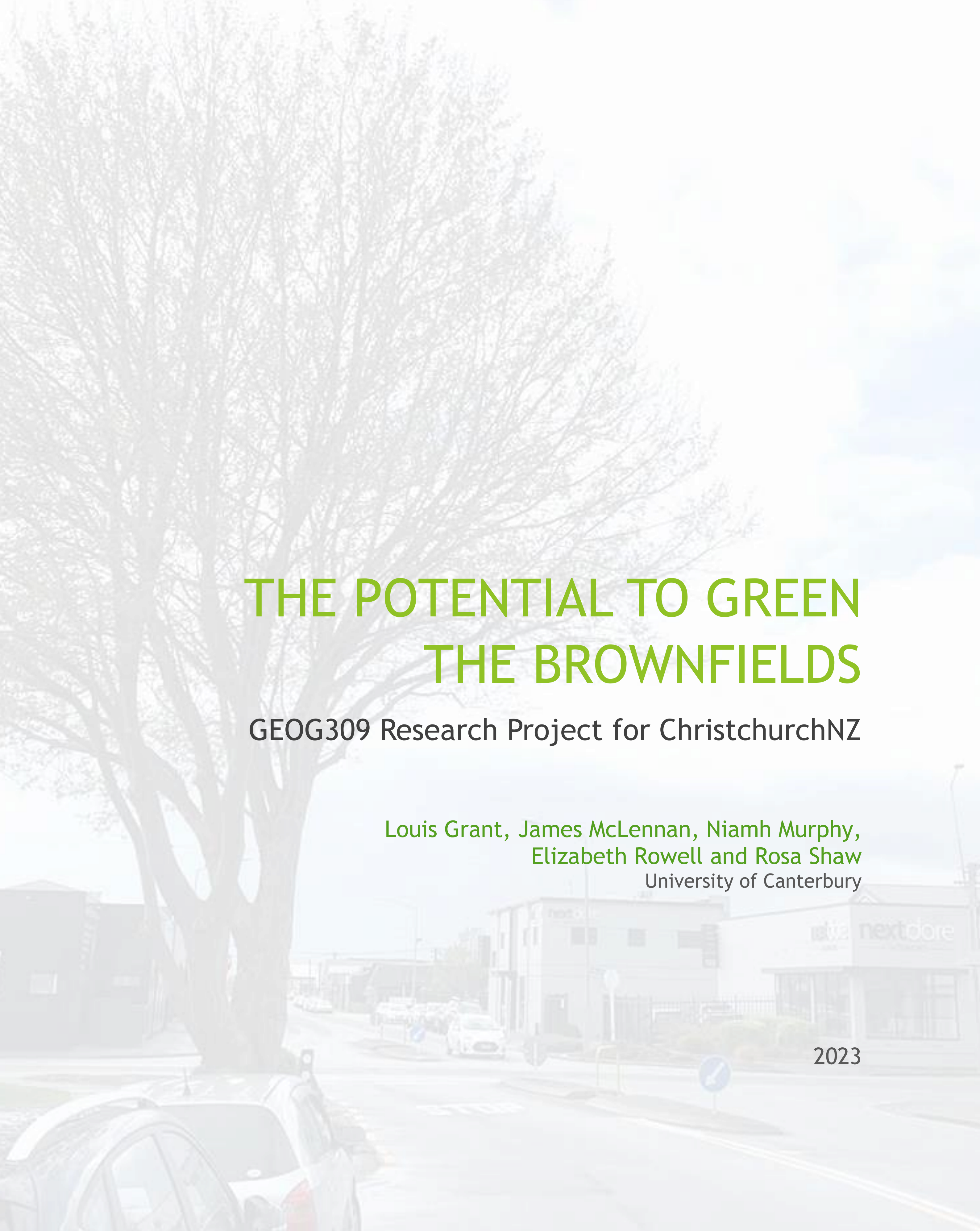

THE POTENTIAL TO GREEN THE BROWNFIELDS

GEOG309 Research Project for ChristchurchNZ

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2023

Contents

1. Executive summary

- ChristchurchNZ is proposing the redevelopment of Sydenham and Waltham, post-industrial brownfield areas in central Ōtautahi. Their vision is to create high-density residential areas, with a goal of increasing urban green space and achieving a 30% tree canopy target.

- Due to the land-use history and nature of brownfields, there may be soil contamination present, complicating redevelopment and greening goals by limiting options for tree species survival.

- This research project investigated the options available by considering the research question, "Which tree species are appropriate for urban greening and increasing canopy coverage in the Sydenham and Waltham industrial area?"

- A literature review informed the early stages of research across five sub-themes: heavy metal contamination, urban greening, ecological restoration, urban redevelopment and climate resilience.

- A range of research methods were employed, including spatial analysis of land cover and existing tree species in the study area, expert interviews, and systematic literature searching of contaminant-tolerant tree species.

- The results identify a list of trees which are most likely to be resistant to heavy metal soil contaminants and may therefore thrive in and enhance the urban environment. These trees will be presented to ChristchurchNZ and future developers as a customised and comprehensive tree species index to help achieve the tree canopy and urban greening goals in Sydenham and Waltham.

2. Introduction

The redevelopment of urban brownfields – former industrial areas – has received growing interest from city planners as a strategic priority for achieving sustainable land resource use. Often advantageously positioned in central-city locations and supported by existing infrastructure (Loures, 2015), brownfields offer a resource for urban regeneration as an alternative to consuming new greenfield land (Loures et al., 2016). Accordingly, brownfield redevelopment helps to densify cities, reducing population growth pressures and avoiding the costs associated with urban sprawl, such as natural resource deterioration, extension of infrastructure and increased travel (Ameller et al., 2020). However, redeveloping brownfields into residential areas can be complicated by the prospect of soil contamination, limiting the options for the planting of trees and other greening features.

ChristchurchNZ, the economic and urban development agency for Ōtautahi Christchurch, is looking into the potential regeneration of the industrial area of Sydenham and Waltham (**Figure 1**) for future high-density housing of up to six storeys. Though currently lacking in local services and amenities, the site's proximity to the city centre and major retail, health, education, recreation and entertainment facilities could make it attractive for future residents (Christchurch City Council, 2012). Regeneration plans for the site include aims for significant urban greening, in particular a 30% tree canopy cover. This target supports the Christchurch City Council's Urban Forest Plan (Christchurch City Council, 2023a), as well as the Proposed Plan Change 14 – Housing and Business Choice, which introduces a new requirement for a 20% tree canopy cover on residential development sites and a 15% canopy cover in new road corridors on brownfield residential subdivisions (Christchurch City Council, 2023b). This research project supports this target by seeking to investigate and inform ChristchurchNZ on the options available for the planting of street trees and gardens where there may be soil contamination.

