What water sources and irrigation systems can be best utilized to continue regenerating the native flora at Pūtaringamotu Riccarton Bush?

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1.0 Executive Summary

- Pūtaringamotu Riccarton Bush is a 7.8-hectare ngahere (forest) in Christchurch that is highly valued by the local community and hapu, Ngāi Tūāhuriri.
- The surrounding landscape has been drained due to urbanization and, in 1998, an irrigation system was installed to ensure survival of the forest. The Riccarton Bush Trust have asked us to investigate how this irrigation system may be improved.
- The research aimed to explore what water sources and irrigation systems could be best utilized to continue regenerating the native flora at Riccarton Bush. This involved determining whether variation in vegetation types and soil moisture across Riccarton Bush should be considered in the design of a new irrigation system.
- A literature review was conducted that focused on irrigation methods, native plant water needs, and the historical context of the site.
- Vegetation surveys at 13 field sites used a 5 x 5 m quadrat method to identify plant species and assess their abundance and maturity.
- Manual soil moisture samples were collected across 13 sites and analysis using ASTM DD2216 methods.
- TOMST TSM-4 soil moisture probes were calibrated and installed at field sites. These collected data over a month for analysis.
- A total of 32 plant species were identified, emphasizing both native species and the differences between mature plants and saplings.
- The relationship between soil moisture and vegetation was insufficient to draw any clear conclusions.
- The research indicates due to regeneration occurring and minimal changes in vegetation type compared to historical data, the current irrigation system appears sufficient to support continued regeneration of the forest.
- Research limitations included the limited number of field sites chosen and the inability to collect data year-round to account for seasonal soil moisture variations.
- Our recommendations for future research include updating the irrigation system with a focus on water conservation and incorporating supplementary water sources such as roof stormwater and potential spring water.

2.0 Introduction

Pūtaringamotu (Riccarton Bush) is a 7.8-hectare urban ngahere (forest) located in Riccarton, Christchurch (Figure 1), and the oldest indigenous podocarp forest in Canterbury. It is highly valued by the local community and hapu, Ngāi Tūāhuriri. However, urbanization has reduced the forest's size and disrupted its natural environment. Natural springs and streams historically irrigated the forest. Today, an industrial irrigation system prevents dry soil and maintains plant health. This system runs for six months of the year during low rainfall periods. However, the irrigation system is arranged randomly, failing to prioritize areas of the forest that require more water. This weakness in the current system means the specific requirements of different plant species and their maturity levels are not taken into account. As a result, native plants may experience stress and fail to reach full growth. This could adversely affect the long-term health of the forest.

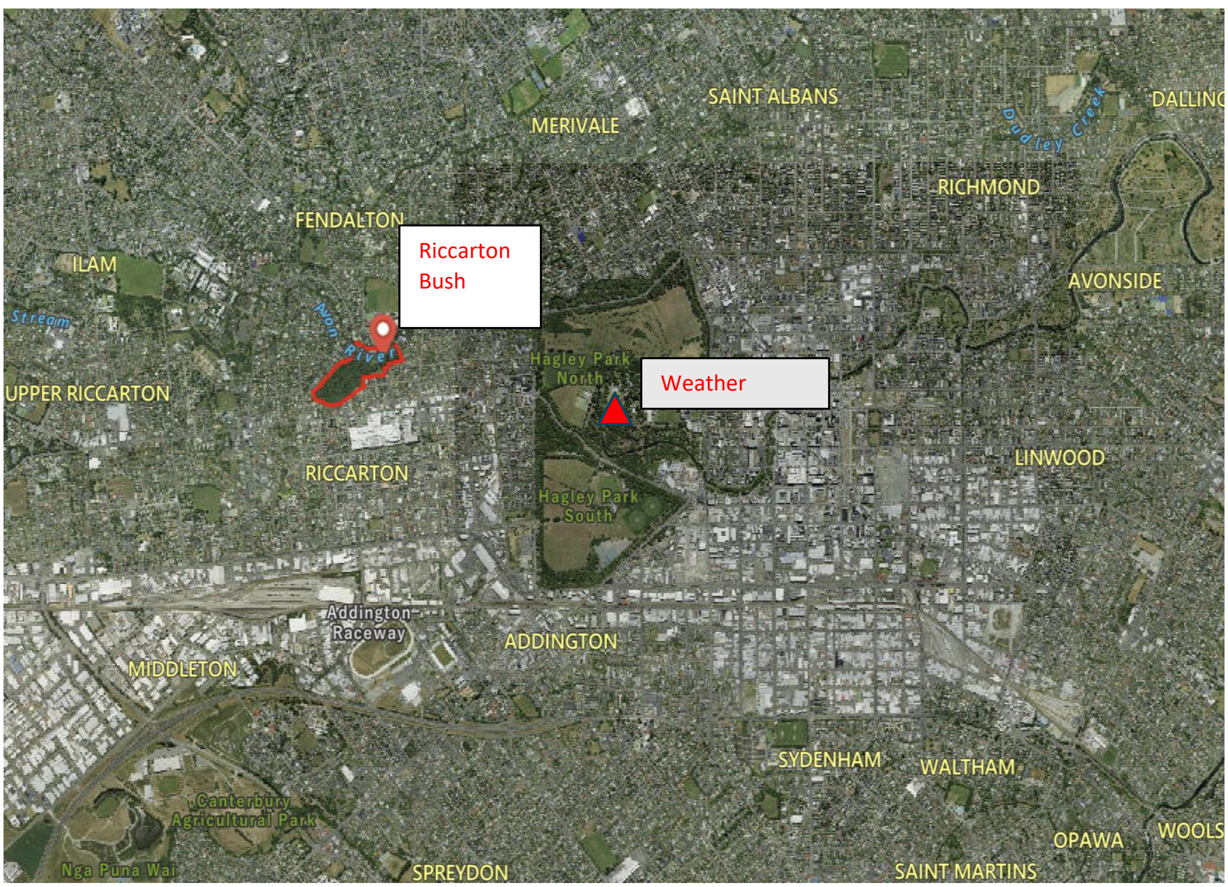

Figure 1: map showing Riccarton Bush, the weather station, and the Avon River (Canterbury maps, 2024).

