyors

Prevalence study; Risk factors study

To meet the case definition of kauri dieback, the symptomatic criteria need to be assessed by an 'approved observer'. In this case all survey team members had been fully trained prior to becoming a 'lead surveyor' and in most cases an additional surveyor was also present when the tree was observed.



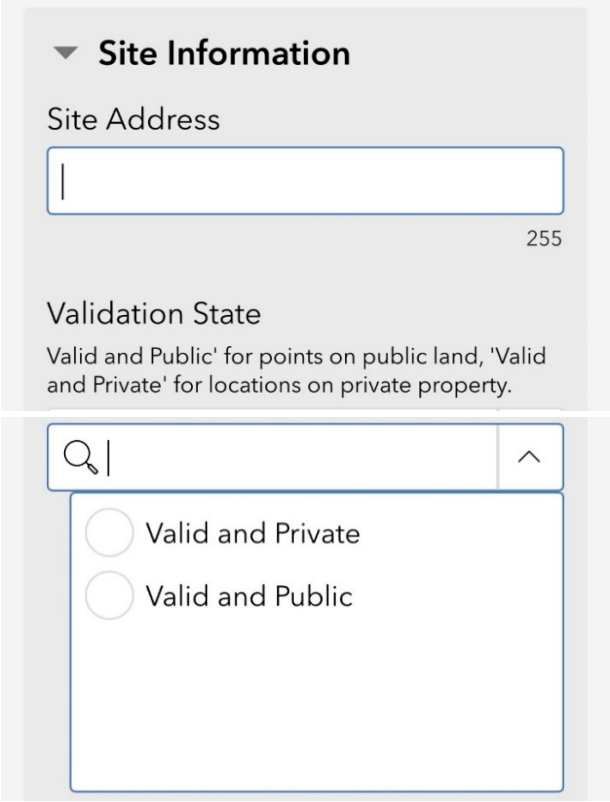
A3 Site information

Ngā pārongo mō te wāhi

Question 4: Site address

Question 5: Validation state

Site address is a placeholder for future surveys and is in line with historic data collection. Validation state has two options which determine whether the survey data can be entered into the publicly available dataset or not once analysis is completed and reported, as private land data may not be made publicly available. This variable was also designed for where iwi/hapū permission was granted for collection of data from sacred or tapu sites to be kept private.



A4 Sampled tree information

Ngā pārongo mō ngā rākau kua tīpakohia

Question 6: Tree/POI location

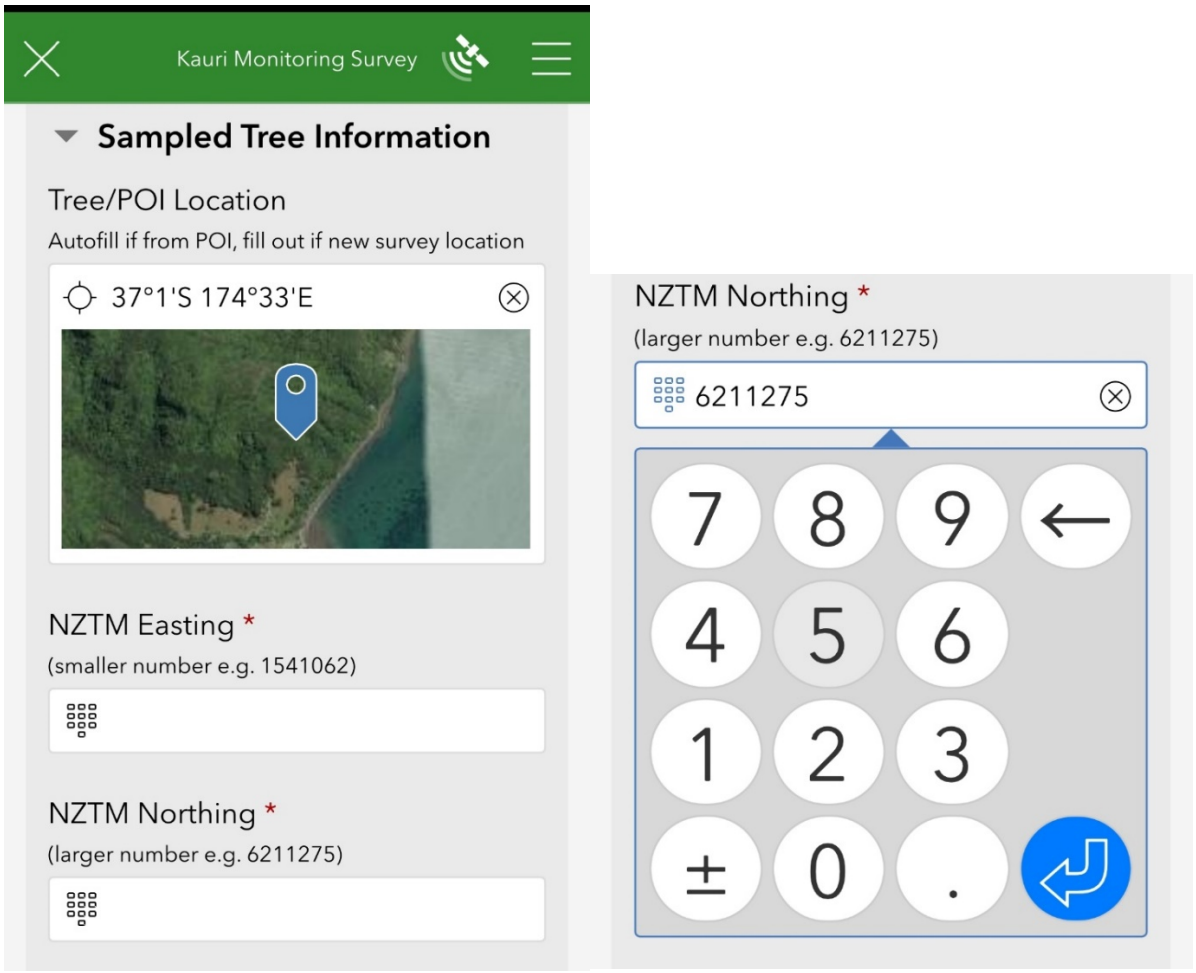
Question 7: New Zealand Transverse Mercator (NZTM) Easting

Question 8: NZTM Northing

Prevalence study; Risk factors study

If the kauri point was selected from the inbox, then this field auto-fills with the GPS coordinates of the tree (derived from the remote sensing LiDAR data on the highest point of the tree crown). Regardless, the handheld GPS coordinates were requested and entered to confirm position of the tree or to georeference the replacement tree.

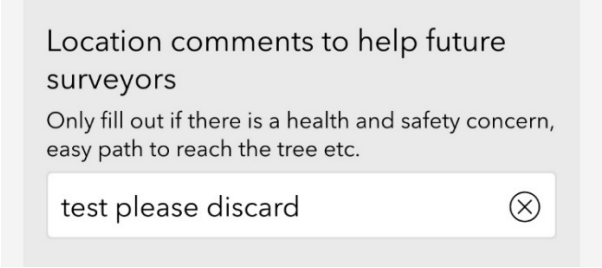
These spatial coordinates, along with GPX track files from each handheld GPS, were used to reconcile the exact GPS points for each monitored tree (validated by the Auckland Council Environmental Services BioInformation team) to assign GIS-related variables values to trees and used to develop prevalence maps.



For future reference, the decimal space should not be available on the keypad for this field, and it should have field protection of only 7 digits.

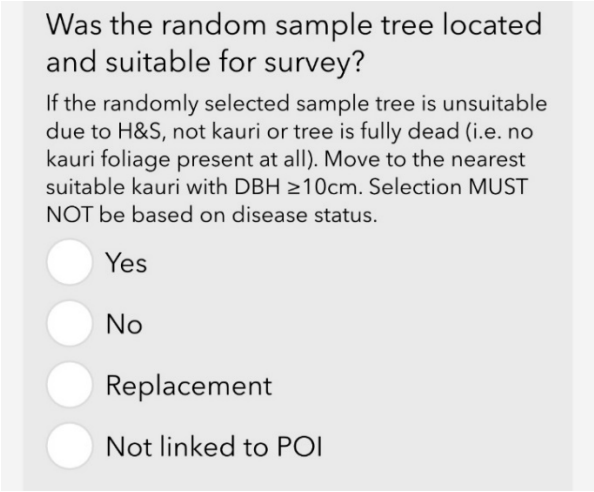
Question 9: Location comments

This field was to inform future survey efforts to locate the same tree. Surveyors were asked to comment if the tree was hard to find or if there was a health and safety concern. In the example below, the comment field has been used to indicate that this is a test which needs to be discarded from the dataset. We recommend a change to the hint text to include an example “e.g., during a return visit, go round slope rather than through gully”.



Question 10: Random sample tree located and suitable for survey?

The field teams used their handheld GPS units to navigate to the pre-loaded kauri points. If the selected tree was located, the survey continued. If the selected tree was fully dead, could not be located as the host species was misclassified by remote sensing, or it was not accessible due to health and safety concerns, a replacement tree was then selected. To avoid any selection bias, the surveyors were tasked to select the closest kauri tree with a DBH of ≥ 10 cm and selection COULD NOT be based on disease status. Note: if the tree was selected for soil sampling but was found to be dead, the soil sample was collected from the dead tree AND a replacement tree selected and soil sampled. For future reference, this section should come prior to the Q7, Q8, Q9 location coordinates and comments section.



If ‘Yes’ or ‘Not linked to POI’ was selected, then the survey continues to the next section. ‘Not linked to POI’ is for ad-hoc surveys on trees that are sampled outside a specific survey effort and are there for future passive surveillance use. It is recommended that this field is excluded or not visible for future surveys where all observations are on pre-selected trees.

If ‘No’ is selected, then additional questions are asked regarding host and dead status.

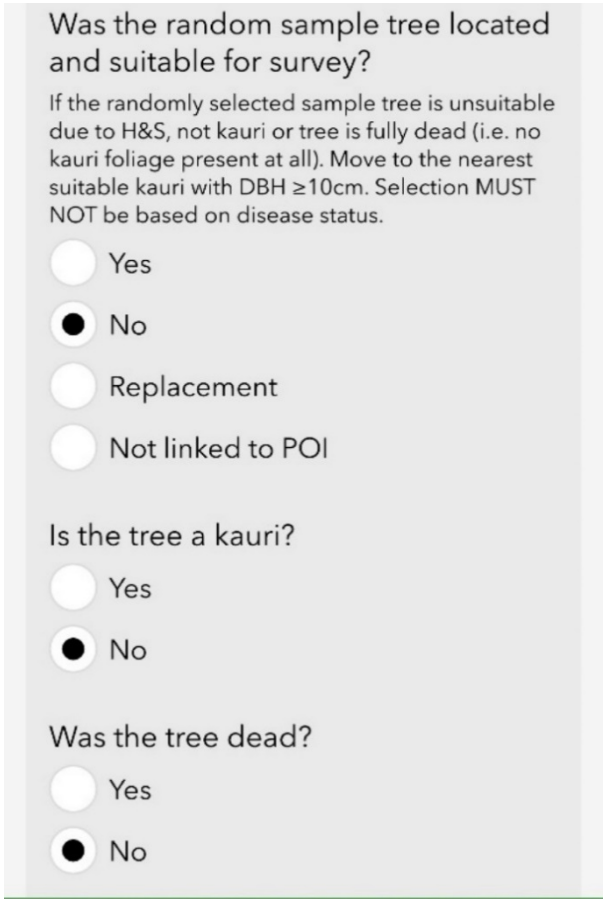
Question 10a: Is the tree a kauri?

