# **Prioritising ecological restoration sites and strategies in Hamilton City, New Zealand**

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## Abstract

Urban ecological restoration faces distinct challenges due to the highly modified biophysical conditions that characterise cities. To overcome these difficulties and assist in decision-making, ecological principles should underpin comprehensive analyses at both the landscape and site-specific scale. With increasing recognition of the role that the environment plays in social and economic prosperity, there are a growing number of strategies focused on increasing native habitat in urban centres. This thesis presents three integrated studies in support of Hamilton City Council's goal under the *Nature in the City Strategy* to increase indigenous vegetation cover from about 1.8% to a minimum of 10% by 2050. Landform and ecological unit representativeness analyses in the city reveal the extent of under-represented environments, but it also presents opportunities to improve this criterion rapidly. Then, a multicriteria ecological prioritisation tool specifically developed for Hamilton City identified the most ecologically intact sites that could support the selection of potential gully and reserve restoration sites following the *Nature in the City Strategy*. Finally, at the site-specific scale, assessments of the vegetation composition and structure of three kahikatea forest remnants determined appropriate restoration strategies that may guide restoration projects in other cities.

Landform and ecological unit areas in Hamilton City that would need to be restored to meet ecological representativeness thresholds under the 10% goal are presented. The peatlands, alluvial plains and hills landform and their respective ecological units are severely under-represented, while the gullies are sufficiently represented. However, gullies tend to contain more micro-environments and diversity than the other landforms, so restoring them may provide greater biodiversity rewards. Compared to previous representativeness studies of Hamilton City, this assessment provides more refined information available on a geographic information system (GIS) and highlights opportunities for its rapid improvement. For example, adequately representing some of the most under-represented ecological units, such as peat domes, would require the least restoration effort by extent (14 hectares (ha)). While improving representativeness could enhance the city's pool of indigenous species, this study demonstrated that it should not be used alone to prioritise restoration sites in highly modified urban environments. Rather, representativeness could be included in a wider range of criteria and more appropriately employed for regional or national strategies.

About 198 ha of Hamilton City is dominated by native vegetation, requiring the restoration of 886 ha or approximately 32 ha annually from 2023 to achieve the 10% goal by 2050. A prioritisation tool specifically developed for the city comprising eight ecological criteria identified 873 gully and reserve sites with the most intact ecological integrity that satisfy this area. These sites were allocated into five prioritisation categories to support the adoption of a staged approach for this city-wide restoration project. Sites that received high ecological scores included sections within Hamilton Gardens, Hammond Park, Minogue Park, Kirikiriroa gully, the major riverside gully and Mangaonua gully. Most high-ranking sites were found in the city's east, although restoring sites on both sides of Hamilton City would enhance ecological connectivity on a regional scale. As the city expands, restoring large undeveloped areas would likely require fewer resources than restoring many dispersed isolated patches. Similarly, restoring whole systems, such as the high-ranking Kirikiriroa gully, is suggested to provide greater biodiversity rewards. Further application of this tool could incorporate social, economic and cultural criteria for a more holistic prioritisation of sites.

The condition of kahikatea (*Dacrycarpus dacrydioides*, white pine) forest remnants at Totara Park, Hillcrest Park and Grove Park was examined and compared with Te Papanui (Claudelands Bush/Jubilee Park) as the reference site to identify restoration strategies. Age structure analyses found that Hillcrest Park comprises the oldest kahikatea population with an average age of 82 years, followed by Grove Park (70 years), Te Papanui (60 years) and Totara Park (32 years). The Kahikatea Green Wheel, life form and epiphyte analyses highlighted the importance of Totara Park's high water table and sheltered conditions. While Te Papanui was found to support the most native vascular plants (64 species), Totara Park's conditions have contributed to its greater species richness (41 species) than Hillcrest Park (15 species) and Grove Park (eight species). More native epiphytes were also identified at Totara Park (nine) than Te Papanui (six), Hillcrest Park (one) and Grove Park (none). Epiphytes absent from Te Papanui found at Totara Park may be due to the loss of the once abundant *Dicksonia squarrosa* (whekī), a prominent host. Differences between the native vascular plants found at Te Papanui and the case studies signal gaps in characteristic species of kahikatea forest that could be filled by relevant planting at each site. While Totara Park's remnant requires a careful manipulation restoration strategy to gradually remove troublesome plants without disturbing its locally rare native flora, the ecological integrity of Hillcrest Park and Grove Park could improve most from buffer, ground cover and shrub tier plantings.