This research aimed to identify what water sources and irrigation systems can be best utilized to continue regenerating the native flora at Pūtaringamotu. To address this, it focused on two main objectives. The first was to identify plant species throughout the bush to identify which areas required more irrigation. The second was to assess which areas of the forest retained soil moisture better. A systematic approach was used, conducting plant surveys and installing soil probes to measure moisture over time. This report draws on a range of literature, methodologies, results and a thorough discussion to address the irrigation issues and make recommendations for moving forward.

3.0 Background literature

To develop an effective irrigation management plan for Riccarton Bush, a comprehensive understanding of irrigation methods, the water requirements of native plants, and the site's historical context is essential. Current literature and research on these topics indicate that urban forest management is shaped by numerous factors. Irrigation strategies vary significantly depending on ecological, cultural, and practical considerations. As urbanisation and climate change impacts intensify, the effectiveness of irrigation systems is becoming more important. Urban forest management involves more than simply providing irrigation to maintain healthy vegetation. Luketich et al. (2019) emphasized how monitoring soil moisture can ensure native plants thrive in fluctuating environmental conditions. Increasingly, soil moisture sensors are recognized as an effective tool for real-time irrigation adjustments. They enable tailored approaches based on the specific needs of plant species in urban environments (Fini & Brunetti, 2017).

Riccarton Bush has a long history of interaction between natural water sources and human intervention (Molly, 1995). The forest currently depends on groundwater from the Christchurch-West Melton aquifer. Concerns about over-extraction have prompted research into diversifying water sources to reduce pressure on the aquifer. Alternatives such as spring water and rainwater harvesting could supplement water supplies (Farreny et al., 2011; Yoshikawa et al., 2014).

Additionally, climate change introduces further challenges to urban forest management. Some plants in drier environments can develop specialised water management strategies to cope with low soil moisture, such as partially closing leaf stomata to conserve water (Leathwick & Whitehead, 2001). Species such as *Prumnopitys taxifolia* and *Pittosporum eugenioides* use these strategies to be more drought tolerant. However, changes in precipitation pattern and temperatures are predicted to outpace the plant's ability to adapt, therefore, increasing their reliance on artificial irrigation systems. Building on this foundational information, this research works toward implementing a sustainable and efficient irrigation system that supports the long-term regeneration of the forest's native flora.

4.0 Methods

4.1 Field Site Selection

A categorical vegetation map of Riccarton Bush was previously uploaded onto ArcGIS Pro by Bridley et al. (2022). Field site collection locations were selected using this map, under the assumption soil moisture would vary with vegetation type due to different moisture requirements. Locations were chosen by eye, ensuring they were well-spaced across vegetation categories as shown in Figure 2. X and Y coordinates were noted for each chosen location. Subsequently, an irrigation map was overlaid onto the ArcGIS map. This allowed identification of field sites that may have been influenced by the irrigation system, which was occasionally turned on by the ranger.

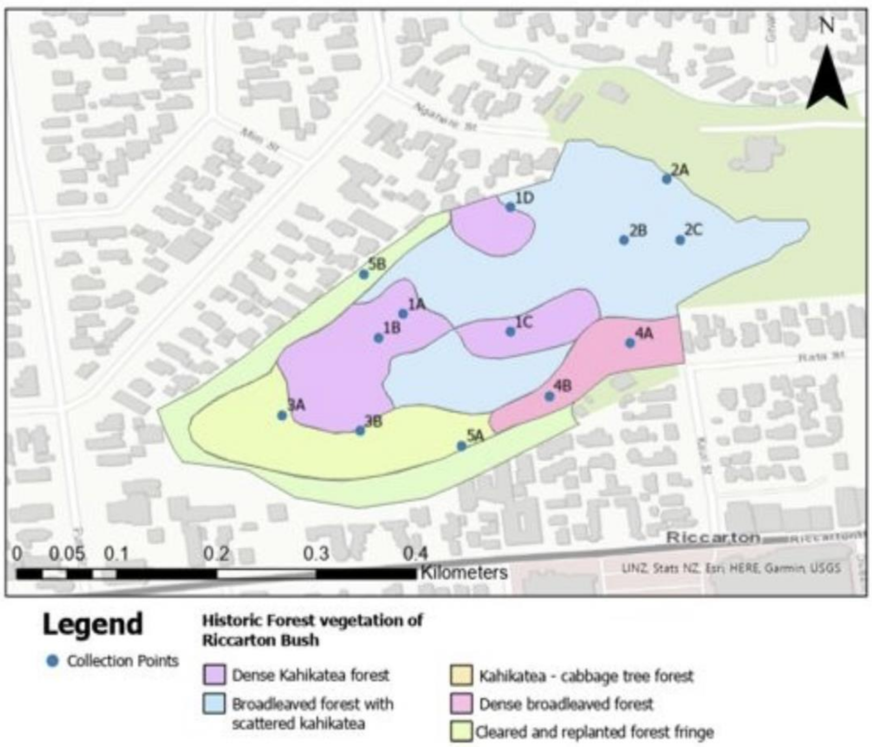

Figure 2: map showing the data collection points at the different field sites overlaid on the historic forest vegetation map for Riccarton Bush.

4.2 GPS

Initially, a Garmin GPS device was used to locate chosen field site coordinates in the forest. However, the forest's dense composition obstructed the accurate obtaining of coordinates. After group discussions, the phone app My GPS Coordinates (2017) was identified as a more reliable alternative. This app was used to accurately locate field sites. Some field sites were adjusted due to inaccessibility of the dense forest and time constraints.

4.3 Manual Soil Samples

Manual soil samples were collected from the 13 field sites to determine soil moisture using the ASTM DD2216 method. Representative soil samples were collected at a depth of 10cm and 22cm using a trowel, then placed into a non-corrodible container. Each container was labelled with the identification details for each site. Upon returning to the lab, all containers were weighed in grams. Subsequently, containers were placed into a preheated oven at

60°C, for 72 hours. The soil was unable to be tested for organic matter or other substances, therefore, lower drying temperatures were used to ensure accurate results (Hossain et al, 2021). After drying, the containers were removed from the oven, cooled, then reweighed. The weight of each sample's container was also recorded in grams. Soil moisture content for each sample was calculated using the following formula $W = \left(\frac{W2-W3}{W3-W1}\right) \times 100$ (Hossain et al, 2021). In this equation, W1 represents the weight of the sample container, W2 is the weight of the wet soil sample, and W3 is the weight of the dry soil sample. The resulting moisture percentages were recorded for each sample, as seen in Appendix A.