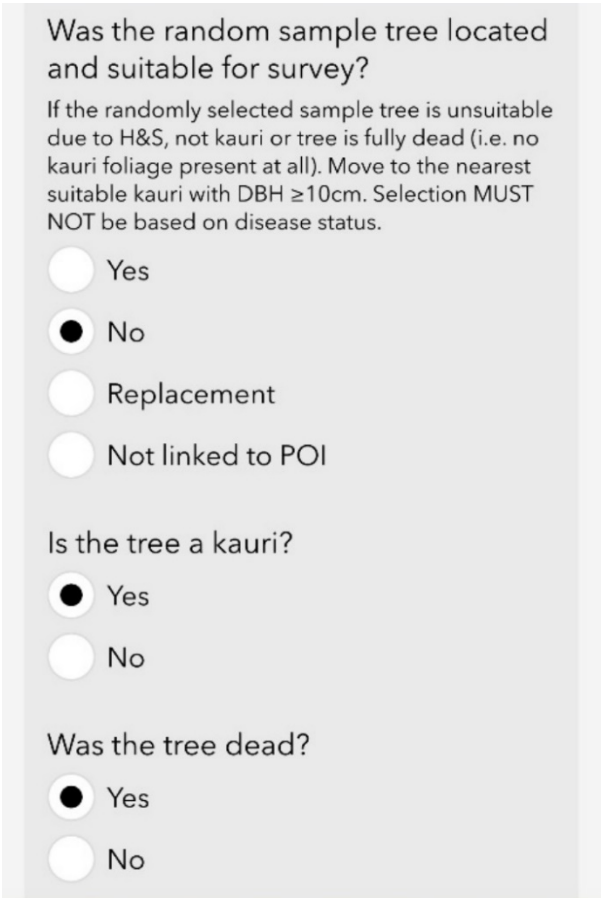
Question 10b: Was the tree dead?

If the POI tree was not suitable for survey, the surveyor is asked if it was a kauri or not, and whether the tree was dead or not.

These results inform validation and future improvement of the methods used to undertake remote sensing detection of host species.

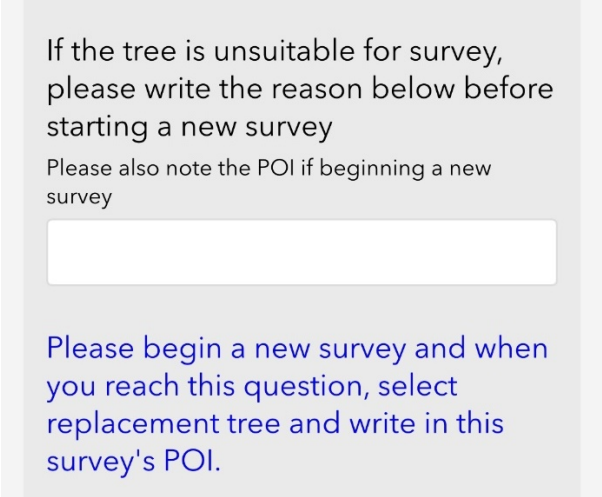
These fields were added during the 24 April upgrade to the two survey forms.





Question 10c: If the tree is unsuitable for survey, please write the reason below before starting a new survey

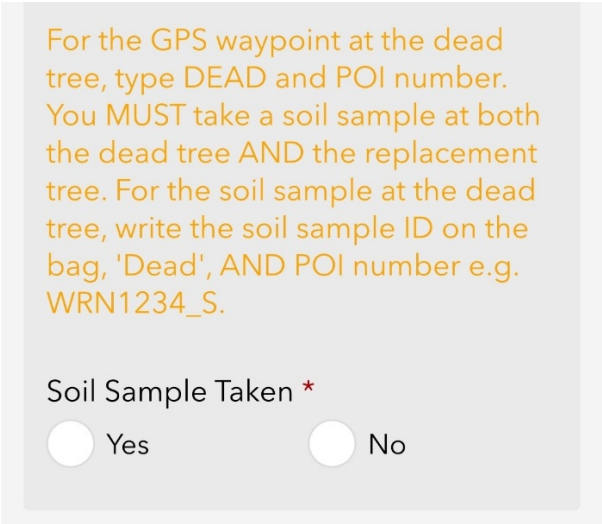
The surveyor was then asked to provide a reason for the tree being unsuitable. Following this, further instructions were provided regarding recording replacement trees. For future reference, the comment field for ‘Not a kauri’ should be compulsory, such that the true tree species is able to be identified and therefore provide information for host detection validation. In some instances, where a whole stand has been mis-classified, e.g., a large stand of pine trees, the surveyors reported back directly to Auckland Council to have these POIs recorded as ‘Not a kauri’ and ‘Pine’ to save time in the field.



Question 10d: Soil sample taken

For trees that had been selected for soil sampling, the surveyors would select 'Yes' and label the soil sample bag with the code that appears on the screen, for use in cross-referencing laboratory results.

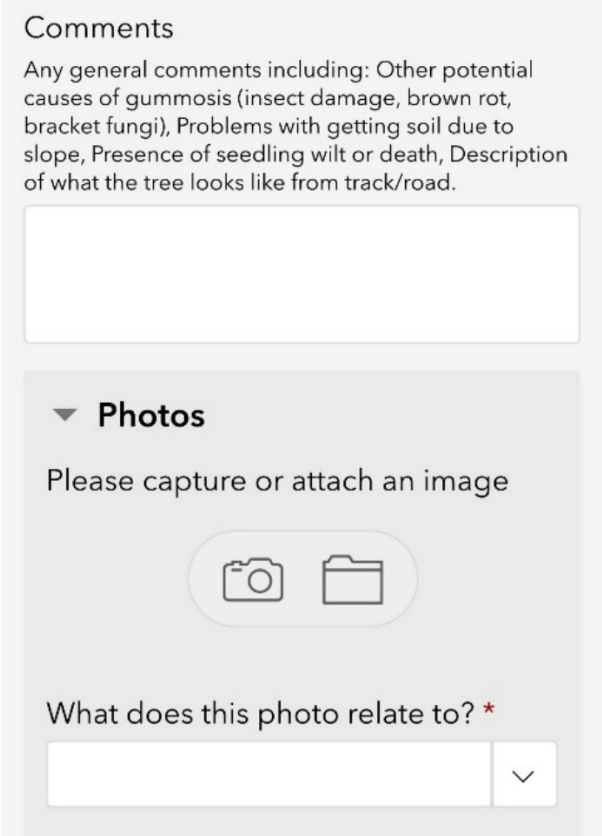
For trees selected for soil sampling that were kauri but were found to be dead, instructions were provided in the form to collect a soil sample for both the dead tree and the replacement tree.



Question 10e: Comments

Question 10f: Photos

Finally, a comments section was provided to enter any other relevant information. Surveyors were also tasked with taking photos of the canopy, basal bleeds, tree tag ID and clearly labelled soil sample bag.



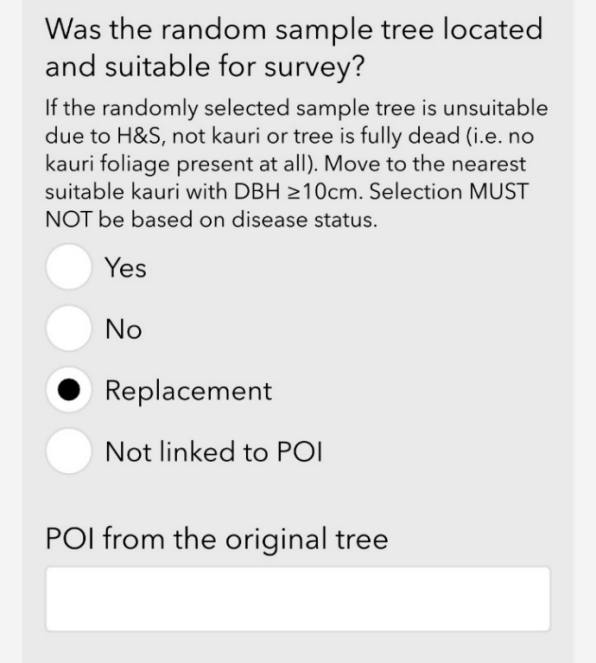
A5 Replacement tree information

Ngā pārongo mō ngā rākau whakakapi

Question 1-9: Repeat for replacement trees

Question 10: Was the random sample tree located and suitable for survey?
If the original kauri POI was unsuitable for survey (i.e., due to it not being a kauri or already dead), another nearby kauri was then selected for survey as a replacement tree. The surveyor would then return to the initial Survey123 screen, selecting the 'Collect' function rather than the 'Inbox', and proceed to fill in Questions 1-9 as per original instructions.

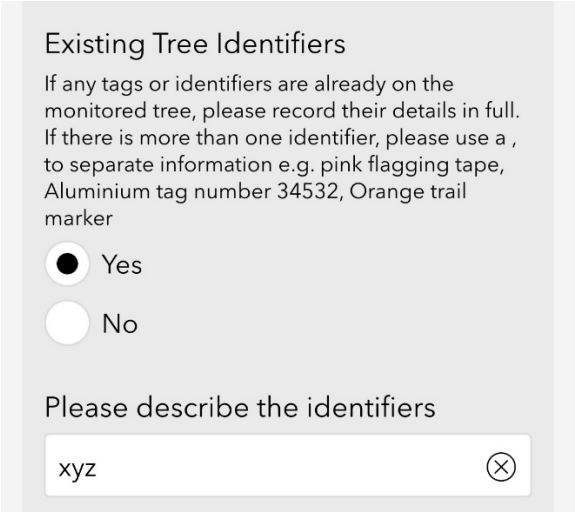
At Question 10 "Was the random sample tree located and suitable for survey?", 'Replacement' is then selected. An additional question would then appear for input of the POI code of the original tree. From this point on, the survey continued as per normal.



Question 11: Existing tree identifiers

Many trees in the Waitākere Ranges have been labelled in the past. They may indicate a bait line trail, phosphite injection trees or other research labels. To identify the tree and any prior history that may be relevant, the surveyor was requested to describe any existing identifiers.

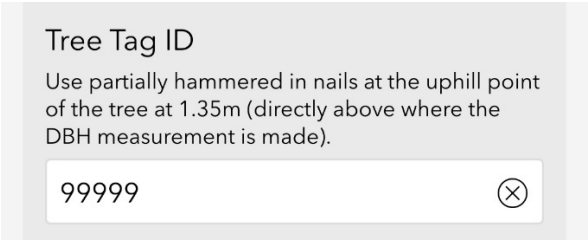
It is recommended that future forms have an extra field with a specific question asking if there is evidence that the tree has been phosphite treated (tagged or drill holes) with the options of Yes/No/Unsure.



Question 12: Tree Tag ID

The tree tag ID was one of the unique data identifiers. Every kauri in the survey was given a tree tag ID that had a unique code imprinted on aluminium. The tree tag was attached by a nail

partially hammered in at the DBH height (1.35 m) at the uphill point of the tree. The tree tag ID was then recorded on the sample form.



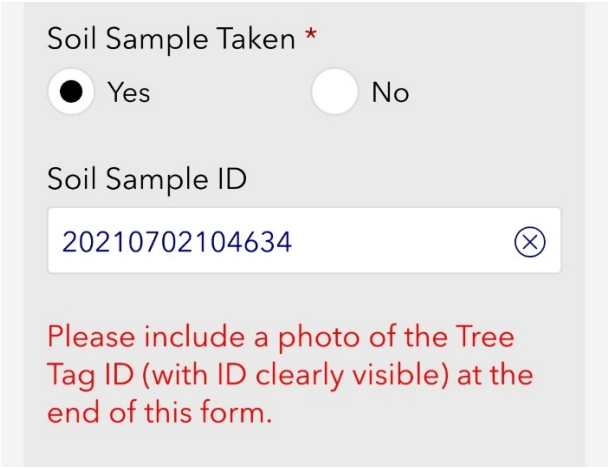
Question 13: Soil sample taken?

Question 14: Soil sample ID

Prevalence study

The question of whether a soil sample is taken is provided on both survey forms to allow the option for the collection of additional soil samples for other purposes.

If 'Yes' was selected for 'Soil sample taken?', a soil sample ID was then generated. The soil sample ID was one of the unique data identifiers. The surveyor was tasked to record this ID on the sample bag and take a photo of this for ease of data cleaning.



