KAURI RESCUE

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Kauri Rescue Citizen Science Evaluation of Kauri Dieback Treatment Tools

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Executive Summary

Kauri dieback caused by *Phytophthora agathidicida* is resulting in decline and death of kauri trees throughout kaurilands. Many diseased or threatened trees are on private land, and landowners are left feeling helpless as their kauri trees decline around them.

Kauri Rescue™ started as a citizen science project in late 2016, working with private landowners to treat and monitor kauri trees suffering from kauri dieback disease on their properties. It became a Charitable Trust (Kauri Rescue Trust) in December 2020.

The current Ngā Rākau Taketake-funded project builds on previous projects with Kauri Rescue's citizen scientists, aiming to follow the fate of trees previously treated with phosphite as part of the earlier citizen science work. The main aims were to assess the effectiveness of phosphite for treatment of kauri dieback, and to assess the accuracy of the participants in implementing the treatment/monitoring protocols and collecting the data.

Participant landowners had, under previous projects, selected one of four treatment options for their trees, or left trees as untreated controls. The concentration of phosphite was either 4% or 6% active ingredient, with 20 ml injections every 40 cm (low dose) or 25 cm (high dose) around the trunk circumference.

The aim of this project was to focus on approximately 500 trees for which there was good historical baseline health and monitoring data, and a prospect of collecting ongoing data. The entire pool of participants (109) and trees (3163) at the start of the project were assessed for potential inclusion, with various criteria employed to distil that number down to the focus trees for detailed analysis. Trees or sites were excluded from the selection if forensic assessment of the data suggested unreliability or obvious inaccuracies or missing information, or if landowners were unwilling to participate or collect further data themselves.

Before treatment, participants were asked to score their trees against potential tree health indicators. However, there were obvious inaccuracies in much of the participant-collected data, and it was also quite time consuming and challenging for participants to collect. Therefore, over time the data collection process was simplified and focussed on the key variables of 'Canopy health score', 'Moss and lichen score' and 'Basal bleed activity', where initial analysis suggested that there would be the greatest confidence in data accuracy when collected by citizen scientists.

The plan was for participants to collect data on selected trial trees on their own land and for trained professionals from BioSense to audit 10 – 30% of the selected trial trees, thus allowing a true citizen science dataset for analysis plus an independent audit of data quality and consistency. For various reasons including unreliability of data entry, landowner unavailability or unwillingness to collect annual reassessment data, participant inaction

and data in accuracy, Kauri Rescue personnel and volunteers increasingly needed to do the health re-assessments on many of the trial trees rather than the participants themselves. This added considerably to time inputs and costs of the project.

To follow tree health over time, the data were filtered to focus on trees that had been observed over multiple years. We used ordinal regression to test how the different treatments influenced symptoms of tree health and whether there were differences in scoring tree health categories between Kauri Rescue participants and auditors from BioSense.

Key observations from this work are:

- There is evidence that phosphite at either 4% or 6%, with 20 ml injected at either 25 or 40 cm intervals around the trunk, reduces the activity of lesions caused by *Phytophthora agathidicida*. The duration of the effect is not as long in the low dose treatments (i.e. 40 cm spacings), with an increase in the number of active lesions noted after 5 or 6 years. In untreated trees there was an increase in the moss and lichen score as time progressed, suggesting a decline in natural bark shedding and tree health. However, there were no obvious trends in canopy health score for the duration of the trial.

- Participant landowners were biased in selecting treatments and untreated trees. They tended to select higher phosphite rates and doses for trees showing kauri dieback symptoms, resulting in over-representation of diseased trees in the higher concentration and dose treatments. In contrast, healthy or asymptomatic trees were over-represented in the untreated controls and low phosphite treatments.

- There were multiple obvious errors in the original data, especially that collected or entered by citizen scientists, and many trees were discarded from the analysis in a data cleaning exercise. The citizen scientist data used for this investigation is therefore highly sanitised. There are likely to be undetected errors in the remaining data, perhaps increasing the 'noise' and blurring potential differences between treatments.

- The measured characteristics for analysis were restricted to lesion activity, canopy health, and moss and lichen score. Other measured characters were discarded from the analysis as there were obvious discrepancies and inconsistencies in how people recorded them. A few simple clear measurements provided much better data than did a lot of data collection on more complex variables. In this case the accuracy gains of a couple of data collection points outweighed a wider approach of trying to follow many variables. Because of the procedural problems observed and the inaccuracy of data collection by some of our citizen scientists, our processes, characteristics to be assessed, and data entry have been substantially simplified. Manuals and training videos have been significantly simplified and improved, and support, training and guidance of participants increased.

- There were differences between Kauri Rescue participants and BioSense auditors in the way they scored canopy health and moss & lichen score. However, these differences were relatively small and the over-all trends were similar. There was close alignment between Kauri Rescue observers and auditors in scoring of lesion activity. Lesion activity scores are a more useful and accurate measure for citizen scientists than are canopy health and lichen scores. The observation that volunteers can detect lesions in a similar (but not perfect) manner to more experienced observers is an especially crucial point as it gives volunteers the confidence to continue. However, it must be noted that the comparisons between Kauri Rescue participants and the BioSense auditors were made on highly sanitised participant data, where multiple obvious errors were removed from the analysis. Additionally, many of the citizen scientist measurements, particularly toward the end of the study, were made by experienced Kauri Rescue personnel and volunteers. This undoubtedly improved the accuracy of the data.

- The willingness of landowners to collect annual or biennial tree health reassessment data waned significantly over time. This meant that to collect the required amount of data for this project much of the later reassessments had to be done by Kauri Rescue personnel, which significantly increased the cost of the project well beyond the funding provided.

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Introduction

Kauri Dieback Background

Kauri dieback, caused by *Phytophthora agathidicida*, is resulting in decline and death of kauri trees in many parts of Auckland, Northland and Coromandel (refs – Beever et al. 2009, Weir et al. 2015). The main symptoms noticed are canopy thinning and/or yellowing, branch dieback and eventually tree death. The characteristic bleeding lesions on the lower trunk just above ground level are often, but not always present (Figure 1).

Figure 1. Kauri dieback symptoms: Basal trunk bleeds (left) and thinning or dead canopies (right).

Tree infection occurs when oospores (resting spores) of *P. agathidicida* in soil or plant debris germinate to produce sporangia and zoospores. These zoospores infect the kauri feeder roots, with subsequent spread to the main roots and lower trunk. Once it reaches the lower trunk, bleeding lesions or cankers appear, gradually advancing up and around the trunk, eventually resulting in girdling and tree death. Some trees die before the pathogen spreads to above-ground portions of the tree, presumably because of substantial root infection. If left untreated, most kauri trees infected with *P. agathidicida* will eventually die.

There is no known cure for kauri dieback, but in scientific trials, injection with phosphite (phosphorous acid) has proven to be an effective treatment in affected trees (Horner et al. 2015, 2020), although many subtleties of treatment methods (e.g. rates, timing, repeat application etc.) remain unknown.

Kauri Rescue

The Kauri Rescue project started from a desire of scientists to see practical application of kauri dieback treatment tools that were emerging from research programmes, and a desperate need in affected communities for treatment to save their dying trees. Property owners with confirmed kauri dieback will likely lose most of their kauri to the disease over time, and this had led to a sense of hopelessness within communities.

Kauri Rescue™ started as a citizen science project in late 2016, working with private landowners to treat and monitor kauri trees suffering from kauri dieback disease on their properties. It was initially housed within Plant & Food Research (PFR) and funded for two years by the New Zealand Biological Heritage National Science Challenge. The funding base grew, with additional ongoing support from Auckland Council and Tiakina Kauri.

The Kauri Rescue Trust was established as a Charitable Trust in December 2020 and is made up of a governing Trust Board and a scientific Technical Advisory Group. The Trust's work has primarily been centralised around a citizen science project based in the Waitākere Ranges, endorsed by Te Kawerau-ā-Maki, but is gradually expanding into the wider Auckland region and Northland.

Kauri Rescue team members include scientists, social scientists, local body representatives, Iwi and members of the public. Much of the work requires assistance from a diverse group of volunteers from local communities.

BioSense is a private company that collaborates with Government organisations, Iwi/Hapū groups, Crown Research Institutes, Universities, and private entities to support the efforts of NZ Biosecurity. The BioSense team have been working in the fight to save Kauri from kauri dieback since 2010 and include a founding member of Kauri Rescue. The team have surveyed over 85,000 kauri across significant ngāhere. As well as conducting kauri surveillance the team are also currently providing training and tools to Iwi and Hapū groups wanting to conduct kauri dieback surveillance within their own rohe as part of the Tiakina Kauri led national response to kauri dieback.

The Kauri Rescue process

Landowners approach Kauri Rescue in various ways, either directly, via Regional Councils or through recruitment efforts in targeted communities. If kauri dieback (i.e. presence of *Phytophthora agathidicida*) is confirmed on their properties by soil testing and the landowner would like to try a treatment regime, they become participants and can commence the treatment programme. If not, they are supported by being provided with information on general kauri care and hygiene and advised to monitor their trees' health and contact Kauri Rescue again if it deteriorates further.

Once recruited, private landowners work alongside Kauri Rescue team members and volunteers to treat trees on their property that are affected by kauri dieback disease. Treatments to date have predominantly been with phosphite, a chemical that has shown great promise in scientific trials, by inhibiting growth of the *P. agathidicida* pathogen that causes the disease, and by stimulating host defences to enable kauri to fight back against the pathogen. It is hoped that other tools will become available for the project to test over time, including those based on mātauranga Māori.

