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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 Ricure6o-5(o)4(be24(a)-Bu(t)-h 3.6 2dJET46h3[00912 i3 0 1-3c0 1-3cTk0 Gb Tm0 G[(in)5(Q0.000

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

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.

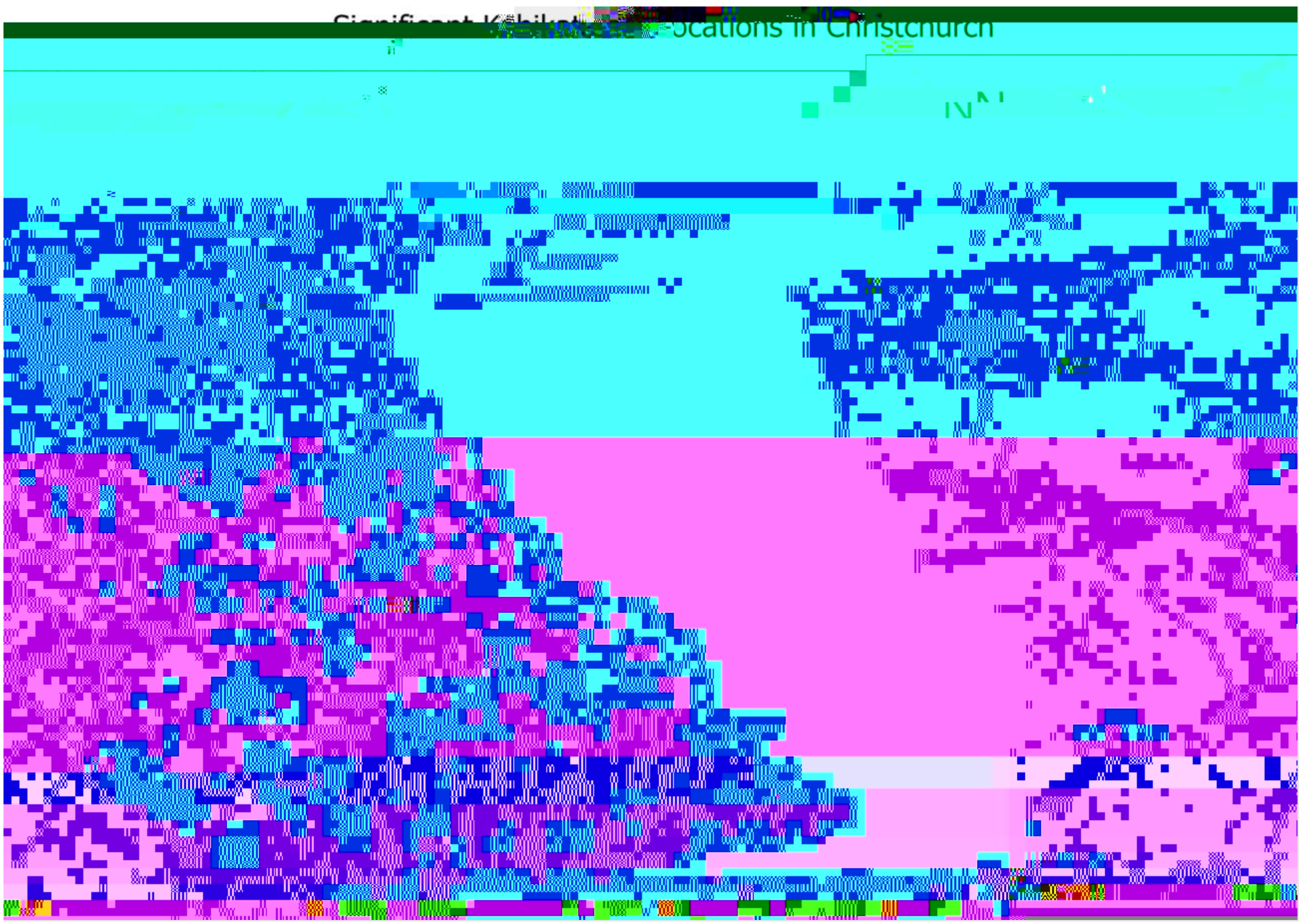

Figure 1: Spatial distribution of kahikatea across Christchurch with a 500 m radius around each site. Overlapping buffer zones (pink) indicate that sites are within 1 km of each other.

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.

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	

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

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

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