A6 Kauri host-related variables

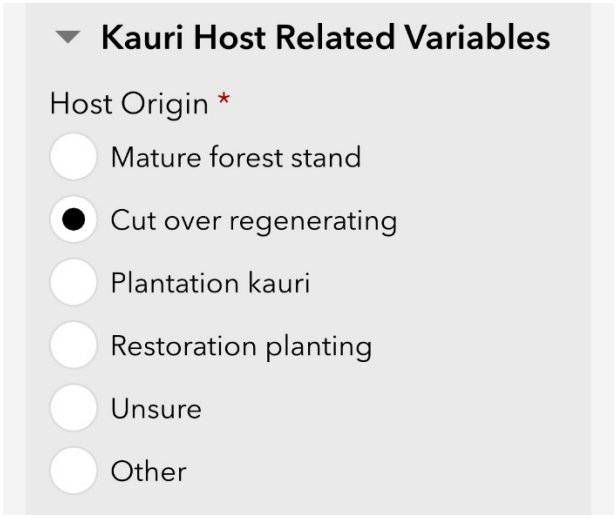
Ngā taurangi ā-papa rauropi kauri

Question 15: Host Origin

Prevalence study; Risk factors study

Host origin was consistently mentioned at all risk factor development hui. This factor will need to be carefully interpreted if it proves to have a significant association with cases of kauri dieback, as there are several hypotheses associated with host origin. Measurement of this factor requires some knowledge of the area and therefore may only be partially completed in the field; however mature forest stand can be implied by the presence of very large mature trees. Cut-over

regenerating areas have evidence of old tree stumps that were cut decades earlier and are dominated by smaller size classes or regenerating trees. Plantation kauri may need to be identified using historic records of the NZ Forestry Service, which would require digitising archived map records identified by Beachman (2017). Information on restoration planting may be reconciled using other GIS layers.

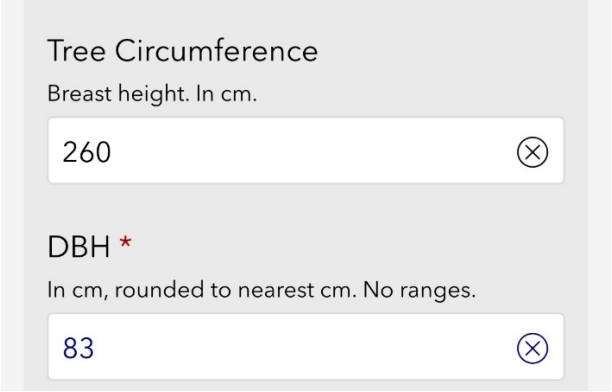


Question 16: Tree circumference

Question 17: Diameter at breast height (DBH)

Prevalence study; Risk factors study

The DBH was automatically calculated in the form following the formula of circumference divided by *pi*. The circumference of the tree was measured at breast height, starting at the uphill point of the tree where the tree tag was placed. In some instances, where the tree was very large and positioned on steep and unstable ground (common in the Waitākere Ranges), it was unsafe to measure the full circumference of the tree. In these cases, the circumference was estimated by measuring the accessible half of the tree and doubling the measurement.



Approximate size classes were calculated to be consistent with historical kauri data based on circumference measures of <150 cm = Ricker, 150-449 = Intermediate, 450 or greater = Mature.

Question 18: Active growth flush in canopy

Question 19: Epicormic growth

Question 20a: Are female cones visible on the tree?

Question 20b: Are there green female cone scales on the ground within the dripline of the monitored tree?

Prevalence study impact variables. Soil sampling trees only.

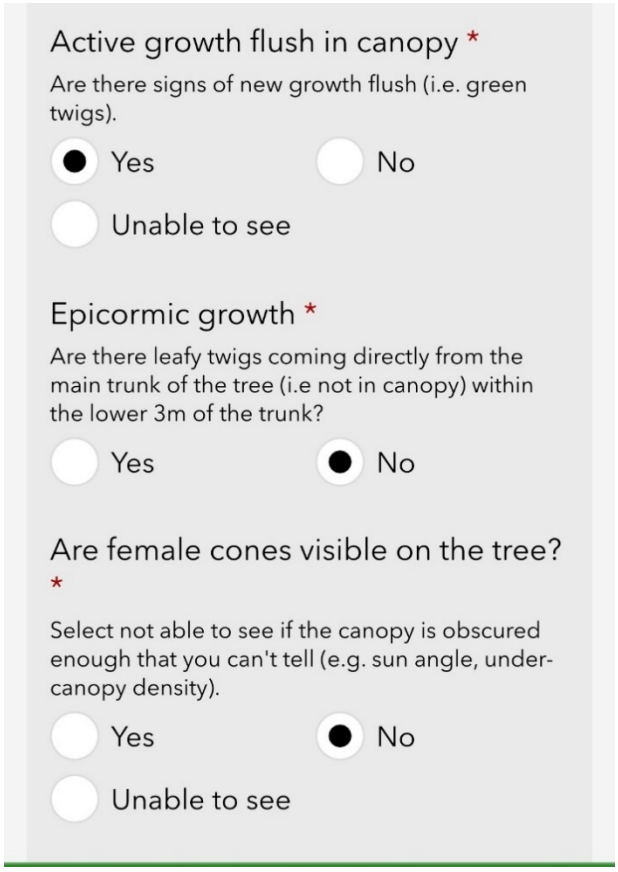
These host variables were aimed at assessing host health in addition to disease symptoms, as we were concerned that symptomatic trees might show epicormic growth, not have active growth or be reproductive (female cones).

Epicormic growth was assessed in the lower 3 m of the trunk and is a common indicator of ill-thrift in trees.

Active growth flush and female cones were measured to determine if the tree was actively growing and/or reproducing this season. New growth flush should be visible throughout the summer months, indicated by lighter green leaves and light green coloured twigs at the end of branches as per the photo included in the form.

We had several concerns with these two fields during the 2021 Waitākere Ranges Monitoring Survey. We planned to check several components of these variables. Firstly, whether these variables were able to be measured as we transitioned from summer into winter (i.e., is there a bias towards ‘no’ over time). In addition, how many observations might be lost due to the difficulty of obtaining this information, potentially because a good view of the canopy was hard to obtain from ground level especially on taller trees or, due to dense canopy and during different times of the day, the daylight contrast made it difficult to detect. It is also important to note that some monitored trees could be too young to be reproductive as small ricker trees are typically not reproductive until they are 25-40 years old (Steward and Beveridge, 2010). Careful assessment of this variable will be needed to address potential confounding of reproductive status with small DBH scores. Absence of active growth, female cones or presence of epicormic growth might be correlated with disease or be a symptom of tree stress. It is useful to understand any associations with symptomatic trees now and into the future as these may be early symptoms for detection and could guide proactive phosphite or other treatments. In addition, if these symptoms are common in the absence of disease, they could indicate that there are wider ecosystem changes that are putting kauri at risk of stress and ill-thrift.

Both active growth flush and female cones were found to be difficult to assess. This difficulty was tree-specific rather than season- or stand-specific, in that they were hard to measure on both densely growing rickers and on very tall mature trees. The field teams reported that these two variables were extremely unreliable to assess, and most female cones were gone after March**.** It is not recommended that they are used for analysis due to unreliability, and recommend that Q18, 20a and 20b be removed from future survey forms.



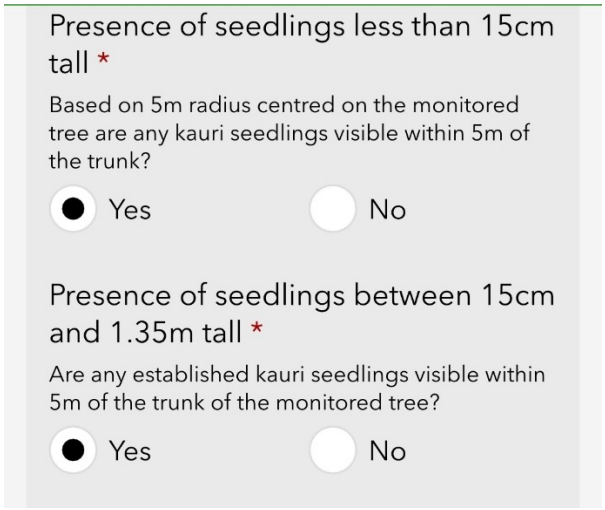
In order to address the potential issue of female cones falling over late summer to early winter, we included an option to observe green female cone scales on the forest floor, which indicated the current season's cones. However, an issue with the electronic form was noted at the end of data collection, in that the question of green female cone scales only appeared after the surveyor selected 'Yes' to 'Are female cones visible on the tree?'. Therefore, the data for this variable need to be assessed carefully. We recommend that 20b is removed from future forms.

Question 21: Presence of seedlings less than 15 cm tall

Question 22: Presence of seedlings between 15 cm and 1.35 m tall

Prevalence study impact variables. Soil sampling trees only

These seedling-related questions aimed to understand if any recruitment was occurring under symptomatic trees, and if there is an association between *P. agathidicida* detection and seedling presence. It is related to the previous group of questions in that disease may be reducing reproduction even if tree death does not occur. In addition, *P. agathidicida* is thought to be particularly lethal to seedlings, so these measurements might provide evidence for this. A consideration in interpretation of this measurement is the potentially confounding effect that there may not be any seedlings near the host parent plant due to the Janzen-Connell hypothesis which in brief implies that seedling survival is greatest further from the parent; however, how well this is supported in temperate species has been questioned (Hyatt et al., 2003).

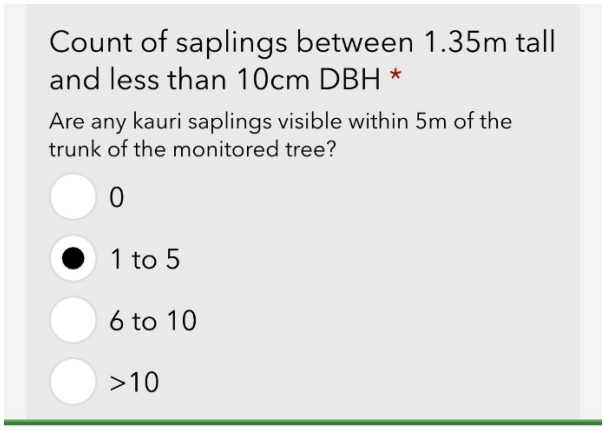


Question 22: Count of saplings between 1.35 m tall and less than 10 cm DBH

Prevalence study impact variables. Soil sampling trees only

As with seedling presence or absence, this is a measure of kauri reproductive activity. Note that Bruce Burns has cautioned against its use as a measure of kauri sapling density as this could be confounded according to the Janzen-Connell hypothesis, with kauri saplings probably less likely to occur close to adult trees than away from them. In addition, for medium-large trees, the 5 m radius circle would all be under the kauri canopy, which should also be considered as a confounder.

If seedlings and saplings are surviving under trees with *P. agathidicida* in the soil, then these trees could represent a source of genetic resistance to the pathogen and will inform sites for future protection, monitoring and research.



A7 Disease-related variables

Ngā taurangi ā-mate

Prevalence study outcome variables; Risk factors study outcome variables; Diagnostic test evaluation test results

The disease-related variables provide the outcome variables for all three studies. It is important to note that all symptoms could be caused by other biotic or abiotic factors, and therefore the opinion of a trained observer is required to determine if the recorded symptoms are consistent with kauri dieback. This is particularly important where basal and lateral root bleeds can be caused by physical damage to the tree. To meet the symptomatic criteria of the case definition, both symptoms and field status were assessed as described below.

Symptomatic criteria for the case definition

The symptomatic criteria for kauri dieback on a kauri tree are met if a National Programme (Tiakina Kauri Partners) approved trained observer detects one or more of the following symptoms that are consistent with kauri dieback: bleeding lesions on the basal trunk, lesions on roots, the presence of canopy thinning, yellowing of the foliage, tree death.