***Figure 1**: Map showing the study area and its location within the wider Christchurch region.*

3. Site context and land-use history

The 2.5km^2 site is underlain by laterally and vertically variable soils, comprising fluvial and estuarine deposits of silt, sand and gravel (Pattle Delamore Partners, 2022a). The particular soil types within the area are Taitapu 21, a gley, poorly-drained loamy soil, and Kaiapoi 17, a recent, loamy soil with imperfect drainage (Landcare Research, 2023) (**Figure 2**). The site has a high water table, ranging in depth between 0-2m in Sydenham and 1-3m in Waltham (Pattle Delamore Partners, 2022a).

***Figure 2**: Map showing soil drainage across the site and the two soil types of Taitapu 21 (poorly drained) and Kaiapoi 17 (imperfectly drained). Data source: S-map Online (Landcare Research, 2023).*

Prior to modification by Europeans, the area was covered by grass, flax and cabbage trees (Canterbury Maps and partners, 2022), and connected to a vast network of waterways and swamps which formed part of the catchments of the rivers Ōpāwaho and Ōtākaro. These environments were sources of mahinga kai for Māori, as well as important transport links (Blundell, 2014; Hobbs et al., 2022). Through the 1860s and 1870s, the site was transformed by rapid subdivision and grew into the railway town of Sydenham, located immediately south of Christchurch City (Morrison, 1948). As industry became concentrated along the southern railway corridor (Christchurch City Council, 2005), Sydenham developed into a major manufacturing hub of factories, railway workshops, malt houses, flour mills, agricultural manufacturing and leather works (Morrison, 1948). The site remained partly residential until further industrial expansion during the 1960s and 1970s pushed most residents out of the area north of Brougham St. Minimal industrial sprawl continued until the 2010/2011 Canterbury earthquakes (Pattle Delamore Partners, 2022a), which resulted in a significant loss of buildings in Sydenham (Christchurch City Council, 2012). The site has retained an strong industrial landscape, largely concreted and dominated by warehouses, carparks and vehicles (Budgett and Bogunovich, 2014).

Based on the Ministry for the Environment's hazardous activities and industries list (HAIL) framework, Pattle Delamore Partners have assessed the potential for soil contamination from historic and current industry in Sydenham and Waltham. The contaminants likely to be present are identified as heavy metals (such as arsenic, cadmium, chromium, copper, lead, mercury, nickel, and zinc), alongside petrochemicals (petrol, diesel, heating and lubricating oils) as well as potentially asbestos as a result of building demolishment (Pattle Delamore Partners, 2022b).

4. Literature review

4.1 Heavy metal contamination

Heavy metals are nonbiodegradable and pose a major hazard to human health, through exposure pathways including dermal contact, inhalation and ingestion (El-Zeiny and Abd El-Hamid, 2022). Depending on exposure, health impacts can include acute symptoms such as diarrhoea, fever and vomiting; chronic effects such as lung cancer and kidney, respiratory, and cardiovascular damage; neurotoxicity/brain damage; and death (Nwaichi and Dhankher, 2016; El-Zeiny and Abd El-Hamid, 2022).

A plethora of remediation methods exist for heavy-metal contamination, including in situ (on-site) methods, such as caps/barriers and phytoremediation – the use of plants to uptake contaminants from the soil. Ex-situ methods involve removal and treatment off-site; these include soil replacement and washing (Chen et al., 2016). While in-situ techniques are typically lower cost and reduce the risk of secondary contamination and ecological disturbance, their remediation efficiency is often lower. Conversely, ex-situ techniques have higher remediation efficiency for a greater variety of contaminants, but incur high costs (Williams, 2006).

4.2 Urban greening

Urban trees provide a number of ecosystem services – benefits that people derive from the presence of nature within the urban environment (Zhong et al., 2020). These include trees' ability to reduce the urban heat island effect by lowering surface and ambient temperatures through shading and evapotranspiration (Morakinyo et al., 2017), sequester CO_2 through photosynthesis (Lin et al., 2018) and reduce stormwater runoff via canopy interception of rainfall and transpiration (Pataki et al., 2021). Trees additionally enhance aesthetics, beautify neighbourhoods and promote human physical and psychological wellbeing (Konijnendijk, 2023).

4.3 Ecological restoration

The Urban Forest Plan emphasises the prioritisation of indigenous and diverse plantings in order to restore ecosystems and bolster canopy resilience to evolving climates, as well as consideration of species' air quality and carbon sequestration potential (Christchurch City Council, 2023). Native flora face many challenges within urban settings, namely altered light exposure, temperature shifts, and soil compaction which hampers root proliferation and drainage. However, a combination of soil ripping to alleviate compaction accompanied by dense planting may foster deeper root growth, while mulch application and sparser planting can expediate plant growth. As weeds can quickly overtake plantings of trees with soil lying exposed, competing for sunlight, nutrients and water, consistent weeding has been found to greatly improve the growth rate and root proliferation of tree plantings (Sullivan et al, 2009).

4.4 Urban redevelopment

With increasing evidence that a compact urban form is more sustainable, cities are prioritising intensification above expansion, often by building more high-density housing and repurposing underused space (Pelczynski and Tomkowicz, 2019). Although in New Zealand a strong preference for stand-alone, private dwellings persists (Gjerde and Kiddle, 2022), the recognised benefits of high-density housing include proximity to amenities, reduced car-dependency, greater social opportunities, and affordability (Haarhoff et al., 2016). In brownfield regeneration, higher landscape quality can increase the liveability and attractiveness of the area to residents (Ruelle et al., 2013); however, common barriers are financial cost (Martinat et al., 2016) along with developers' prioritisation of profits over implementing sustainable and "green" infrastructure (Singh et al., 2022).

