University of Canterbury

GEOG309 Assignment 5:

How Existing Stands of Lowland Kahikatea Can Inform Future Restorative Plantings

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Executive Summary

- Kahikatea (*Dacrycarpus dacrydioides*) are Aotearoa New Zealand's tallest indigenous tree, growing up to 60m tall. Kahikatea forest once dominated the Canterbury plains before the arrival of humans, with the only surviving remnant located at Pūtaringamotu/Riccarton Bush in Ōtautahi Christchurch. Trees for Canterbury (T4C), a not-for-profit community welfare organisation, are planting native kahikatea forests to restore degraded sub-urban areas such as: Cranford Basin, Ōruapaero/Travis Wetland, and the Pūharakekenui/Styx River Catchment. As our community partner, T4C have asked us to collate data from Riccarton Bush and fossiled kahikatea stumps in Hoon Hay to help inform their future plantings.

- In response to the brief from T4C, we developed the research question: 'how can existing stands of lowland kahikatea inform future restorative plantings?'. This simplified scope was elaborated upon within our three aims: map the existing kahikatea-dominated plantings across Christchurch, develop a planting guide that considers the optimal ecological conditions for facilitating and maintaining a lowland kahikatea forest, and calculate the carbon sequestering potential of the stands planted by T4C.

- Beginning with a comprehensive literature review across five sub-themes, we were able to acquire a wide range of background information relating to the interspecific processes, spatial arrangement, and ecosystem services of kahikatea forests across different regions of Aotearoa.

- Spatial analysis was completed using co-ordinate data from Riccarton Bush, the Hoon Hay fossil forest, and any T4C plantings. This data enabled us to map these locations and determine potential sites for future plantings.

- An extensive literary study on restoration ecology was undertaken to identify any positive interactions (among both biotic and abiotic factors) that have been found to underpin kahikatea growth across NZ. These findings were complemented by informative personal communications from T4C representatives during visits to several local planting sites.

- We have determined that there is a lack of native forest in the southern and western ends of Christchurch city. Some suburbs such as Avonhead, Burnside, Russley, Hornby and McLean's Island could be ideal locations for future kahikatea plantings by Trees for Canterbury due to their proximity (<5 km) to other substantial kahikatea stands. Strengthening these inter-fragment connections will allow for greater ecosystem function by facilitating the dispersal of seeds/wildlife, thus improving genetic exchange.

- According to reviewed data, the optimal distance between kahikatea stems when planting saplings is roughly three metres, as this accounts for a survival rate of 80% while allowing room in the understory for various co-planting species to be successfully recruited.

- Carbon sequestering potential was estimated using equations and conversions obtained from the literature. We discovered that the 10-hectare planting at Cranford Basin sequesters about 169 t.CO_2/ha/yr, under the condition that all trees survive to maturity at the current stem spacings of 1.3-1.5 m. The total carbon stocked in mature kahikatea at the 7.8-hectare Riccarton Bush remnant is 231 t.CO_2. However, there are limitations to our carbon sequestration measurements, including inaccuracies which tend to arise when converting previous estimates to fit our focal plantings. Nevertheless, these are the most accurate measurements available given our time constraints. A recommendation for future research involves measuring parameters in new plantings and applying these to equations from the literature.

1. Introduction

The indigenous forest communities that once sprawled across lowland Aotearoa New Zealand (NZ) prior to human settlement are now so poorly represented that many mature-phase tree species such as kahikatea (*Dacrycarpus dacrydioides)* have become functionally or locally extinct (Wardle, 1974; Forbes et al., 2020). This is a key incentive for our exploration of how existing lowland kahikatea stands can inform future restorative plantings. Understanding the dynamics and biological interactions of this emergent swamp conifer is paramount to the realisation of its inherent benefits. Not only do kahikatea-dominant stands provide a myriad of ecosystem services, human well-being enhancements, and rich biodiversity havens, but they also facilitate tikanga Māori (social practices) such as the use of taonga (treasured) species for mahinga kai (food gathering), whakairo (traditional wood carving), and rongoā (traditional medicine; Wallace & Clarkson, 2019). Facilitating the persistence of these cultural practices into the distant future could be invaluable to mana whenua, as well as providing the tools for upcoming rangatahi (younger generations) to learn from mātauranga Māori (Māori knowledge and wisdom). This may involve a more biculturally inclusive education that focusses on principles such as kaitiakitanga (environmental guardianship) and 'Te Mana o te Taiao' (biodiversity health).