For these studies, 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'

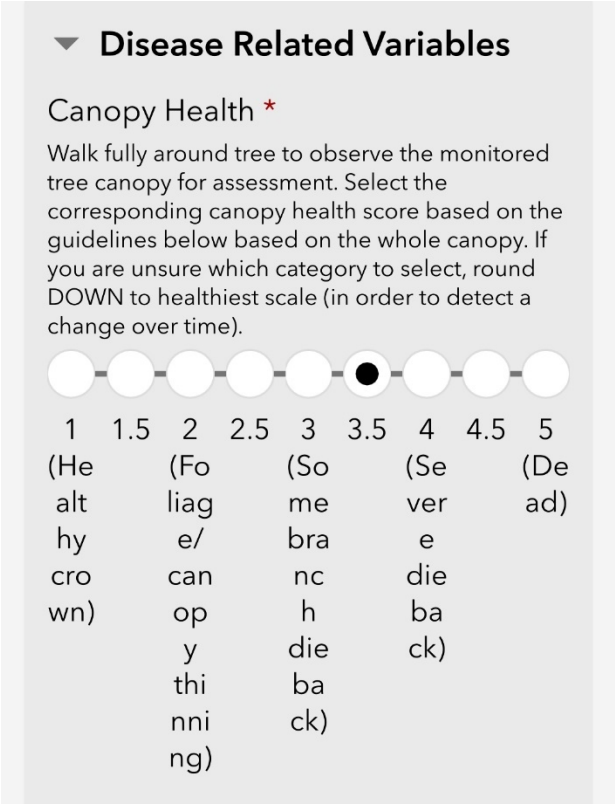
NOTE: Dead trees (canopy score = 5 or canopy colour = dead) are excluded as a tree cannot be considered diseased after death.

Question 23: Canopy Health

Prevalence study outcome variables; Risk factors study outcome variables; Diagnostic test evaluation test results

Canopy health is one of the listed symptomatic criteria for the case definition of kauri dieback. This variable is included in the formula for classifying symptomatic trees. The level of canopy health score required to be included in the case definition has tentatively been set to a canopy score of 3 or higher after discussion with the field team and I. Horner (Plant and Food Research, pers. comm.). 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. For the purposes of calculating prevalence of disease, trees that scored 5 and were considered dead were excluded as a tree cannot be considered diseased after death. Dead trees are reported separately from prevalence.

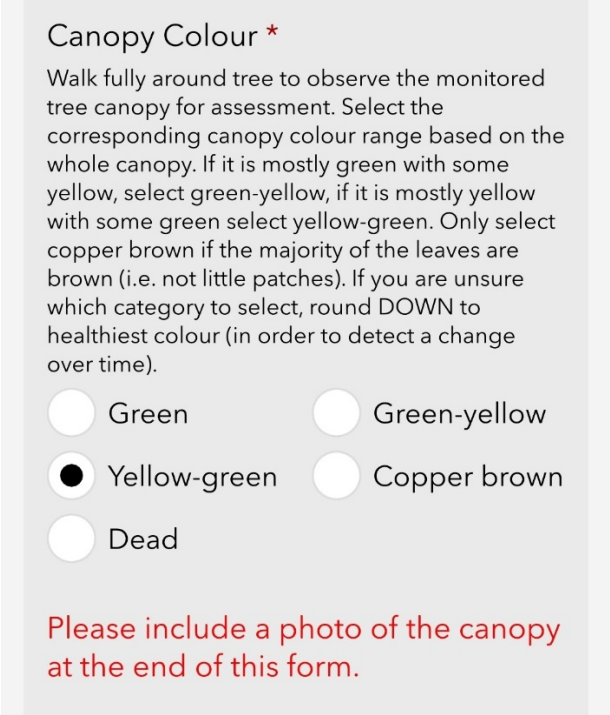
The baseline **severity** of disease is quantified based on the Dick and Bellgard (2012) 5-scale canopy health score. However, under guidance from experts, it was adjusted to include half-points to provide more differentiation, particularly between 2-3 and 3-4 canopy scores (I. Horner and N. Williams, Plant and Food Research, pers. comm.).



Question 24: Canopy Colour

Prevalence study outcome variables; Risk factors study outcome variables; Diagnostic test evaluation test results

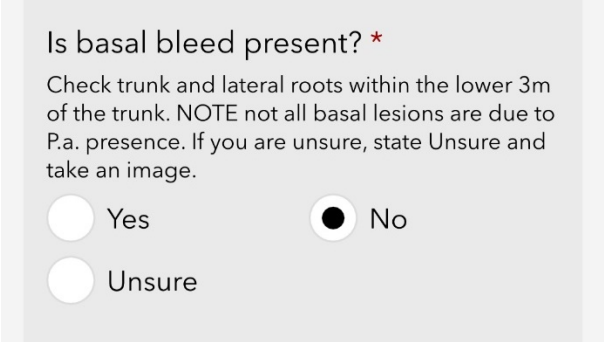
Canopy yellowing is one of the listed symptomatic criteria for the case definition of kauri dieback. Canopy colour is included in the symptomatic criteria formula to classify cases. The canopy colour score required to be included in the case definition has tentatively been set to a canopy colour that is more yellow than green and includes 'Yellow-green', 'Copper brown' and 'Dead'. Dead trees are reported separately from prevalence.



Question 25: Is basal bleed present?

Prevalence study outcome variables; Risk factors study outcome variables; Diagnostic test evaluation test results

Basal bleeds (bleeding lesions on the lower 3 m of the trunk) are one of the listed symptomatic criteria for the case definition of kauri dieback. The surveyors were trained in the variety of basal lesion presentations that have been associated with kauri dieback caused by *P. agathidicida*, and only selected 'Yes' if the bleed presented as such. Further, they were instructed to select 'Unsure' when they could not rule out a basal bleed due to kauri dieback but probably due to other causes (e.g., physical damage). Both 'Yes' and 'Unsure' were included in the symptomatic criteria formula to classify cases. Images of basal bleeds were taken for future assessment and development of training guides.



If ‘No’ was selected, then the surveyor moves to the next question. If ‘Yes’ or ‘Unsure’ were selected, then a further series of questions about the basal bleed appear.

Question 25a: Basal bleed age

Prevalence study outcome variables

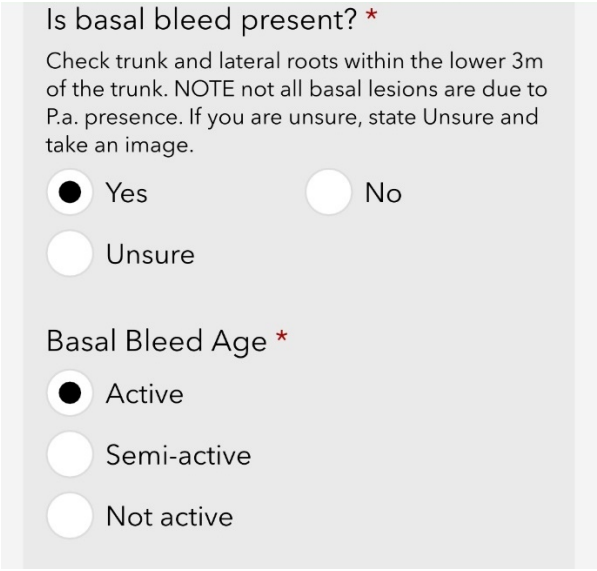
The basal bleed age indicates how active a bleed is. This will be useful to indicate if bleeds heal over time with or without interventions. Dick and Bellgard (2010) described a binary resin category to identify basal lesion activity, to classify between fresh resin bleeds and old resin (that is, pus-like, soft and squishy versus hard to the touch), under guidance from several experts it was adjusted to state ‘Active’, ‘Semi-active’ or ‘Not active’ (I. Horner and N. Williams, Plant and Food Research, pers. comm.). For comparison with older surveillance data, ‘Active’ and ‘Semi-active’ correspond to fresh bleeds and ‘Not active’ correspond to old bleeds. This classification follows the Horner 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. Where more than one category of bleed is present on the trunk, the most active one is selected.

The assessment guide is:

Active = Bleed soft and sticky

Semi-active = Not sticky, but slightly soft and can be dented with fingernail

Not active = Hard and dry and cannot be dented with fingernail.



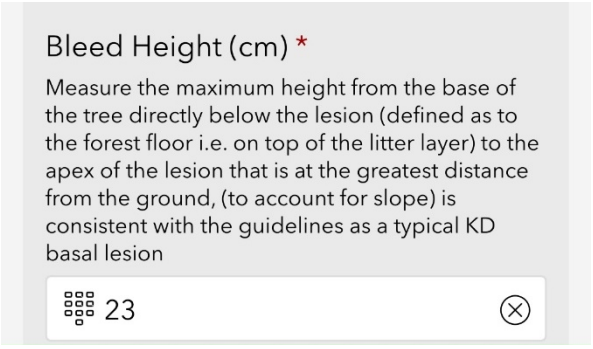
Photos are requested for all basal bleeds.

Question 25b: Bleed height (cm)

Prevalence study outcome variables

The bleed height is a measure of 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 will form a comparison for ongoing monitoring to determine how fast lesions develop over time and if there is an association between canopy score and lesion height.

Where more than one bleed is present on the trunk, then the highest one is assessed.



Question 25c: Percentage of basal bleeds

Prevalence study outcome variables

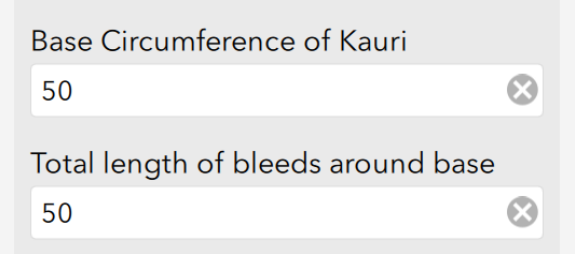
This question was changed during the April form update as the original question was too difficult and time-consuming to measure accurately. Initially the question stated:

Base circumference of kauri (cm): Measure the circumference around the base of the tree.

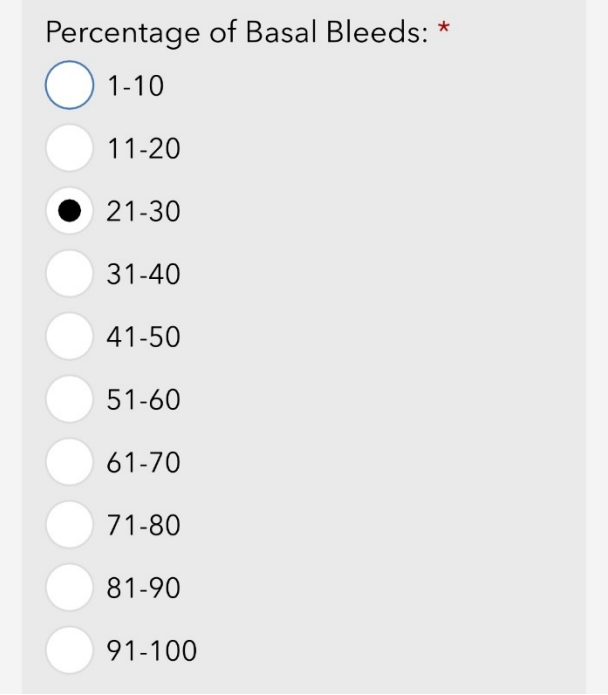
Total length of bleeds around base (cm): Measure the horizontal length (width) of the bleed around the base.

If there are multiple basal bleeds, add the lengths up to one number.

Basal bleed percentage is automatically calculated from the above two numbers and showed like this on screen:



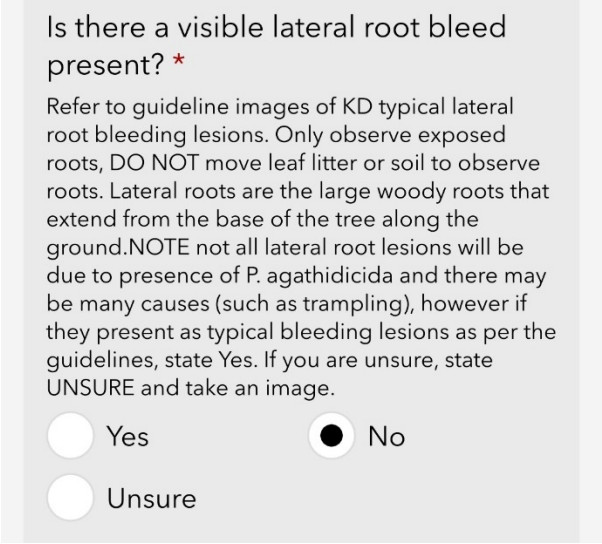
However, it was changed in April to ‘Percentage of basal bleeds’ as an estimate (in deciles) of the base of the trunk that was affected by the basal bleed. This is a measurement of severity and gives a crude indication of the diameter of girdling that has occurred through pathogen infection.