4.5 Climate resilience

Poorly-planned urban intensification can lead to increased carbon emissions, stormwater run-off, and heat island effects (Christchurch City Council, 2022). Literature identifies qualities that improve urban resilience to climate-related hazards as extensive integration of green space, infrastructure for active transport and policies towards lower carbon emissions. Barriers to this are financial cost and lack of knowledge (Center for Climate and Energy Solutions, 2019). Several studies promote alignment of the United Nations Sustainable Development Goals (Sanchez Rodriguez et al., 2018), identifying active transport (Macmillan, et al., 2020) and other low-carbon commuting options as beneficial to communities' climate resilience (Howden-Chapman et al., 2019).

5. Methods

To gain a greater understanding of topics relevant to the project, experts in various fields were consulted. Two methods of data collection were used: a series of informal, semi-structured interviews were conducted with ecologist Dr Colin Meurk and geographers Prof Simon Kingham and Dr Lindsey Conrow, alongside email-correspondence interviews with urban forestry expert Dr Justin Morgenroth and Stephanie Koviessen, a hydrogeologist from Environment Canterbury with expertise in land contamination.

A random-point sampling method was used to assess land cover within the study area, classifying it into the following classes: tree, shrub, soil or grass, building and impervious surface. The random sample was generated using i-Tree Canopy, a free-use software tool developed by the USDA Forest Service (i-Tree, 2023), in which Google Earth aerial photography was interpreted at random points within shapefile boundaries of the study area. A sample size of 1000 random points was used, as cover percentage stabilises between 600-1000 points (Jacobs and Mikhailovich, 2013, as cited in Jacobs et al., 2014). A map of soil and grass-covered areas across the site, where trees could potentially be planted, was made by digitising these features from aerial photography.

Data on existing tree species on the site were obtained from the "Tree" dataset in the city council's Spatial Open Data Portal, which catalogues trees that fall within the territorial local authority of Christchurch, their geographic coordinates, and attributes of interest (Christchurch City Council, 2023c). The coordinates were used to create a map of the trees. Trees with a service status of "Removed" or "Stump" were removed from the data.

A systematic literature search was conducted to compile an index of trees found to be tolerant of heavy metal soil contaminants or capable of phytoremediation in existing peer-reviewed research. Search terms containing keywords of heavy metals, tree genera and botanical names were searched in the Google Scholar database. Identified species were cross-referenced with the council's *Tree Planting Guide Species List,* a dataset cataloguing, as of July 2023, 1,255 tree species that may be considered appropriate to plant in Christchurch, and attributes including height and preferred soil type (Christchurch City Council, 2023d). Species were also checked against the Christchurch District Plan's minimum mature height requirement of 8m for street trees (Christchurch City Council, n.d.). The selection process for inclusion and exclusion of tree species in the index is shown in **Figure 3**.

