What are the main indicators of forest health in Riccarton Bush and how can they be assessed and monitored?

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1 Executive Summary

- Pūtaringamotu/Riccarton Bush is a small 600-year-old remnant kahikatea forest in Riccarton, Christchurch.
- It was an important site for mahinga kai gathering by Ngāi Tūāhuriri, before being bought and preserved by the Deans family in the early 1900s. It was then purchased by the City Council and the Riccarton Bush Trust was set up to maintain it, as it remains today.
- To aid in their conservation of the site, the Trust sought our advice on how to measure the health of the Bush. They were interested in different perspectives of defining and measuring forest health.
- We developed a research question; 'what are the main indicators of forest health in Riccarton Bush and how can they be assessed and monitored?' Within this, we aimed to identify important indicators and methods relevant to the site and investigate the feasibility of their implementation. We examined these from different perspectives relevant to the site.
- We undertook a review of existing research literature, to identify relevant indicators and methods of measuring forest health in Riccarton Bush.
- Next, microclimate variability was measured in the Bush through installation of two weather stations. These measured soil temperature, air temperature, wind speed and solar radiation. The latter helped to assess feasibility of using solar power to charge equipment batteries.
- Finally, GNSS coordinate data of the site was used to create a base map in ArcMap, to collate and display data. Existing tree and soil data was added to demonstrate use of the tool.
- An ecological approach was found to be the most suitable to assess the health of Riccarton Bush. Research identified the most important indicators at the site to include vegetation state, soil and water, bird and pest numbers, and climate. Relevant methods to assess these were ground and aerial imagery, species counts and chemical and biological testing.
- Testing at the site found significant microclimate variations, and low solar radiation beneath the canopy.
- We therefore recommend that the Trust take a wide range of measurements and distribute monitoring evenly around the bush site to ensure the accuracy of findings.
- As the use of solar power to run equipment does not appear feasible, we also recommend installing mains power along with their proposed new boardwalk. This would provide a reliable, long-term power source for monitoring equipment.
- We anticipate use of the baseline map tool in future research, to collate and display data and compare changes through time.

- Future work could include the development of an index specific to Riccarton Bush, to provide a long-term, reliable method of measuring its health. This could also involve local iwi in identifying taonga plant and animal indicator species and weighting them for use within the bush health index.

2 Introduction

Pūtaringamotu, more commonly known as Riccarton Bush, or Deans' Bush, is a 600-year-old remnant kahikatea forest located in the suburb of Riccarton, in Ōtautahi Christchurch. The small 7.8ha site is also attached to the Riccarton House and the grounds surrounding it (Molloy, 1995). This bush is one of the last remaining naturally established patches of kahikatea wetland forest in Canterbury, as the majority had been cleared back in the 19th century to make way for urban development. It was an important mahinga kai site for the local hapū, before European settlement in the 19th century (Molloy, 1995).

The continued preservation of the bush can be mostly attributed to the Christchurch City Council (CCC) and the Deans family. The family had leased the land off mana whenua Ngāi Tūāhuriri from 1843, until the land was bought by the family in 1850 after the period of wrongful Māori land seizures by the government in the 1840's (Molloy, 1995). In 1914, the family gifted 6.4 ha of the bush to the people of Canterbury. This was sanctified by the Riccarton Bush Act 1914, which outlined the terms of the donation and the establishment of a Board of Trustees. In 1947, the CCC purchased the remaining 1.4 ha of the surrounding land and vested it to the Riccarton Bush Board of Trustees, who have maintained the grounds since (Riccarton Bush Trust, 2015).

Figure 1. Aerial view of Riccarton Bush and House (Harvie, 2022).

Remnant kahikatea forests in New Zealand are in significant decline due to deforestation, human development, and intentional degradation (Burns et al., 1999). Subsequently, native biodiversity and ecological processes have suffered as the survivability of native plants and animals has reduced

(Janssen, 2006). The protection of these indigenous forests is important, not only for their environmental value, but also their cultural, spiritual, and social importance for New Zealanders.

Our group was asked by the Riccarton Bush Trust to investigate methods of measuring bush health utilising a variety of perspectives on forest health. Considering the forest's unique environment, other existing kahikatea forest research was unable to be directly applied to the site, therefore, interpretation and adaptation of research was required. We aimed to explore the topic with awareness of their management objectives, which include to "promote the natural and cultural heritage values" and "protect and enhance the indigenous flora, fauna and ecology of Pūtaringamotu/Riccarton Bush, including mahinga kai and taonga species" (Riccarton Bush Trust, 2021b).

To investigate this, we developed a research question: What are the main indicators of forest health in Riccarton Bush and how can they be assessed and monitored? Within this, we aimed to identify relevant perspectives on forest health, the main indicators, and the assessment methods utilised for continued monitoring. Applicability and feasibility of assessment methods was then implemented at the site, alongside the development of a base map to collate and display data. To conclude, we will provide an overall summary and recommendations to the Riccarton Bush Trust.

3 Background literature

A review of literature and existing research found a wide range of definitions of forest health. Perspectives on this subject differ significantly between cultures and individual opinions, as well as management objectives of individual forests. Generally, native forest management in New Zealand has an ecological approach, with focus on sustainable use (Ministry for Primary Industries, n.d.). This approach aims to maintain ecological processes and the natural state of forests, by planting native trees and clearing pest plants such as wilding pines and other invasive species (Forbes et al., 2020). Conversely, a utilitarian approach aims to follow management objectives and support provisions for humans, which is a common approach to private forest management (Kolb et al., 1994).

Differences in perspectives of forest health can also be found between Western and indigenous communities. The Western scientific view defines health through measuring the condition and function of a forest. This commonly includes factors like vegetation health, soil and water quality and bird and pest numbers.

The Matauranga Māori perspective of forest health is more holistic than the Western view. Tangata whenua see ecosystems as an interconnected system, in which humans have an integral part (McAllister et al., 2019). The collection of mahinga kai especially, is a fundamental part in the reciprocal relationship between humans and the environment. Physical forest health is still a major aspect, however cultural, spiritual, and social factors are considered just as important for an overall healthy forest (McAllister et al., 2019).

A more holistic view of forest health can include provision of ecosystem services to the wider community. These are the benefits that the forest ecosystem provides to the environment surrounding it. Direct services benefit humans, while indirect benefit the forest itself (Bolund & Hunhammar, 1999). Riccarton Bush could provide the surrounding community with air filtering, climate regulation, noise reduction, rainwater drainage, and recreational and cultural benefits.