As for ecosystem services, native reforestation is one of the best tools available to mitigate global warming. With the ever-increasing threat of anthropogenically-induced climatic change, the need for ways in which to mitigate these environmental extremes is growing. Substantial amounts of carbon are stored in the biosphere, with trees acting as a natural carbon sink (Wang & Gao, 2020). As a result, carbon sequestering potential is an important aspect of any forest restoration project because it accounts for the ability of new plantings to remove and store atmospheric carbon. The respective sequestering potential of kahikatea forests indicates that revegetation initiatives similar to this project could contribute toward the mitigation of climate warming, while achieving NZ's one billion trees programme and carbon neutral 2050 goal.

Our community partner is Trees for Canterbury (T4C), a not-for-profit community organisation who have been donating and planting native trees across Canterbury for over 30 years. The equivalent of over 100 hectares has been planted by them in that time. Their latest major location for planting is the Cranford Basin, which was chosen as it is ideally located between Styx Mills, Riccarton Bush, and Travis Wetland to facilitate the natural dispersal of plants and wildlife. The basin has also experienced a rise in water levels following the construction of the Northern corridor motorway, limiting its use for residential dwellings and agriculture. Kahikatea have been found to grow with high success rates in wet environments and so, when deciding what should be planted in the Cranford Basin, a kahikatea-dominated forest was the best option. We worked closely with T4C members, Antony Shadbolt and Richard Earl, who proposed a research project for our GEOG309 group at the University of Canterbury. They requested that an investigation into existing lowland kahikatea stands be undertaken to inform T4C on how best to plant new kahikatea forests. Data from Riccarton Bush, the fossilised stump forest at Hoon Hay, and other stands throughout New Zealand were to be analysed and compiled for guiding our suggestions. Arriving upon a succinct project question provided better clarity for our research scope and allowed us more freedom with the aims to elaborate on our sub-themes and their respective methods.

The first aim was to map all the kahikatea sites across Christchurch, including: the remaining old-growth forest at Riccarton Bush, the stands planted within the last 3 decades by Trees for Canterbury and other 'greenifying' trusts, as well as the clusters of fossilised kahikatea stumps that have been uncovered near Hoon Hay. The second aim was to use the biomass data from kahikatea stems at Riccarton Bush to calculate the carbon sequestration potential of the newly planted stands in Cranford Basin. Our third and final aim was to create a planting guide for T4C that specifies optimal spatial layout (according to both tree spacing and patch proximity), ecological conditions, and any facilitation or enrichment effects based on compatible co-planting species of kahikatea. For our study, we define a kahikatea stand as an area with 10 or more stems. The ensuing report contains a review of all the literature that we have collated and applied throughout the project, followed by an overview of the methods used to meet our aims, as well as a presentation and discussion of our research results.

2. Literature Review

2.1 Restoration Theory

In order to gain background knowledge on our topic and begin to answer our research question, we studied various journal articles, books, and reports. One of our methods for meeting our research aims involved the analysis of content and data within the literature and synthesising any relevant information they contained. The foundational knowledge of kahikatea forests, and their place in Christchurch, was derived from several sources. The 'Kahikatea Forest Fragments: Managing a Waikato Icon' factsheet (Waikato Regional Council, 2018) gave an overview of kahikatea biology, as well as the importance of kahikatea forests to both the surrounding ecosystem and to tangata whenua. This factsheet also contained its own guide for managing and creating stands of kahikatea. These guidelines were used in conjunction with information from other sources to develop our own recommendations. A report from the Waikato Regional Council (2019) introduced a tool for assessing the recovery of kahikatea forest remnants called the 'Kahikatea Forest Green Wheel'. This report gave us an understanding of what successful kahikatea forest restoration looks like and which factors need to be included when offering guidance on planting and maintenance. Wallace and Clarkson (2019) used the method of analysing and synthesising various pieces of research to highlight key information for urban forest restoration. As our research aim was to use existing stands of kahikatea to inform future stands, we adopted this method for our own project due to the quality of the research already completed in Riccarton Bush, the Hoon Hay fossil forest, and those in other regions. One source of information for Riccarton Bush is a book written by Dr Brian Molloy (1995). This book, and in particular the chapter regarding kahikatea, informed much of our knowledge on kahikatea distribution, spatial layout, life-cycle, and co-planting species.