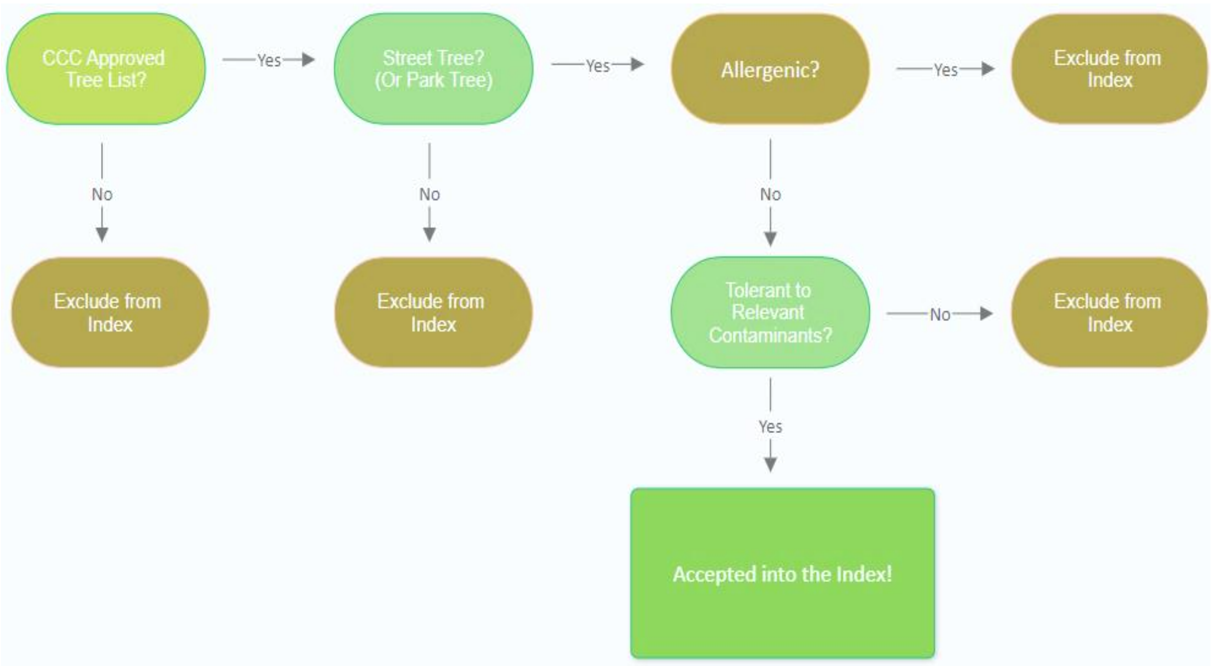


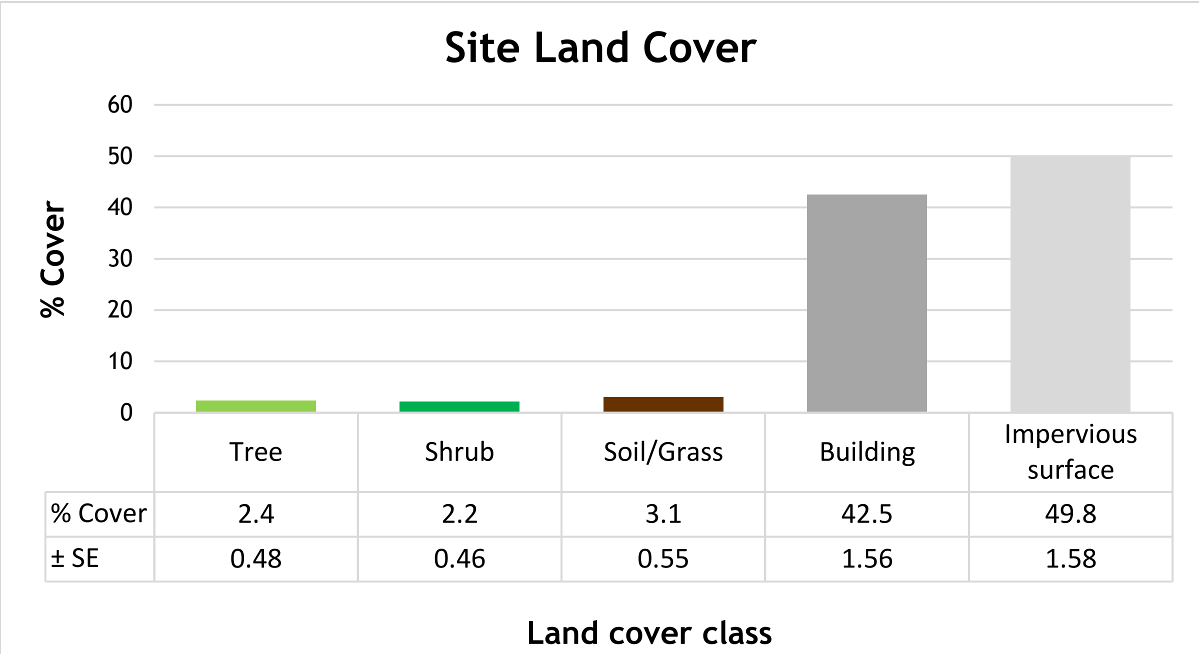
***Figure 3**: Flow chart demonstrating the selection process for the trees species index*

A list of native trees suitable for the specific soil types of the site and a list of potential soil remediation options were compiled using information from relevant literature.

6. Results

6.1 Site assessment

The results of the land cover assessment show that cover on the site is more than 90% impervious surfaces and buildings, with a tree canopy coverage of approximately 2.4% and shrub cover of 2.2%. Soil and grass-covered areas constitute approximately 3.1% of the total land cover (**Figure 4**). **Figure 5** shows the locations of soil and grass-covered areas across the site where trees could potentially be planted without requiring concrete removal.



	Tree	Shrub	Soil/Grass	Building	Impervious surface
% Cover	2.4	2.2	3.1	42.5	49.8
± SE	0.48	0.46	0.55	1.56	1.58

***Figure 4**: Bar graph and table of land cover statistics for the site estimated by random-point sampling, displaying cover percentage and standard error (SE).*

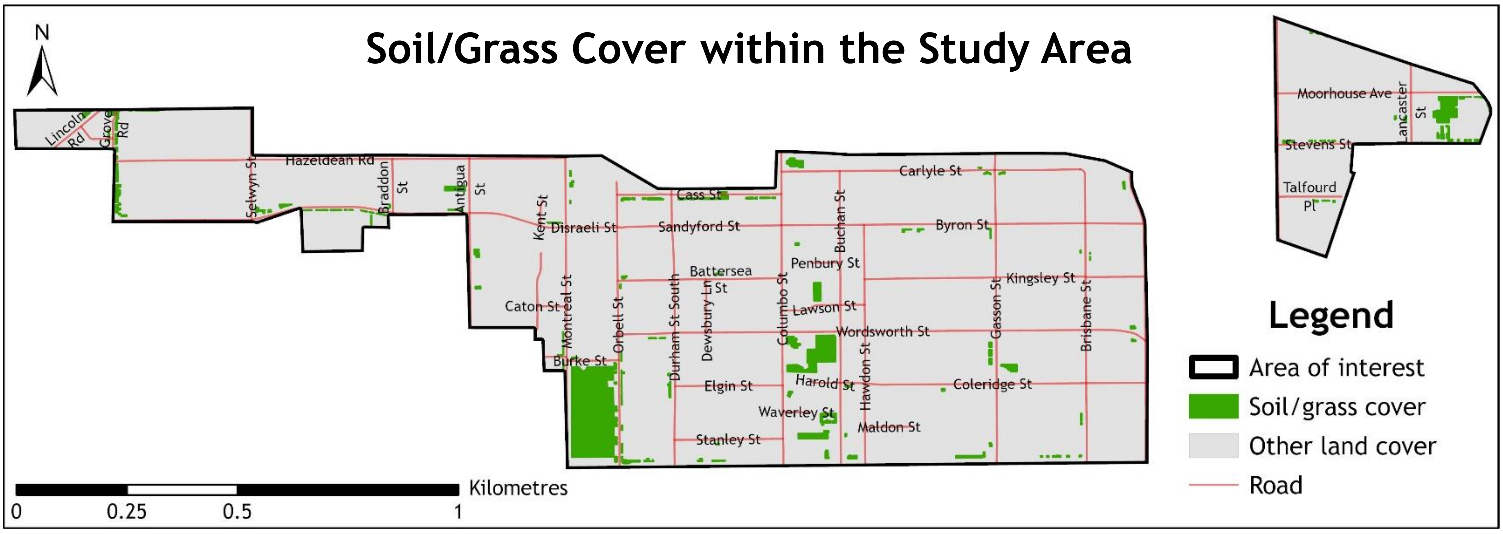


***Figure 5**: Map of the site showing locations of soil and grass land cover. Road centrelines data sourced from Land Information New Zealand (2023).*

The largest area of soil or grass cover was identified as a vacant plot at 32 Burke St, between Montreal and Orbell St (**Figure 6**). Approximately 20,853m^2 in area, this site was previously a textile manufacturing complex (Pattle Delamore Partners, 2011) and now contains a mix of debris from demolished buildings and topsoil (Site Solutions Ltd., 2014). Two other significant areas of grass cover were identified as Buchan Playground, a park on the corner of Wordsworth St and Buchan St (**Figure 7**), and a large empty plot at 574 Moorhouse Ave (**Figure 8**).