A key ambition of the programme is the two-way exchange of information and effort. Initially, the core project team provides information about kauri dieback and kauri health, materials for treatment, a training video and treatment manual, and personal guidance and training where needed. For large properties with multiple trees and in some circumstances where assistance is required, a team of Kauri Rescue members and volunteers assists the landowner with treatment. The citizen scientists collect data on their trees and how they respond to the treatment (preferably annual or bi-annual assessment), feeding this back into the project. In this way, landowners with kauri dieback problems on their land can treat the disease to minimise the impact of kauri dieback on their properties and communities, while at the same time contributing to the pool of knowledge about this experimental treatment and tree responses. As time goes on, the experiences of the landowners help modify and refine treatment protocols.

The project also aims to foster community engagement in forest health and biosecurity issues, with wider impacts than just treatment and monitoring of diseased kauri.

Ngā Rākau Taketake (NRT) project

The current NRT project, fitting within the 'NRT Tools' workstream, aimed to build on the existing knowledge from the early years of Kauri Rescue. Specifically, the project aimed to annually monitor selected trees that were treated in the first 3 or 4 years of the programme, to analyse the efficacy of the various treatments applied. Many of the trees selected for this study were treated under previous Kauri Rescue projects funded by New Zealand's Biological Heritage National Science Challenge (NZBHNSC) and Auckland Council (AC).

At present, the optimum phosphite dose for different sizes and health conditions of trees is unknown, as is any re-treatment protocol, or the health condition at which trees may still die despite treatment. Gathering research data on how trees respond to a variety of treatment doses, concentrations and starting health conditions was a key purpose of this project, along with facilitating the reduction of symptoms and extended life expectancy for trees with kauri dieback – trees that would otherwise die.

Another aim was to improve the tree assessment and data collection practices, based on an assessment of the accuracy and reliability of the data. Ultimately, practices should be modified to simplify procedures for landowners/participants and increase the value, accuracy and consistency of data collected.

Materials and Methods

Site/tree selection

For this study, our aim was to focus on approximately 500 trees for which there was good historical baseline health and monitoring data, and a prospect of collecting ongoing data. The entire pool of participants (109) and trees (3163) at the start of the project were assessed for potential inclusion in the project, with a plan to distil that number down to 500 focus trees for detailed analysis.

The criteria set to determine which sites or trees to include in the study were:

- The selection should include trees on 5-10 different properties, covering a range of geographical and ecological scenarios
- There should be a range of pre-treatment symptomology within the selected trees
- Participants from across the timeline of Kauri Rescue should be included
- Owners should be easily contactable and willing to participate in an ongoing study, and willing to collect annual data on tree responses.
- Tree selection decisions should not be biassed by any post-treatment assessments.
- There should be a diversity in land use/ecology of trial sites
- There should be geographic dispersal of trial sites

Trees or sites were excluded from the selection if:

- forensic assessment of the data suggested unreliability or obvious inaccuracies or missing information
- landowners were unwilling to participate or collect data themselves

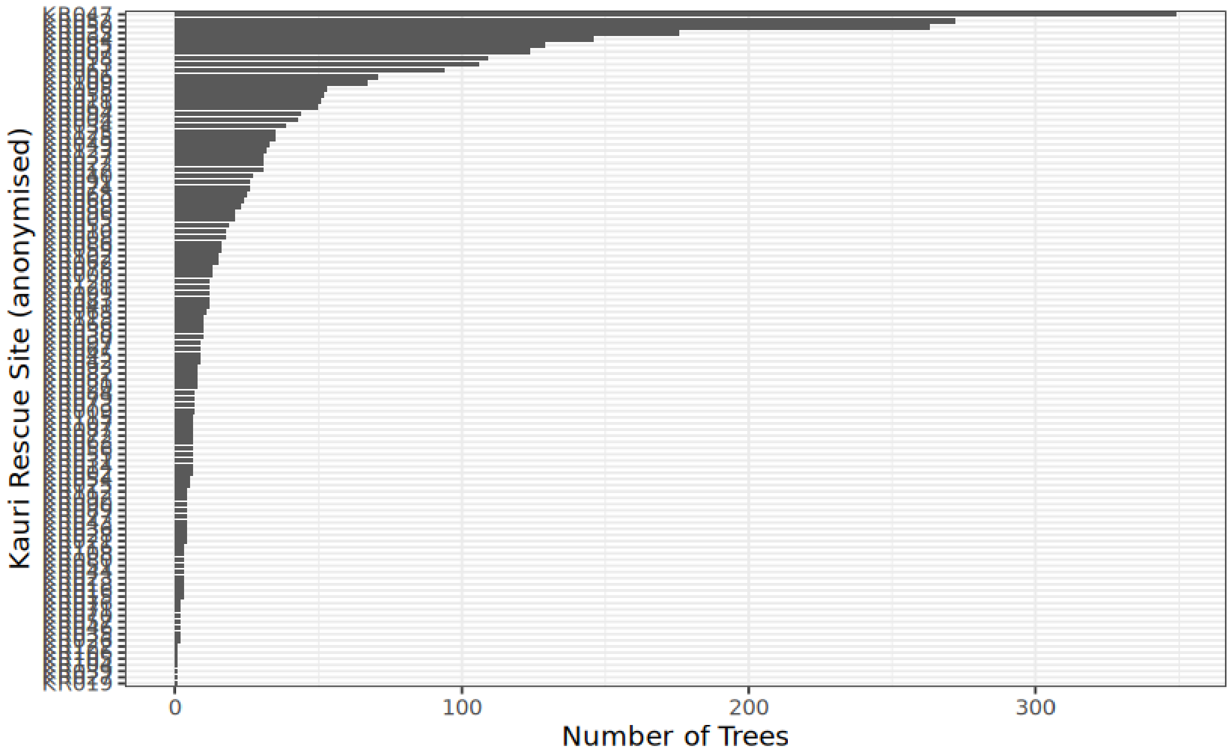

Figure 2. Histogram of the total number of kauri trees at each site for all the trees monitored as part of Kauri Rescue project. The number of trees ranged from 1 to 349 trees at a site with the median being 9.

The plan was for participants to collect data on selected trial trees on their own land and for trained professionals from BioSense to audit 10 – 30% of the selected trial trees. This was to allow a true citizen science dataset to be used for analysis plus an independent audit of data quality and consistency to be undertaken by using the data captured by BioSense. For various reasons including unreliability of data entry, landowner unavailability or unwillingness to collect annual reassessment data, participant inaction, concerns about data accuracy etc., Kauri Rescue personnel and volunteers increasingly needed to do the health re-assessments on many of the trial trees rather than the participants themselves. This added considerably to time inputs and costs of the project.

Data collection/ Baseline measurements

Before treatment, participants were asked to score their trees against potential tree health indicators, following processes set out in the initial Kauri Rescue treatment manual and instructional video. This work was primarily done under previously funded projects. Initially participants were asked to track individual bleeds on a tree. However, in early analyses of the data it became apparent that many participants struggled identifying the same bleed in sequential assessments. There were obvious inaccuracies in much of the participant-collected data. It was also quite time consuming and challenging for participants to collect, so this measure was simplified.

Over time, the data collection process was simplified and focussed on some key variables where initial analysis suggested that there would be the greatest confidence in data accuracy when collected by citizen scientists. For this study, the key variables were:

<u>Canopy health score</u>: 1 (healthy) to 5 (dead) (see Figure 3). Half scores were allowed where it was difficult to decide between two potential categories.

<u>Moss and lichen score</u>: A scale from 1 (95-100% clean bark) to 5 (less than 20% clean bark) was devised (see Figure 4), with strict criteria on which side of the tree should be assessed.

<u>Basal bleed activity</u>: absent, not-active, semi-active, active (see Figure 5).

Participants were asked to record their observations into a Google form. Most fields were pre-set although some fields were free text (e.g., date, as the default at the time used an American format which was not intuitive to New Zealanders).

The intention was for data analysis to investigate the success of the treatment in reducing the impact of kauri dieback and the accuracy of the participants in implementing the treatment/monitoring protocols and collecting the data.