4 Methods

4.1 Review of Research Literature

The first method involved an investigation of relevant indicators of forest health, and what methods could be employed at Riccarton Bush. A literature review was conducted by subdividing the literature into 4 topics, soil and moisture, flora and fauna, social indicators linked to forest health, and Māori indicators of forest health. All references were obtained by utilising academic search engines.

4.2 Installation of Weather Stations

Microclimate variability was measured by installing two weather stations within Riccarton Bush on the 5th of September 2022. The weather stations were composed of a mobile aluminium tripod that housed climate surveying equipment. Measurements of shortwave radiation, wind speed, air temperature, and soil temperature were taken at 10 minutes intervals for a period of 4 weeks (Table 1).

Table 1: Weather station equipment

Equipment	Specifications and Frequency	Purpose	Units
10-Watt solar panel	Configured to face the conventional west	Recharged the weather station battery.	-
12.8V, 7.5AH Lithium Battery	The batteries were replaced on 19th and 26th of September 2022.	Powered the weather station equipment.	-
Apogee pyranometer	Placed 1.5m above the ground. Measurements taken every 10-minutes.	Incoming Shortwave Radiation	(W/m²)
Young model 920000 Response one weather transmitters	Each placed 2.5m and 0.5m above the ground. Measurements taken every 10-minutes.	Wind Speed	(m/s)
Young model 920000 Response one weather transmitters	Each placed 2.5m and 0.5m above the ground. Measurements taken every 10-minutes.	Air Temperature	(°C)
Thermocouple	Inserted 10cm into the soil. Measurements taken every 10-minutes.	Soil Temperature.	(°C)

The installation locations were decided upon based on local knowledge provided by the Riccarton Bush Ranger, Michael Steenson. The first station was placed in the wettest area of the bush. The vegetation in this location is dominated by cabbage trees, which creates the conditions for low canopy cover, and subsequently, high light levels in the understory, as shown in Figure 2. The second station was placed in the driest area of the forest in which old growth dominates. In this location, relatively low light conditions in the understory were caused by the high canopy cover, as seen in Figure 2.

Figure 2. Weather stations installed at Riccarton Bush. Damp site (left) and dry site (right)

To test applicability of solar panels they were used to recharge the weather stations battery. In both sites the solar panels were attached facing the conventional west orientation. Once the data was captured, it required editing due to errors within the equipment. Firstly, electrical noise of the apogee pyranometer caused negative numbers in the incoming shortwave radiation data, which were edited with 0 integer. Secondly, data labelled as “NaN” (Not any Number) within the soil temperature and wind speed data were removed as they were caused by the battery voltage being too low for the instrument to function. After the data was edited, the microclimate variability was analysed between the two weather stations using the data analysis tool within excel. A T-test was conducted to compare incoming shortwave radiation, soil temperature, air temperature, and wind speed between the two sites.

4.3 Creation of GNSS Base map

The creation of the base map included the collection of GNSS points to capture different features of Riccarton Bush. A Trimble GEO 7X handheld GNSS data collector was used to collect GNSS points for the perimeter, walking tracks, and other features. The GNSS handheld device was attached to an aluminium tripod to ensure the GEO7X remained at a consistent height of 1m at all locations.

Firstly, the predator proof fence, which marks the perimeter of the native bush, was captured as an area shape file. This was conducted by placing the tripod at all the vertices, where the angle of the fence changed. Secondly, the walking track was conducted similarly by placing the GEO 7X at the vertices of the track and was recorded as a line shapefile. Due to public foot traffic, the instrument was placed on the right-hand side of the track and angled to be directly above the edge of the foot path, as viewed in Figure 3. To ensure consistency this method was conducted at every vertex point. Lastly, the track features were captured as a point shapefile, and was separated into different feature classes. Measurements were conducted by placing the GEO 7X either above or in front of each feature, as observed in Figure 3.

Figure 3. Trimble GEO 7X being used to collect track features (left) and the track (right)

In all instances, the instrument remained stationary for at least 2 minutes until accuracy fell below 1m. However, accuracy diminished within some sections of the bush due to the poor satellite signal beneath the forest canopy. Subsequently, when accuracy did not fall below 1m, the instrument was left for a maximum of 5 minutes to reduce the accuracy error. Once the data points were collected, the data was converted into a shapefile in the WSG 1984 projection format using ArcMap. The predator fence perimeter was compared against satellite imagery and corrected accordingly (Figure 4). The track location and data points were smoothed and adjusted for by comparing the vertices' to photographs of the track at each location, like the right hand-side figure 3.

Figure 4: Showing GNSS error data of the perimeter fence compared against the satellite corrected perimeter fence

The implementation of two secondary sources of data were included into the final base map. The first was from Molloy (1995) which were soil and vegetation type maps. They were digitised, manually georeferenced, then traced to create shapefiles within ArcMap. The second was sourced from Permanent Forests NZ LTD (2017), which identified and located trees with a 30cm or more diameter-at-breast-height (DBH) at Riccarton Bush. The data's Easting and Northing coordinates were converted from New Zealand Transverse Mercator to WSG84 using the LINZ online coordinate converter. Then the data was added into ArcMap and overlaid on top of the base map.

5 Results and discussion

5.1 Review of Literature

Review of a wide range of research literature found many methods and models for measuring forest health, and many factors that can contribute toward an overall assessment. Their relevance to Riccarton Bush varies, due to the unique nature of the site and feasibility of implementation and monitoring.

5.1.1 Forest Health Indicators

The main indicators that are likely to be relevant in Riccarton Bush include state of vegetation, soil and water quality and bird and pest numbers. Assessment of vegetation health can include measurement of disease and pest levels, vegetation damage, growth rates, species diversity, and regenerative ability (Trumbore, et al., 2015). This can also include the state of the forest canopy, considering typical canopy layers, understorey and expected species (Forbes et al., 2020). Vegetation is generally measured through visual observation, which can be hard to quantify. This can involve field-based observation and/or remote-sensing to assess the structural and morphological state of vegetation and tree canopy. (Lausch et al., 2018). Bird species and pest counts can be used to assess biodiversity and population changes over time (Canterbury et al., 2000). Healthy bird and insect numbers can indicate biodiversity and structural complexity in a forest. The diets of many NZ native birds like kererū, tūī and bellbird consist of seeds and small fruit in kahikatea forest, and variation in their numbers can be used to indicate the healthy seeding and fruiting processes of kahikatea trees. Conversely, high numbers of pests like rats, stoats, and possums, which often prey on birds, bird eggs and eat native plants, can indicate a decline in forest health. Assessment of soil and water includes nutrient levels and contamination, soil moisture and water table levels. These are heavily interrelated and hugely important for vegetation growth. Pollution and excess nutrient levels in water can leach into soil and have detrimental effects on plants themselves, and overall soil quality. Poor quality soil can have low soil organic matter, compaction, poor structure, and drainage issues (Gavrilescu, 2021).