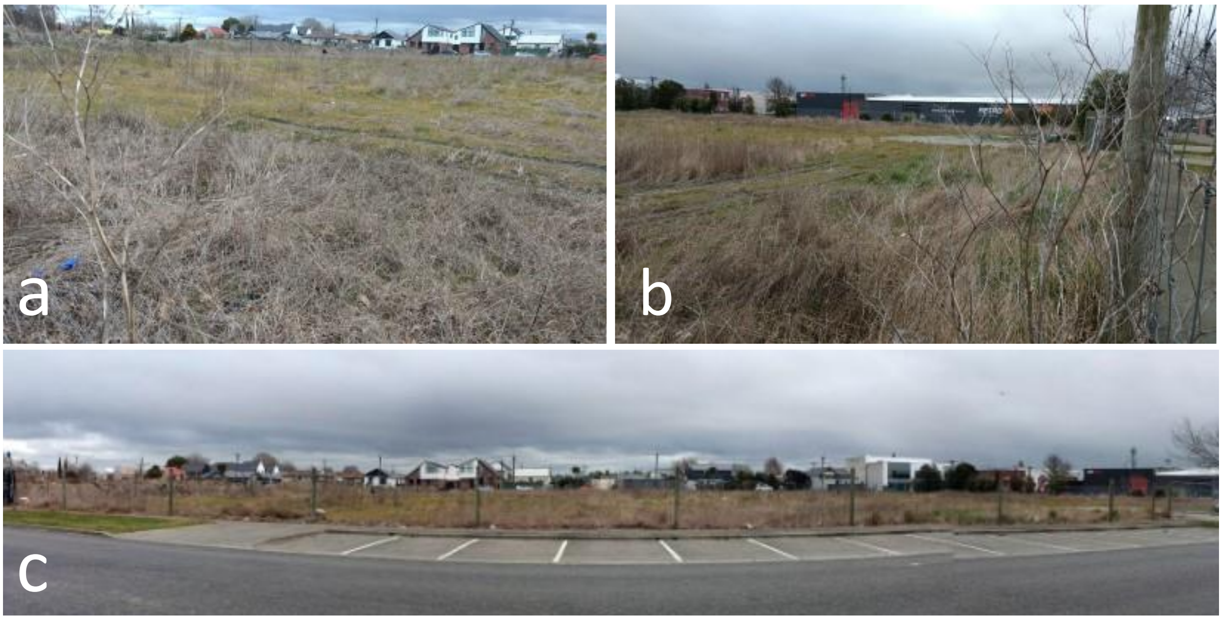


***Figure 6**: Vacant plot at 32 Burke St, photographed from Orbell St facing **a)** south-west, **b)** north-west and **c)** west.*

***Figure 7**: Buchan Playground on the corner of Wordsworth St and Buchan St.*

***Figure 8**: Vacant plot at 574 Moorhouse Ave.*

Figure 9 shows the location, species and crown spread of current trees present on the site. The cluster of trees in the lower centre of the map are mostly contained inside Buchan Playground, containing among others Pin oak, alder, elm and kōwhai trees.

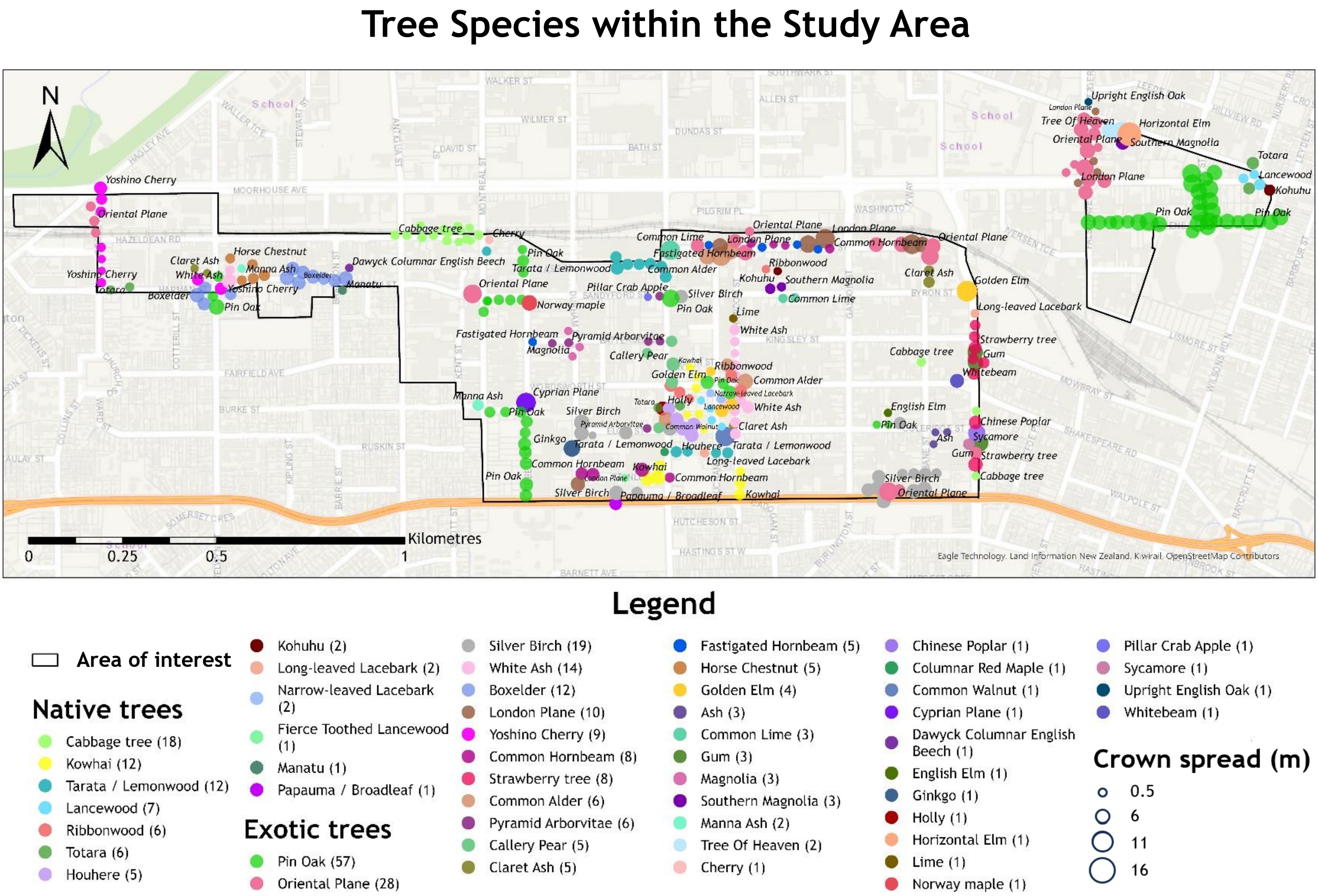


__Figure 9__: Map of current tree species' locations within the area of interest, showing crown spread (the average diameter of individual trees' crowns) with native and exotic species ordered by count. Data sourced from the Christchurch City Council Spatial Open Data Portal https://opendata-christchurchcity.hub.arcgis.com/

6.2 Tree species selection

The tree species selection index (**Table 1**) lists trees tolerant to heavy metal contamination.