2.2 Spatial Layout

The literature available on information regarding the spatial arrangement of kahikatea stands was mostly from other regions around New Zealand. The most notable of which was related to the Waikato region. The plainest answer to the question of spatial distribution came from Waikato Regional Council (2018) which states that they should be planted five metres apart. Aside from this, there is limited literature that specifically states the optimal distances between individual trees. Studies performed by Duncan (1991) outline the different spatial distributions that kahikatea can arrange themselves in. Finding that within wider and closer thresholds the trees will be arranged either in clustered or random distributions respectively. One limitation of the available information on kahikatea is that each study is specific to individual stands in differing regions across the nation. There are yet to be any studies comparing the growth of kahikatea across different environments that we can reliably apply to a wet plains ecosystem type.

2.3 Facilitation and Enrichment

Nursing effects of pioneer species as well as enrichment effects of late-successional plantings play a huge role in building a more favourable habitat for both old and new kahikatea sites. According to Wallace and Clarkson (2019), native forest remnants located in urban environments tend to be more dynamic and depauperate than larger rural patches due to greater fragmentation, invasive pressure, urban heat island, and pollution levels. Ecological restoration of these stands thus requires intensive management strategies such as successional co-planting for them to achieve a more functional ecosystem state. Due to the slow-growth and long lifespan of kahikatea, they may be the ultimate benefactor from having biodiverse nursing neighbours in an otherwise limited environment, a phenomenon widely regarded as facilitation (Padilla & Pugnaire, 2006; Waring, 2017). Other niche benefits might include: the conditioning of soil and microclimate, the displacement of competitive exotic plants, hydraulic lift of water from deeper roots to the understory, exchange of mycorrhizal fungi, and even attracting a wider range of pollinators/seed-dispersers (Padilla & Pugnaire, 2006; Waring, 2017). Beyond these first few years of establishment, restoration of mature forest composition and structure is a lengthy process in which the changing understory conditions and habitat requirements cannot be overlooked throughout its succession (Forbes et al., 2020). Numerous papers indicate that enrichment planting is the tool to mitigate the forest community from becoming arrested in a biologically deficient ecosystem state. A pro-active introduction of late-successional species would address light competition via canopy manipulation as well as fill the gaps where weeds would otherwise occupy (Wallace & Clarkson, 2019; Brock et al., 2020; Forbes et al., 2020). However, further research is needed to ascertain how well these practices apply to wetland environments.

2.4 Fragmentation Ecology and Succession

Fragmentation of native ecosystems is a key driver in the loss of biodiversity and the disruption of ecosystem functions through population shifts, loss of habitat, and dominance of invasive species. These drivers can influence community structure by opening resource gaps through natural and artificial processes (e.g., storms and logging). In wetland environments where they are most often found, varying water levels are one of the major controls on seedling survival as well as impacts of oxygen and nutrient availability in the area (Waring, 2017). Relevant literature predominantly covered kahikatea stands across Westland and the North Island, detailing how disruption influences the distribution of these stand formations. They also illustrate the type of secondary succession that would take advantage, namely rapid-growing plants that provide shelter, like totara and coprosma species (Wardle, 1974). Alluvial kahikatea forests are strongly molded by climate conditions such as temperature which can control the distribution of lower-level canopy composition (Burns et al., 1999). This composition can in turn act upon the level of light that reaches the forest floor to influence the community structure of lower standing foliage, providing a diverse range of benefits to the community. Overall, the fragmented ecological remnants of kahikatea forests can provide major opportunities for indigenous biodiversity conservation, while the differing ecological conditions within the stands themselves can support a myriad of mutualistic interactions.

2.5 Carbon Sequestration

Allometric equations are a common method of estimating the biomass of a forest stand based on the biophysical parameters of the species present (Kebede & Soromessa, 2018). They have the potential to improve our understanding of carbon sequestration in woody vegetation, which is critical in the fight to mitigate the effects of human-induced climate change (Marden et al., 2018). Species-specific allometric equations have been developed for indigenous tree species in New Zealand, including for kahikatea (Beets et al., 2012). Beets et al (2012) also highlight the importance of including live tree density in allometric equations, especially with native tree species which have such diverse types of wood. The specificity of their equation which considers the wood density of kahikatea is likely to give more accurate estimates than a general mixed species equation. Paul (2021) used a C-Change model (Beets et al., 1999) which incorporates knowledge of stem growth, mortality, and decay to predict stem volume over time and hence predict carbon stocks. This was applied to a forest restoration project in Southland and the sequestration potential of several native species (including kahikatea) was estimated.