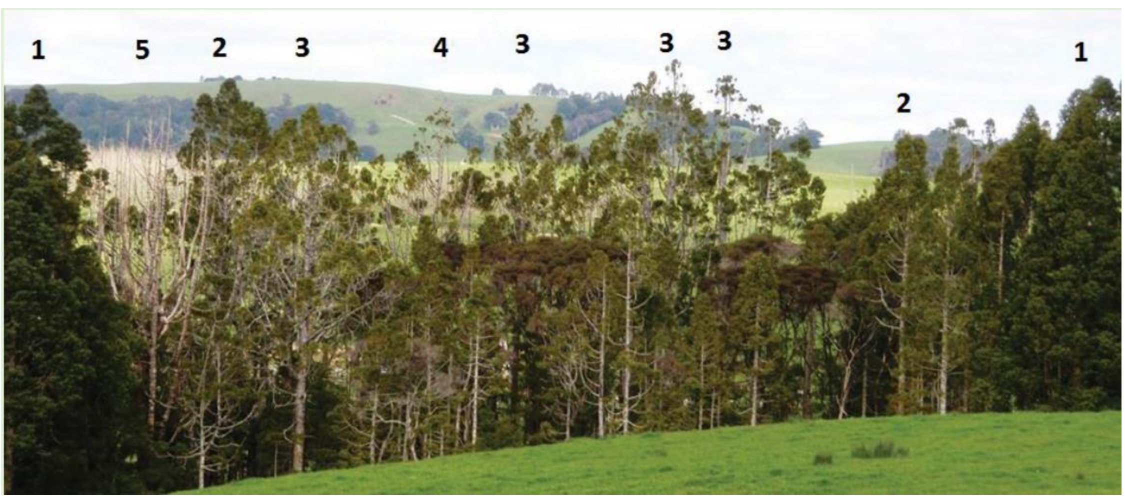

Figure 3: Canopy health score. 1= healthy, 5 = dead

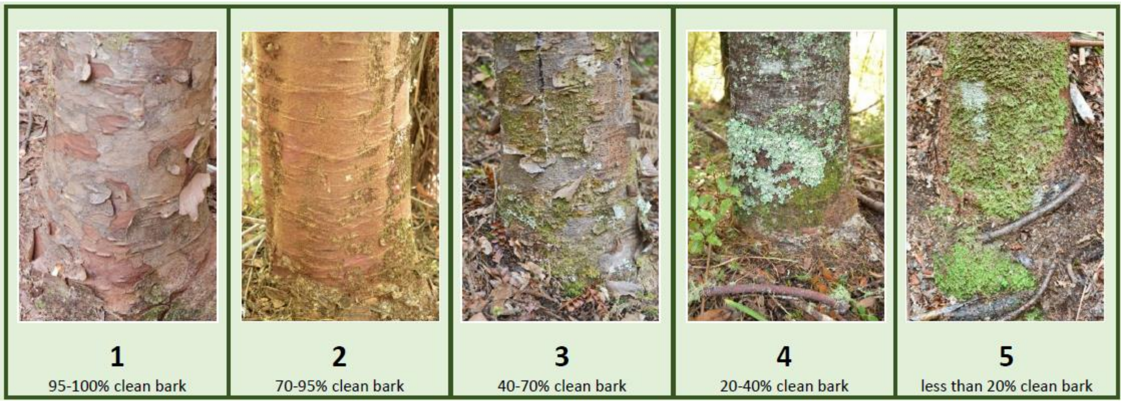

Figure 4: Moss and lichen score.

Figure 5: Basal bleed activity assessment.

Treatment

Following pre-treatment assessments of the tree health parameters outlined above, participant landowners selected one of four treatment options for their trees, or left trees as untreated controls. The concentration of phosphite was either 4% or 6% active ingredient, with 20 ml injections every 40 cm (low dose) or 25 cm (high dose) around the trunk circumference. Thus, treatment options were, in order of increasing total phosphite:

- untreated control
- 4% phosphite, 20 ml injected at 40 cm spacings around the trunk (low4)
- 6% phosphite, 20 ml injected at 40 cm spacings around the trunk (low6)
- 4% phosphite, 20 ml injected at 25 cm spacings around the trunk (high4)
- 6% phosphite, 20 ml injected at 25 cm spacings around the trunk (high6)

Landowners chose which trees were treated and which (if any) were left untreated. In most cases this was not an unbiased decision, with people influenced by tree health, proximity to diseased areas, how much they wanted to save particular trees etc. in determining treatment options. A simple chart was provided to help landowners calculate doses, based on tree circumference (Figure 6).

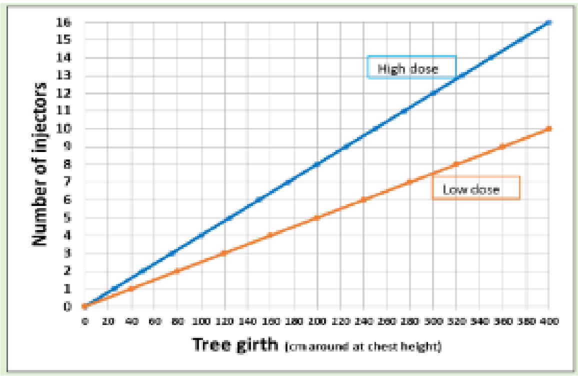

Figure 6. The number of injections recommended on a tree for high or low dose treatments, based on trunk circumference.

The chemical used was Agri-fos®600, a 60% solution of phosphorous acid, diluted to the appropriate concentration with clean water. Injection was with Chemjet® tree injectors, into a hole drilled to a depth of approximately 4 cm (Figure 7).

Figure 7. Trunk injection of phosphite with Chemjet tree injector.

Data collection / Ongoing monitoring

As a key part of the current study, participant landowners were asked to reassess tree canopy health, moss/lichen score and trunk lesion activity on an annual basis, using the same scoring criteria as for initial assessments. The plan was for participants to collect data on selected trial trees on their own land and for trained professionals from BioSense to audit 10 – 30% of the selected trial trees. The aim was to use this to determine how accurate participants were in scoring indicators of tree health. However, as time progressed it became apparent that annual checks were infrequently done by participants, and this task was increasingly completed by Kauri Rescue personnel and volunteers, especially in the later years (Table 1; Figure 8).

Data cleaning and summary

Because much of the initial (and some follow-up) data had been collected and entered by citizen scientists, a lot of data cleaning was needed. Generally, this resulted in obscure entries being removed from the final dataset. Despite intensive cleaning, there are likely to still be inaccuracies or errors that have not been picked up.

Data was cleaned to remove duplicated entries and obvious data entry errors (e.g. impossible or missing dates, and missing treatments). Occasionally participants entered an assessment twice but giving different answers. In this situation we used the first entry for that assessment. After cleaning, 1442 unique trees had been measured more than once (i.e. an initial assessment and at least one subsequent assessment). A total of 552 trees had been measured four or more times.

To follow tree health over time, the data were filtered to focus on trees that had been observed over multiple years. For Kauri Rescue data, some trees had multiple assessments in a calendar year. In such instances the first observation in each calendar year for a tree was taken, to avoid biasing the data to trees with multiple assessments in a year. BioSense conducted audits in Year 5 and 6 of the study and the modelling explicitly included a term to compare the audited trees with trees in the Kauri Rescue dataset.

After filtering data to the first observation each year, the dataset comprised of 6594 observations made on kauri trees (including BioSense audits). Of these 3516 were made by landowners or other participants in the KR project, 1334 were by KR personnel and 1744 were BioSense audits. Table 1 shows the total number of trees reassessed by KR participants. There is a general trend that Kauri Rescue personnel completed more of the later observations than volunteer citizen science participants (Figure 8).

Table 1. The number of trees assessed by Kauri Rescue participants (landowners and other volunteers) or KR personnel following treatment (years 0-6). KR personnel assessed more trees in the later parts of the programmes as volunteer and landowner enthusiasm waned. Assessment number is the number of times a tree was assessed over the different years (if there were multiple assessments in a year only the first assessment was kept for that year).

		Years since treatment						
Kauri Rescue category	**Assessment number**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
Landowners or other participants	**1**	2245						
	2	88	479	117	247			
	3			130	125	3		
	4			3	27	29	18	
	6					5		
KR personnel	**1**	663						
	2		65	75	28	2		
	3			92	167	4	1	
	4					15	47	
	5					77	101	

Figure 8. The proportion of trees assessed by Kauri Rescue participants. Kauri Rescue participants are landowners and other volunteers, Kauri Rescue personnel are paid coordinators and other experienced members of Kauri Rescue who have reassessed trees to ensure longitudinal collection of data.

The distribution of treatments in trees

After data cleaning, processing and filtering the study included a total of 3127 trees across 109 sites. Landowners had a choice of high (6%) or low (4%) phosphite concentration combined with high or low dose (see Figure 6) with which to treat trees. Treatments were not allocated randomly; rather the combination of concentration and dose were selected by the landowner, but advice was given by Kauri Rescue personnel to try and leave every tenth tree untreated. Most landowners treated their trees with the highest phosphite concentration (6% a.i.). Of these, slightly more also treated their trees with the highest phosphite dose than with the lower dose (Table 2). Fewer landowners treated their trees with the lower phosphite concentration, but for those that did the majority combined this with the lowest phosphite dose.

Table 2. Number of trees treated with each treatment combination (a.i. is active ingredient).

Dose	**Phosphite concentration (% a.i.)**		
	0%	**4%**	**6%**
Untreated	407		
Low		620	831
High		211	854

There were significant differences in the distribution of treatments based on the initial basal bleed status (chi-square test: p <0.001). Trees that had basal bleeds absent were overrepresented in the untreated group, while trees that had active bleeds were overrepresented in the higher phosphite treatments (Table 3). This likely reflects people's desire to treat trees showing obvious symptoms, while being more prepared to leave apparently asymptomatic trees untreated.

Table 3. The distribution of phosphite concentrations in trees with different levels of basal bleed activity. Numbers in brackets are the values expected if there was no association between basal bleed activity and phosphite concentration selected.

	Phosphite concentration				
Score	**Untreated**	**Low 4**	**Low 6**	**High 4**	**High 6**
Absent	362 (310)	453 (472)	645 (631)	136 (160)	625 (645)
Not active	5 (4)	6 (6)	7 (7)	2 (2)	8 (8)
Semi-active	11 (31)	54 (48)	81 (64)	16 (16)	61 (65)
Active	29 (62)	106 (95)	96 (126)	55 (32)	158 (129)

Data analysis

We wanted to predict observers' subjective scores of symptoms of kauri dieback (basal bleed activity, canopy health score (1-5), moss and lichen score (1-5)) over time, following the particular treatment of phosphite applied to the tree (if any), given the initial presence or absence of kauri dieback symptoms on the tree. We were interested in testing four specific hypotheses for these tree health scores:

1) does phosphite treatment result in lower levels of kauri dieback symptoms, stabilisation of symptoms, or slower decline?
2) how does the effect of treatment change over time?
3) does phosphite have a preventative effect for trees not initially showing symptoms?
4) can participants in citizen science projects describe symptoms in a similar manner to professionals who are working in the field? Here we compared observations by participants in the Kauri Rescue project (landowners, volunteers and paid staff) to audits by Biosense.