Table 1*: List of tree species tolerant of heavy metals, either by exclusion or accumulation.*

Botanical Name	Common Name	Heavy metal tolerance: Excluder or Accumulator*	Soil Type	Height	Suitable for street
Acer cappadocicum	**Cappadocian Maple**	Pb*[1]	Chalk, clay, loam, sand. Prefers moist conditions	10-18m	Yes
Acer platanoides	**Norway Maple**	Cu*, Pb*, Zn*[2]	Chalk, clay, loam, sand. Prefers moist but well drained	12-15m	Yes
Acer rubrum	**Red Maple**	Ni, Zn[3]	Chalk, Clay, Loam, Sand. Prefers moist conditions	12-21m	Yes
Aesculus hippocastanum	**Horsechestnut**	Cu, Zn[4]	Clay, loam, and sand. Prefers moist but well drained	15-21m	Yes
Carpinus betulus	**Hornbeam**	Ni*[5], Hg*[6]	Loamy, or sandy soil	12-18m	Yes
Dodonaea viscosa	**Hop Bush**	Zn*, Cu*, Cd*, Fe, Pb, Zn[7]	Clay, Loam, and Sand.	Up to 8m	Yes
Fraxinus ornus	**Flowering Ash**	Ca*[8]	Clay, loam, chalk, sand. Prefers moist conditions	10-15m	Yes
Koelreuteria paniculata	**Goldenrain Tree**	Mn[9]	Sandy, loamy, and clay soils. Tolerates dry or moist soil.	9-12m	Yes

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Table 1 *(Continued)*

Magnolia grandiflora	**Bull Bay**	Pb, Cd[10]	Chalk, clay, loam, and sand. Prefers moist conditions.	18-24m	Yes
Platanus acerifolia	**London Plane Tree**	Cu*[11]	Chalk, clay, loam, and sand. Medium to wet conditions suitable.	20-30m	Yes
Platanus orientalis	**Oriental Plane Tree**	Pb, Cd, Cr[12]	Clay, sand, loamy soil. Tolerates dry, moist, wet conditions.	30-35m	Yes
Platycladus orientalis	**Oriental Arborvitae**	Pb, Cd[13]	Chalky, clay, loamy, sandy. Prefers moist but well-drained	9-12m	No (Park tree)
Populus lasiocarpa	**Chinese Necklace Poplar**	Zn*, Cu*, Cd*[14]	Clay, sand, loamy soil. Moist to wet conditions.	10-15m	No (Park tree)
Quercus acutissima	**Sawtooth Oak**	Cd[15]	Loamy, clay, and heavy clay soil. Prefers moist conditions	15-20m	Yes
Quercus ilex	**Holly Oak**	Pb, Cd, Zn[16]	Chalk, clay, loam, and sand.	12-21m	Yes (Park tree)
Quercus phellos	**Willow Oak**	Zn[17]	Medium textured, silty or loamy	15-20m	Yes (Park tree)
Quercus rubra	**Red Oak**	Ni[18]	Loamy, clay, and heavy clay soil. Prefers moist soil	15-20m	Yes
Ulmus pumila	**Siberian Elm**	Cd*, Pb*[19]	Prefers loams, but tolerant of sands and clay.	15-21m	Yes

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The native trees table (**Table 2**) provides information on the native tree species suitable for the area based on soil type.

***Table 2**: List of native trees suitable for soil types of the site, made with information adapted from Lucas Associates Ltd. (2011) and Greenwood (1951).*

Botanical Name	Common Name	Soil moisture tolerance	Ideal soil type	Biodiversity benefits
Cordyline australis	**Tī kōuka (cabbage tree)**	Tolerant to both wet and dry	Taitapu 21, Kaiapoi 17	Fruit for birds and insects, nectar
Dacrycarpus dacrydioides	**Kahikatea (White Pine)**	Prefers wet/ swampy areas	Taitapu 21	Fruit for birds
Elaeocarpus dentatus	**Hīnau**	Somewhat tolerant to both wet and dry	Kaiapoi 17	Fruit for birds and insects
Nothofagus fusca	**Tawhai raunui (Red Beech)**	Prefers well drained, not waterlogged	Kaiapoi 17	Honeydew for bees and birds
Plagianthus regius	**Mānatu (Ribbonwood)**	Somewhat both, free draining (not waterlogged)	Kaiapoi 17	Fruit for insects, bud/foliage
Podocarpus totara	**Tōtara**	Prefers dry, well drained	Kaiapoi 17	Fruit for birds
Prumnopitys taxifolia	**Mataī (Black Pine)**	Prefers wet, tolerates dry	Taitapu 21, Kaiapoi 17	Fruit for birds
Sophora (genus)	**Kōwhai**	Prefers dry, well drained	Kaiapoi 17	Nectar, bud/foliage

6.3 Soil remediation options

Potential soil remediation options and their advantages and disadvantages are listed in **Table 3**.