3. Methods

3.1 Spatial Analysis

Site data with either co-ordinates or addresses (to be geocoded) were sourced from Matiu Prebble, Antony Shadbolt, and various crowdsourced observations. These were converted into excel files for upload to the ArcMap Pro platform, where point data were edited to display locations of kahikatea throughout the city. The buffer tool was then applied to create overlap of stands at different radii. With these maps produced it was easier to visualise the spatial distribution of kahikatea across the city. With this visualisation it was easier to see which areas are sufficient or lacking in coverage for kahikatea stands.

3.2 Planting Guide

Information for the planting guide has been synthesised from various sources of secondary data and peer-reviewed literature to provide an in-depth understanding of the optimal way for a restored kahikatea forest to be planted.

3.3 Carbon Sequestration

Data from mature forest at Riccarton Bush was collected by Mark, Ollie, and Mischa Belton and was provided to us by Matiu Prebble for investigation. This data contained information relating to the features of the trees present at Riccarton Bush which is a well-preserved remnant of old-growth kahikatea forest. We were able to use this data and apply it to equation 2 created by Beets et al (2012), using the species-specific *a* parameter for kahikatea (Beets et al., 2012).

Equation 2 is the formula for estimating carbon stocks in a forest:

$$Y = aX^{b}$$

Where parameters are:

- Y = stem and branch carbon (kg/tree)
- a = 0.0105 (specific to kahikatea density)
- X = DBH^2*H (cm^2*m)
- b = 0.936

Using this formula, the carbon stocks of all trees (which data was available for) at Riccarton Bush were estimated, as well as the carbon stocks of all kahikatea at Riccarton Bush. It has previously been estimated that newly planted stands of kahikatea at 1000 stems per hectare have an annual sequestration rate of approximately 2.6 tonnes of carbon per hectare (Paul, 2021). This study estimated both the above-ground biomass and the total biomass (including that in the roots). We applied this to the stands at Cranford Basin which have been planted at 1.2-1.5 m spacings meaning there are up to 6,500 trees per hectare. Simply converting the carbon estimate of 1000 stems per hectare to a site planted at 6,500 stems per hectare gave us our estimate for annual sequestration at Cranford Basin. For the optimal spatial arrangement of 3 m separation that we have proposed, a similar conversion factor has been applied to the trees. Three metre spacing would provide space for 1,111 stems of kahikatea per hectare. A simple conversion from the 1000 trees estimate gave us our estimate for the carbon sequestration of kahikatea planted at optimal distances.

4. Results and Discussion

4.1 Map of Kahikatea Sites across Christchurch

The two maps we have constructed show all the locations across the city in which there have been kahikatea plantings or public observations (see Figure 1 below). There will be some exceptions such as individual trees on private property, but all the significant plantings and mature stands are accounted for. When originally given the project, our community partner mentioned that dispersal of plants and wildlife becomes increasingly limited between large forest fragments that are spaced any more than 5 km apart. These barriers can be ameliorated by adding stepping-stone refuge patches at 1 km intervals between these. The 2.5 km buffer zones (in figure 2) assist in visualising which areas of the city have adequate kahikatea forest concentration, and which areas may need more plantings to fill the gaps.