These require evaluation of physical, chemical, and biological indicators (Lehmann & Kleber, 2015). Chemical testing can be used to determine nutrient and contamination levels in both, and soil profiles can be taken to assess soil structure and soil organic matter (Mishra et al., 2015; Rabot et al., 2018). The benefit of these indicators is the ease of assessment. They are mostly assessed visually or with small-scale monitoring equipment, which is well within the abilities of the Riccarton Bush Trust.

5.1.2 Methods of measuring forest health

An ecological approach is found to be the most effective method of measuring forest health, as it provides a definitive measure of overall health. A common tool for this approach is an index, where results of main indicators are collated and scored based on their importance, and an overall score is generated. The Kahikatea Green Wheel, created by the Waikato Regional Council is a great example of this (Denyer et al., 2019). This method can provide issues, as published indexes vary greatly between locations, climate, forest types and other varying factors. There is limited research relevant to Riccarton Bush, as its unique location and situation means that the importance of individual factors may vary from other studied sites. They also require significant amounts of data, which can be difficult, expensive and time consuming to obtain. Use of an index at this site would likely require adaptation of existing indexes to suit, or creation of an entirely new index would be needed. This would require significant assessment and effort to rank and weight indicators accordingly, however, would provide a valuable long-term method of measuring the health of the Bush, which would be of great benefit to the Trust.

5.1.3 Matauranga Māori perspective and ecosystem services

Matauranga Māori also emphasises the importance of ecological indicators, however it also includes community indicators to assess social, spiritual, and cultural aspects (Lyver, et al., 2017, McAllister et al., 2019). This can involve interviews and discussion with hapū and iwi, to assess how they feel about and interact with the site. The inclusion of Matauranga Māori in assessing forest health is important, as there are cultural heritage values associated with forests (Lyver, et al., 2017). Ngāi Tūāhuriri have already provided significant input into development so far but are unable to contribute further at this time. There is a seat available for them on the Riccarton Bush Board of Trustees, however it is not currently filled due to other commitments. It would not be appropriate for ourselves or the Trust to assess Māori perspectives on their behalf, however it should be considered in the future. There are also some ways it can be included now, based on the input they have already provided. This could include priority of taonga species for indicator measurement, and higher weighting within an index.

Ecosystem services can play an important role of the Bush within the wider community, however they can be difficult to assess and monitor. They can include assessment of social benefits like mental health, through surveys and interviews, contribution to surrounding air soil and water quality, cooling effects, and particulate matter levels through extensive testing (Bolund & Hunhammar, 1999). However, there is a high cost, time and effort associated in undergoing these assessments. Their sensitivity to outside factors also makes them an unreliable indicator for specifically measuring forest health.

5.2 Weather Station Data Analysis

5.2.1 Incoming shortwave radiation

The weather stations are known to run for 4.5 days without additional power. These lasted between 9 and 14 days which showed that there was some recharge, however, not enough to sustain continued monitoring. This is due to solar radiation not being able to make way through the tree canopy. An option to improve this would be to change the locations of the solar panels to a more open area, further away from the weather stations. Potentially the solar panels could also be put in a higher location, above the tree canopy, but that may be difficult. The proposed boardwalk upgrade could solve these issues with the installation of mains power throughout the Bush (Riccarton Bush Trust, 2021a). This would provide direct power for equipment instead of relying on batteries and solar, which take significant effort to install and maintain.

Incoming shortwave radiation gives us an idea on how much sun is reaching the solar panels, and therefore how long the weather stations may last for. As seen in Table 2 and Figure 5, there is a significant difference in the amount of shortwave radiation between sites. Due to the p-value being less than the significance level of 0.05, it indicates the shortwave radiation follows a normal distribution and that there is a difference between sites. It was assumed that there was more sunlight in the damp site compared to the dry, as the damp site weather station battery always lasted longer than at the dry site, which was the case.

Table 2: *Two sample t-test assuming unequal variances for the incoming shortwave (SW) data between the damp & dry weather station sites.*

	Damp Site	**Dry Site**
Mean	19.78	4.51
p-value	1.71E-52	
t-stat	15.68	

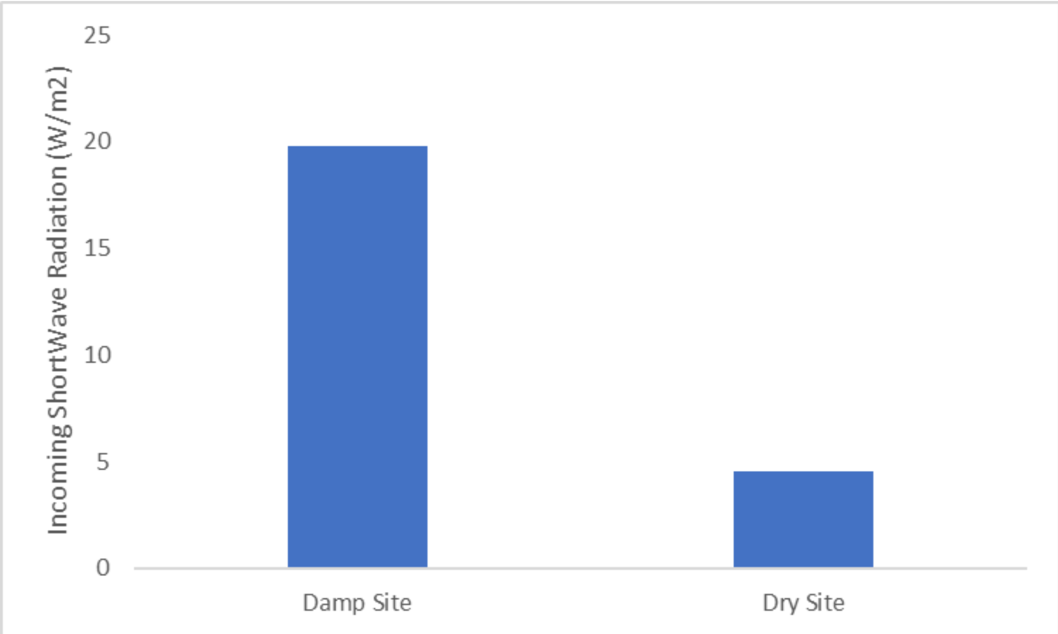

Figure 5. Mean incoming shortwave radiation from the weather stations in the damp site versus dry site at Riccarton Bush.