Question 26: Is there a visible lateral root bleed present?

Prevalence study outcome variables; Risk factors study outcome variables; Diagnostic test evaluation test results

Visible lateral root bleeds (bleeding lesions on the exposed (above ground) large lateral roots) are one of the listed symptomatic criteria for the case definition of kauri dieback. It was important not to disturb the kauri roots during this measurement and the surveyors were provided with guideline images. Further, they were instructed to select ‘Unsure’ when they could not rule out a lateral root bleed due to other causes (obvious physical damage). Lateral root bleed = ‘Yes’ or ‘Unsure’ are included in the symptomatic criteria formula to classify cases.



If ‘No’ is selected, then the surveyor moves to the next question. If they select ‘Yes’ or ‘Unsure’, then a bleed activity question was asked.

Question 26a: Lateral root bleed age

Prevalence study outcome variables

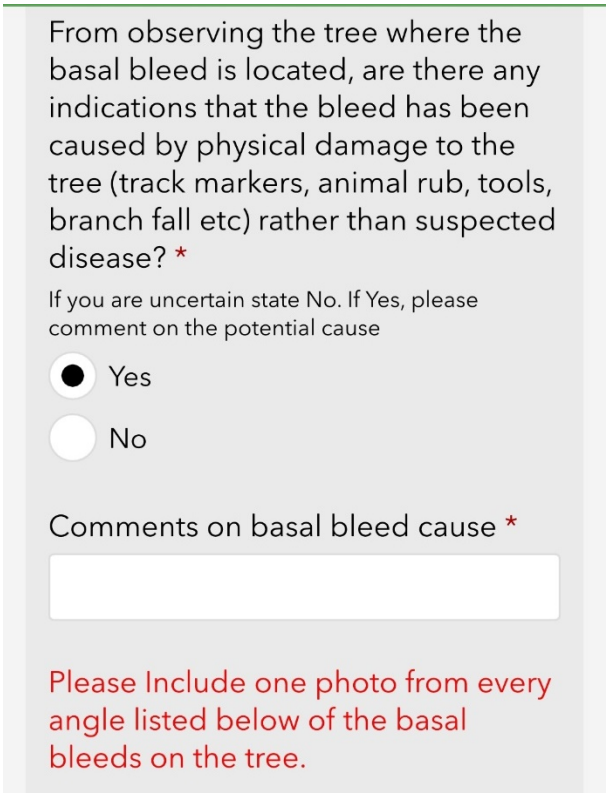
Lateral root bleed age uses the same method as basal bleed age.

Question 25d: Basal bleed cause

Question 25e: Basal bleed cause comment

Prevalence study outcome variables

This question allows the surveyor to list any observations that indicate that a basal bleed is caused by abiotic factors rather than indicating kauri dieback disease. These reasons will allow us to build up a group of common causes of abiotic basal bleeds which can be included in a dropdown menu in future versions of the monitoring form.



Question 27: Kauri dieback field status

Prevalence study outcome variables; Risk factors study outcome variables; Diagnostic test evaluation test results

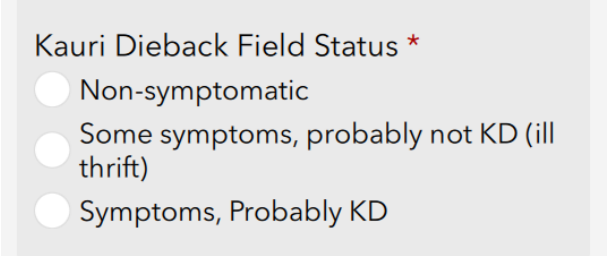
The trained observer assesses all observed symptoms, the surroundings of the tree and any other potential causes of symptoms and makes a field diagnosis, i.e., the 'kauri dieback field status'.

After feedback from the field teams that an additional category was useful for the kauri dieback symptomatic category to differentiate between the possible/probable and obvious kauri dieback observations, we revised this from a 3-point scale to an improved 4-point scale to differentiate between possible kauri dieback and severe kauri dieback described in the monitoring field guide as shown in **Table A-2**. All 'Symptoms, probably kauri dieback' scores were converted to 'Kauri with possible kauri dieback symptoms' after the review as this did not affect classification to the case definition.

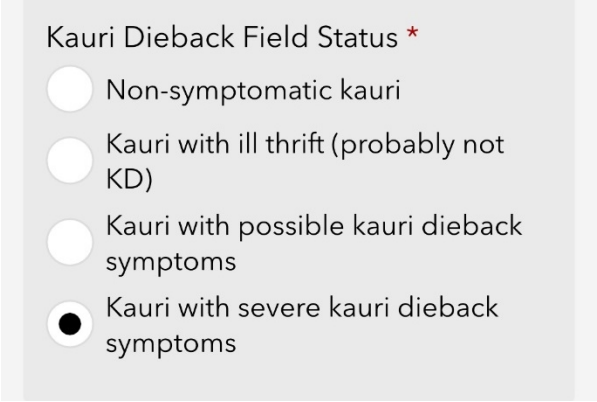
Table A-2. Kauri dieback field status wording compared between the first 6 weeks of monitoring and the remaining 10 weeks of monitoring.

Initial field status categories	Post-review field status categories
Non-symptomatic kauri	Non-symptomatic kauri

Some symptoms, probably not kauri dieback	Kauri with ill-thrift (probably not kauri dieback)
Symptoms, probably kauri dieback	Kauri with possible kauri dieback symptoms
	Kauri with severe kauri dieback symptoms



Changes from the original form to an improved wording with a 4-point scale to differentiate between possible kauri dieback and severe kauri dieback as below.



A8 Disturbance-related variables

Ngā taurangi ā-whakararu

Question 28a: Was there evidence of disturbance?

Question 28b: Evidence of disturbance – details

Prevalence study; Risk factors study

This environmental variable was included to assess if there were external factors that could explain ill-thrift in the hosts and contribute to disease development. If there was no evidence of disturbance, the surveyor selected 'No' and moved to the next question. If they ticked 'Yes', a checklist of options was displayed to select from including common expected disturbances, with the option of selecting 'Other'. They were also asked to provide more details on the disturbance if

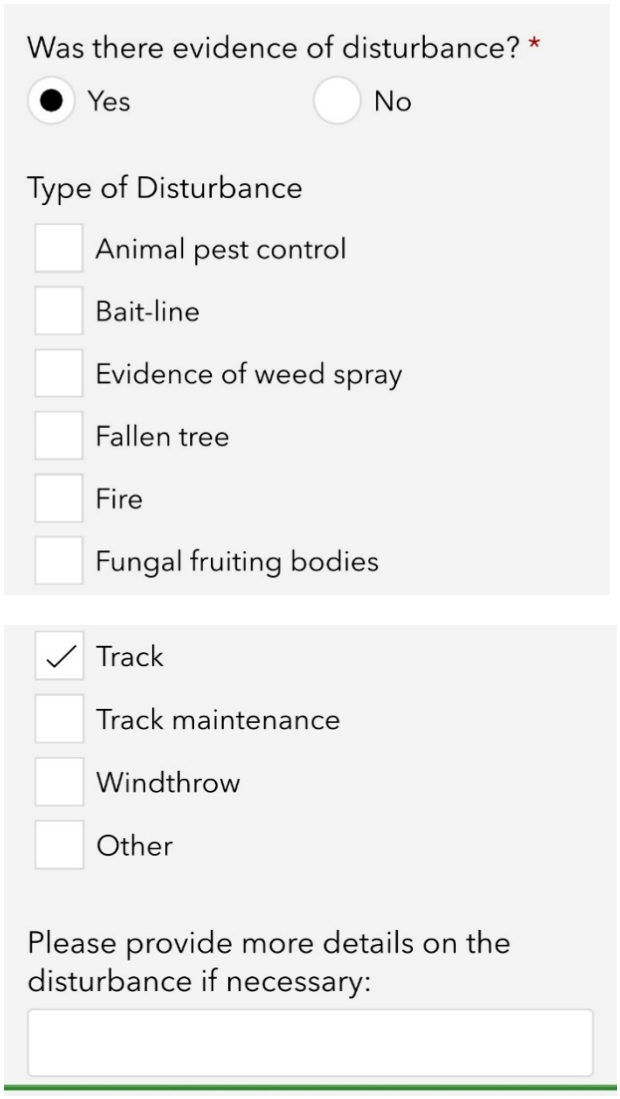
necessary. In a future form format, a comment describing ‘Other’ should be enforced when Other is selected.

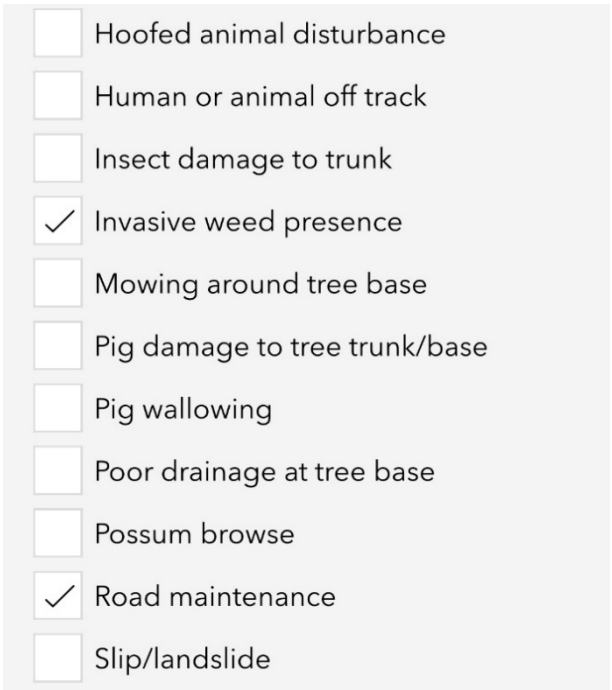
While this is a single question, each of the options for disturbance need to be split into individual columns with binary Present/Absent values (1,0) for analysis.

Several disturbance options that are not fully independent need to be managed carefully when modelled and only one included at a time, e.g., animal pest control, bait-line, human or animal off-track, possum browse, pig damage, pig wallowing.

‘Pest control’ indicates that pest control is active (e.g., rat bait stations) and ‘Bait-lines’ indicate that off-track activities occur within the rootzone of the trees, which are directly related to pest control. Likewise, human off-track and bait-lines are related, as are animal off-track, pig damage and wallowing, and track and track maintenance. In addition, possum browse and animal pest control; and Invasive weed presence and weed spray may be the inverse of each other.

In the future, it is recommended that phosphite injections and soil erosion are added to the list as this was common in the ‘Other’ disturbance comments.

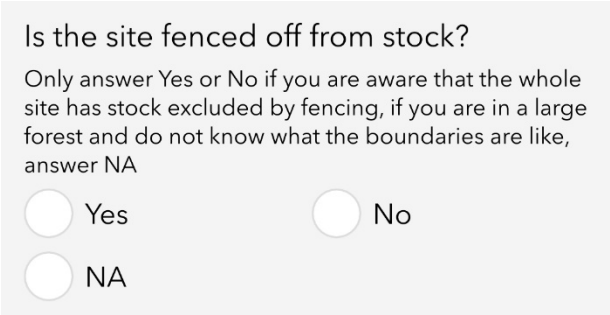




Question 29: Is the site fenced off from stock?

Prevalence study; Risk factors study

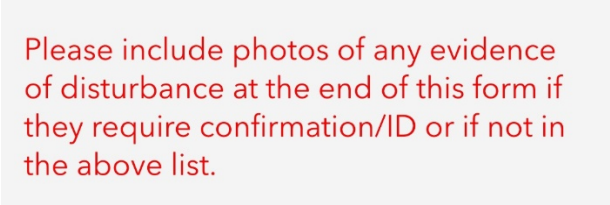
We asked surveyors to assess if the site was fenced off from stock. This is mostly a placeholder for future surveys and not very applicable to the Waitākere Ranges Regional Park, where we expect almost all values to be 'NA' with a few 'Yes' entries on trees close to the Park boundary. This has limited value depending on the location of survey; however, in areas where stock fencing may be available to protect kauri, it is useful to have this information.