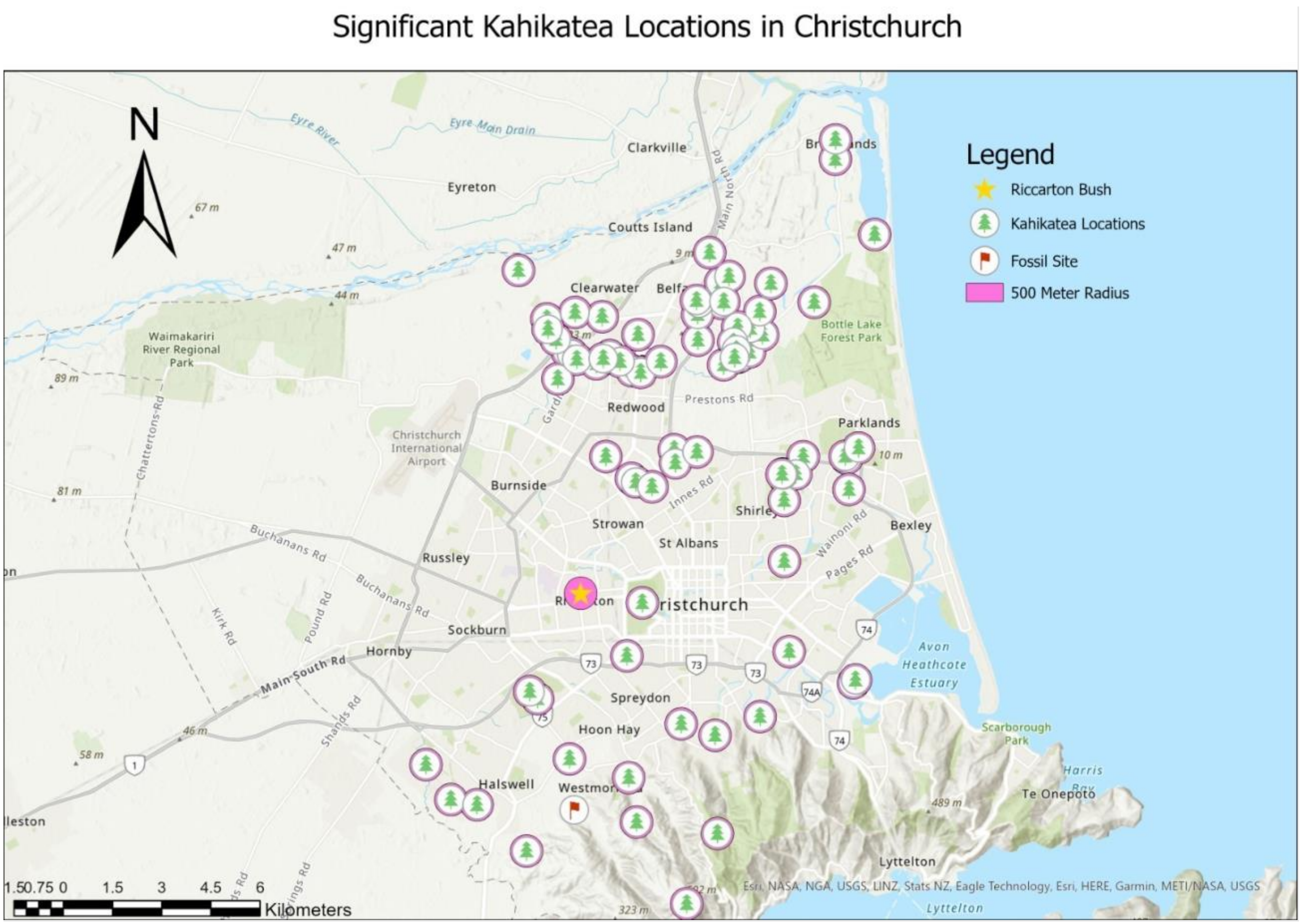

Figure 1: Spatial distribution of kahikatea across Christchurch with a 500 m radius around each site. Overlapping buffer zones (pink) indicate that sites are within 1 km of each other.

Figure 2 below shows that the vast majority of mature and newly planted kahikatea are clustered in the northern end of the city, while there appears to be a lack of stands in the west. Aside from some small sites in the south-west corner, the most western site is Riccarton Bush. Since Riccarton bush is the oldest and healthiest stand in Christchurch, having more sites nearby will complement the corridor effect in connecting this substantial urban forest fragment to any smaller patches yet to be planted on the city margin. This can be seen by the absence of overlapping 2.5 km buffer zones, where sites are too inhibited by fragmentation for natural dispersal mechanisms.