Table 3*: List of soil remediation methods and their advantages and disadvantages, made with information adapted from Chen et al. (2016), Khalid et al. (2017), and Evanko and Dzombak (1997).*

Remediation Method	Description	Advantages	Disadvantages
Caps and Barriers (horizontal and vertical)	Physical barriers to contain contaminated material	• One of the cheapest options • Widely applicable to heavy metal contaminants • Barriers help to prevent contaminant migration	• Soil resources being covered and unproductive • Breaches in caps and barriers are expected over time
Soil Replacement	Replacing or partly replacing contaminated soil by non-contaminated soil, to dilute/ eliminate present contaminants	• Maintains the productivity of the land • Simple to implement, and effective	• New soil can be costly (especially productive topsoil) • Transport and landfill costs can be very expensive
Solidification and Stabilization	Stabilization decreases the solubility and mobility of heavy metals through chemical additives. Solidification, converts contaminated soil into inert solids, to contain the contamination.	• Can be applied to wide range of contamination • Relatively inexpensive • Contamination kept onsite, conserving landfill space and associated transportation costs	• Risk of leaching over time • Solidified material may restrict site use
Vitrification	Use of electricity to heat contaminated soil hot enough (1300–1500°C) to produce a molten liquid that can be cooled into an inert glass product, storing the contamination long-term.	• Can be very effective	• Very expensive in comparison to other methods available • Is not a usable method for all contaminants (e.g. mercury contamination)
Soil Washing	Use of reagents and a mechanical soil mixing process to separate out soil from contaminants.	• Very high effectiveness • Generally considered cost effective	• Still relatively expensive with cheaper alternatives available • Lower effectiveness for soils with multiple sources of contamination (e.g. multiple heavy metals).
Electrokinetics	Remediation using an electric current and electrodes setup.	• Can be very effective	• Cost of remediating increases for soils with higher electrical conductivities • Soil conditions dictate whether the method can be used • It is an expensive technique
Phytoremediation	Using plants to remediate contaminated soils	• One of the cheapest methods • Reduces soil erosion • Aesthetic benefits	• Much less effective than other methods • Contamination must be shallow for plant root systems to access • Remediation takes longer to achieve (years not months)

7. Discussion

7.1 Tree species suitability

There are a number of otherwise useful tree species that are excluded from the city council's list of approved trees, for reasons ranging from invasiveness, poor suitability for Christchurch's climate, to disease susceptibility and hybridisation risk. For example, Willow (*Salix*) trees have demonstrated a high effectiveness for phytoremediation by accumulating a wide range of heavy metals (Labrecque et al., 2020), but are not recommended for Christchurch due to being weedy and commonly invasive (Christchurch City Council, 2023d). Similarly, Black poplar (*Populus nigra*) is also known for high accumulation of some heavy metals (Biró and Takács, 2007) but is not recommended due to large amounts of allergenic pollen released (Christchurch City Council, 2023d). Meanwhile, English oak (*Quercus robar*) trees, which are suitable as street trees, can be a hazard on contaminated land because they are deciduous and take up significant levels of heavy metals into their leaves rather than woody parts, causing a risk of recontamination when the leaves fall (Placek et al., 2016; Stojnić et al., 2019).

7.2 Maximising the benefits of urban trees

7.2.1 Thermal regulation

With average maximum temperatures in Christchurch projected to increase by up to 3-4°C by the end of this century due to climate change (Christchurch City Council, 2023a), trees will become increasingly important for their direct cooling effects. The most significant factors in positive microclimate effects of individual trees are leaf area index and canopy area, followed by canopy shape (Sansusi et al., 2016). At the street scale, cooling effects are a function of canopy coverage level (Pataki et al., 2021) and planting density, more so than individual tree species characteristics (Shashua-Bar et al., 2010). Cooling effects are highly localised, particularly from shade, and therefore regular distribution of trees throughout the urban area is important (Coutts et al., 2013), as this has a greater areal cooling effect compared to large or aggregated, but isolated, trees (Bao et al., 2016).

Strategic placement of trees around streets and buildings can also maximise thermal benefits. Streets aligned in an east-west direction receive greater sunlight exposure throughout the day than do north-south oriented streets, which experience shading from buildings during mornings and afternoons (Thorn et al., 2016). Wider, more open roads with lower height-to-width ratios are also exposed to more solar radiation than narrower, sheltered streets, causing greater heat stress (Norton et al., 2015). Therefore, east-west and wide streets should be prioritised in efforts to increase tree canopy coverage for shading benefits. Furthermore, southern sides of east-west streets and the eastern sides of north-south oriented streets should be targeted for planting (Coutts and Tapper, 2017), as in the Southern Hemisphere, north-facing walls are exposed to the greatest solar radiation throughout the day while west-facing walls are exposed to more sunlight at the peak daytime heating period (Thorn et al., 2016).

In addition to enhancing thermal comfort during summer by providing shade, deciduous trees allow sunlight to filter through during winter months (Perini et al., 2018), which can be important for preventing hazardous icy road conditions (Qing and Ying, 2011), as well as providing passive solar heating during winter to save building energy use (Huang et al., 2015).

7.2.2 Carbon sequestration

The attributes of trees which possess the greatest carbon sequestration ability include having a large diameter at breast height and being evergreen (Weissert et al., 2017). Unlike deciduous trees, evergreen species have a capability to sequester CO_2 year-round (Gratani, 2020) and therefore could play an important role during the autumn and winter months when urban emissions of CO_2 are elevated due to increased fossil fuel combustion (Mitchell et al., 2018).

7.2.3 Biodiversity

For promoting biodiversity, the cultivation of indigenous plants is essential, as they furnish fruit and habitat for native insects and birds (Christchurch City Council, 2023a). An important concept gathered from our discussion with Colin Meurk was the differentiation between species richness and biodiversity; while Christchurch may have a diverse urban canopy, exotic tree species tend to be present in much greater numbers than natives. Thus, while species richness is high, biodiversity is poor. He also emphasised that visible species such as birds gain attention while insects – just as important for biodiversity – are often forgotten. Many native insects have adapted to survive exclusively on native plant species (C. Meurk, personal communication, September 8, 2023).

Although native birds will feed on some exotic trees such as English Oak and Sycamore in comparable amounts as on indigenous trees (Gray and van Heezik, 2015), the predominance of exotic, often deciduous trees in Christchurch means there can be food shortages for native birds during winter months. With the exception of kōwhai, native trees aren't classified as suitable for streets in the council's list (Christchurch City Council, 2023d), and therefore indigenous plantings should be prioritised in off-street spaces. High-density and medium-rise buildings in Sydenham and Waltham will save space to allow for greater integration of urban green space, offering opportunities to create core sanctuary habitat for wildlife (Ignatieva et al., 2008).