4.4 Soil Moisture Probes

TOMST TSM-4 soil moisture probes were used to collect continuous soil moisture data for one month. Firstly, the probes were calibrated by connecting the data logger to Lolly software on a field laptop. Soil moisture probes were checked to be active, set to the correct time zone, and to 15-minute intervals for data logging. The probes were installed at the 13 field sites on the 19/8/2024 using a metal sheet to create a hole. This avoided damage and ensured easy installation. On the 21/08/2024, three probes were checked at random using the data logger, to ensure proper functioning. The probes collected data until 17/09/2024. The data logger and Lolly software were again used to download data and export it into excel files for analysis.

Excel pivot tables were created to calculate daily average soil moisture for each field site based on the downloaded data. The soil moisture data was divided into equal quantiles to allow for consistent comparison between the manual soil moisture values and the average soil moisture values. Following this, ArcGIS was used to create two maps – one for manual and another for average soil moisture data, with the symbology changed to reflect these quantiles. Each field site or data point was colour-coded and resized according to its quantile, emphasizing differences in moisture levels (Figure 3, Figure 4).

4.5 Rainfall data collection

Rainfall data was obtained from Environmental Canterbury (n.d.) at the Botanic Gardens weather station, 2 km from Riccarton Bush, for comparison with soil moisture results. Data for the week prior to manual soil moisture sampling, the week prior to probe installation, and the duration of the probe data collection were downloaded. Rainfall data for the soil probes was aggregated into weekly totals, while manual soil sampling measurements remained daily.

4.6 Vegetation Surveys

To identify relationships between soil moisture and vegetation, surveys were conducted at the 13 field sites. Plant species were identified in a $5m^2$ quadrat around each field site. All plant species within the quadrat were identified using the Aotearoa Species Classifier app (2023), ensuring a minimum identification certainty of 65%. Historical vegetation records from Molloy (1995) were also referenced for verification. The common name and count of each plant species were recorded, and plants were classified as saplings or mature based on their expected growth, as seen in Appendix F. Canopy percentage and ground cover were visually estimated for each quadrat, determining the vegetation percentage compared to bare soil. The assessment was repeated across all 13 field sites. This comprehensive approach allowed for analysis of species types, abundance and regeneration.

5.0 Results

5.1 Manual soil moisture

Manual soil moisture percentages were calculated for the field sites across Riccarton Bush at a depth of 10cm and 22cm (Appendix A.) Soil moisture percentages measured at a depth of 22 cm, ranged from 22.36% to 52.37%. The highest soil moisture was recorded at field site 5A, found in the southwestern corner of the forest. Several field sites showed comparatively moderate moisture levels between 40% and 47.99%, including 2A, 1D, 1C, 4B, 3B, and 3A. These field sites were scattered across the forest, as seen in Figure 3. In contrast, the lowest moisture levels, ranging from 24% to 31.99%, were observed at field sites 1B, 2B, and 4A, located in the northern and eastern sections. Sites with moisture levels between 32% and 39.99% were found close to those with the lowest values, including 5B, 1A, and 2C. Rainfall data from the botanic gardens weather station indicated 5 mm of rainfall on August 9 and an additional 2mm on August 12. There was no recorded rainfall in the three days prior to moisture probe installation. For further details refer to Appendix C.

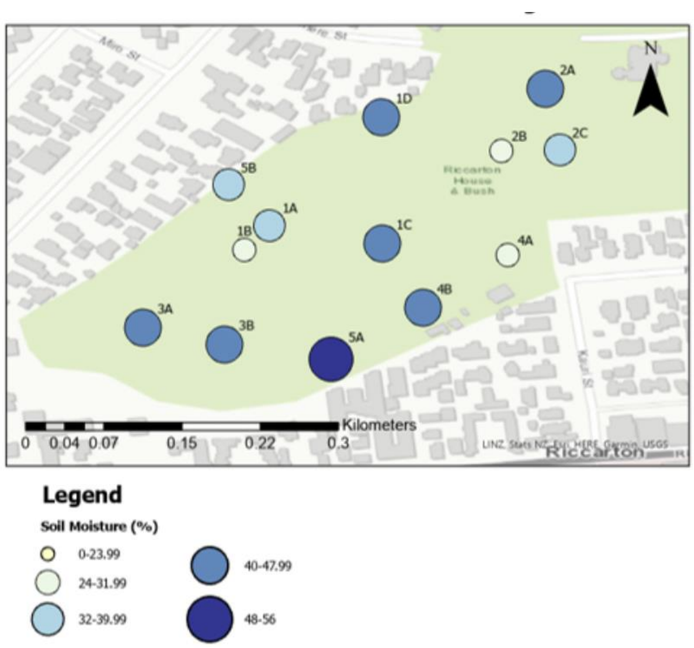

Figure 3: map showing the spatial analysis of manual soil moisture at 22cm depth for Riccarton Bush collection on 16th August 2024.

5.2 Soil moisture probes

The average soil moisture values across Riccarton Bush from August 20 to September 17, 2024, followed a similar pattern to those observed on August 16. Overall, the moisture values recorded were lower than the manual soil samples. Refer to Appendix B for further details. Field site 5A again had the highest recorded soil moisture value at 48.46%, while field site 4A had the lowest, with 18.26%. Only field site 1D had an average moisture level between 40% and 47.99%, this was 45.95%. Moderate moisture levels were recorded at field sites 1B, 1A, 1C, 4B and 2A, while lower moisture levels were recorded for 5B, 3B, 2B, 2C and 4A. The rainfall data from the botanic gardens weather station indicated a significant amount of rain (40mm) fell in the week prior to the probe's installation. This was followed by minimal rainfall over the next two weeks, with 15 mm recorded in the final week of soil moisture data collection (Appendix D). The irrigation system was also active at irregular intervals during data collection (Appendix E), due to the short intervals this did not significantly impact soil moisture levels.