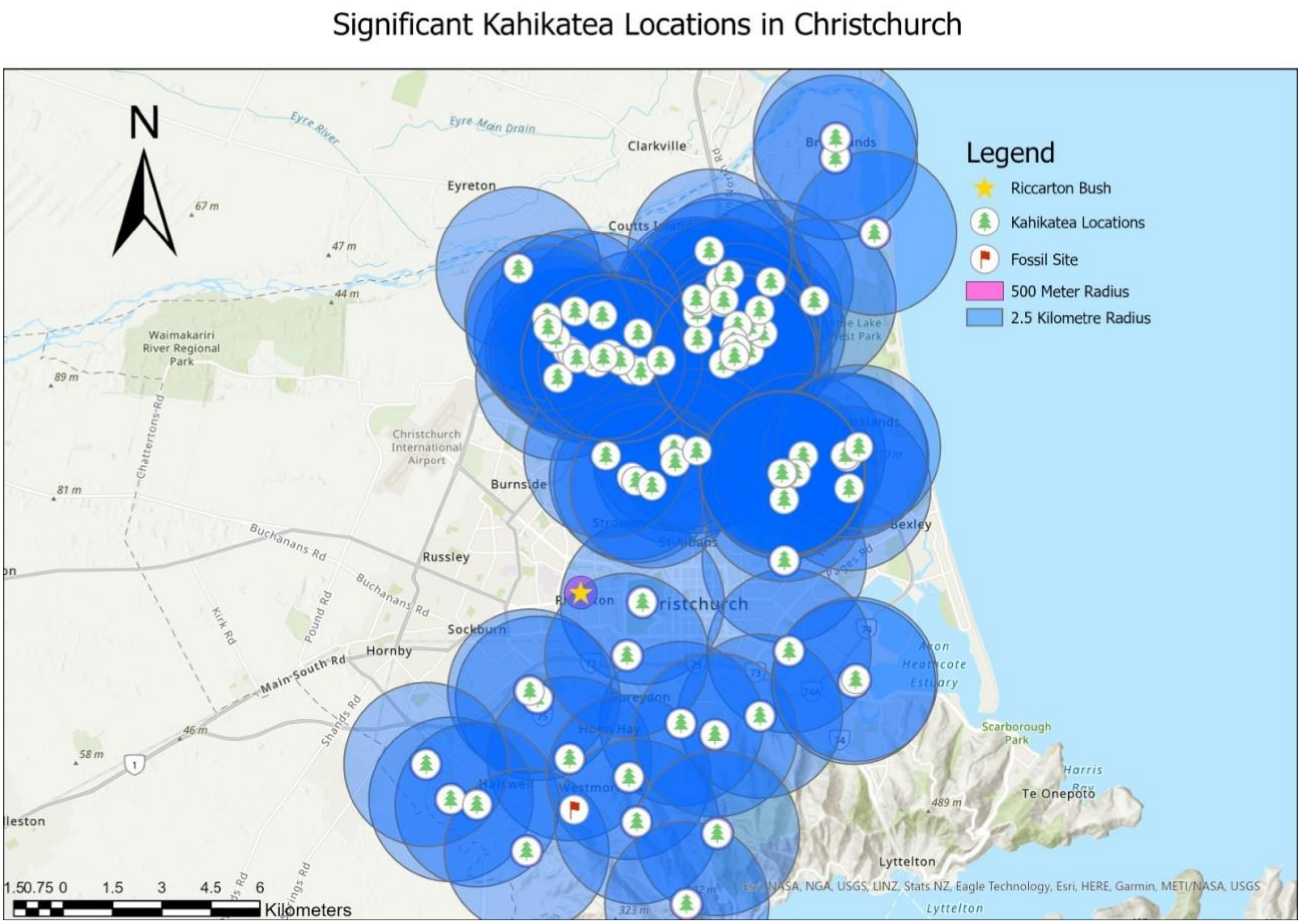

Figure 2: Spatial distribution of kahikatea across Christchurch with a 2.5 km radius around each site. Overlapping buffer zones (blue) indicate that sites are within 5 km of each other.

From the spatial analysis on forest patch arrangement at a city scale, we discovered that there is a clear deficit of kahikatea in the western parts of the city compared to the clustered distribution in the northern, eastern, and southern parts of the city. Filling these western coverage gaps is necessary to provide sufficient and reachable habitat for native bird species and allow safe travel between stands throughout the city in an all-encompassing seed distribution system. Within the stands, the optimal distribution of trees being planted was found to be approximately three metres. When planted in monoculture, a smaller planting distance may be used (as seen at Cranford Basin); however, this does not allow room for positive interactions with other plant species and the impact of intensive intraspecific competition. To lessen the mortality of individual kahikatea and increase biodiversity health of new stands, it is proposed that a wider distance between plantings be adopted. Although fewer kahikatea stems would feature in each stand, we predict that these plantings will see higher survivability.

4.2 Planting Guide

A successional co-planting strategy would see that 'Stage 1' plantings include the first nurse species to establish forest structure, initiate soil-conditioning processes, and provide a bit more shelter for 'Stage 2' plantings (second year; see Table 1 below). Kahikatea are light-demanding but fairly robust trees so could be among some of the first to be planted; however, then they would not reap the benefits of improved soil condition nor protection from wind, frost, or grazer-related injury. For these reasons, withholding the slightly older/larger seedlings from nurseries until the second or third year of plantings may be advantageous as they could see accelerated growth by being incorporated directly into an already hospitable environment, while their extra height should keep them from being shaded out by any 'Stage 1' trees or shrubs. 'Stage 3' species tend to be understory plants which are more sensitive to micro-climate and therefore selective of stable, humid conditions (Wallace & Clarkson, 2019). Introducing these second/third successional enrichment plants 20+ years down the track (following canopy closure) would complement any recruitment limitations of the now mature-phase forest. While the below species are all known to suit a wet plains ecosystem type, it is still important to consider their optimal niche within a given planting site (Lucas Associates Ltd, 2011; see Tolerances below).