Question 30: Please include photos of any disturbance

Prevalence study; Risk factors study

Finally in this section, surveyors were reminded to take photos of any evidence of disturbance if they required confirmation, an identification of disturbance type, or if they selected 'Other'.



A9 Ecological variables

Ngā taurangi ā-hauropi

Question 31a: Forest floor layer (depth) left (cm)

Question 31b: Forest floor measure to tree distance left (m)

Question 31c: Forest floor measure orientation left

Question 31d: Forest floor layer (depth) right (cm)

Question 31e: Forest floor measure to tree distance right (m)

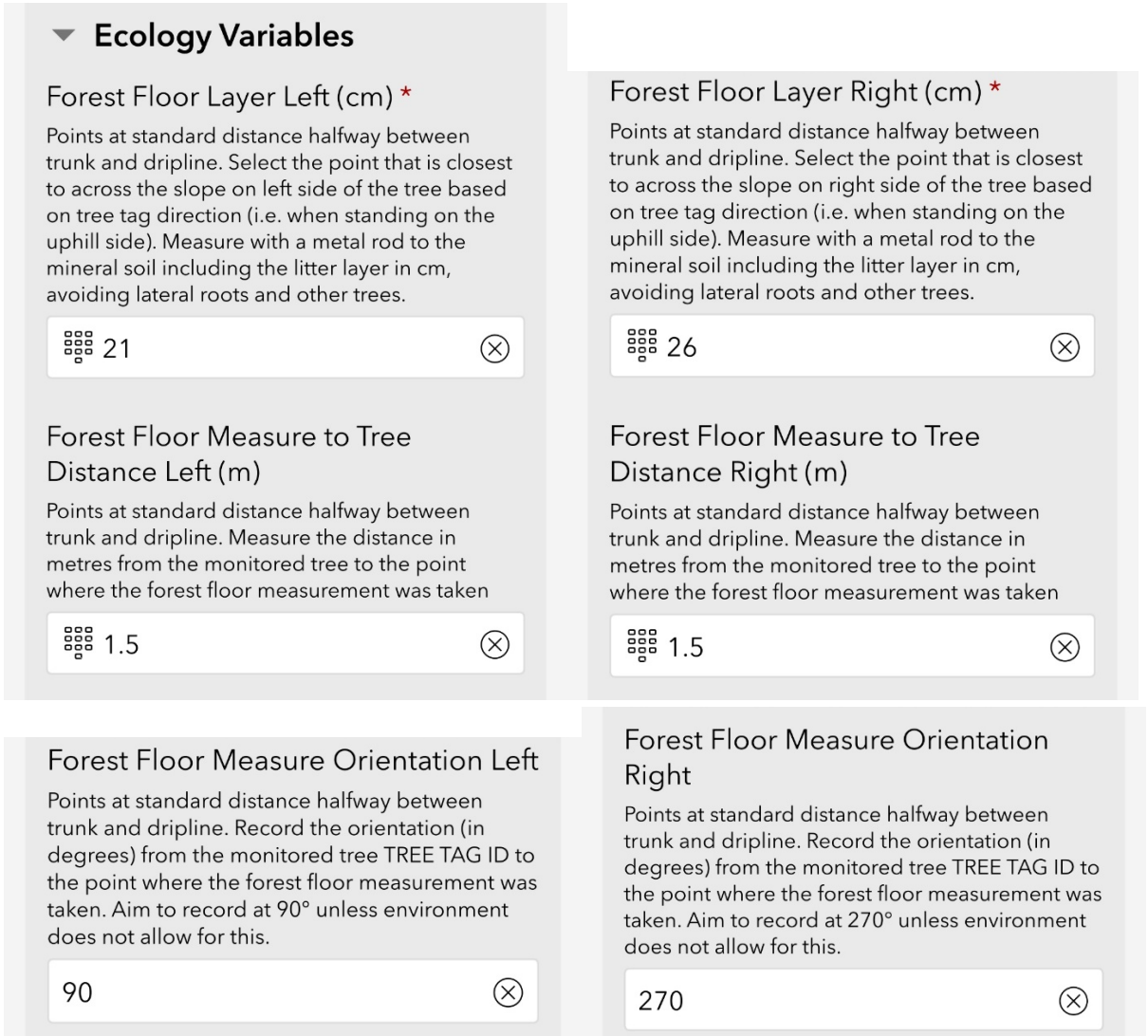
Question 31f: Forest floor measure orientation right

Prevalence study impact variables. Soil sampling trees only

The forest floor measurement gives a baseline indication of potential changes in ecosystem functions (e.g., forest productivity, nutrient cycle) and needs to be remeasured over time.

The ‘forest floor measure to tree distance’ was measured in metres halfway between trunk and dripline. The method measures the depth of the soil organic layer, which includes the partially decomposed leaf litter and soft organic layer that makes up the forest floor above the mineral soil (Silvester and Orchard, 1999). Surveyors were asked to measure the layer at 90° and 270° from the tree tag (i.e., the left and right across-slope points from the uphill tree tag point), and halfway between the trunk and the dripline at these points. The organic layer was measured in cm using the rigid Perspex rod which was disinfected after each tree.

The coordinates were recorded to enable return visits to the tree and consistent measurements at approximately the same point for future impact studies.



Question 32a: Distance to nearest neighbouring tree (m)

Question 32b: Circumference of closest neighbour (breast height in cm)

Question 32c: DBH of closest neighbouring tree (cm)

Question 32d: Closest neighbour species name

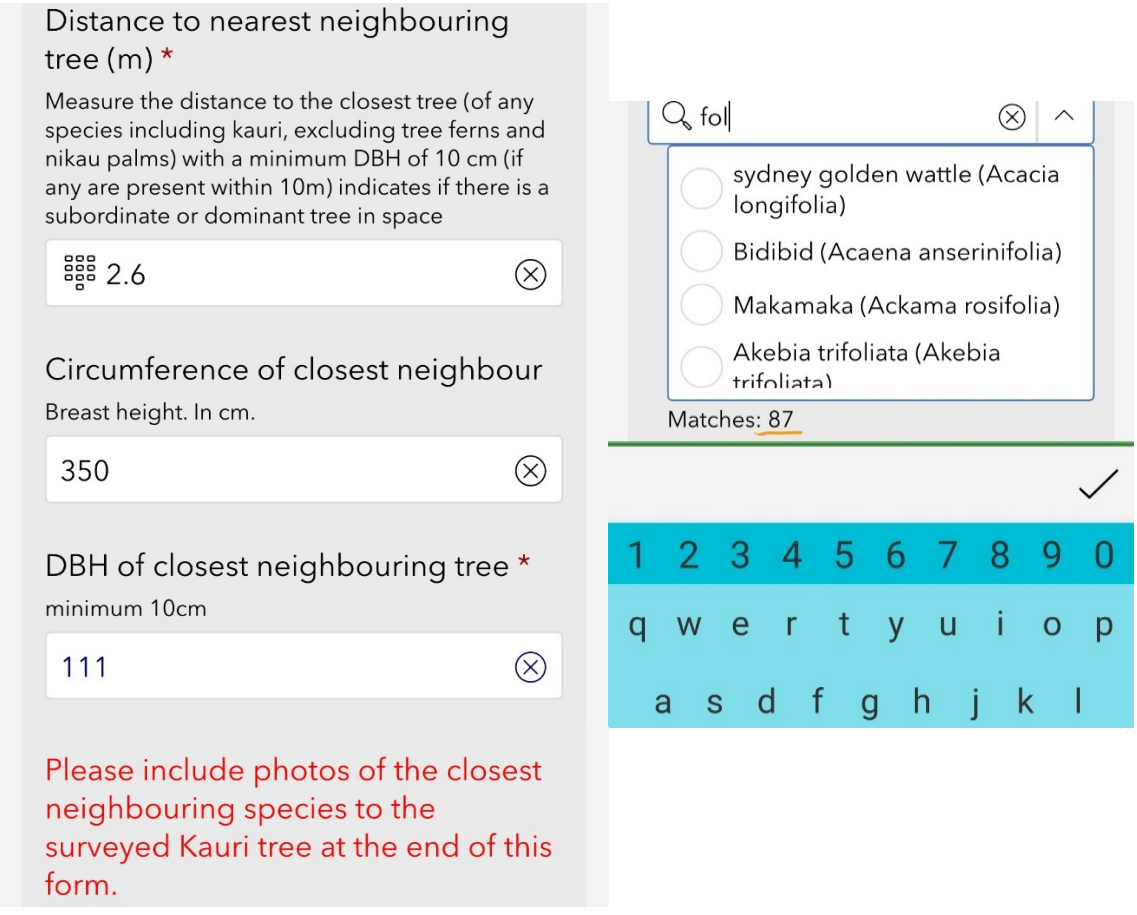
Question 32e: Closest neighbour photo

Prevalence study; Risk factors study

These variables were collected for all trees to indicate if there is a subordinate or dominant tree in the space. It provides a measure of competition intensity/stress that each tree is under within the subject-neighbour relationship, usually measured in terms of the distance, diameter and identity of the tree (see examples in Orso et al. (2020)).

The surveyors were asked to measure the distance to the closest tree (of any species including kauri, excluding tree ferns and nīkau palms) with a minimum DBH of 10 cm (if any were present within 10 m). The circumference of the nearest neighbouring tree was also measured and the DBH was auto calculated.

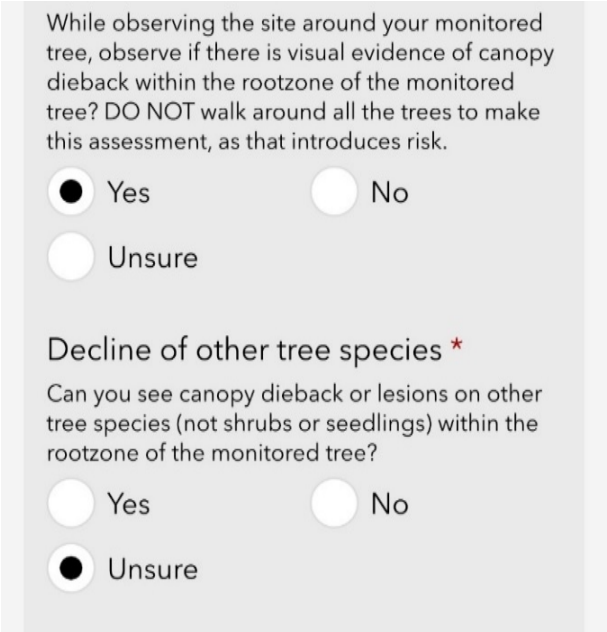
The surveyors were asked for the species of the closest neighbour, which was added using a search-based look-up of either the common or scientific name using an in-house list of flora in the Auckland region, as illustrated in the example image below.



Question 33: Suspected kauri dieback on nearby kauri – canopy

Prevalence study impact variables. Soil sampling trees only

This variable was introduced to determine if there was evidence of widespread disease in some areas around our selected trees. Surveyors were asked to look for canopy dieback on nearby kauri trees. This can be used to indicate if the observed tree is largely alone or within a group of trees expressing canopy dieback symptoms. For future form development, we need to also ask if there are any kauri within the rootzone of the kauri before asking if any are showing canopy dieback. We deliberately excluded a similar observation of basal bleeds after the 28 April 2022 form update as we felt that these were not easily observed without walking around the tree plot, increasing the risk of root damage and reducing hygiene efficacy.



Question 34: Decline of other tree species

Question 34b: Select all species showing decline

Question 34c: Are any other species declining?

Prevalence study impact variables. Soil sampling trees only

This variable was to understand if there was evidence of other tree species within the rootzone of kauri trees showing signs of decline including canopy dieback or lesions. This information may inform future studies for sites to investigate alternate hosts.

We found this very difficult to assess in the field and was of questionable value. We recommend removing this question.

Where the surveyor selected ‘Yes’ for observed decline in other species, they were prompted to record all of the tree species affected from a short list of likely species of interest and had the ability to write in any additional species as needed.

Decline of other tree species *

Can you see canopy dieback or lesions on other tree species (not shrubs or seedlings) within the rootzone of the monitored tree?