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# Chapter 1: Introduction

Ecological restoration is increasingly considered a pragmatic solution to many environmental issues caused by anthropogenic disturbance (Suding *et al.*, 2015; Benayas *et al.*, 2009 & De Groot *et al.*, 2013). A primary goal of ecological restoration is to return an ecosystem to its pre-disturbed condition, ultimately becoming self-sustaining in its functioning (Simenstad *et al.,* 2006). Besides improving ecological integrity, restoration provides a surplus of ecosystem services, which are the benefits people derive from ecosystems and are commonly categorised as regulating or provisioning services (Millennium Ecosystem Assessment, 2005). Regulating ecosystem services include crop pollination, water purification, improved air quality, flood regulation and reduced soil erosion. Provisioning ecosystem services include the supply of rongoā (medicinal plants), fresh water and food. Restoration also fosters educational opportunities and community involvement, enabling people to reconnect with nature. Recognition of these benefits has instigated a rise in the number of restoration projects globally (Busbridge *et al.*, 2021).

Urban ecological restoration presents novel challenges and opportunities because both stem from human activities (Standish *et al.*, 2013). Anthropogenic pressures intensify in densely populated urban centres, which can impede a sustainable co-existence between humans and nature. Reinstating ecological integrity in such highly modified, depauperate environments often requires the complete *reconstruction* of past ecosystems and their species assemblages (Choi, 2004; Clarkson *et al.*, 2018). In contrast to restoration, reconstruction refers to the active establishment and management of an ecosystem where few biotic features remain from its pre-disturbed state.

Urban restoration also provides a wealth of ecosystem services and the chance to expand traditional restoration goals. Greenspaces improve urban residents' health and connection with the environment and community (Klaus & Kiehl, 2021). The successful management of biodiversity is often dependent on the effective communication between local government, organisations and private landowners. Measurable goals like conserving existing biodiversity while increasing indigenous vegetation cover can be tracked and reviewed with consistent monitoring frameworks (Local Government New Zealand [LGNZ], 2020).

In Hamilton City, community-led ecological restoration projects predominantly focused on the intricate gully systems have contributed significantly to extant indigenous vegetation. For example, a restoration group facilitated the regeneration of locally uncommon *Syzygium maire* at Hammond Park. The return of *Prosthemadera novaeseelandiae* (tūī) may also be partially attributed to local restoration projects alongside Waikato Regional Council's (WRC) Hamilton Halo pest control efforts that began in 2009; tūī sightings rose from 34 in 2009 to more than 500 by 2013 (Fitzgerald *et al.*, 2021). Removing exotic species and planting natives has expanded the habitat of indigenous fauna and reduced forest edge effects, creating conditions conducive to native plant regeneration. Regular restoration activities occur at parks such as Waiwhakareke Natural Heritage Park, Donny Park, Hammond Park and Te Papanui and gullies like Mangaonua Esplanade and Mangaiti gully. While these projects have made remarkable progress, achieving Hamilton City Council's (HCC) goal under the *Nature in the City Strategy* to attain 10% indigenous vegetation cover by 2050 would require the inception of many more.

This chapter outlines the city's demography and boundary extensions before delving into its climate, geology, physiography, soils, and historical and current vegetation cover. It also outlines relevant national and local policy, including the Protected Natural Areas Programme (PNAP), the Resource Management Act (RMA), WRC's significant natural areas (SNAs) and HCC's *Nature in the City Strategy*. Finally, it presents the topic, objectives and research questions that have guided this thesis and an overview of its structure.