Table 1: A small selection of native flora from a variety of plant guilds we propose as either pioneer, nurse, or enrichment species for the enhanced growth of neighboring kahikatea. Tolerances are scaled by colour: green = tolerant/required, yellow = semi-tolerant, red = intolerant.

Succession	Native Co-Planting Species	Plant Guild	Bird Supplement	Tolerances
Stage 1	*Cordyline australis* Tī kouka / cabbage tree	Tall tree	Fruit, nectar, insects	Sun, Wet, Dry, Wind, Shade
	Plagianthus regius Manatu / lowland ribbonwood	Tall tree	Insects, foliage	Sun, Wind, Shade, Wet, Dry
	Coprosma propinqua Mikimiki	Shrub	Fruit, lizard fruit	Sun, Wet, Dry, Wind, Shade
	Carex secta / virgata Pukio / swamp sedge	Grass	Seed	Sun, Wet, Wind, Shade, Dry
	Phormium tenax Harakeke / NZ flax	Herb	Nectar, lizard fruit	Sun, Wet, Dry, Wind, Shade
Stage 2	*Dacrycarpus Dacrydioides* Kahikatea / white pine	Tall tree	Fruit	Sun, Wet, Wind, Shade, Dry
	Pseudopanax crassifolius Horoeka / lancewood	Tall tree	Fruit, foliage, nectar, insects	Sun, Dry, Wind, Shade, Wet
	Sophora microphylla Kowhai	Tall tree	Nectar, foliage	Sun, Dry, Wind, Shade, Wet
	Aristotelia serrata Makomako / wineberry	Shrub	Fruit, insect, foliage	Sun, Shade, Wet, Dry, Wind
	Pseudowintera colorata Horopito / peppertree	Small tree	Fruit, nectar, insects	Sun, Shade, Wet, Wind, Dry
Stage 3	*Melicytus ramiflorus* Mahoe / whiteywood	Small tree	Fruit, insects	Shade, Sun, Wet, Dry, Wind
	Hedycarya arborea Porokaiwhiri / pigeonwood	Small tree	Fruit, insects	Shade, Wet, Sun, Dry, Wind, Frost
	Carex solandri Forest sedge	Grass	Seed	Sun, Shade, Wind, Wet, Dry
	Dicksonia fibrosa Whekī-ponga / golden fern	Tree fern	-	Shade, Wet, Sun, Dry, Wind, Frost

Note. Adapted from *Christchurch Ōtautahi Indigenous Ecosystems* by Lucas Associates Ltd (2011).

Regarding the wider literature, our results were aligned with the findings of previous research papers concerning kahikatea development/restoration. Based on research into various locations including areas in Westland and the North Island, patterns of ecological succession, and species diversity were reaffirmed to be essential. They influence the health of an ecosystem through providing direct and indirect benefits across trophic levels. These benefits range from shelter to genetic protection against diseases. Thus, our findings are of interest to the community groups in providing updated data around carbon sequestration, patterns of ecological processes and common successional species in an area which can help them make decisions around various aspects of restoration efforts.

4.3 Carbon Sequestration

From literature-sourced equations and estimations, we were able to compare the carbon sequestration stocks at Riccarton Bush (Table 2) with the sequestering potential of newly planted stands (Table 3).

Table 2: Estimates of the carbon stocks at Riccarton Bush.

Sample Group and Stem Densities	Total carbon stocks ($t.CO_2$)	Total carbon stocks ($t.CO_2$; average per hectare)	Median carbon stocks per tree ($t.CO_2$)
Kahikatea trees at Riccarton Bush	231.65	29.70	0.43
All trees at Riccarton Bush (that we have data on)	250.03	32.05	0.40

Table 3: Estimates of the annual sequestration ($t.CO_2/ha/yr$) of kahikatea plantings over a period of 80 years and the final stocks at 80 years.