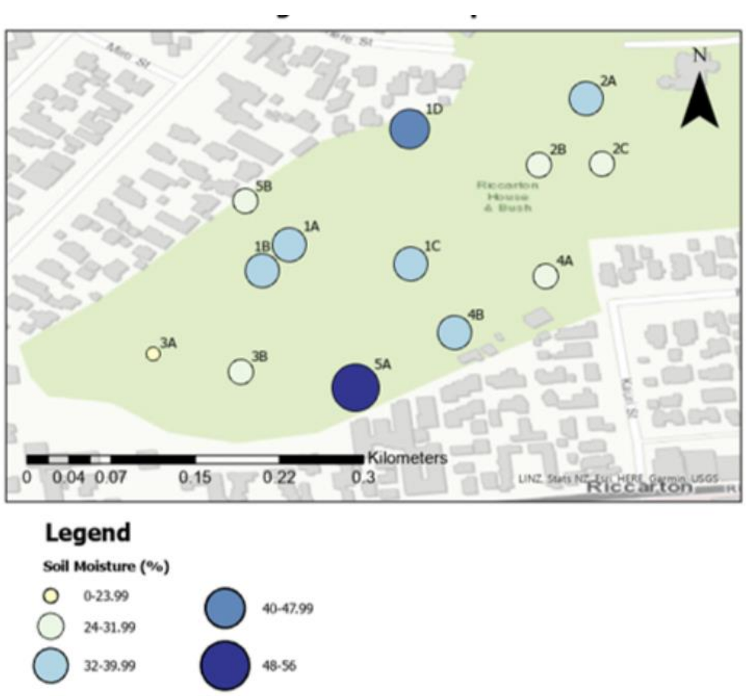

Figure 4: showing the spatial analysis of average soil moisture for Riccarton Bush from 10th-17th September 2024.

5.3 Vegetation

Vegetation surveys across Riccarton Bush resulted in identifying 32 species across the 13 field sites. The full list of the scientific names of the 32 plant species as they are referred to throughout this paper can be found in Appendix F. The species were classified into five vegetation categories, as shown in Table 1.

Table 1: Abundance of species in each vegetation categories.

Types of Vegetation	Number of Species
Forest Floor	7
Climbing plants/vines	3
Understory Shrubs	7
Understory trees and canopy	14
Emergent Layer	1

Due to the limited sample sizes for the majority of plant species, a selection process was defined to determine common plant species that appear throughout the 13 field sites. The criteria required the plant species to have been identified at three or more field sites and over ten individual plants to be surveyed. Figure 5 illustrates the abundance of the six most common plant species identified in comparison to average soil moisture.

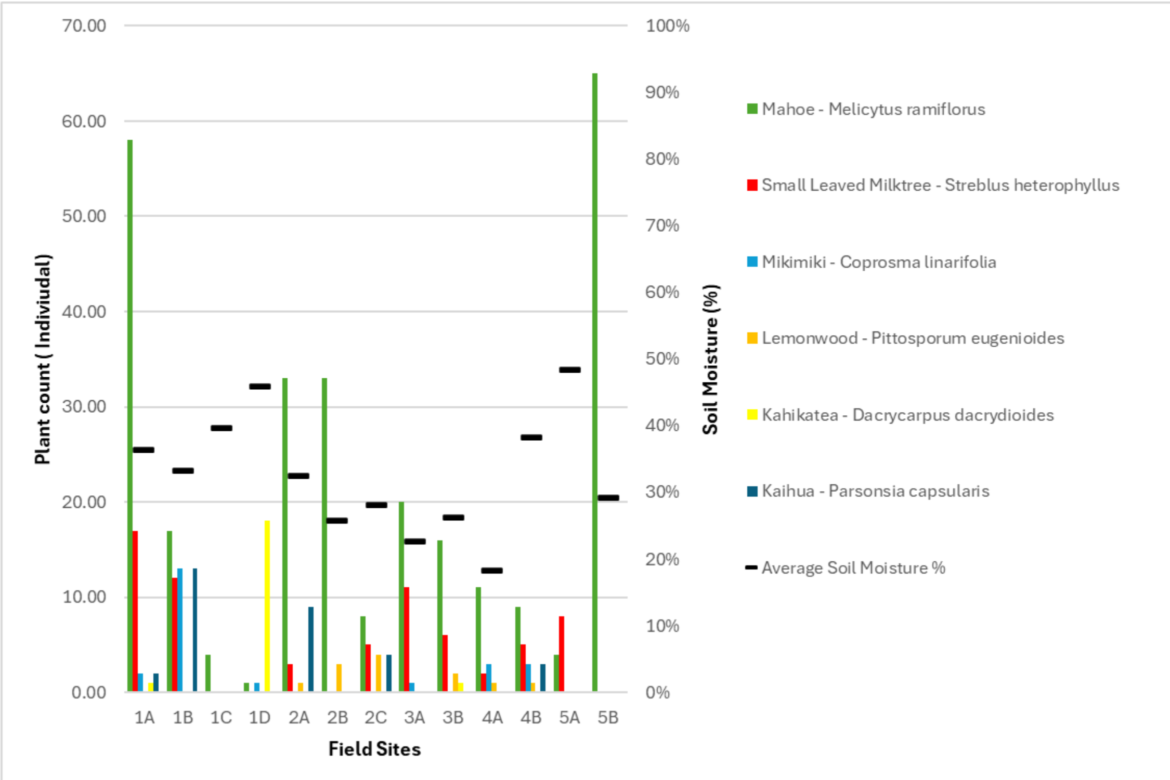

Figure 5: Comparison of Common plants species, and soil moisture across field sites.

This research focused on the regeneration of the forest, this included examining the differences between saplings and mature plants. Figure 6 displays a comparison between saplings and mature plants, to provide an indication of the regeneration potential within the forest. Nine of the sites were identified to have a greater number of saplings than mature plants.