To test these questions, we used a Bayesian implementation of ordinal regression models implemented in Stan using the R-package brms (Bürkner 2017). While scores are allocated by observers in a roughly linear manner (e.g, 1-5), we used ordinal regression rather than linear regression because we cannot assume that the assessors always consistently assess the scores in an equidistant way. For example, the difference between a 1 and a 2 may be much greater than a 4 and a 5 (Liddell and Kruschke 2018). In addition, what might be considered a score of 2 for canopy health by a Kauri Rescue observer might be considered differently by trained BioSense staff involved in the audit. Ordinal regression allows us to address these considerations specifically.

For all models, tree was considered a random effect (as trees were re-assessed over a number of years) and we examined the fixed effects of Kauri Rescue / BioSense coding of participants, years since treatment, years since treatment2, phosphite treatment and presence of an initial lesion, and the inclusion of a three-way interaction of treatment x initial lesion presence × years since treatment2. We included the polynomial term (years since treatment2) as we hypothesised that dose-related changes in symptoms over time may not be strictly linear if, for example, the effect of phosphite gradually reduces. Phosphite dose and concentration were an incomplete-factorial design but treatments resembled a linear combination of the amount of phosphite applied to the tree (untreated, low dose 4% concentration, low dose 6% concentration, high dose 4% concentration, high dose 6% concentration). This linear combination was similar to the most popular treatment combinations chosen by participants (Table 2).

We initially modelled response of kauri to treatment using a cumulative model that assumes that the observed variable (for example basal bleed activity, which was scored as absent, not active, semi-active or active) reflects an underlying continuous variable where the thresholds between the categories might be influenced by certain factors (Bürkner and Vuorre 2019). For example, professional auditors (BioSense staff) may score bleeds consistently more conservatively than Kauri Rescue observers. We then compared these models with models that included 1) flexible distances between category cut-offs but consistent between types of observers or 2) category-specific effects to test whether observer experience impacts the placement of thresholds between the health indicator categories. For example, experts and other participants may score absent and not-active basal-bleeds similarly but have a different understanding of semi-active compared to active bleeds. We also incorporated the possibility that the variances of the responses may differ between groups. We selected the best model using leave-one-out cross-validation (Vehtari, Gelman, and Gabry 2017). For all three indicators of tree health, incorporating flexible cut-offs effects resulted in better fits of the posterior predictions to the data and had a better expected predictive accuracy, and for canopy health score and moss and lichen score where the cut-offs between any two categories occurred depended on the experience of the scorer. This suggested that there are differences between participants in the Kauri Rescue project (citizen scientists) and professional BioSense auditors, although these differences are often subtle.

Results and Discussion

Does phosphite treatment result in lower levels of kauri dieback symptoms?

Based on previous work, we estimated that trees should show the best response to phosphite, especially for bleed activity, within 1-2 years post treatment. We first focus on the first two years post-treatment to examine if there was an improvement in tree-health symptoms, especially for trees that initially had active lesions. The next section focuses on years 3-6 to look for waning effects of treatment.

Basal bleed activity

When trees had bleeding lesions at the beginning of the study, treatment with phosphite tended to result in a reduction of the proportion of trees that had active or semi-active basal bleeds in the first few years (see). Most trees in the initial lesion group were treated with low6 or high6 phosphite treatments. When trees did not initially show any basal bleed systems, there was a small increase in the number of trees that exhibited basal bleeds over time. The greatest increase in trees exhibiting basal bleeds over time was when lower concentrations of phosphite were applied with much lower levels of bleed activity developing in the high4 and high6 treatment concentrations (Figures 9&10).

For untreated controls, there were very low numbers of trees categorised into 'lesion present at start' category. Moreover, the numbers of trees that had continued ongoing monitoring declined sharply, so conclusions about trends should be made with caution.

Bayesian ordinal regression suggested that, in the first two years post-phosphite treatment, trees that initially had no lesions, or low lesion activity showed increases in the number of lesions or activity of lesions, especially in BioSense audited untreated trees (Figure 10).

When treated trees already had lesions at the start of the trial, lesion activity declined sharply over the first few years. Unintuitively, active lesion activity declined for untreated trees, although the decrease was not as marked as seen in all treated trees and characterised by wide 95% credible intervals. This was probably not due to the experience of the observers as the trends were similar between Kauri Rescue observations and audits by BioSense (Figure 10).

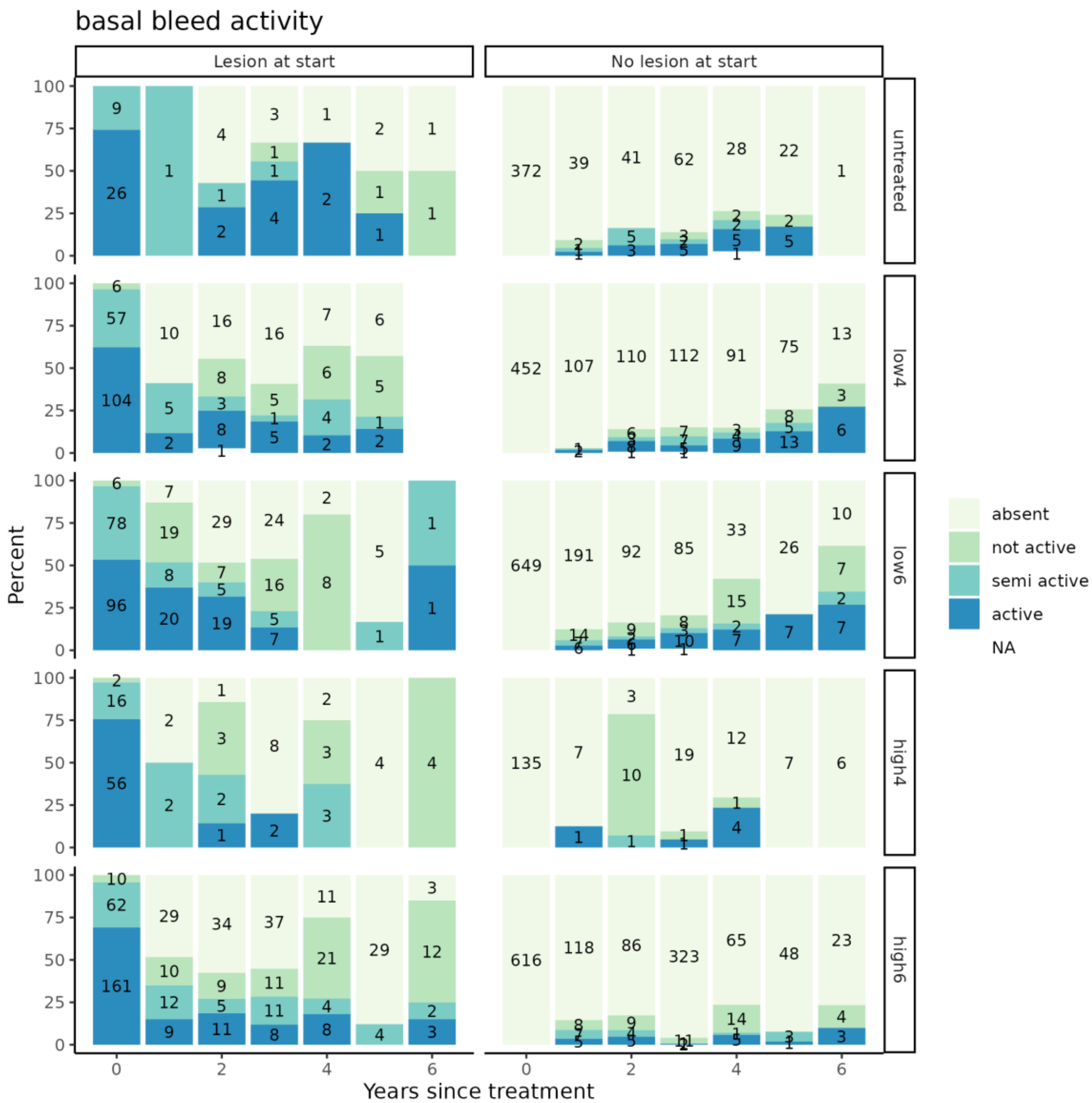

Figure 9: Basal bleeds for trees with and without lesions at the time of treatment. Numbers on the bars represent the actual number of individual trees in each category at each assessment time.