5.2.2 Wind speed

Wind speed is a major contributing factor to stress on vegetation. Studies have shown that strong winds will cause the roots of the trees to stretch, disrupting the amount of contact that the roots will have with the soil. This decreases the amount of water that trees can uptake (Gardiner et al., 2016). As seen in Table 3 and Figure 6, the data is statistically significant due to the p value being less than 0.05, which tells us the wind speed data follows a normal distribution. We can conclude that there were higher wind speeds at the dry site. Due to the mean wind speed being under 5.5 metres per second on both sites, wind would have little effect on vegetation in that area, as this speed is classed as calm. Results would likely be more statistically different above the canopy, however, would require raising monitoring equipment to a significant height.

Table 3: Two sample t-test assuming unequal variances for the wind speed upper data between the damp & dry weather station sites.

	Damp Site	**Dry Site**
Mean	0.16	0.33
p-value	6.54E-36	
t-stat	-13.18	

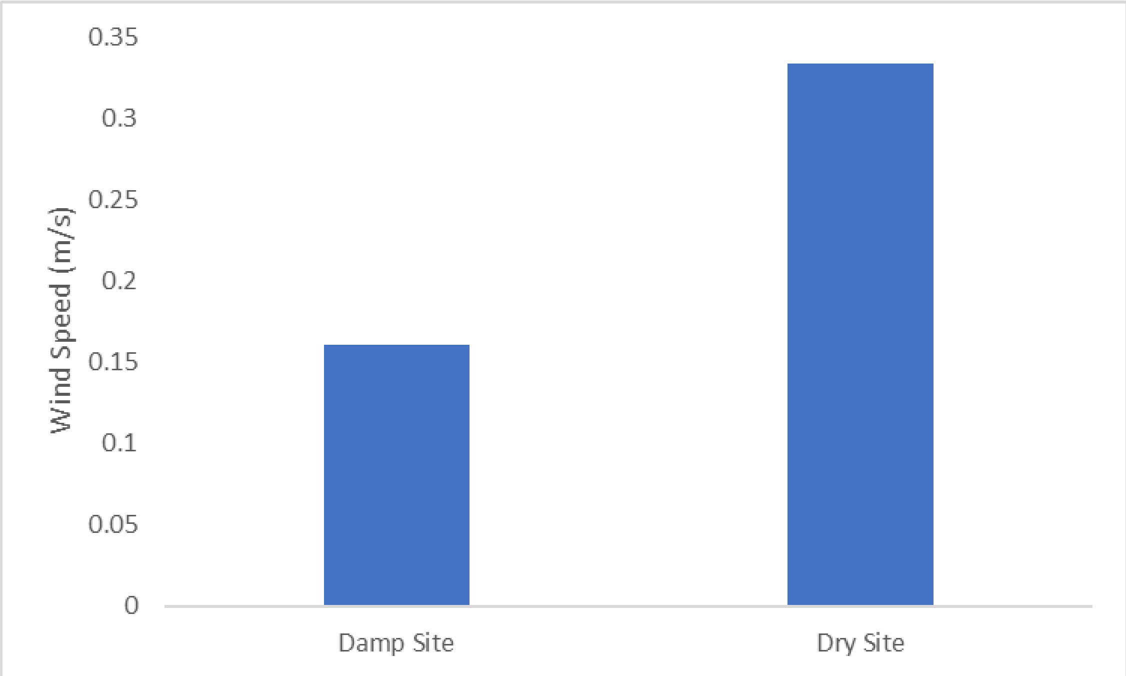

Figure 6. Mean wind speed from the weather stations in the damp site versus dry site at Riccarton Bush.

5.2.3 Soil temperature

Soil temperature is an important factor relating to how plants will grow and distribute themselves. The minimum temperature for most plants to grow in is 10 degrees Celsius. The data produced from the weather stations showed a mean temperature of around 9 degrees. Extreme temperatures can significantly affect plant growth. Studies show there is a decrease in water uptake, nutrient uptake, and the root growth of the plants when there is a decrease in soil temperature, which could be an occurrence at both sites due to the results shown in Table 4 and Figure 7 (Onwuka & Mang, 2018). Due to the p-value being less than 0.05, we can conclude that the air temperature data is normally distributed and that there is a difference between sites. We can also conclude soil temperature was higher at the damp site.

Table 4: Two sample t-test assuming unequal variances for the soil temperature data between the damp & dry weather station sites.