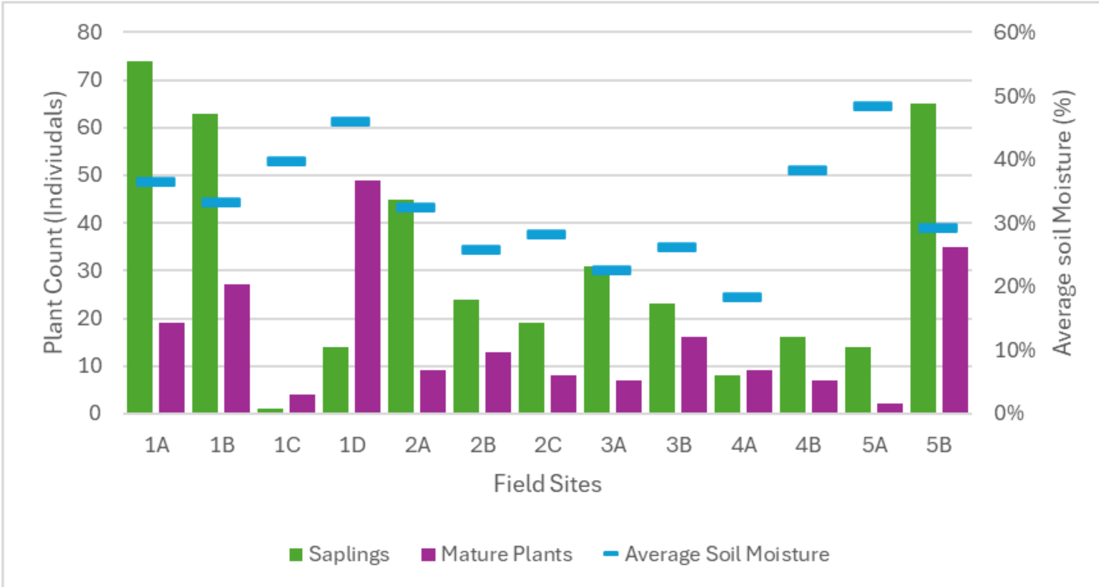

Figure 6: Comparison of sapling and mature plants in relation to average soil moisture across field sites.

There was significant contrast between vegetation and ground cover present between field sites, as seen in Figure 7. Field site 1D has a high level of ground cover and variation in vegetation types. For field site 1C, only two plant species were identified, *Melicytus ramiflorus* and *Prumnopitys taxifolia*. These are both canopy trees, resulting in limited ground cover.

Figure 7: Comparison of vegetation variation at field sites.

6.0 Discussion

Surveying plant species and monitoring soil moisture in Riccarton Bush over four weeks helped to address the research objectives: identifying plant species across different areas and determining which areas retain soil moisture more effectively.

Soil moisture data collected from probes and manual samples revealed manual soil moisture percentages were lower than probe averages. This difference was anticipated, as the manual soil moisture was measured at a depth of 22 cm, while analysis from the probes was concentrated in the top 10 cm of soil. The varying depths likely reflect different levels of hydraulic lag in the infiltration process.

Manual soil sampling was also completed at a depth of 10cm. However, further analysis was not completed on this data due to some containers being mislabeled, which led to uncertainty regarding the results. Both data sets exhibited clear variability between the moisture levels at different field sites (Figure 3, Figure 4). This variability is unlikely to stem from different soil types. Seed at al. (2023) discovered Riccarton Bush primarily consists of similar clay-based soils.

Instead, a variety of factors such as vegetation type, canopy cover, and topography of each field site may explain the moisture level variations. During data collection, the irrigation system was tested by the Riccarton Bush Ranger. Field sites located near sprinklers may have higher moisture readings as a result of this irrigation. The field sites and times irrigation was turned on can be seen in Appendix E. As seen in Figure 4, field site 1C had an average of 32-39% soil moisture, whereas field site 1D had 40-47.99%. The abundance of plants at these sites may explain this difference. Site 1C had a 10% ground cover, while site 1D had a 70% ground cover. Plant roots can help to retain moisture in the soil. This indicates at sites where there are more saplings and regeneration occurring, there is likely to be higher soil moisture (Feifel et al, 2023). Other influential factors could include the proximity of sites to the irrigation system, canopy interception of rainfall, soil slope variations, and potential disturbances during sampling.

Thirty native plant species and two exotic species were identified across the thirteen sites. The forest floor and understory shrubs exhibited a range of species that reflect the dense vegetation within the forest (Table 1). *Melicytus ramiflorus* was not only the most dominant species among the understory shrubs and canopy but also overall in the surveyed field sites. Reaching heights of up to 60m above the prominent canopy cover, *Dacrycarpus dacrydioides* was the only species identified in the emergent layer (Norton, 1995). As seen in Figure 5, the six most common species span all vegetation categories except for forest floor cover. This indicates a range of vegetation is prominent throughout the forest. Partially due to the sample size available, a relationship between soil moisture conditions and the prominence of *Melicytus ramiflorus* was unable to be established.

Vegetation survey results, as seen in Figure 5 and Appendix F, were compared to a historical Riccarton Bush vegetation survey completed by Norton (1995). This comparison revealed no extensive changes in forest vegetation type in the last 30 years. Although the environment has undergone prominent changes during this period, the irrigation system likely helped to maintain the current state of the forest. Additionally, the impacts of climate change, such as severe droughts, have yet to be faced. For instance, *Melicytus ramiflorus* has remained the dominant plant species, historically and currently. However, as droughts become more frequent, more drought-tolerant species such as *Phormium tenax* are likely to become more dominant. This is given that *Melicytus ramiflorus* is only of medium-drought-tolerant (Hall & McGlone, 2006).

There was a large variation in plant species across the different field sites. Of the 32 plant species identified, over 50% were identified at 2 or less sites. This variation is attributed to the differing characteristics of each field site, despite being in the same 7.8-hectare forest (Figure 2). Field site 1C, shown in Figure 7, was historically a grass lawn used as a recreation area (Molloy, 1995). This site is located in the central part of the forest under a dense canopy, where natural regeneration is not occurring. As a result, there is very little undergrowth of saplings compared to field site 1D. In contrast, field site 1D has a higher number of mature plants and significant forest floor cover. This site is experiencing active regeneration, as indicated by the number of saplings present (Figure 6).

Overall, these results indicate regeneration is occurring in the forest, and the vegetation type has not changed significantly compared to historical data. This suggests the current irrigation system may be sufficient to support ongoing regeneration of the forest. A significant relationship between soil moisture and vegetation was not identified, however, additional factors may be significant in determining soil moisture.

Limitations of this research include the limited number of field sites selected. In part, this was designed to limit disturbance of the natural environment in dense areas of the forest. The dispersed field site locations restrict further data analysis. The area lacked sufficient data points to conduct an interpolation analysis. Additionally, data collection occurred between August 16th and September 17th, during which the irrigation system was not operational. This meant seasonal weather patterns were not encapsulated in the data. As a result of these limitations, a relationship between the vegetation and soil moisture at each field site was unable to be determined. A greater sample size and further research into seasonal differences in soil moisture are needed. This would allow for a more thorough analysis of the irrigation system's effectiveness. Future research should clearly map the irrigation system's sprinklers and compare them to soil moisture levels in different areas of the forest.