### 1.1 Geography

Hamilton City is located at the centre of the North Island, New Zealand. It is the fourth largest city, covering 11,000 hectares (ha) (Statistics New Zealand, 2018). With a population of about 170,000 occupying more than 58,000 residential properties, it has grown by 18.5% since 2006 (HCC, 2020a). Hamilton City's rising population fosters the rapid development of subdivisions, schools and health centres. Development projects place substantial pressure on the natural environment and signal the urgent need to protect and restore biodiversity in the city. Some consequences of densely populated communities include water and air pollution, habitat fragmentation and the urban heat island effect (Zipperer *et al.*, 2020). Urban development also threatens biodiversity through habitat loss, increased competition and predation from introduced species (Convention on Biological Diversity [CBD], 2013).

There have been three recent boundary extensions of Hamilton City between 2004 and 2011. In 2004 Temple View was transferred from the Waipa District to Hamilton City, extending the southwest boundary (Cornes *et al.*, 2012). Subsequently, in 2011, the city's boundary was expanded to include Te Rapa in the north and Ruakura in the southeast. The Te Rapa expansion comprised 240 ha, while the Ruakura extension added 730 ha, enlarging the city's area from 9,860 to 11,080 ha (Cornes *et al.*, 2012). The total area of Hamilton City is about 11,080 ha or 10,845 ha if all water bodies are excluded.

**1.2 Climate**

Global temperatures are predicted to increase by 1.5°C between 2030 and 2052 (Intergovernmental Panel on Climate Change [IPCC], 2018). This temperature rise will likely vary across scales, significantly impacting the planning and management of restoration projects. For example, Hamilton City may experience an annual mean temperature rise of 1.3°C by 2050 and 3.1°C by 2090 relative to 2014 (National Institute of Water and Atmospheric Research [NIWA], 2021). The city's mean annual precipitation is also expected to decline by 0.3% by 2050 (NIWA, 2021). Some examples of the impact of climate change on vegetation include seasonal and distribution shifts with increased mean temperatures, precipitation changes and an increased incidence of extreme weather events (Harris *et al.,* 2006).

Hamilton's climate is mild, with a mean annual temperature of about 14.6°C, a mean minimum temperature of 8.6°C in July and a mean maximum temperature of 18.8°C in February. The average annual precipitation is 1108.2 mm, the average minimum precipitation is 68.7 mm in February, and the maximum is 118.2 mm in July (Hall, 2020). There are an average of 52 frost days, with most occurring in July (Figure 1.1). The seasons in Hamilton are fairly stable, with warm, humid summers and mild winters. Climate change will likely have mild to moderate consequences for Hamilton City (Gasper & Blohm, 2011). Nevertheless, environmental pressures such as human population growth and associated pressures necessitate effective climate mitigation and adaptation strategies. For example, water shortages appear unlikely up until 2050, but on a regional scale, short-term scarcity may occur, increasing the demand and competition for water (Gasper & Blohm, 2011). Ecological restoration is a tangible climate action that enhances carbon sequestration through native plantings (Harris *et al.*, 2006). Native species generally sequester more carbon

(Waller *et al.*, 2020) and require less water than exotic plants, which alter community dynamics and often degrade ecosystem services and processes (Charles & Dukes, 2008).