	Damp Site	**Dry Site**
Mean	9.19	9.04
p-value	0.00045	
t-stat	3.33	

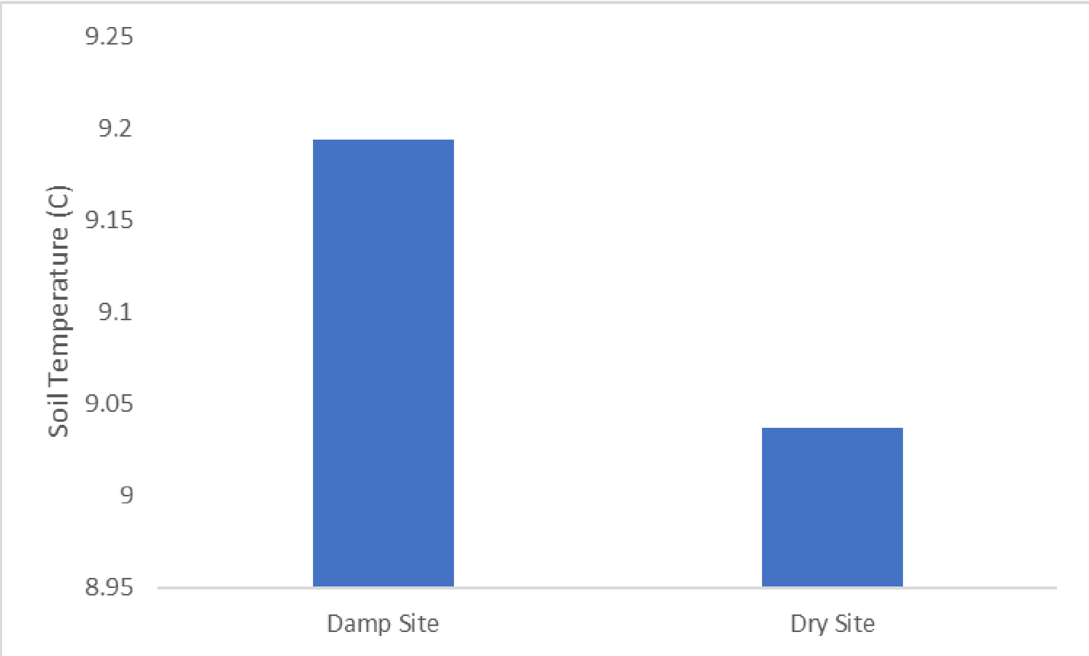

Figure 7. Mean soil temperature from the weather stations in the damp site versus dry site at Riccarton Bush.

5.2.4 Air temperature

Air temperature influences plant growth and distribution similarly to soil temperature. Higher temperatures can cause plant processes to decline once certain temperatures are met (Hatfield & Prueger, 2015). This may not influence the vegetation at Riccarton Bush, as the mean temperatures were below any extremes, which can be seen in Table 5 and Figure 8, but it is still worth monitoring this to ensure the bush doesn't exceed them in the future. Due to the p-value being less than 0.05, we can conclude the air temperature data follows a normal distribution and that there is a difference between the two sites. We can also conclude air temperature was higher at the damp site.

Table 5: Two sample t-tests assuming unequal variances for the air temperature data between the damp & dry weather station sites.

	Damp Site	**Dry Site**
Mean	7.32	6.38
p-value	1.22E-07	
t-stat	5.20	

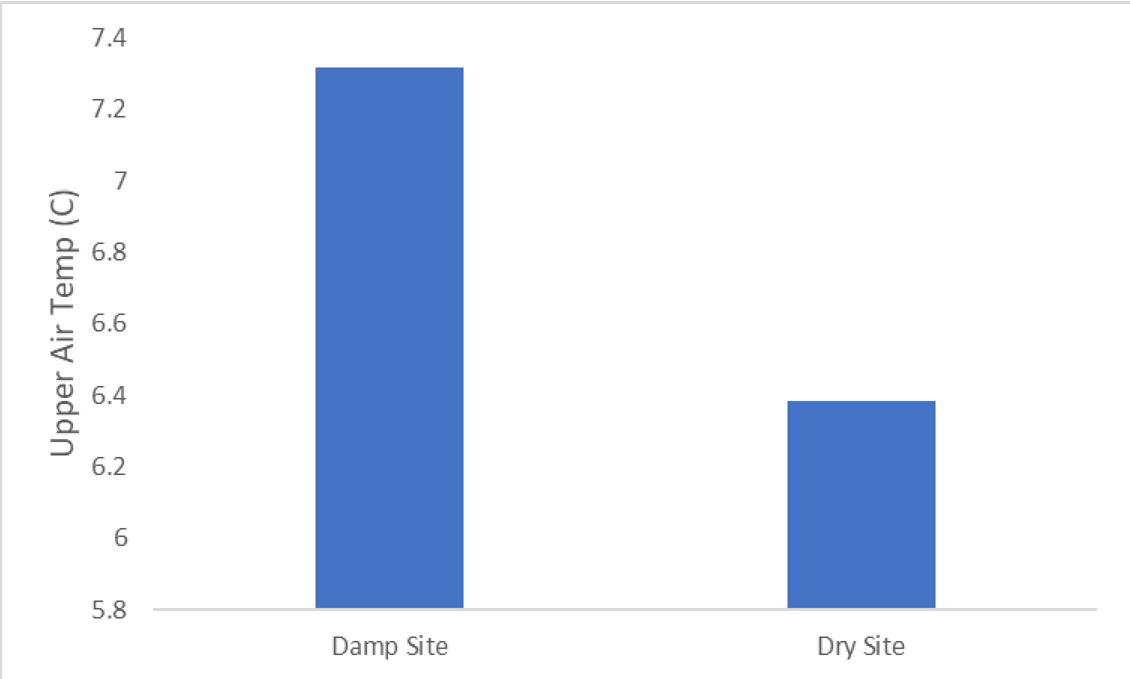

Figure 8: Mean air temperature from the weather stations in the damp site versus dry site at Riccarton Bush.

5.3 GIS base map tool

The GIS base map tool aimed to provide an accurate database to visualise research layers at the site. Collation and comparison of data is essential for continued monitoring of the state of the forest's health, especially in assessing changes over time. Figure 9 shows the base map tool, with accurate GPS coordinates of the track and boundary. Appendix B provides examples of existing research data displayed on the base map, including soil types, and tree locations and species.