7.0 Conclusion

The manual soil moisture sampling and average soil moisture probe data shows there is variability in soil moisture across Riccarton Bush (Figure 3, Figure 4). Several factors, including vegetation and natural canopy or ground cover, may contribute to this variability.

No direct relationship between moisture variability and plant regeneration was found, as the data did not provide significant evidence. Lack of knowledge surrounding seasonal data and each location's water requirements means it cannot be determined if specific locations are more vulnerable than others.

The vegetation data collection suggests a potential relationship between moisture levels, species diversity, and regeneration. For example, field site 1D encompassed a diverse range of vegetation species and had a high soil moisture average. Historical data indicated no significant changes in vegetation that would impact regeneration. This suggests the current irrigation system and natural weather patterns may sufficiently support forest health. Continuous soil moisture monitoring would enhance understanding of this relationship.

Identification of mature plants compared to saplings is also an indicator of forest regeneration. Nine of the thirteen sites had a higher number of saplings to mature plants. This indicates natural regeneration within the forest. However, without long-term studies, it remains unclear whether these saplings will reach maturity. Sites with denser canopy cover, such as 1C, displayed a lack of natural regeneration and were dominated by mature species such as *Melicytus ramiflorus* and *Prumnopitys taxifolia*. This suggests a potential relationship between sapling growth and mature species.

Combining data from 1995 to the present has shown no significant change in the dominant forest types. Introduction of the irrigation system has not likely altered the dominant species within the forest. However, climate change and extreme weather patterns increasing in frequency may lead to shifts in dominance. Stress-resistant and drought-tolerant species are likely to become more commonplace. Continued monitoring of the forest will allow changes in future forest composition to be identified.

8.0 Recommendations

The Riccarton Bush Trust has consent from the Christchurch City Council (CCC) to draw from the underground aquifer for both irrigation and firefighting. However, water scarcity is a growing concern in urban areas as the demand for resources continues to increase. This issue poses a threat to the sustainability of urban forest irrigation (Rambhia et al., 2023). The following recommendations aim to identify alternative water sources that could supplement the existing irrigation system.

The first potential alternative water source is a water flow, located on Kauri and Rata Street adjacent to Riccarton Bush. This water flow is an asset of the CCC and was previously investigated during a street upgrade in 2009, led by stormwater engineer Peter Wehrmann. The project involved the development of an artificial spring (P. Wehrmann, personal communication, September 17, 2024). However, the source of the spring water remains uncertain, as the cost of analysis has previously been considered too high. Consequently, it was not possible to complete testing and confirm the source of the water during the duration of the research process. CCC suggested two possible sources. First, the water flow may originate from the nearby Avon River, creating a shallow gravel layer of water (P. Wehrmann, personal communication, September 17, 2024). Second, there may be a connection to the dewatering process implemented across Christchurch to lower the water table following the 2010 and 2011 earthquakes (D. Veale, personal communication, September 13, 2024). As water becomes an increasingly valuable resource, further investigation of this water source could enhance the irrigation system.

Another potential supplementary water source is rainwater harvesting (RWH) from surrounding roof tops. The RWH potential (in L/year) of a roof can be estimated based on local precipitation (P, in mm/year), the catchment area (A, in m^2), and the runoff coefficient (RC, nondimensional). This is shown in the equation RWH = P x A x RC (Farreny et al., 2011). As of 2024, the average annual rainfall in Christchurch was 617.7 mm (NIWA, 1991-2020). To meet the irrigation demand of up to 54,390,000L annually, a rooftop catchment area of

83,650m^2 is needed. Based on an average townhouse roof size of 150m^2, 550 surrounding homes would be needed for RWH. Therefore, while RWH is unfeasible as a sole water source, it could serve as a supplementary option.

The existing irrigation system at Riccarton Bush uses a rotary sprinkler system arranged in a linear layout. Recommendations for improvement are limited as the irrigation system was not operational during the data collection period. However, implementing a more precise irrigation design could reduce water wastage and enhance efficiency. Dripline irrigation is a favorable option as it delivers water directly to vegetation roots, minimizing evaporation and runoff (Mohamadzade et al, 2021). Installing a dripline system in an established forest presents challenges, particularly in accessing dense areas with varying levels of ground vegetation cover. An alternative option is a misting sprinkling system, which can support positive microclimatic conditions in urban forests (Livesley et al., 2021). This system would not only enhance irrigation but also serve as a fire prevention measure, as cooler microclimates reduce fire risk.

Furthermore, the need for better accessibility of the irrigation system for fire prevention was identified. The dense forest and perimeter fence limit navigation between key points of the irrigation system. To improve accessibility, it is recommended key access points of the irrigation system align with established walking tracks.

Another recommendation is to enhance the biodiversity of the forest. This is crucial in areas of bare soil and minimal ground cover, so as to reduce the risk of drought (Brandt et al, 2016). A larger variety of plants establishes complex root systems in the soil. These work together to hold moisture in the soil, creating an underground water source. With Canterbury expected to experience more droughts due to climate change, retaining soil moisture will be crucial to the forest’s survival (Zhang et al., 2021).

Finally, forming connections with residents near the forest is recommended. This aligns with the earlier recommendation of establishing rainwater collection systems on nearby rooftops. Understanding their values and attitudes towards the forest, as well as teaching them the role of kaitiakitanga is essential for successful implementation (Barona, 2015). This engagement could be achieved through workshops or door-to-door surveys. Involving the community will strengthen their connection to Riccarton Bush and enhance collaborative efforts toward sustainability.