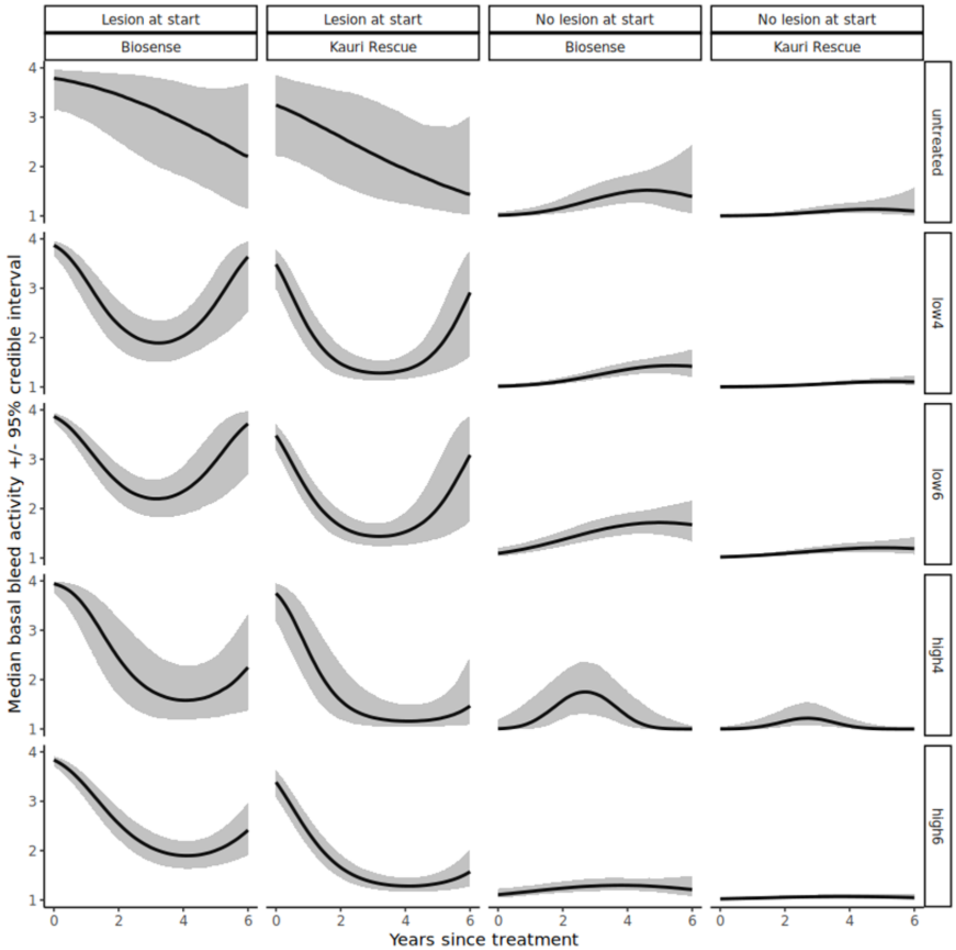

Figure 10: Basal bleed activity score (transformed onto a latent scale from a probability of a tree classed in a basal bleed activity score) in the years after phosphite treatment. No basal bleed activity was considered a 1 and active basal bleeds was considered a 4. Effects were conditioned on whether a tree initially had a lesion, and whether the observer was part of the Kauri Rescue project or a BioSense auditor.

It is possible or even likely that some of the bleeds recorded in treated trees in later assessments were from people noting bleeds from injection points, which can sometimes be difficult to distinguish from natural PA-caused trunk bleeds. It could also be that bleeds were noticed more as people became more familiar with the process. The number of non-active bleeds that were noted 2-3 years after injection in trees that earlier had no lesions recorded would suggest this might be the case. Non-active bleeds do not just suddenly appear but are a result of drying of earlier active bleeds.

Canopy symptoms

Canopy health was scored on a nine-point scale from 1 to 5 with 0.5 increments. For trees exhibiting lesions pre-treatment, canopy health scores were relatively stable in the first few years, with differences more reflecting low sample sizes in some categories than obvious trends (see Figure 11). Bayesian ordinal regression models suggested that the median canopy health score differed between untreated trees with and without lesions (estimate = -0.95 95% CI -13.1, -0.60). Untreated trees that started with lesions showed a slight increase in health score (i.e. a decline in canopy health), while those with no lesions declined slightly. For treated trees, canopy health scores were very stable (see Figure 12), with only slight increases or decreases in median score over time.

There was no strong difference between Kauri Rescue observations and observations by BioSense auditors in these two categories, with the only difference being in the positioning of cut-offs in the thresholds of categories (see discussion below).

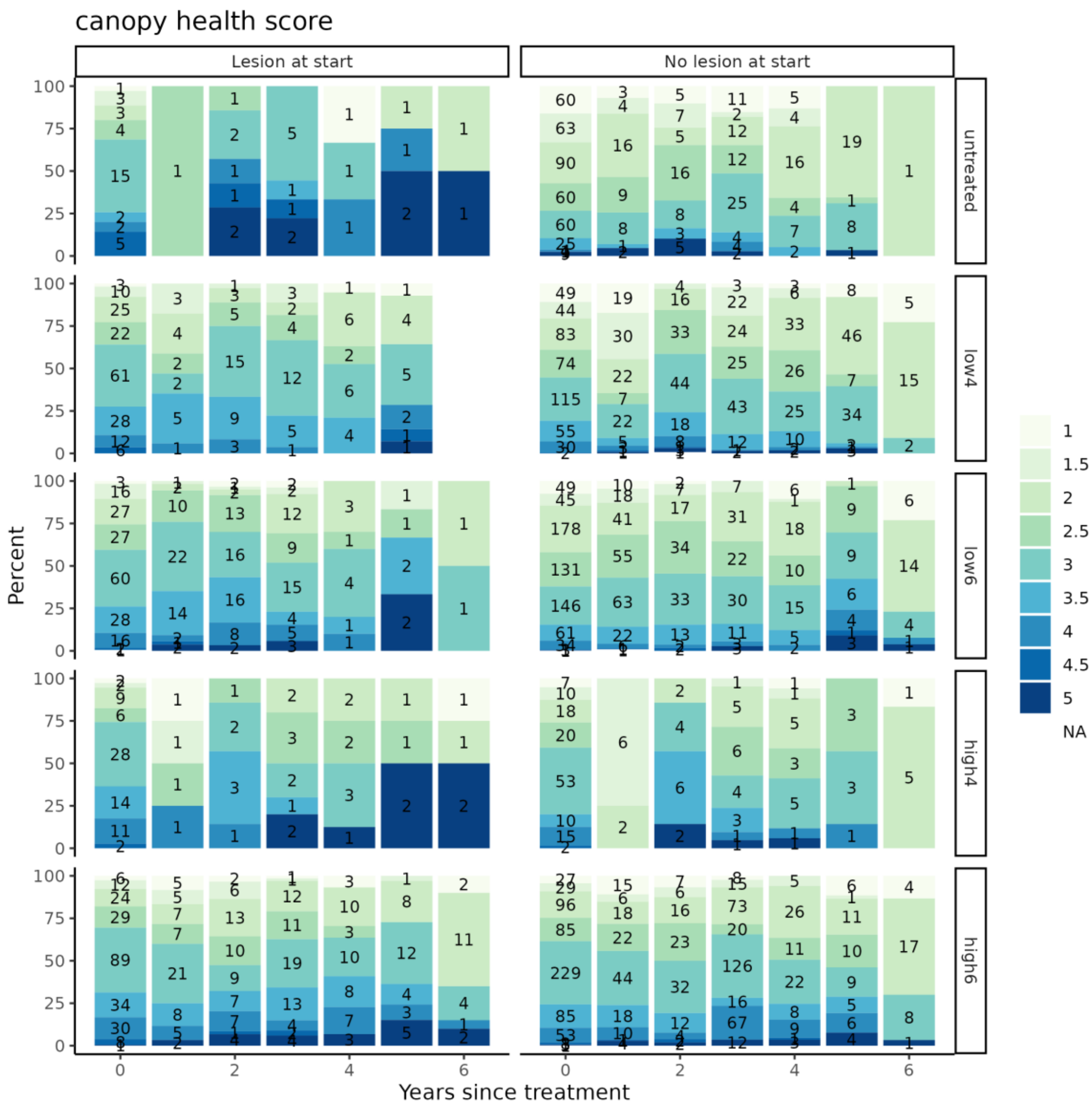

Figure 11: Changes in the proportion of trees in a canopy health score category for trees with and without lesions. Numbers on the bars are the number of trees in each category over time. Health was scored on a scale from 1 (healthy) to 5 (dead).

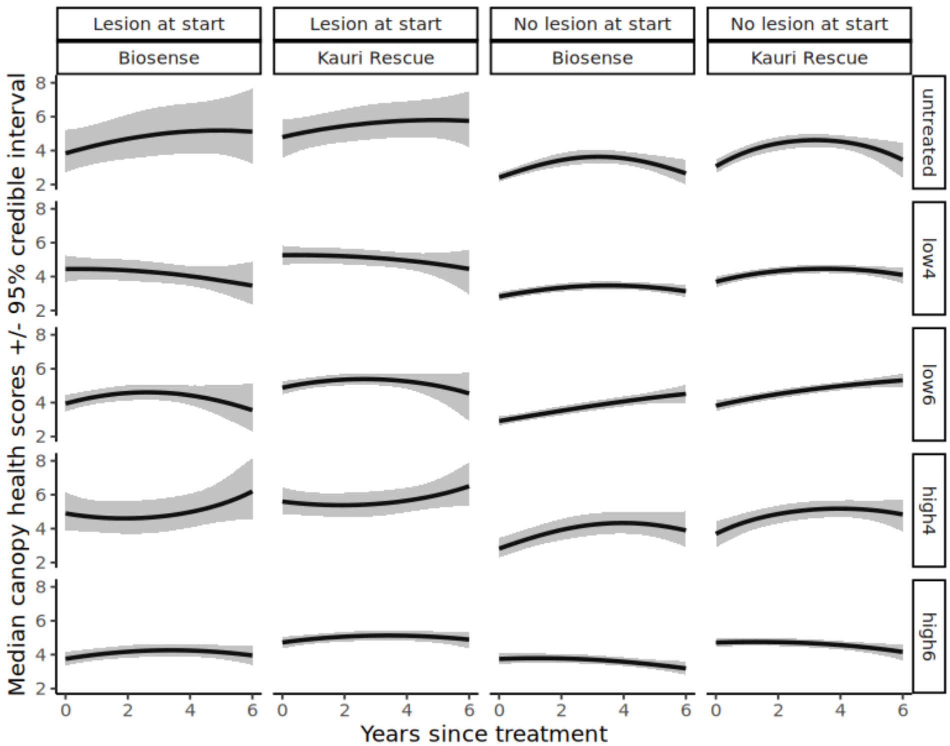

Figure 12: Median canopy health score +/- 95% credible intervals in the first 6 years after phosphite treatment. Effects were conditioned on whether a tree initially had a lesion, and whether the observer was an expert or a public member volunteer.