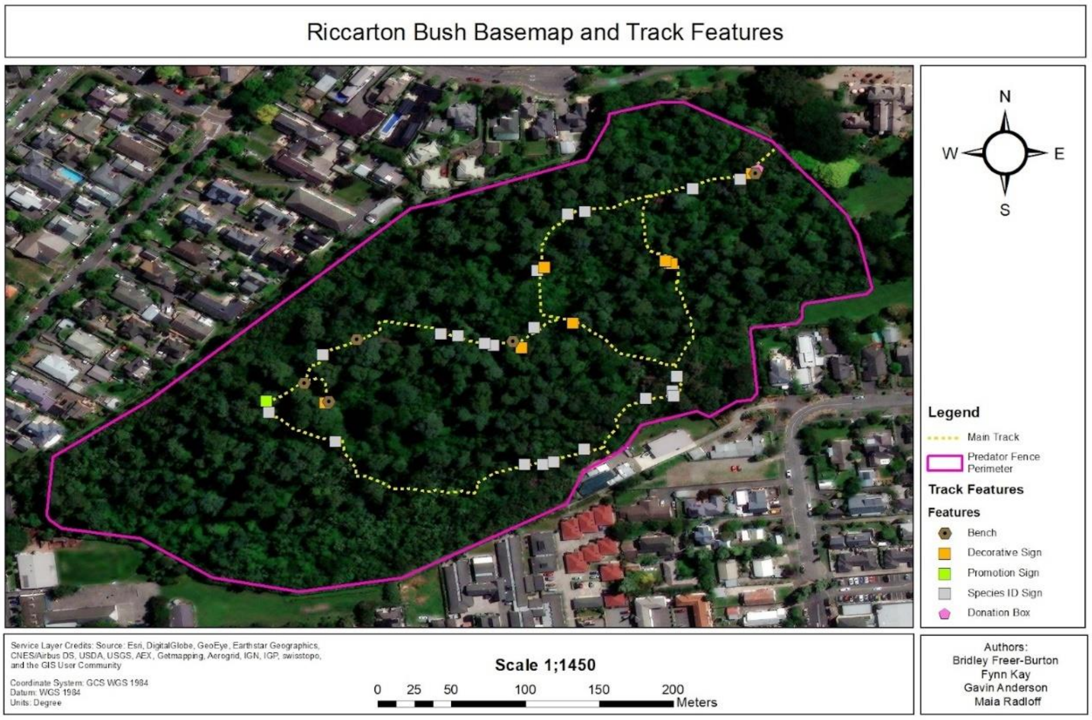

Figure 9: GNSS base map of Riccarton Bush, showcasing perimeter, track, and track features.

The limited scope and capabilities of this project restricted the extent of our research. Therefore, with provision of the base maps, we hoped to provide a tool that could be used and built upon with future research, to aid in assessment and monitoring of the Bush's health. Future research could compare tree data over time to assess population changes, which contribute to overall forest health. Similarly, the soil type layer could be used in future research to display, assess, and consider the effects of soil type on soil quality.

6 Recommendations

Based on the results of this project, the aims of the Riccarton Bush Trust and their capabilities, we recommend continuing monitoring using an ecological approach. This includes visual assessment of vegetation and canopy using imaging, species counts of trees, birds and pests, chemical and biological testing of water and soil, and soil profile analysis.

As our testing found significant variability in results from different areas at the site, we recommend that numerous measurements are taken in a wide area, to ensure accuracy. To avoid issues with powering monitoring equipment long-term, we recommend the installation of mains power along with the proposed boardwalk. This will provide a constant source of power, therefore reducing work for the Trust to install and maintain batteries and solar panels.

We anticipate the use of the GIS base map tool to collate and display data as previously shown. We recommend its use to show changes over time for data like tree numbers and locations.

Finally, future research could involve the creation of an index specific to Riccarton Bush to define and measure health and assess changes over time. This could be derived from a range of existing indexes and adapted to suit the unique environment of the site. If further iwi engagement were to occur, identification of taonga species and prioritisation within the index would also be valuable.

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We would like to acknowledge and thank our community partner, the Riccarton House and Bush Trust, and Mike Steenson, the Riccarton Bush Ranger for the research opportunity, and their support in our work. We would also like to thank our tutor, Heather Purdie, for her continued help with the project, and Justin Harrison with equipment recommendations and field work.

8 References

B. R. Burns, C. Smale, M., & F. Merrett, M. (1999). Dynamics of Kahikatea Forest remnants in middle North Island: implications for threatened and local plants. *Science for Conservation, 113*, 22.

Bolund, P., & Hunhammar, S. (1999). Ecosystem services in urban areas. *Ecological economics, 29*(2), 293-301.

Canterbury, G. E., Martin, T. E., Petit, D. R., Petit, L. J., & Bradford, D. F. (2000). Bird communities and habitat as ecological indicators of forest condition in regional monitoring. Conservation *Biology, 14*(2), 544-558.

Denyer, K., Deng, Y., & Waikato Regional Council (2019). *Kahikatea Forest Green Wheel: Developing a tool to assess ecosystem recovery of Kahikatea remnants in the Waikato region.* Waikato Regional Council

Forbes, S. F., Wallace, K. J., Buckley, H., (2020). Restoring mature-phase forest tree species through enrichment planting in New Zealand's lowland landscapes. *New Zealand Journal of Ecology, 44*(1), 10.20417/nzjecol.44.10

Gardiner, B., Berry, P., & Moulia, B. (2016). Wind impacts on plant growth, mechanics and damage. *Plant science, 245*, 94-118.

Gavrilescu, M. (2021). Water, Soil, and Plants Interactions in a Threatened Environment. *Water, 13,* 2746. https://doi.org/10.3390/w13192746

Harvie, W. (2022, May 05). *The native forest in the middle of Christchurch could get a $1m revamp.* Stuff. https://www.stuff.co.nz/environment/128551189/the-native-forest-in-the-middle-of-christchurch-could-get-a-1m-revamp

Hatfield, J. L., & Prueger, J. H. (2015). Temperature extremes: Effect on plant growth and development. *Weather and climate extremes, 10*, 4-10.

Janssen, H. J. (2006). *Bush vitality assessment: Growing common futures.* New Zealand Department of Conservation.

Kolb, T., Wagner, M.R., & Covington, W.W. (1994). Concepts of forest health: utilitarian and ecosystem perspectives. *Journal of Forestry, 92* (7). 10-15. https://doi.org/10.1093/jof/92.7.10

Lausch, A., Bastian, O., Klotz, S., Leitão, P. J., Jung, A., Rocchini, D., ... & Knapp, S. (2018). Understanding and assessing vegetation health by in situ species and remote-sensing approaches. *Methods in ecology and evolution, 9*(8), 1799-1809.

Lehmann, J., & Kleber, M. (2015). The contentious nature of soil organic matter. *Nature, 528*(7580), 60-68.

Lyver, P. O. B., Timoti, P., Gormley, A. M., Jones, C. J., Richardson, S. J., Tahi, B. L., & Greenhalgh, S. (2017). Key Māori values strengthen the mapping of forest ecosystem services. *Ecosystem services, 27*, 92-102.

Lyver, P., Timoti, P., Jones, C. J., Richardson, S. J., Tahi, B. L., & Greenhalgh, S. (2017). An indigenous community-based monitoring system for assessing forest health in New Zealand. *Biodiversity and Conservation, 26*(13), 3183-3212.

McAllister, T.G., Beggs, J.R., Ogilvie, S., Kirikiri, R., Black, A., and Wehi P. M. (2019) Kua takoto te mānuka: Mātauranga Māori in New Zealand ecology. *New Zealand Journal of Ecology, 43*(3).

Ministry for Primary Industries. (n.d.). *Native (indigenous) forests* https://www.mpi.govt.nz/forestry/native-indigenous-forests/

Mishra, P., Mapara, S., & Vyas, P. (2015). Testing/monitoring of soil chemical level using wireless sensor network technology. *International Journal of Application or Innovation in Engineering & Management, 4*(11).