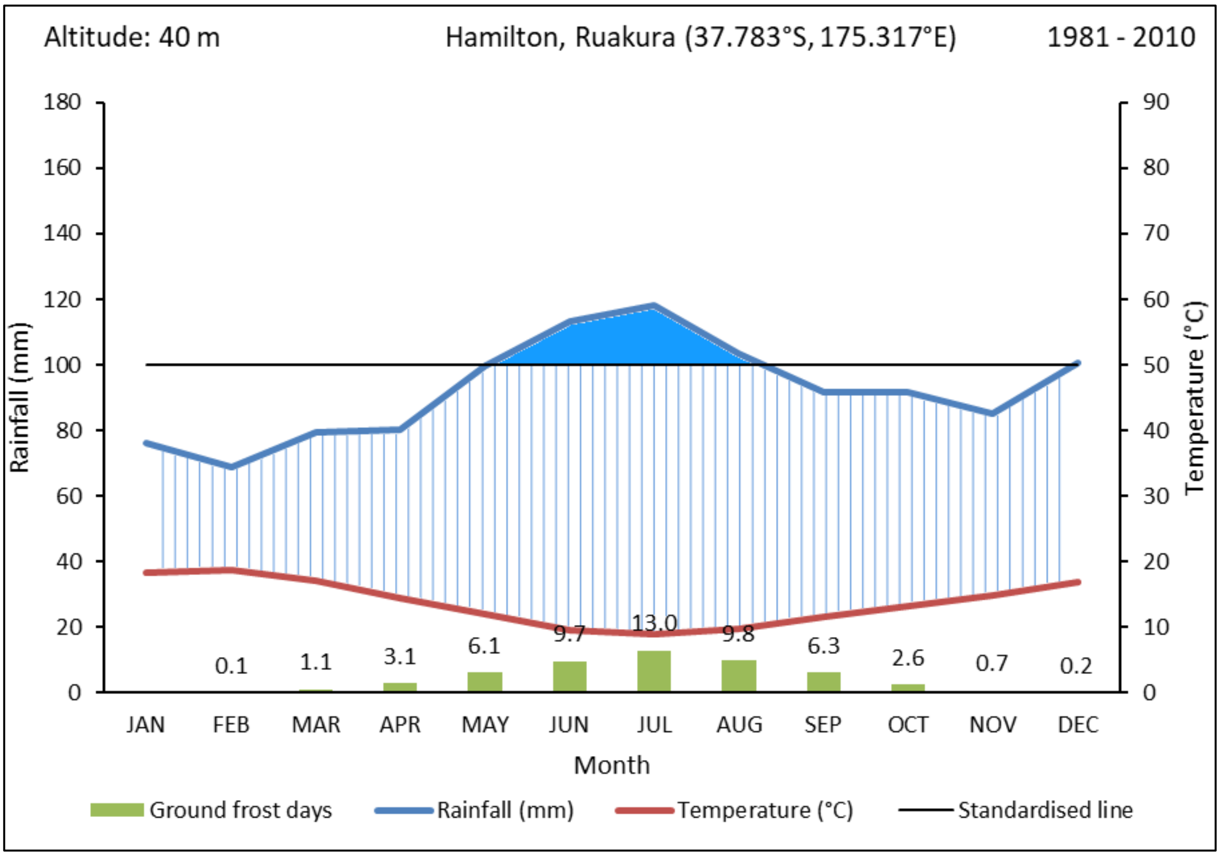


Figure 1.1: The climate of Hamilton City summarised with a Walter diagram (Hall, 2020). The red line represents the average monthly air temperature (°C), the blue line represents the average monthly rainfall in millimetres (mm), and the green bars represent the monthly average number of ground frost days (days with a recording of 0°C at ground level) using data from 1981-2010. The blue vertical lines indicate the wet season, where months receiving rainfall >100 mm are solid blue (Chappell, 2017).

Although Hamilton City's macroclimate is consistent, its microclimates present significant heterogeneity. Microclimate refers to the variation in climate at a small scale (Davies-Colley *et al.*, 2000). Differences between macro and microclimate are particularly evident where habitats include a vertical dimension of environmental gradients (Lembrechts *et al.*, 2019). Knowledge of the city's microclimates can contribute to information about the structure and functioning of vegetation for specific ecological units (De Frenne *et al.*, 2021). Variables commonly used to study microclimate consist of solar radiation, wind exposure, precipitation, temperature, humidity and soil moisture. For example, shade offers refuge to species such as *Beilschmiedia tawa*, cool sites with winter frosts host species such as *Dicksonia fibrosa*, and humid environments support ferns like *Leptopteris hymenophylloides* and epiphytes such as *Tmesipteris elongata*.

A prominent example of microclimate effects on vegetation composition is Hamilton's gullies. Higher soil moisture, more shelter from the sun and increased water availability in deep gullies support different species assemblages than gully slopes or crests. On clear nights, cold and dense air near the ground collects on the gully floors, where frost may persist longer than on gully slopes and crests. Conspicuous vegetation patterns occur along such temperature gradients (Wardle, 1991). For example, temperature-sensitive *Laurelia novae-zelandiae* and *Freycinetia banksii* are typically found on damp sites that are less exposed to frost. Species tolerant of occasional frosts and characteristic of Hamilton's gully floors include *Elaeocarpus hookerianus* and *Fuchsia excorticata*. In comparison, frost-intolerant plants on terrace scarps and gully sides may include *Ptisana salicina* and *Agathis australis* (Wardle, 1991). The careful selection of species suited to a site's microclimate can significantly contribute to the success of a restoration project. A comprehensive assessment of the effect of microclimates on vegetation structure and composition in Hamilton City was not within the scope of this thesis.