Moss and lichen score

Our hypothesis was that the amount of moss and lichen on a tree could be an indicator of tree health as infected trees have slowed growth and stop shedding bark. However, it is to be noted that other conditions (e.g., orientation, humidity and moisture) also influence epiphyte growth. By always observing the same side of the tree in any assessment, the 'noise' created by environmental effects should be minimised.

For untreated trees, scores initially increased over time (i.e. more moss and lichen on the bark, Figures 13 and 14). This was true for both trees that had lesions initially and those without, but the increase in moss and lichen score was slower for trees starting with no lesions. This trend is consistent with declining tree health, and a slowing of the natural bark shedding. There was also a similar increase in moss and lichen score for trees with no initial lesions and a low4 phosphite treatment.

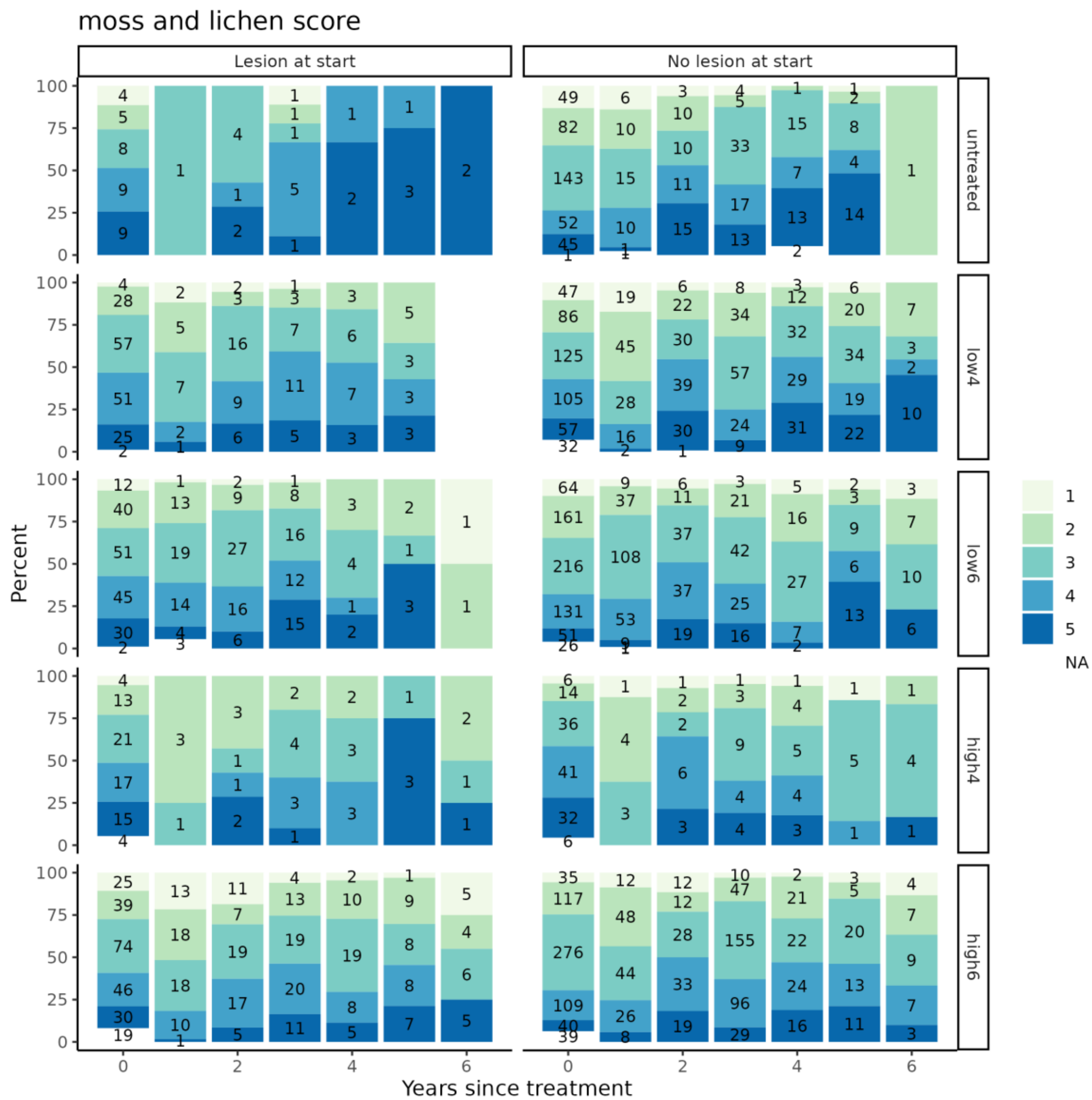

Figure 13: Changes in the proportion of trees in a moss and lichen score category for trees with and without lesions. Numbers are the number of trees in each category.

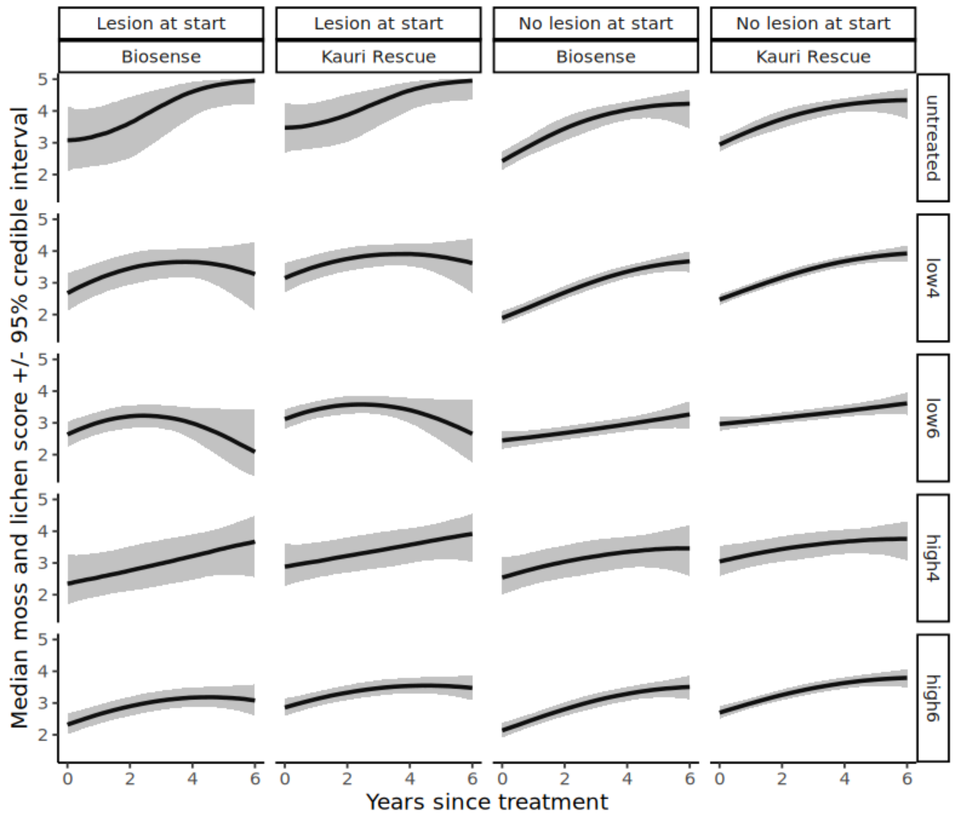

Figure 14: Moss and lichen score in the first 6 years after phosphite treatment. Effects were conditioned on whether a tree initially had a lesion, and whether the observer was part of the Kauri Rescue project or a BioSense auditor.

How does the effect of treatment change over time?

There was a marked effect of phosphite in the first two to three years after treatment, especially in reducing the basal bleed activity (Figures 9 and 10). However, in later years the effect of phosphite on reducing lesion activity appears to lessen, likely as the phosphite concentration within the tree gradually declines. This was true for most treatments but especially true for trees treated with a lower phosphite dose. For example, in phosphite treated trees that started with lesions (Figure 10), trees in the low4 and low6 phosphite treatment groups, trees were much more likely to be scored as having higher basal bleed activity 6 years after treatment than the high4 and high6 treatments. This does suggest a waning effect of the treatment, but that higher doses had more sustained effect.

When trees were untreated, the probability that a tree would have a high basal bleed score decreased steadily over time if initially scored with a lesion, while there was a slight increase over time for trees that started with no lesions. These probabilities are associated with large 95% credible intervals suggesting a lot of uncertainty around those estimates and very low numbers of untreated trees.

The other estimates of canopy health score and moss and lichen score were more stable over time, not showing as strong a polynomial effect with years since treatment (see Figures 12 & 14) suggesting that these are more subtle estimates or less likely to change over short time periods.

Does phosphite have a preventative effect for trees not initially showing symptoms?

Trees not initially showing symptoms were presumably either in areas where PA was not present, not infected by the pathogen or were still at an early stage where symptoms were not yet observable. There were differences in the basal bleed activity scores between trees that initially had lesions and those without. Trees that weren't exhibiting lesions at treatment did show slight increases in lesion activity over time (Figures 9 and 10), especially if trees were untreated.