- ○ Yes
- ● No
- ○ Unsure

Decline of other tree species *

Can you see canopy dieback or lesions on other tree species (not shrubs or seedlings) within the rootzone of the monitored tree?

- ● Yes
- ○ No
- ○ Unsure

Select all species showing decline

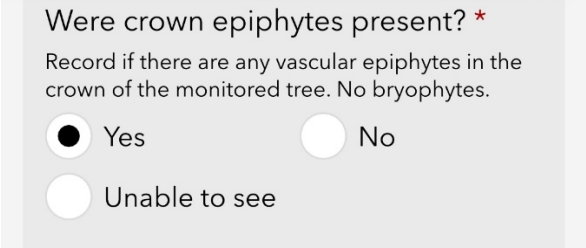
- ☐ Astelia trinervia – kauri grass
- ☐ Brachyglottis kirkii – Kirk's tree daisy
- ☐ Coprosma arborea - mamangi
- ☐ Coprosma lucida – shining karamu
- ☐ Dacrydium cupressinum – rimu
- ☐ Knightia excelsa – rewarewa
- ☐ Kunzea robusta – kanuka
- ☐ Leucopogon fasciculatus – mingimingi
- ☐ Melicytus macrophyllus – large-leaved mahoe
- ☐ Myrsine australis – mapou
- ☐ Nestegis lanceolata – white maire
- ☐ Olearia rani – heketara
- ☑ Pectinopitys ferruginea – miro
- ☐ Phyllocladus trichomanoides – tanekaha
- ☐ Pseudopanax crassifolius – lancewood
- ☑ Toronia toru - toru
- ☐ None

Any other species declining?

Question 35: Were crown epiphytes present?

Prevalence study impact variables. Soil sampling trees only

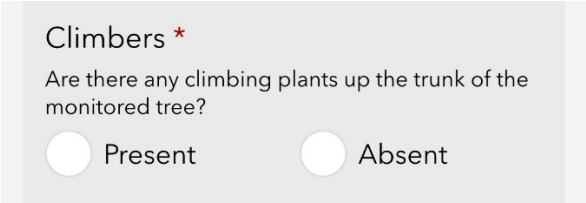
This question focused on the presence of vascular epiphytes in the crown of the target kauri. This will be correlated with DBH as epiphytes are typically in larger mature trees. It may also be of use in the tracking of host decline using remote sensing. Trees may appear to be recovering but this may be due to the loss of foliage exposing crown epiphytes rather than true recovery.



Question 36: Climbers?

Prevalence study impact variables. Soil sampling trees only

This question investigated the presence of climbing plants on the trunk of the target kauri. This was a presence-only question as the aim of this was to find out if there were any correlations between kauri health and presence/absence of climbers.

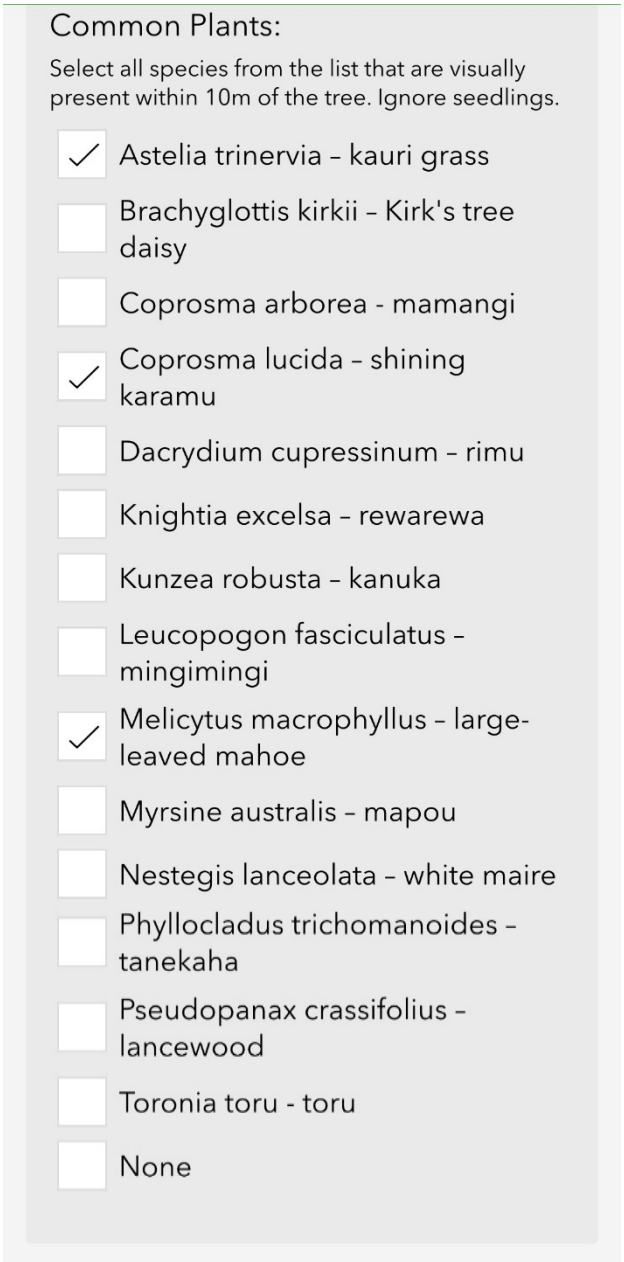


Question 37: Common plants

Prevalence study impact variables. Soil sampling trees only

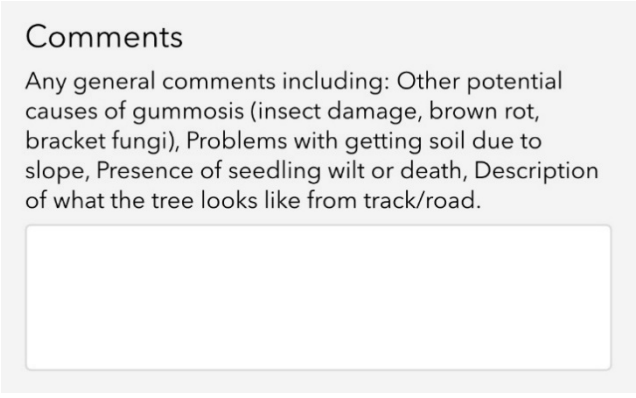
This question was time-consuming and was only undertaken on trees selected for soil sampling.

Surveyors were asked to select all plants on the list of common plants present within 10 m of the tree (ignoring seedlings) and without walking around the area, to ensure roots were not disturbed more than necessary.



Question 38: Comments

At the end of the survey, surveyors were provided an opportunity to add any general comments about the tree or site.



A10 Photos

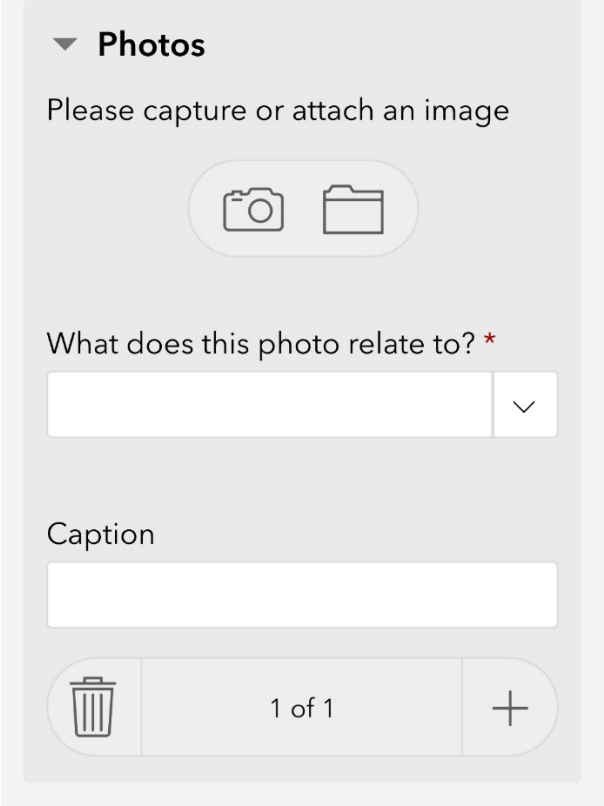
Ngā whakaahua

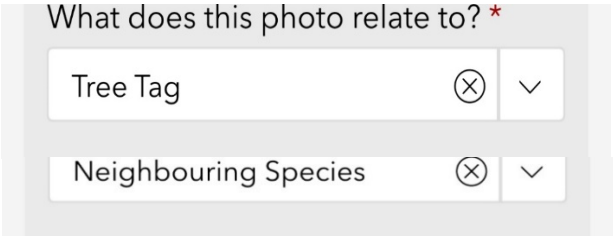
Question 39a: Please capture or attach an image

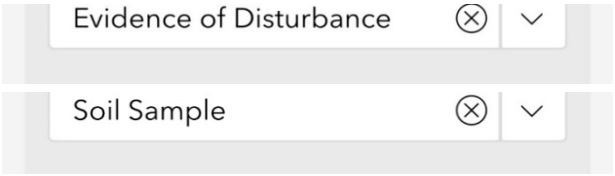
Question 39b: What does this photo relate to?

Question 39c: Caption

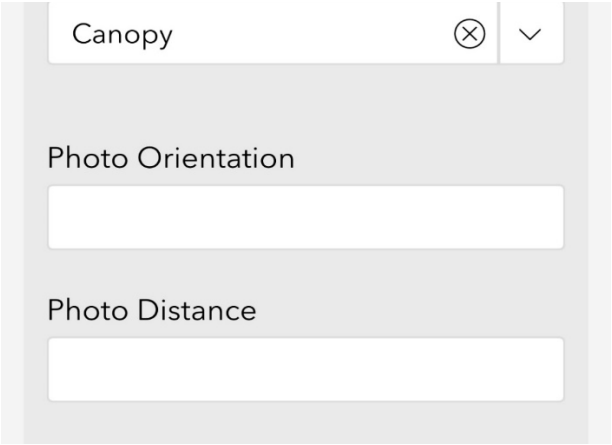
At the end of the survey, surveyors are tasked with taking images of canopy health, basal bleeds (if any), tree tag ID, soil sample ID (if required), neighbouring species (if required) and evidence of disturbance (if required).