Molloy, B. P. (Ed.). (1995). *Riccarton Bush: Putaringamotu: natural history and management.* Riccarton Bush Trust.

Onwuka, Brown. (2016). Effects of soil temperature on Some Soil properties and plant growth. *Journal of Agricultural Science and Technology, 8*(1), 34-37.

Permanent Forests NZ LTD (2017). *An assessment of dominant trees in Riccarton Bush*. Prepared for the Riccarton Bush Trust.

Rabot, E., Wiesmeier, M., Schlüter, S., & Vogel, H. J. (2018). Soil structure as an indicator of soil functions: A review. *Geoderma, 314*, 122-137.

Riccarton Bush Trust. (2015). *The Riccarton Bush/Pūtaringamotu management plan.* Christchurch: Author.

Riccarton Bush Trust. (2021a*). Pūtaringamotu/Riccarton Bush – Major Enhancement Project*. https://riccartonhouse.co.nz/putaringamotu-riccarton-bush-major-enhancement-project/

Riccarton Bush Trust. (2021b). *Statement of Intent for the year ending 30 June 2021.* https://riccartonhouse.co.nz/wp-content/uploads/2021/04/2020-21-RBT-SOI-Final.pdf

Trumbore, S., Brando, P., & Hartmann, H. (2015). Forest health and global change. *Science, 349*(6250), 814-818. https://doi.org/10.1126/science.aac6759

9 Appendices

Appendix A

Table 6: Two sample t-test assuming unequal variances for the incoming shortwave (SW) data between the damp & dry weather station sites.

	Damp Site	**Dry Site**
Mean	19.78	4.51
Variance	1456.11	42.98
Observations	1660	593
Df	1908	
t Stat	15.68	
P(T<=t) one-tail	1.71E-52	
t Critical one-tail	1.65	
P(T<=t) two-tail	3.42E-52	
t Critical two-tail	1.96	

Table 7: Two sample t-test assuming unequal variances for the wind speed upper data between the damp & dry weather station sites.

	Damp Site	**Dry Site**
Mean	0.16	0.33
Variance	0.023	0.093
Observations	1601	593
Df	704	

t Stat	-13.18	
P(T<=t) one-tail	6.54E-36	
t Critical one-tail	1.65	
P(T<=t) two-tail	1.31E-35	
t Critical two-tail	1.96	

Table 8: Two sample t-test assuming unequal variances for the soil temperature data between the damp & dry weather station sites.

	Damp Site	**Dry Site**
Mean	9.19	9.04
Variance	1.08	0.91
Observations	1638	583
Df	1109	
t Stat	3.33	
P(T<=t) one-tail	0.00045	
t Critical one-tail	1.65	
P(T<=t) two-tail	0.00091	
t Critical two-tail	1.96	

Table 9: Two sample t-test assuming unequal variances for the air temperature data between the damp & dry weather station sites.

	Damp Site	**Dry Site**
Mean	7.32	6.38
Variance	14.92	13.89
Observations	1660	593
Df	1077	
t Stat	5.20	
P(T<=t) one-tail	1.22E-07	
t Critical one-tail	1.65	
P(T<=t) two-tail	2.45E-07	
t Critical two-tail	1.96	

Appendix B

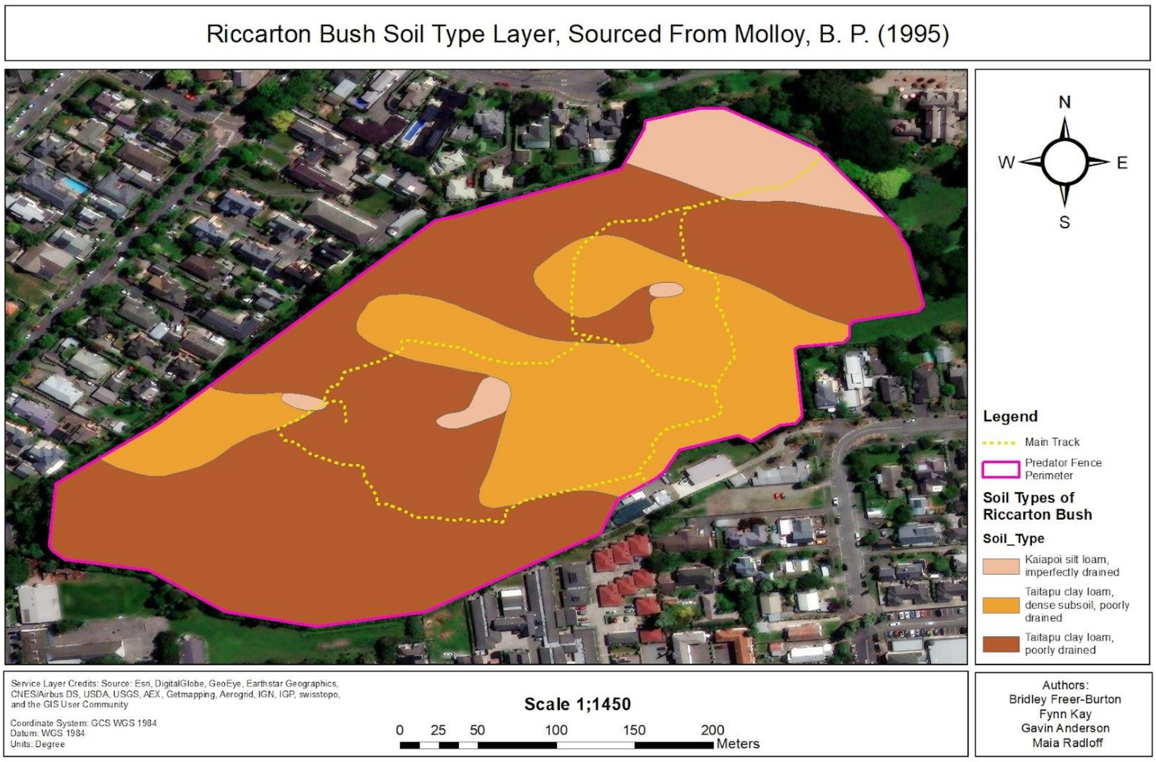

Figure 10: Map of Riccarton Bush, showcasing the soil type layer, sourced from Molloy (1995). The original map was digitised, georeferenced, then traced using ArcMap.