## 1.3 Geology

The geologic history of Hamilton Basin resulted in the distribution of ignimbrite and other volcanic material across the city and the formation of the Waikato River and surrounding hills (Cornes *et al.*, 2012). Hamilton's bedrock comprises greywacke that eroded to create a plain about 100 million years ago (mya) (Cornes *et al.*, 2012). Tephra deposits have also been identified across Hamilton City from the late Pleistocene and Holocene, predominantly originating from Okataina and Taupo Volcanic Centres (Lowe, 1981).

About 50 mya, the greywacke began sinking and warping, encouraging the formation of peat bogs. Around 30 mya, the sea level advanced above the land, depositing sandstone and compressing the peat into coal (McCraw, 2002). The asymmetrical movement of faults five mya created the rough topography that characterises the Hamilton Basin. More recently, about one to 0.1 mya, alluvium was deposited in Hamilton, forming a hill and valley landscape. The Hinuera Formation deposits filled in the previously hilly landscape of Hamilton, leaving only a few protruding hills from the previous landscape (Lowe, 2010).

Approximately 19 to 14 thousand years ago (kya), the Waikato River re-entered the Hamilton Basin, burying more hills to form the current landscape (McCraw, 2002).

The Waikato River is the most prominent physical and ecological feature of Hamilton City. It is the longest river in New Zealand, weaving through the city's centre, which splits it into east and west. The Waikato River's position endorses the progression of a major urban restoration goal to further incorporate green (terrestrial) and blue (aquatic) corridors around the city, improving connectivity between remaining indigenous fragments (Clarkson & Kirby, 2016). The four landforms are also significant physical characteristics of the city and include the hills, alluvial plains, peatlands, and gullies, with alluvial plains as the dominant landform.

**1.4 Soils**

Hamilton City's soils were formed by accumulation, pedogenic mixing and weathering processes (Lowe, 1981). The city is primarily composed of Horotiu soils that constitute tephra on coarse alluvium, forming the dominant, well-drained alluvial plains. The soil types range from deep organic peat (Kaipaki and Rukuhia soils) to mineral soils of the alluvial plains (Horotiu, Te Kowhia and Te Rapa soils), the porous river margin and lower terrace soils (Tamahere and Waikato soils) and thicker clay soils of the aged hills (Hamilton and Kainui soils) that bulge through the wash of alluvium. Inter-grades also exist amongst these soil categories.

The composition of the alluvial plains soils is complex, with alluvial deposits creating Horotiu soils on the levees from gravelly rhyolite with some tephritic alluvium. On the swales, Te Kowhai soils are developed on fine alluvium (Bruce, 1979). Conversely, the primary soils of peatlands include the poorly drained Rukuhia, Kaipaki and Te Rapa soils. Rukuhia soils form the deepest peat, Kaipaki soils indicate shallower peat, and Te Rapa peat soils are about 30 to 40 centimetres deep. The extensive peat bogs of Hamilton were once scattered on the Hinuera Surface. Around 13 kya, substantial peat bog formation began as the water table rose and rainfall increased (Lowe, 2010).

The hills comprise four broad soil categories: Rotokauri, Ohaupo, Hamilton, and Kainui soils. These soils were formed on highly weathered tephra (Bruce, 1979). Lastly, the gully soils comprise the Tamahere, Tamahana and Kirikiriroa classes. Alongside the Waikato River, the Tamahere series soils represent human-modified soils with thickened, charcoal-bearing topsoil. Early Māori added sand and gravel to these soils to create ideal kumara-growing conditions (Lowe, 2010). The low river terrace soils are poorly consolidated and have formed on the Taupo Pumice Alluvium (Bruce, 1979). The poorly drained Tamahana soils of the gully bottoms formed on the recent alluvial deposits, constituting grey moist silt loam and abundant organic matter. Finally, the Kirikiriroa soils dominate the gully sides and terrace scarps (Lowe, 2010). These soils have developed on rhyolitic material from tephra and the Hinuera Formation.