Kahikatea Stem Densities	Mean total annual sequestration rate over 80 years ($t.CO_2/ha/yr$)	Above-ground carbon stocks at age 80 years ($t.CO_2/ha$)	Total carbon stocks at age 80 years ($t.CO_2/ha$)
1000 stems/ha (Paul, 2021)	2.60	173.90	210.50
6,500 stems/ha (Cranford Basin)	16.90	1,130.35	1,368.25
1,111 stems/ha (our proposed optimal spacing)	2.89	193.20	233.89

Based on the average annual carbon sequestration which has been estimated for Cranford Basin, the 10-ha planting at the site would sequester 169 $t.CO_2/ha/yr$ on average over a period of 80 years. This is assuming that all trees are spaced at 1.3-1.5 m, and all survive to maturity. However, carbon sequestered per hectare by kahikatea at Riccarton Bush (Table 2) is much lower than the estimations of newly planted stands after a period of 80 years. Kahikatea at Riccarton Bush are planted at around 5 m spacings and would therefore be stocking a smaller amount per hectare than trees planted at higher densities, assuming that these trees are growing at the same rate. However, the differences are more significant than what would be expected when comparing to conversion estimates from Paul (2021) (Table 3). If we were using the estimate conversion from Paul (2021), kahikatea planted at 5 m spacings would have an above-ground carbon stock of 69.56 $t.CO_2/ha$

after 80 years. The stocks in kahikatea at Riccarton Bush are less than half of this estimate, suggesting that Paul (2021) may overestimate the carbon stocks in a forest. This has implications in terms of estimating the carbon stock of forests in Canterbury. The most accurate measurements are likely to come from data collected and applied to the species-specific equations (or mixed species equation when looking at a forest as a whole) provided by Beets et al. (2012).

4.4 Assumptions

One assumption of this research was that Riccarton Bush is a good example of a mature kahikatea forest. Potentially there are some issues with this due to human alterations to the stand. It was also assumed that the fossil record of the kahikatea stumps in Hoon Hay is accurate and a good representation of the forest that used to exist there.

Assumptions have also been made to estimate carbon stores which need to be acknowledged because they could give rise to potential issues, leading to slight inaccuracies. The estimation of carbon stocks at Riccarton Bush come from applying our data to Beets et al. (2012) equation 2. This equation estimates only above ground biomass (stem and branch carbon) and therefore carbon stocks are likely to be higher when roots are included, particularly for kahikatea which have extensive root systems.

The 1000 stems estimate (Paul, 2021) for newly planted stands takes both above and below ground biomass into account. However, further assumptions have been made when converting this to be applied to both the sequestration potential at existing plantings at Cranford Basin, as well as potential future plantings for which we have recommended an optimal spatial layout. The estimates assume that the survival rate at the different densities is equal, however, it is likely that intraspecific competition will play a role, particularly in the more densely planted Cranford Basin. This means that the potential carbon sequestration in this stand is likely to have been overestimated. Conversely, the sequestration potential for new stands planted at the recommended optimal layout is likely to have been underestimated. This is particularly the case when considering other species recommended to be planted alongside kahikatea, which will have their own carbon sequestration potential and increase the overall potential of the stand.

4.5 Project Limitations

Conflicting schedules meant that the initial site visit was pushed back until the semester break and then postponed due to Christchurch entering a month-long Level 4 lockdown. This delay meant that we were unable to discuss the project in depth with T4C until mid-September, and therefore could not gather data ourselves. Simply due to the lack of time remaining, primary measurements of biomass, spatial layout, and biological data became unattainable. We relied heavily on data collected and reported on by others, which limits the applicability and accuracy of our own research. To improve this, measurements for these parameters should be taken at various established kahikatea sites in Christchurch and other regions to make applicative statistical inferences. These measurements should be taken and analysed with reliable technology such as an Abney level (Vijayalaxmi, 2021) to measure the height of trees for biomass estimates. These give accurate results for a parameter which is difficult to measure physically but is needed for biomass equations.

Using drones, airborne LiDAR data could also be used to determine the distancing between kahikatea stems and improve knowledge on spatial layout.

5. Conclusion

Our central research question, "How Existing Lowland Kahikatea Stands Can Inform Future Restorative Plantings" has been answered through the detailed analysis of the geographic distribution of already established stands, the ecological processes underlying the environmental conditions, and the carbon sequestration potential of mature forests and newly planted stands. The information gathered around the current conditions of the plantings by a range of literature as well as our own efforts across Canterbury and elsewhere we consider sufficient to inform future restoration.

Future research should be done to calculate the biomass of kahikatea stands throughout the country to assess how the levels change with the age of the stand. This would give more accurate annual carbon sequestration estimates which could be included into future equations for long-term biomass estimates. T4C should monitor their stands using a framework to assess success and use the results to inform their plantings and maintenance of the kahikatea forests. Further research should be done to assess the soil needs for a juvenile kahikatea forest and what other plants should exist in the stand to optimise its growth and ecosystem services.

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