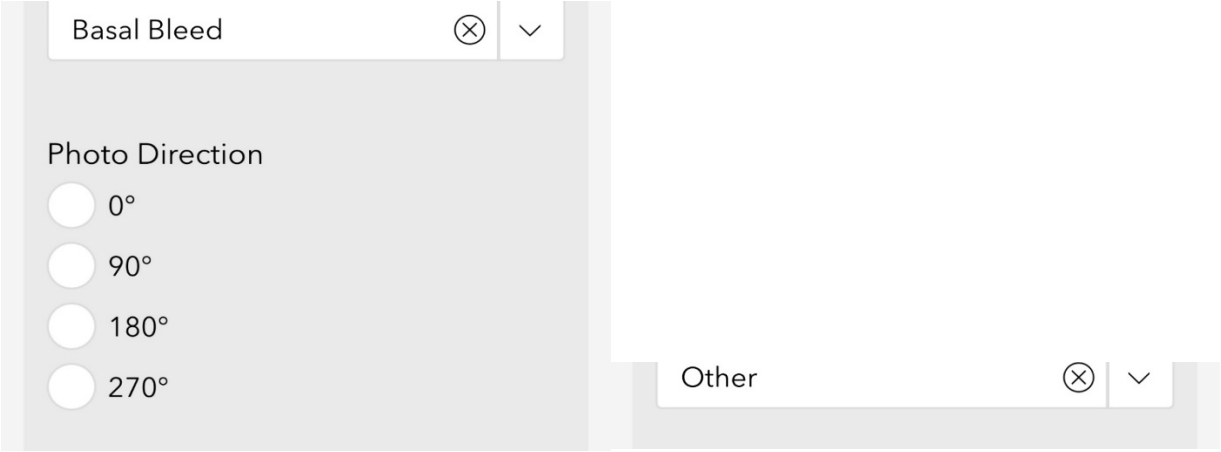




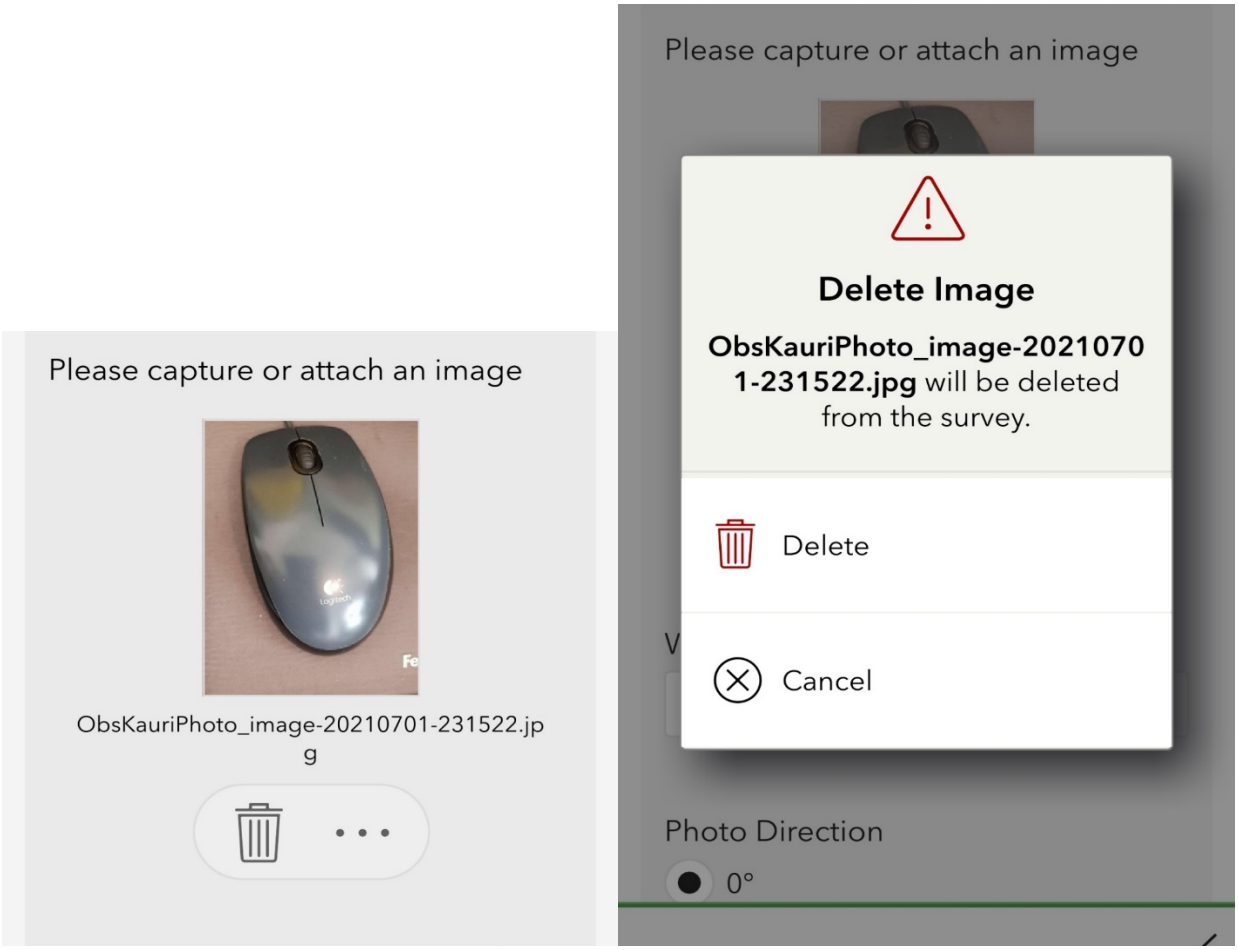
If Canopy is selected from the drop-down, then additional information is requested so that images can be compared in future surveys.



If Basal Bleed is selected from the drop-down, then additional information is requested so that images can be compared in future surveys.



Once the image is captured (example of a computer mouse below) then a filename is generated, and the image can be checked to make sure it is clear and then saved or deleted if a better image is required.



Once photos have been acquired, a ‘Survey completed’ message is generated. If more photos are required, then ‘Continue this survey’ is selected to add additional images.

Question 40: Survey completed

When the survey is completed, the surveyor can check if the device is online and send the survey to the database immediately or save the survey to the outbox.

A11 Variables calculated using existing data sources

Ngā taurangi kua tātaihia mā te whakamahi i ngā puna raraunga o te wā

A11.1 Host-related risk factors

Host factors included epicormic growth, if active growth flush or female reproductive cones were visible and if immature kauri growth stages were present within a 5 m radius around the monitored tree. Growth stages were split into small seedlings <15 cm tall, tall seedlings between 15 cm and 1.35 m (breast height) and saplings which were characterised as >1.35 cm tall and less than 10 cm DBH. Saplings were also counted into groups of 0, 1-5, 6-10 and >10 saplings present.

A11.2 Anthropogenic risk factors

There were several potential anthropogenic risk factors that were able to be calculated using existing GIS data both from the Auckland Council GIS layers and other geospatial data sources. The calculations of these GIS related variables are described in Table A-3.

All distance measures were from the point of interest which was the canopy central point to the centre of the feature if not otherwise described.

A11.3 Environmental risk factors

There were many potential environmental risk factors that could be calculated using existing GIS data both from the Auckland Council GIS layers and other geospatial data sources. The calculations of GIS related variables are described in Table A-3.

Table A-3. GIS derived variable names, units and a description of how they were derived.

Variable name	Unit	Description
Canopy height	metres	Tree height based on LiDAR
Distance to closest track	metres	Distance to closest track
Closest track name	text	Name of closest track
Uphill distance to track	metres	Distance from kauri tree and the closest uphill track point - based on two conditions: i) tree and track are in the same sub-catchment; ii) elevation of the track is higher than the elevation of the kauri tree
Natural sub-catchment	text	Name of the delineated natural drainage sub-catchment the tree is located within
Stream sub-catchment	text	Name of the smaller stream based sub-catchments within the natural drainage sub-catchments
Distance to closest road	metres	Distance from closest public road
Distance to ocean	metres	Distance from mean high-water mark from closest coastline including harbours and estuaries

Elevation	metres	Elevation in metres above sea level at location where tree is growing
Aspect	degrees	The geographical direction in degrees the slope is facing at the tree location
Slope	degrees	Slope at location where tree is growing
Depth to water index	Metres	Depth to water index (DTW) – a soil moisture index. The DTW output is a 32 bit 1x1 m surface raster. It was created using a multistep process; first, smoothing the high-resolution hydro conditioned 2016 DEM. Smoothing was used to blur DEMs to remove the changes in elevation that are too small to indicate features of interest (i.e., microtopographic noise), which are ubiquitous in high-resolution DEMs. The default Perona Malik smoothing method and 10 m smoothing width with 50 iterations were applied. This smoothed DEM is the primary input for the Depth to Water index tool (Archydro toolbox). The other is a surface water raster layer – this was generated from a combination of the water bodies in the 'Inland Water Bodies' feature from the Auckland Council Ecosystems layer and the permanent streams layer. These layers were rasterised for use in the DTW tool. This tool calculates the cartographic depth-to-water index (DTW). The DTW, developed by Murphy et al. (2007), is a soil moisture index based on the assumption that soils closer to surface water in terms of distance and elevation are more likely to be saturated.
Distance to closest overland flow path	Metres	Distance to overland flow path
Distance to park boundary	Metres	Distance to park boundary
Distance to historic timber sites	Metres	Distance to early European timber mills/saw pits
Landcover database types	Text	New Zealand Landcover database (LCDB) class from the LCDB v5.0 - Land Cover Database version 5.0, Mainland, New Zealand, Manaaki Whenua Landcare Research
Ecosystem types	Text	Habitat types e.g., wetlands vs shrubland, clearings, forest types (Native, Plantation, Restoration, Remnant, Riparian, Urban) based on Singers and Rogers (2014)
Within 500 m of archaeological features	Count	Number of archaeological features within 500 m

Closest confirmed *P. agathidicida* site	Text	Distance to closest confirmed *P. agathidicida* site from current and historic soil test results as defined in Stevenson and Froud (2020)

A12 Updated summary of the Stevenson and Froud (2020) draft kauri dieback case definition

Te whakarāpopoto hou i tā Stevenson rāua ko Froud (2020) whakamahuki i te hukihuki o te rangahau iti mō te puruheka patu kauri

Case definition	Case classification	Soil test positive	Symptomatic criteria	Epidemiological criteria	Approved observer
Symptomatic	Confirmed	Yes	Yes	Yes	Yes
Symptomatic	Probable	No	Yes	Yes	Yes
Symptomatic	Suspect	No	Yes	No	Yes
Non-symptomatic	Ill-thrift	Yes or no	No but ill-thrift	Yes or no	Yes
Non-symptomatic	Healthy	Yes or no	No	Yes or no	Yes or no

A13 Common species method development

Te huarahi whakawhanake mō ngā momo māori

A common kauri tree community species checklist was developed using the following methods:

The Auckland University Waitākere kauri plot data (unpublished data) were assessed, and the most common tree species were extracted from those plots. Based on both the number of plots they occurred in and the mean ranking of these species within plots, the top 15 species were identified as:

1. *Coprosma arborea* - māmāngi
2. *Cyathea dealbata* - ponga
3. *Pseudopanax crassifolius* – lancewood
4. *Myrsine australis* – māpou
5. *Dacrydium cupressinum* – rimu
6. *Knightia excelsa* – rewarewa
7. *Phyllocladus trichomanoides* – tanekaha
8. *Kunzea robusta* – kānuka
9. *Nestegis lanceolata* – white maire
10. *Leucopogon fasciculatus* – mingimingi
11. *Geniostoma ligustrifolium* – hangehange

12. *Coprosma lucida* – shining karamū
13. *Leptospermum scoparium* – mānuka
14. *Melicytus macrophyllus* – large-leaved māhoe
15. *Pittosporum ellipticum*

A potential criticism of this list is that it includes some species that occur equally commonly with and without kauri, e.g., *Cyathea dealbata, Geniostoma ligustrifolium, Leptospermum scoparium*

A second source of information was the research carried out by Wyse et al. (2014) which looked at the strength of association of species with kauri at Waipoua and Russell forests using large plot databases. The results from Wyse et al. (2014) were used to come up with a list of 15 tree species that had the highest mean association between kauri and each species, as follows:

1. *Phyllocladus trichomanoides* – tanekaha
2. *Leucopogon fasciculatus* – mingimingi
3. *Olearia rani* – heketara
4. *Brachyglottis kirkii* – Kirk's tree daisy
5. *Toronia toru* – toru
6. *Myrsine australis* – māpou
7. *Podocarpus laetus* – Hall's tōtara
8. *Pseudopanax crassifolius* – lancewood
9. *Dacrydium cupressinum* – rimu
10. *Coprosma lucida* – shining karamū
11. *Kunzea robusta* – kānuka
12. *Knightia excelsa* – rewarewa
13. *Nestegis lanceolata* – white maire
14. *Pectinopitys ferruginea* – miro
15. *Coprosma arborea* – māmāngi

These lists shared many species and a final list that combines them by removing the three species that are common with and without kauri in the Waitākere Ranges (*Cyathea dealbata, Geniostoma ligustrifolium, Leptospermum scoparium*), and excluding species that are rare in the Waitākere Ranges, e.g., *Podocarpus laetus, Pittosporum ellipticum*, was developed. The final list is as below:

1. *Coprosma arborea* – māmāngi
2. *Pseudopanax crassifolius* – lancewood
3. *Myrsine australis* – māpou
4. *Dacrydium cupressinum* – rimu
5. *Knightia excelsa* – rewarewa
6. *Phyllocladus trichomanoides* – tanekaha
7. *Kunzea robusta* – kānuka
8. *Nestegis lanceolata* – white maire
9. *Leucopogon fasciculatus* – mingimingi
10. *Coprosma lucida* – shining karamū
11. *Melicytus macrophyllus* – large-leaved māhoe
12. *Olearia rani* – heketara

13. *Brachyglottis kirkii* – Kirk's tree daisy
14. *Toronia toru* – toru
15. *Pectinopitys ferruginea* – miro