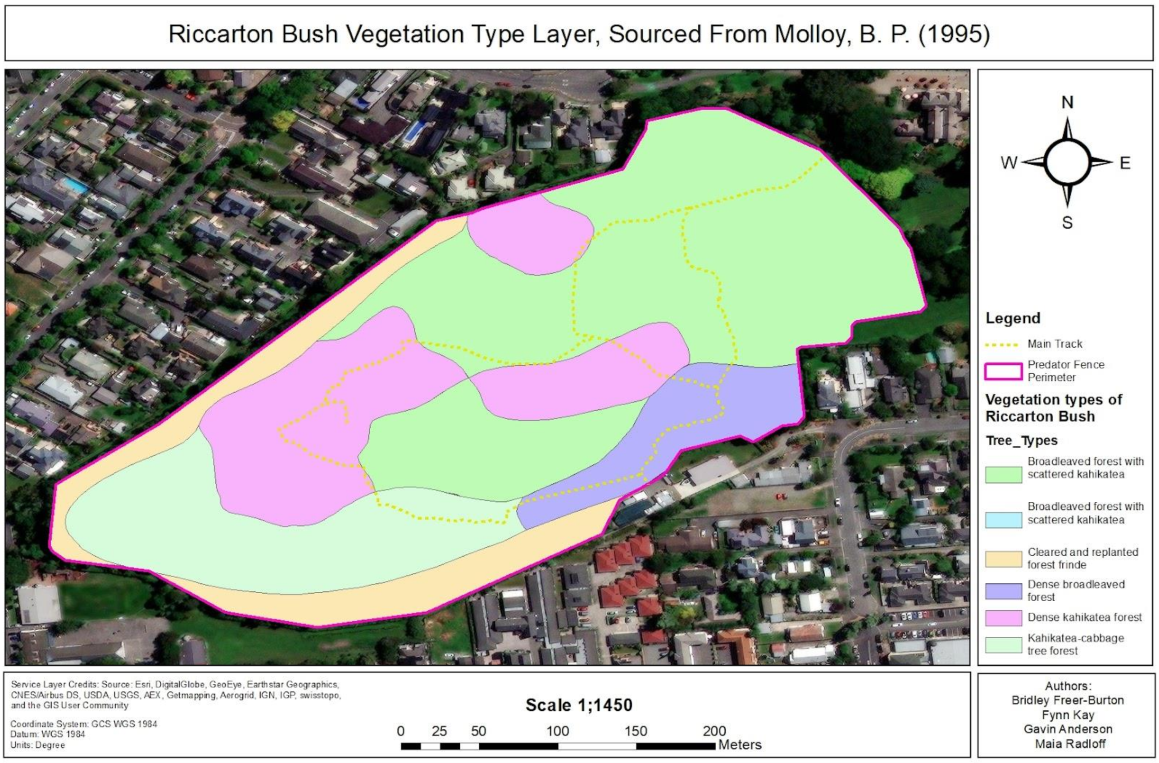

Figure 11: Map of Riccarton Bush, showcasing the vegetation type layer, sourced from Molloy (1995). The original map was digitised, georeferenced, then traced using ArcMap.

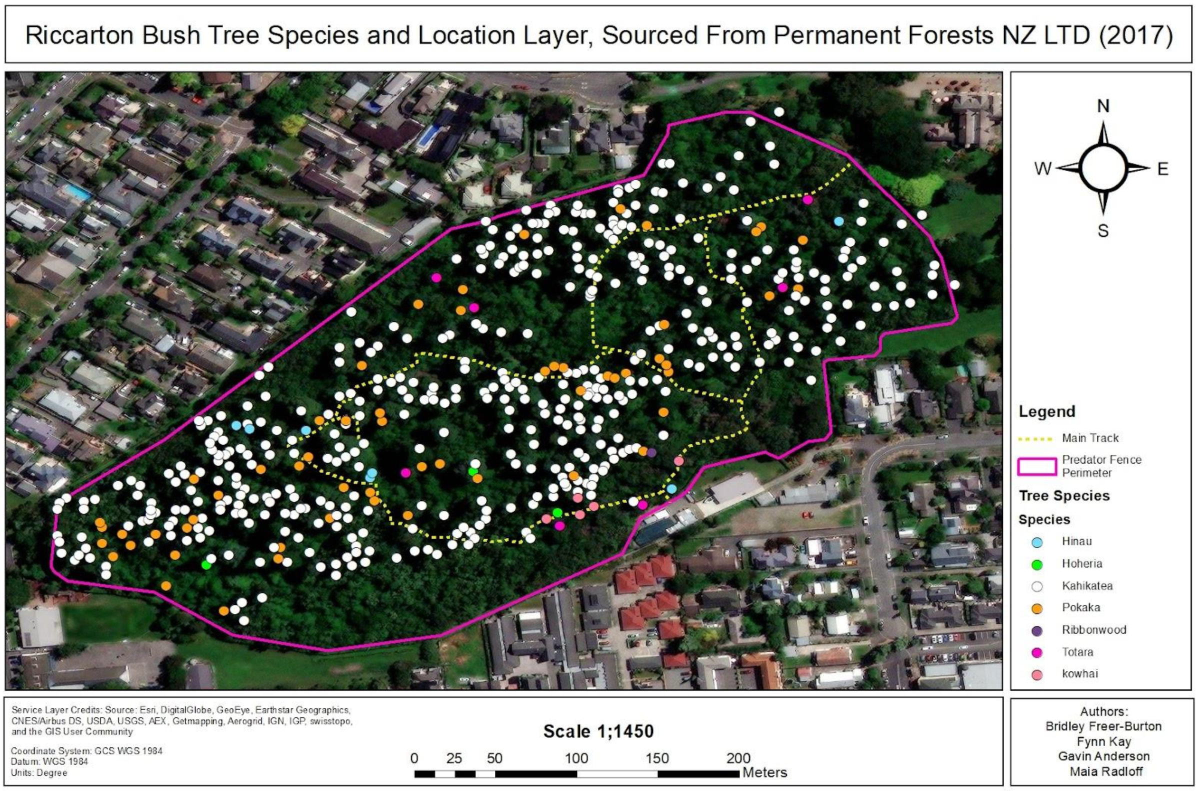

Figure 12: Map of Riccarton Bush, showcasing the tree species and location layer, sourced from Permanent Forests NZ LTD (2017). The original survey data's easting and northing coordinates were converted into WS G1984, then imported as a layer.