9.0 Acknowledgements

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11.0 Appendices

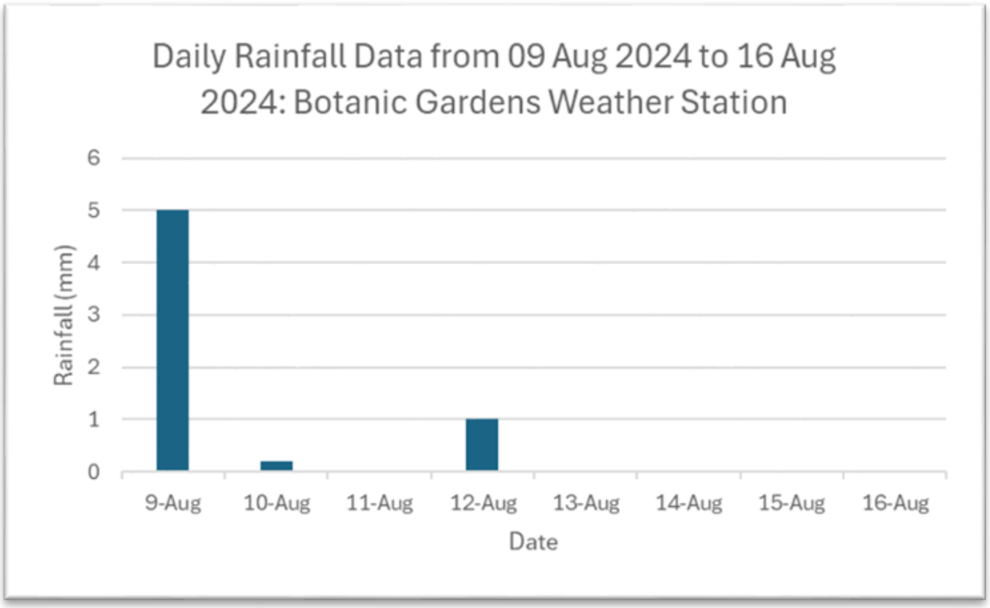
Appendix A – Results of Manual soil moisture sample, displayed as soil moisture percentage.

Field Sites	Depth 10cm	Depth 22cm
1A	38.20%	38.52%
1B	22.95%	26.21%
1C	47.90%	47.10%
1D	36.18%	44.03%
2A	40.96%	40.10%
2B	31.86%	30.74%
2C	35.09%	33.28%
3A	44.85%	44.83%
3B	62.30%	47.90%
4A	20.30%	22.36%
4B	37.52%	41.97%
5A	60.76%	52.37%
5B	36.33%	37.37%

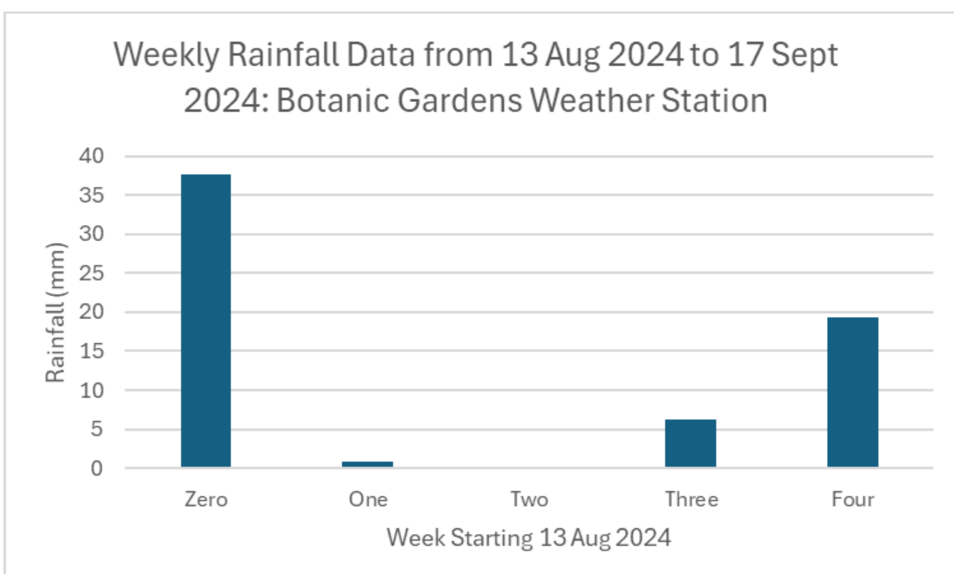
Appendix B – Results soil moisture probe daily average soil moisture percentage.

Dates	1A	1B	1C	1D	2A	2B	2C	3A	3B	4A	4B	5A	5B
2024.08.20	44.14%	38.51%	44.67%	50.71%	36.33%	31.31%	33.63%	22.67%	26.45%	20.18%	45.60%	49.96%	37.21%
2024.08.21	45.00%	38.64%	44.56%	50.48%	35.86%	30.89%	33.21%	22.83%	26.51%	20.13%	45.01%	49.49%	36.88%
2024.08.22	44.78%	38.52%	44.37%	50.35%	35.59%	30.30%	32.43%	22.42%	26.43%	19.84%	44.29%	49.26%	36.34%
2024.08.23	44.03%	38.32%	44.23%	50.48%	35.34%	29.58%	31.78%	21.78%	26.40%	19.46%	43.19%	48.95%	35.81%
2024.08.24	44.59%	37.89%	43.96%	50.53%	34.96%	29.40%	30.95%	21.39%	26.47%	19.22%	41.95%	48.56%	35.26%
2024.08.25	43.98%	37.53%	43.64%	50.34%	34.58%	28.69%	30.37%	20.97%	26.48%	19.00%	40.83%	48.36%	34.75%
2024.08.26	43.44%	37.60%	43.60%	50.49%	34.70%	28.45%	30.51%	20.97%	26.53%	18.98%	40.70%	48.55%	34.73%
2024.08.27	43.23%	37.26%	43.28%	50.53%	34.38%	28.11%	30.03%	22.56%	26.59%	18.81%	40.06%	48.53%	34.48%
2024.08.28	42.44%	36.68%	42.88%	50.41%	33.93%	27.53%	29.44%	23.69%	26.45%	18.56%	39.11%	48.49%	34.00%
2024.08.29	40.95%	35.74%	41.97%	50.02%	33.29%	26.62%	28.78%	22.58%	26.36%	18.83%	37.62%	48.02%	32.78%
2024.08.30	39.83%	34.82%	41.01%	49.42%	32.56%	25.86%	28.18%	21.82%	26.15%	18.66%	36.52%	47.70%	31.31%
2024.08.31	39.17%	34.21%	40.37%	48.79%	32.10%	25.38%	27.91%	21.68%	26.11%	18.28%	35.70%	47.68%	30.07%
2024.09.01	37.13%	33.43%	39.57%	47.94%	31.49%	24.97%	27.57%	21.83%	26.10%	17.99%	34.79%	48.02%	28.92%
2024.09.02	35.81%	32.54%	38.79%	46.64%	30.87%	24.48%	27.23%	21.54%	25.99%	17.61%	33.80%	47.84%	27.77%
2024.09.03	34.79%	32.14%	38.31%	45.62%	30.69%	24.25%	27.04%	21.53%	25.99%	17.40%	33.20%	48.28%	27.12%
2024.09.04	34.86%	32.06%	38.20%	45.15%	30.96%	24.49%	27.07%	21.88%	26.08%	17.53%	32.98%	48.14%	27.26%
2024.09.05	33.65%	31.65%	37.70%	44.60%	30.64%	24.16%	26.88%	21.86%	26.19%	17.48%	33.29%	49.15%	27.00%
2024.09.06	32.79%	31.03%	36.99%	43.90%	30.19%	23.53%	26.58%	21.31%	26.12%	17.23%	38.01%	49.10%	26.35%
2024.09.07	31.48%	30.31%	36.39%	43.35%	29.98%	23.29%	26.51%	21.53%	26.20%	17.09%	34.93%	48.59%	25.30%
2024.09.08	31.41%	30.06%	36.62%	43.13%	29.92%	23.45%	26.44%	21.49%	26.21%	17.47%	33.90%	48.64%	25.37%
2024.09.09	30.63%	29.29%	36.26%	42.43%	29.40%	22.92%	26.01%	21.17%	26.09%	17.32%	33.50%	48.35%	24.64%
2024.09.10	29.69%	28.83%	36.14%	41.59%	30.22%	22.97%	25.85%	22.77%	26.02%	17.15%	41.56%	48.22%	24.11%
2024.09.11	29.69%	28.93%	36.01%	41.30%	30.99%	23.07%	25.83%	23.61%	26.00%	17.41%	38.35%	48.41%	24.58%
2024.09.12	29.09%	28.32%	35.73%	39.97%	30.32%	22.85%	25.58%	22.92%	25.84%	17.08%	35.65%	48.02%	23.70%
2024.09.13	29.30%	28.38%	35.73%	39.43%	30.20%	23.04%	25.73%	23.43%	25.84%	16.94%	35.03%	47.89%	23.85%
2024.09.14	29.57%	28.37%	35.70%	39.16%	30.51%	23.12%	25.77%	23.39%	25.88%	17.00%	34.93%	47.87%	24.04%
2024.09.15	29.50%	28.21%	35.44%	38.83%	30.16%	23.03%	25.71%	23.33%	25.83%	16.85%	39.62%	47.62%	23.76%
2024.09.16	29.60%	29.58%	37.49%	40.75%	33.14%	25.65%	26.35%	26.86%	25.90%	18.18%	41.54%	47.60%	23.89%
2024.09.17	30.82%	33.85%	41.36%	46.24%	37.91%	28.34%	27.32%	30.60%	26.36%	21.94%	43.58%	50.14%	26.89%
Total	**36.39%**	**33.20%**	**39.69%**	**45.95%**	**32.46%**	**25.85%**	**28.16%**	**22.63%**	**26.19%**	**18.26%**	**38.25%**	**48.46%**	**29.25%**