### 1.5 Historical and current vegetation

New Zealand is a biodiversity hotspot, with a significant proportion of vascular plant endemism (82%) at the species level (McGlone *et al.*, 2001). As a biocomplex parameter, vegetation is reflective of pollination vectors, climate, dispersal mechanisms and succession (Pickett *et al.*, 2011). Knowledge of vegetation composition before European settlement allows restoration project managers to direct sites towards their original, pre-disturbed condition. It also facilitates the selection of restoration practices in tune with natural processes such as succession. For example, ensuring that species are planted in a suitable location supports their establishment and growth and reduces the cost of projects. Decision-making based on scientific knowledge can save restoration projects considerable resources (Kentula, 2000).

Before the arrival of humans, the Waikato region was dominated by tall indigenous forest species such as *Phyllocladus trichomanoides* and *Agathis australis*. Other prominent vegetation features included extensive bogs and deep swamps (Clarkson *et al.*, 2002). The alluvial plains are thought to have been dominated by *Dacrycarpus dacrydioides* forest, and the hillslopes were covered by *Dacrydium cupressinum* and *Beilschmiedia tawa* forest (Leathwick, 1998).

The arrival of Tainui (the first Māori canoe) is thought to have been around AD 1350. Māori settled into the Waikato valleys from roughly AD 1500, clearing the lowlands for kumara cultivation, travel, transportation, and security purposes (Clarkson *et al.*, 2002). Fires were easily lit and seen to be an effective clearing strategy. However, confining the fires was challenging with strong winds and drought, which is thought to have exacerbated indigenous vegetation clearance. Later, an even more destructive period began with the arrival of the Europeans, who adopted intensive land-use practices and introduced significantly more exotic species (Clarkson *et al.*, 2002).

Since European settlement in 1840, New Zealand's lowland indigenous vegetation cover has been reduced to just 18% (Leathwick *et al.*, 1995). This highly desired productive lowland environment, with a warm climate and abundant rainfall, has been dramatically modified by anthropogenic pressures. The Waikato region's vegetation cover has not noticeably changed since the beginning of the 20$^{th}$ century due to intensive agricultural practices that led to its thorough clearance in the 19$^{th}$ century. The vegetation of Waikato's lowlands is now dominated by grasses, clovers and exotic trees (Clarkson *et al.*, 2002).

The 1840 vegetation map of Hamilton City (Figure 1.2) is divided into four broad vegetation classes, including alluvial and hills secondary vegetation, freshwater wetlands and lakes. About 87% of the city was secondary forest, and 13% were wetlands in 1840 (Leathwick *et al.*, 1995). By 1995, less than 0.1% of Hamilton City was under primary forest, and 0.3% were freshwater wetlands, with only 0.1% covered by indigenous vegetation. Hamilton is one of the most dramatically modified areas in New Zealand, with significantly less than 10% indigenous vegetation among seven other urban districts (Clarkson & Kirby, 2016). Almost all primary forest has been cleared, and less than one per cent of wetlands remain in Hamilton (Leathwick *et al.*, 1995)

About 198 ha (1.8%) of Hamilton City is currently dominated by indigenous vegetation (Figure 1.2). This estimate was derived from WRC's (2021) Biodiversity Inventory, which used the Singers and Rogers (2014) classification to assess numerous vegetation data sources, including Waikato Local Authority Shared Service's (2012) Biodiversity Vegetation layer, unpublished data from John Leathwick, and aerial imagery. Based on this area predicted to be dominated by indigenous vegetation, a further 886 ha would need to be restored for Hamilton City to achieve 10% indigenous vegetation.