Trees that started out with no lesions were equally likely to develop lesions by the end of the study (Table 4; X-squared = 7.4, df = 4, p-value = 0.12). However, low4 and low6 treatments did have the highest rate of lesion development. Trees that started with no lesions and were treated with a higher dose of phosphite had a lower rate of developing lesions than did those treated with a lower dose or left untreated. It is not clear whether these trees were initially uninfected or whether the higher doses provided protection. Soil sampling of every tree would be required to demonstrate whether asymptomatic trees were not infected or just at an early stage of infection.

Table 4. The number of trees with lesions at their last observation for trees that had no lesions at treatment. Lesions present were trees which had non-active, semi-active or active lesions.

Phosphite	**Lesion absent**	**Lesion present**	**Percent present**
untreated	346	24	6.49
low4	408	42	9.33
low6	596	54	8.31
high4	126	8	5.97
high6	585	34	5.49

The differences in lesion activity were not mirrored by a corresponding decline in canopy health score as the probability of a tree assigned into a canopy health score was relatively stable in both trees with initial lesions and those without. Increases in the moss and lichen score did occur, most notably in the untreated trees. This suggests that there might be some suppression of the ability of a tree to keep shedding bark when affected by the disease.

As noted earlier, it is possible or even likely that some of the bleeds recorded in treated trees in later assessments were from people noting bleeds from injection points, or that bleeds were noticed more as people became more familiar with the process. This is difficult to assess as the BioSense audit was not conducted during the initial assessments when starting treatments, as it was prior to the beginning of this project. The number of non-active bleeds that were noted 2-3 years after injection in trees that earlier had no lesions recorded would suggest this might be the case. Non-active bleeds do not just suddenly appear but are a result of drying of earlier active bleeds. Additionally, because of the bias observed in participant treatment selection (such as being more likely to leave trees untreated if they were some distance from symptomatic trees) we must be cautious about any comparisons between treatments regarding development of lesions on previously lesion-less trees.

Can citizen-science participants describe symptoms in a similar manner to trained professional auditors?

For basal bleed activity score, a flexible threshold model fitted best, suggesting that scores of classes were not equidistant between the two categories of observers (Kauri Rescue / BioSense). There was an overall effect of Kauri Rescue / BioSense observers, with BioSense auditors more likely across all categories to score trees with a higher bleed activity score than Kauri Rescue observers (Figure 15, estimate = -1.61 95% CI = -1.90; -1.32). This effect was consistent across all score categories.

To more specifically compare trees that were assessed by both BioSense auditors and volunteer Kauri Rescue participants (citizen scientists), we selected the shortest interval of reassessment between observers for each tree and compared the score for the professional audit and citizen scientist. Table 5 shows the distribution of basal bleed scores of professional audits and citizen scientists that observed the same tree. The expectation is that most trees will show little change between assessments and so professional auditors and citizen scientists should often be consistent (and counts should fall on the diagonal, see Table 5). For the professional (BioSense) audit/citizen scientist (Kauri Rescue) comparison 63% of lesion scores were the same between the two assessments. This can be compared to assessments where two BioSense auditors conducted subsequent assessments (Table 6) where 69.5% of the time the tree was assessed as having the same score. It is important to note that these are two comparisons of the same tree but with different intervals between observations and an overall set that consists of many different trees. While one tree may not change much between assessments, another tree may show substantial improvement or decline and much of the ‘noise’ may be due to differing tree circumstances. However, taken together the similarity of reassessment scores suggests that bleed categories are probably a reasonable indicator that can be used in citizen science assessments, albeit Kauri Rescue observers might be slightly more conservative than BioSense assessors.

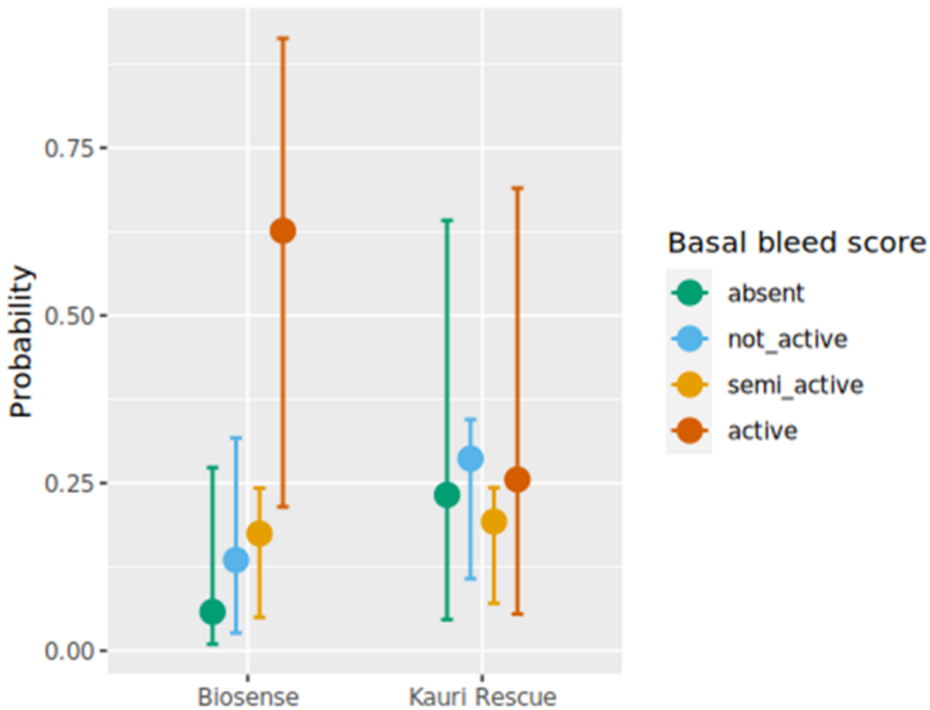

Figure 15: The probability of a tree being in a basal bleed activity score class for Kauri Rescue observers and BioSense auditors.

Table 5. Basal bleed scores by for a tree in a Kauri Rescue assessment (rows) compared to a score on the same tree in the same year by a BioSense auditor (columns). If trees do not change much between observations, then we would expect most values to lie on the diagonal.

Kauri Rescue score	**BioSense observer score**			
	absent	**not active**	**semi-active**	**active**
absent	253	82	17	13
not active	0	0	0	0
semi-active	3	2	3	3
active	10	6	7	14

Table 6. Comparison of basal bleed scores recorded by a BioSense auditor (rows) and the next assessment by another BioSense auditor (columns). If trees do not change much between observations, then we would expect most values to lie on the diagonal.

	Second Biosense score			
First BioSense score	**absent**	**not active**	**semi-active**	**active**
absent	73	6	1	4
not active	7	10	2	7
semi-active	2	2	3	6
active	3	1	1	10

There were some differences between Kauri Rescue observers and BioSense auditors in the scoring of canopy health (Figure 16). The best Bayesian model that described the data included adjacent category-specific effects, with the cut-offs between each category not equidistant. For some of the thresholds between adjacent categories, there was a difference in the position of the cut-offs for BioSense auditors compared to Kauri Rescue observers.

Tabulation of subsequent scores on a tree by BioSense and Kauri Rescue observers showed that most observations fell within 0.5 points with each other suggesting that while observers are a half-score out most often the overall assessment of tree canopy health is similar (Table 7). Overall, 17% of scores did not change between observations. This number is expected to be lower than the basal bleed score because of the larger number of categories. In comparison, when subsequent observations were made by Kauri Rescue personnel (Table 8), there was often a greater difference between scores that differ by 0.5, with 13.2% of reassessments by BioSense auditors unchanged.

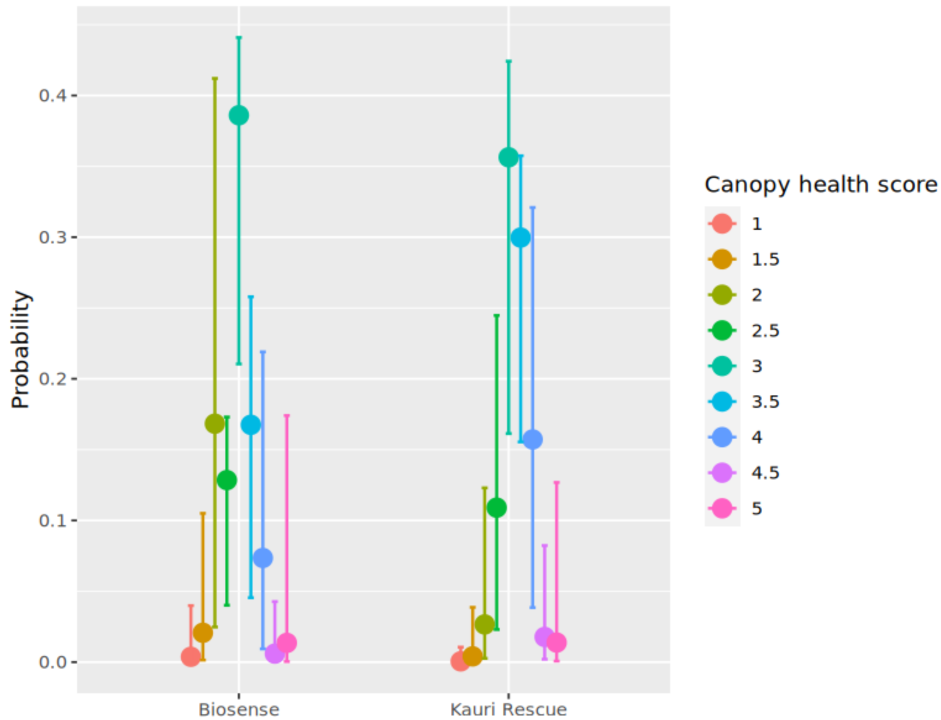

Figure 16: The probability of a tree being in a canopy health score class for Kauri Rescue observers and BioSense auditors.