Appendix C – Rainfall Data - Manual Soil Moisture daily average, Botanic Garden weather station CCC



Appendix D - Soil Moisture Probes, Rainfall data weekly averages, Botanic Garden weather station CCC.



Appendix E – Irrigation Log

Date	Start Time	Finish Time	Duration (Minutes)	Field Site
5/09/2024	10:30:00 AM	10:35:00 AM	5	3A, 3B, 5A
6/09/2024	10:11:00 AM	10:16:00 AM	5	3A, 3B, 5A
6/09/2024	10:39:00 AM	10:44:00 AM	5	3A, 3B, 5A
6/09/2024	11:01:00 AM	11:06:00 AM	5	3A, 3B, 5A
10/09/2024	9:31:00 AM	9:36:00 AM	5	3A, 3B, 5A
10/09/2024	10:08:00 AM	10:13:00 AM	5	3A, 3B, 5A
10/09/2024	11:16:00 AM	11:21:00 AM	5	3A, 3B, 5A
10/09/2024	11:37:00 AM	11:47:00 AM	10	3A, 3B, 5A
15/09/2024	8:00:00 AM	8:30:00 AM	30	3A, 3B, 5A
15/09/2024	8:30:00 AM	9:00:00 AM	30	1B, 1C, 4B, 4A.
15/09/2024	9:00:00 AM	9:30:00 AM	30	5B, 1A
15/09/2024	9:00:00 AM	10:00:00 AM	30	1D, 2A
15/09/2024	10:00:00 AM	10:03:00 AM	30	1C
15/09/2024	10:30:00 AM	11:00:00 AM	30	2B

Appendix F – Vegetation Data

Scientific Name	Common Name	Exotic	Number of Saplings	Number of Mature Plants
Melicytus ramiflorus	Mahoe	No	118	98
Streblus heterophyllus	Small Leaved Milktree	No	64	5
Parsonsia heterophylla	Kaihua	No	35	0
Carex uncinata	Bastard Grass	No	0	30
Coprosma linariifolia	Mikimiki	No	9	14
Dacrycarpus dacrydioides	Kahikatea	No	8	12
Microlaene avenacea	Bush Rice grass	No	20	0
Pittosporum eugenioides	Lemonwood	No	0	12
Asplenium bulbiferum	Hen & Chicken Fern	No	8	3
Paesia scaberula	Pig Fern	No	0	9
Passiflora tetrandra	New Zealand Passion Flower	No	7	1
Pennatia corymbosa	Kaikomako	No	8	0
Pterophylla racemosa	Kamahi	No	7	1
Cordyline australis	Ti Kouka	No	1	5
Pittosporum tenuifolium	Kohuhu	No	3	2
Myrsine australis	Mapou	No	0	4
Coprosma repens	Coprosma	No	1	3
Phormium tenax	Harakeke	No	0	2
Lophomyrtus obcordata	New Zealand Myrtle	No	1	0
Ripogonum scandens	Supplejack	No	1	1
Prumnopitys taxifolia	Matai	No	0	2
Aristotelia serrata	Wineberry	No	0	2
Plagianthus regius	Ribbonwood	No	0	1
Rubus fruticosus	Blackberry	Yes	1	0
Potentilla indica	Mock Strawberry	Yes	1	0
Pseudopanax crassifolius	Lancewood	No	0	1
Beilschmiedia tawa	Tawa	No	1	0
Hedycarya arborea	Pigeonwood	No	1	0
Cytisus scoparius	Common Broom	No	1	0
Podocarpus totara	Totara	No	1	0
Laurelia novae-zelandiae	Pukatea	No	1	0
Melicope simplex	Poataniwha	No	0	1