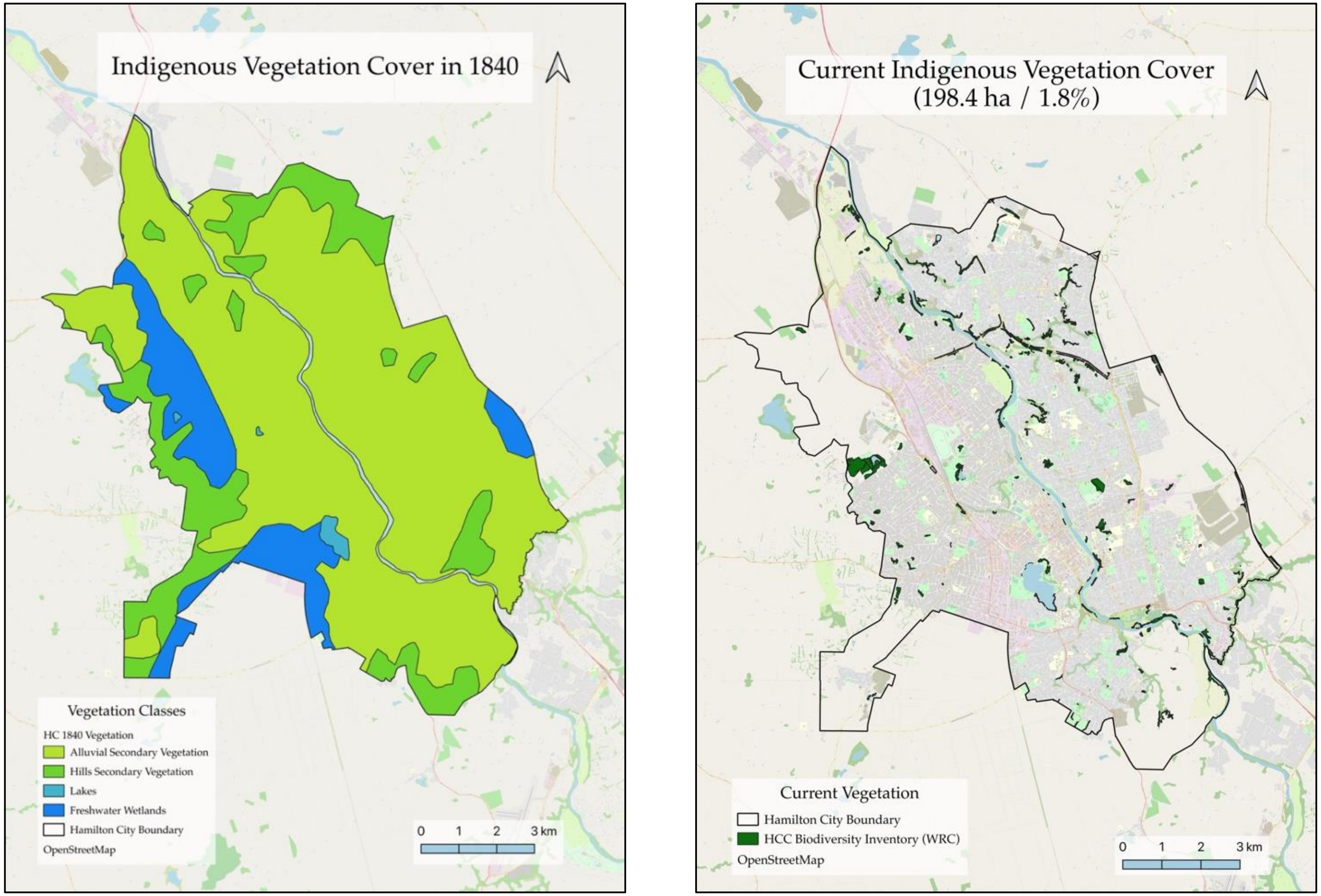


Figure 1.2: The indigenous vegetation cover of Hamilton City in 1840 compared with the current cover (about 198 ha or 1.8% of the city). The 1840 map is divided into four broad vegetation classes: alluvial secondary vegetation, hills secondary vegetation, lakes, and freshwater wetlands (Leathwick *et al.*, 1995). Data for the current indigenous vegetation cover map was sourced from WRC's (2021) Biodiversity Inventory.