Table 7. Canopy health scores on a tree in a Kauri Rescue assessment (rows) compared to a score on the same tree in the same year by a BioSense auditor (columns). If trees do not change much between observations, then we would expect most values to lie on the diagonal.

	BioSense score								
Kauri Rescue score	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
1	0	0	2	0	0	0	0	0	1
1.5	1	3	4	3	3	0	0	0	0
2	2	7	11	15	14	3	1	0	0
2.5	3	9	17	17	30	11	2	0	0
3	0	5	27	31	56	14	8	0	0
3.5	0	1	8	10	27	20	10	2	0
4	0	1	2	3	2	9	3	0	0
4.5	0	0	0	0	2	2	1	1	0
5	0	0	0	1	1	2	1	0	5

Table 8. Comparison of canopy health score scores recorded by BioSense auditors (rows) and the next assessment by an auditor (columns). If trees do not change much between observations, then we would expect most values to lie on the diagonal.

	First BioSense score								
Second BioSense score	**1**	**1.5**	**2**	**2.5**	**3**	**3.5**	**4**	**4.5**	**5**
1	0	4	3	1	2	1	0	0	0
1.5	0	3	7	19	3	1	1	0	0
2	0	0	0	10	10	2	0	0	0
2.5	0	3	2	6	9	2	0	0	0
3	1	0	1	4	16	4	2	0	0
3.5	0	2	0	0	5	5	1	0	0
4	0	0	0	0	0	2	2	0	0
5	1	0	0	1	0	0	0	0	3

For moss and lichen score, there were small differences in the probability that a tree would be scored differently between Kauri Rescue or BioSense observers (Figure 17). However, for the most part these differences were subtle and do not change the overall conclusions greatly.

When we examined subsequent assessments of moss and lichen score for a tree between BioSense auditors and Kauri Rescue observers, 34% of the scores remained unchanged. This compared to 35% for subsequent comparisons by BioSense auditors (Tables 9&10).

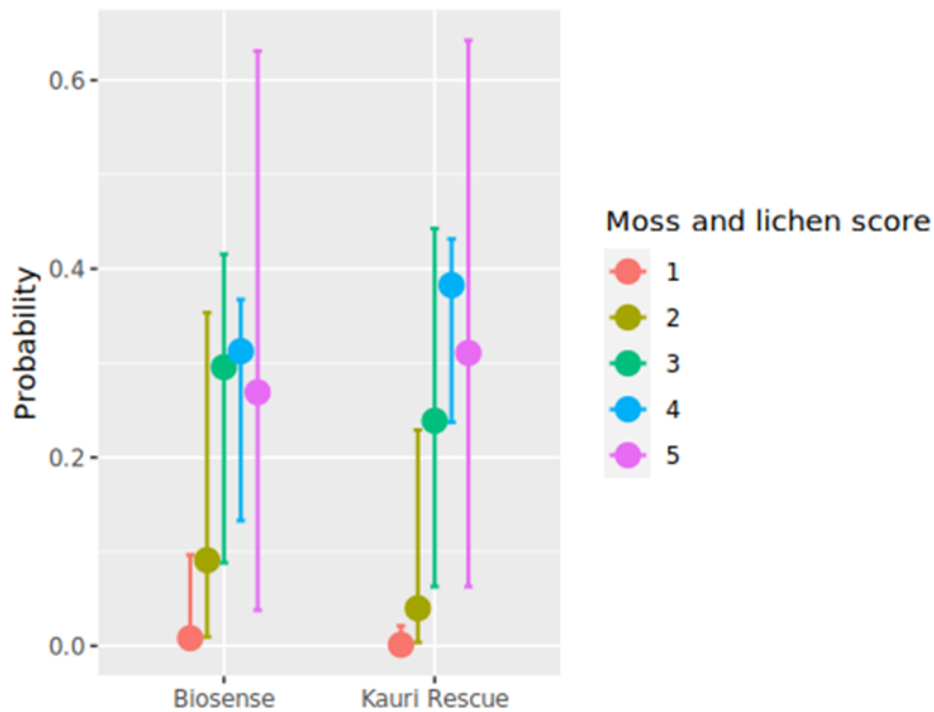

Figure 17: The probability of a tree being in a moss and lichen score class for Kauri Rescue and BioSense observers.

Table 9. Comparisons of moss and lichen scores by Kauri Rescue observers (rows) compared to a score on the same tree in the same year by a BioSense auditor (columns). If trees do not change much between observations, then we would expect most values to lie on the diagonal.

	BioSense score				
Kauri Rescue score	**1**	**2**	**3**	**4**	**5**
1	9	2	0	0	0
2	10	31	12	10	2
3	6	41	50	23	9
4	7	20	32	37	16
5	3	31	29	24	9

Table 10. Comparison of moss and lichen score recorded by BioSense auditors (rows) and the next assessment by another BioSense auditor (columns). If trees do not change much between observations, then we would expect most values to lie on the diagonal.

	Second Biosense score				
First Biosense score	1	2	3	4	5
1	0	3	2	0	0
2	1	9	8	1	2
3	0	2	19	17	4
4	1	3	6	10	10
5	0	5	7	16	12

Conclusions

Key observations from this work are:

- There is evidence that phosphite at either 4% or 6%, with 20 ml injected at either 25 or 40 cm intervals around the trunk, reduces the activity of lesions caused by *Phytophthora agathidicida*.
- There is evidence that the duration of the effect is not as long in the low dose treatments (i.e. 40 cm spacings), with an increase in the number of active lesions noted after 5 or 6 years.
- In untreated trees there was an increase in the moss and lichen score as time progressed, suggesting a decline in natural bark shedding and tree health.
- There were no obvious trends in canopy health score for the duration of the trial
- Participant landowners were biased in selecting treatments and untreated trees. They tended to select higher phosphite rates and doses for trees showing kauri dieback symptoms, resulting in over-representation of diseased trees in the higher concentration and dose treatments. In contrast, healthy or asymptomatic trees were over-represented in the untreated controls and low phosphite treatments.
- There were multiple obvious errors in the original data, especially that collected or entered by citizen scientists, and many trees were discarded from the analysis in a data cleaning exercise. The citizen scientist data used for this investigation is therefore highly sanitised. There are likely to be undetected errors in the remaining data, perhaps increasing the 'noise' and blurring potential differences between treatments.
- The measured characteristics for analysis were restricted to lesion activity, canopy health, and moss and lichen score. Other measured characters were discarded from the analysis as there were obvious discrepancies and inconsistencies in how people recorded them.
- A few simple clear measurements provided much better data than did a lot of data collection on more complex variables. In this case the accuracy gains of a couple of data collection points outweighed a wider approach of trying to follow a large number of variables.
- Because of the procedural problems observed and the inaccuracy of data collection by some of our citizen scientists, our processes, characteristics to be assessed, and data entry have been substantially simplified. Manuals and training videos have been significantly simplified and improved, and support, training and guidance of participants increased.
- There were differences between Kauri Rescue participants and BioSense auditors in the way they scored canopy health and moss & lichen score. However, these differences were relatively small and the over-all trends remarkably similar.

- There was close alignment between Kauri Rescue observers and auditors in scoring of lesion activity.
- Lesion activity scores are a more useful and accurate measure for citizen scientists than are canopy health and lichen scores. The observation that volunteers can detect lesions in a similar (but not perfect) manner to more experienced observers is an especially crucial point as it gives volunteers the confidence to continue.
- It must be noted that the comparisons between Kauri Rescue participants and the BioSense auditors were made on highly sanitised participant data, where multiple obvious errors were removed from the analysis.
- Many of the citizen scientist measurements, particularly toward the end of the study, were made by experienced Kauri Rescue personnel and volunteers. This undoubtedly improved the accuracy of the data.
- The willingness of landowners to collect annual or biennial tree health reassessment data waned significantly over time. This meant that to collect the required amount of data for this project much of the later reassessments had to be done by Kauri Rescue personnel. This significantly increased the cost of the project well beyond the funding provided.

<u>The future – where to from here</u>?

- The collection of a simpler data set with increased accuracy of collection by citizen scientists outweighed the wider approach of trying to follow many variables. The data collection / reassessment of tree health will be quicker and less erroneous in future, thereby increasing efficiency of the data analysis.
- Motivating landowners to continue to collect health reassessment data for their trees needs to be a priority for future work, or else there needs to be resourcing provided that is adequate for the data to be collected by Kauri Rescue personnel.
- Kauri Rescue intends to launch a Re-treatment Strategy that will require landowners to first reassess the health of their trees, so that they can be advised which trees need to be re-treated. Only then will they be provided with a treatment kit. It is hoped that this will provide sufficient motivation for landowners to undertake a health reassessment on a regular basis.
- The aim is that analysis of health data from trees that have been re-treated will show whether re-treatment with phosphite suppresses symptoms that have recurred. To determine how frequently re-treatment should be applied these re-treated trees need to be followed for several years to ascertain when symptoms recur.
- Re-treatment with a range of concentrations and doses will be important to investigate the optimum re-treatment regime for the longest possible suppression of symptoms.

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This report was prepared by Ian Horner and Linley Jesson (Plant & Food Research), Lee Hill (BioSense) and Mels Barton (Subliminal/Kauri Rescue).

KAURI RESCUE

Kaitautoko - community & science working together