7.2.4 Human wellbeing

Trees could play a significant role in the design of an urban environment for Sydenham and Waltham to be both attractive to residents and conducive to wellbeing. In the absence of private gardens, visible street trees can provide nature experiences to residents of high-density housing (Cox et al., 2019) and greater amounts of neighbourhood trees and gardens may improve residential satisfaction (Buys and Miller, 2012). Further, the positive physical and psychological health impacts of trees may be enhanced by urban green space design that takes human preferences into account; people generally perceive deciduous and densely-leafed trees with high crown-size-to-trunk-height ratios as the most attractive (Gerstenberg and Hofmann, 2016). Meanwhile, reduced temperature and ambient light levels by evergreen trees during winter may have negative impacts on health, such as increasing Seasonal Affective Disorder (de Vries et al., 2013; Salmond et al., 2016).

The greening of brownfield land also presents opportunities to reconfigure underused landscapes to serve new functions, such as transport links for pedestrians and cyclists (Sanches and Mesquita

Pellegrino, 2016). Interconnected lines of trees that follow roads and corridors through a city can afford relatively higher amounts of natural shading and align cool areas with space for active travel (Rakoto et al., 2021); urban greening can further encourage and improve active travel by increasing the attractiveness of environments, fostering social connectivity, and bettering air quality (Ta et al., 2021). On-street trees and greenery are particularly important, as walking and cycling behaviours are influenced more by street settings than parks or residential environments (Lu et al., 2018, Rosenberg et al., 2010).

While an oft-cited disbenefit of street trees for transportation is vehicle crashes, the relationship between trees and accident rate and severity is dependent on the surrounding landscape. Along low-speed streets designed for multiple transport modes, trees can play a role in reducing crash incidence and severity by acting as traffic calming measures and clearly delineating footpaths from roadways (Eisenman et al., 2021); separated lanes for active modes also improve users' safety perceptions (Lee et al., 2021; Gössling and McRae, 2022). However, street trees need to be effectively managed to prevent obstructed views, buckled pavements and littered surfaces, as these factors can pose safety hazards to drivers, cyclists and pedestrians (Eisenman et al., 2021).

7.3 Other green interventions

In spaces where room for tree growth is limited (eg. by above or underground infrastructure) or specific land use or soil conditions prevent the planting of trees, climbing plants over structures can be used as an alternative for greening. Green roofs and walls can improve building energy efficiency by cooling; however, their capacity for regulating human thermal comfort at the street level is limited as they do not provide shade (Coutts and Tapper, 2017).

If the land is found to be too contaminated for tree planting, metal hyper-accumulating non-tree flora could instead be used for phytoremediation, such as sunflower (*Helianthus annuus*), as they are more widely studied and generally more effective. Other remediation methods might also be possible depending on the contaminants present, although financial cost may be a barrier. Green infrastructure such as rain gardens and bioswales, while useful for filtering contaminants via runoff, removing pollutants before they enter streams or groundwater (Prudencio and Null, 2018), act to contain and concentrate heavy metals rather than remove the problem (Evans et al., 2019).

8. Limitations

A major limitation for this project was the uncertainty around locations and concentrations of soil contaminants in the study area. The HAIL framework bases potential land contamination on previous land use, grouping similar industries together that may use or store hazardous substances. Classification is based on the likely contaminants that could enter the environment through use, and whether these substances escaped from safe storage or were disposed of onsite (Ministry for the Environment, 2021). As the HAIL list is based on potential contamination, rather than precise soil testing results, the classification of contaminated land in the study area is not yet confirmed. The lack of clarity around contaminant levels across the site has acted as a research limitation, and a barrier for tailoring tree species and greening methods to specific contaminants and concentrations.

There are also a number of limitations in our research methods and data. While our random sample was of a recommended number of points, our land cover/tree canopy estimation includes some level of uncertainty, as do all canopy estimation techniques (Richardson and Moskal, 2014). Although the map of existing trees on the site is comprehensive of species variety, not every tree present was recorded in the data source. We made a number of site visits to physically locate and identify trees on the site before becoming aware of the council's tree dataset; however, this primary data collection was excluded from results for reasons including: our inability to accurately and reliably identify trees due to many being on private property and timing of the research when deciduous species were not in leaf; our lack of knowledge and skills to assess the health and size of trees; and constraints on the time that would be required to geocode every tree.

The tree species selection index was limited to a focus on only heavy metal contaminants, due to a paucity of studies on petrochemical-tolerant trees. While asbestos is also a potential contaminant in the redevelopment area, as it does not bioaccumulate and may have little effect on plant growth (Gonneau et al., 2017) it does not pose an issue for tree species selection. The tree species index was further limited by a current lack of available research on New Zealand native trees' tolerance to soil contaminants and their potential for phytoremediation, and so contains only exotic trees. The differing units and experimental conditions used in different studies limit comparison of the phytoremediation and tolerance levels of the different species in the index. It should also be noted that the presence of other contaminants alongside the target contaminant can have a significant negative effect on plant uptake of a given heavy metal, or in other cases can have little to no effect on phytoremediation ability (Mleczek et al., 2022). It was also found in the literature that even in "tolerant" plants, soil contaminants can reduce species' height and biomass despite no change in survival and or ability to germinate (Pajević et al., 2016). These factors emphasise that more research is needed to better understand co-contaminant interactions with species and research for a greater number of species of relevance, including natives.

9. Conclusion

The tree index produced may provide a guide for ChristchurchNZ and future developers to achieve tree canopy targets and create environmentally resilient and attractive residential areas on former industrial land in Sydenham and Waltham. When redevelopment of the area commences, most sites will require investigation into contaminant concentrations. Combining the contaminant information obtained through soil testing with the tree planting guide that we have produced may allow for tree species to be tailored to contaminant types across the site. Besides contamination tolerance, tree species selection and placement should consider species' other attributes to best provide ecosystem services, including thermal regulation, air and water quality, facilitation of biodiversity, and promotion of resident wellbeing. Areas for future research could include investigation into how indigenous flora and fauna may be better accommodated in urban settings.

Acknowledgements

We would like to acknowledge and thank our community partner, Adele Radburnd, and our supervisor, Karen Banwell, for their help on this project. We are very grateful to our expert interviewees, Colin Meurk, Simon Kingham, Lindsey Conrow, Justin Morgenroth and Stephanie Koviessen, for their time and knowledge. We also thank Gorden Jiang for technical advice. Special thanks to Simon Kingham for constructive feedback which greatly improved the presentation of our findings.

Photography

Louis Grant and Elizabeth Rowell

Title page photo

Oriental Plane tree on Disraeli St

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