## 1.6 National and local policy

Despite the RMA requiring regional and territorial authorities to protect significant natural areas (WRC, 2019), New Zealand's indigenous biodiversity is declining (Brown *et al.*, 2015). Lowland ecosystems naturally comprise rich and complex environments, but intensive land-use practices have degraded them. As a result, most of New Zealand's lowland environments have less than 10% indigenous vegetation cover (Clarkson *et al.*, 2018). Ambiguously defined roles and responsibilities across regional and territorial authorities that lack a consistent approach have led to the shortfall of the commitment under the RMA to maintain biodiversity (Biodiversity Collaborative Group [BCG], 2018; LGNZ, 2020). The miscommunication of roles commonly results in unfulfilled activities or overlapping tasks (LGNZ, 2020). Another limitation of the RMA's requirement to protect significant areas of indigenous flora and fauna is the lack of incentives for landowners to practice good biodiversity management (Norton *et al.*, 2020). It is predicted that 20% of threatened vascular plants occur only on private land (Norton, 2000; Ministry for the Environment [MfE], 2007).

### 1.6.1 Protected Natural Areas Programme

The PNAP was created in 1983 "to protect representative examples of the full range of New Zealand's natural ecological diversity" (Kelly & Park, 1986, p. 9). A fundamental concept of the programme is representativeness, which is embodied in New Zealand's legislation, encouraging "the preservation of representative samples of all classes and natural ecosystems and landscape" (Reserves Act, 1977, p. 15). About 33% or nine million hectares of New Zealand's land is legally protected for conservation (MfE, 2010). However, lowland and coastal environments remain seriously under-represented by these protected areas (Saunders & Norton, 2001). The PNAP was created over concern for these environments and the state of many ecosystems in New Zealand. Conspicuously scarce lowland ecosystems across their natural range include kahikatea forest, peatlands, totara forest and broad-leaved forest (Molloy, 1980).

The PNAP also responds to the RMA by contributing to local authority plans and reporting on changes in biodiversity over time (Bellingham, 2001). This programme led to the creation of recommended areas for protection (RAPs) and significant natural areas (SNAs). It has identified many protected sites and provided quality data for more than 83 of 270 ecological districts in New Zealand (Bellingham, 2001).

Key steps within the PNAP include reconnaissance, surveillance and local analysis before publication and implementation (Myers *et al.*, 1987). Reconnaissance occurs with team leaders and scientific advisers, compiling local information and field knowledge to select study areas. The survey stage assesses sites to inform locals. The local analysis involves defining representative areas of ecosystems and summarising the findings from the survey. The representativeness study in this thesis (Chapter 2) has adopted a similar procedure to the PNAP's local analysis step, elucidating ecological units and representative areas.

### 1.6.2 Significant Natural Areas

In 2016, WRC released eleven criteria for determining the significance of indigenous biodiversity (WRC, 2016). The objectives behind recognising SNAs include protecting natural heritage for future generations, improving ecological connectivity and integrity, minimising extinction and meeting the RMA's requirements. The criteria for SNAs include sites that support threatened species, under-represented vegetation, rare features like geothermal ecosystems, natural wetland habitat, a large representative remnant of indigenous vegetation, self-sustaining aquatic habitat or ecological corridors. A site needs to meet one or more of these criteria to be considered an SNA.

An assessment of Hamilton City's ecological condition in 2000 identified 72 key sites (Downs *et al.*, 2000), which reduced to 70 by 2011 (Cornes *et al.*, 2012). Two privately owned sites from the original study were degraded beyond the required criteria. However, between 2000 and 2011, the total area of the sites, average size and quality improved. These improvements stem from restoration efforts by HCC and local restoration groups. The assessment identified key sites from all landform types, from gullies, alluvial plains, hills and peatlands to riverbanks and islands. However, most of the key sites were gullies; the alluvial plains and peat bogs represented less than one per cent of them (Cornes *et al.*, 2012).

### 1.6.3 Nature in the City Strategy

On 1st December 2020, HCC adopted the *Nature in the City Strategy*. Its primary goal is to reach 10% indigenous vegetation cover in Hamilton City by 2050 (HCC, 2020b). The 10% threshold has been adopted in an attempt to mitigate species extinction (Hanski, 2015; Clarkson *et al.*, 2018); below 10% native habitat, the rate of extinction is expected to accelerate (Figure 1.3). Acknowledging the lack of indigenous vegetation cover throughout the city, HCC (2020b, p. 7) recognises that "Nature plays an essential role in economic, environmental, cultural and social wellbeing, and the more vibrant and healthy nature is, the more these benefits are multiplied."

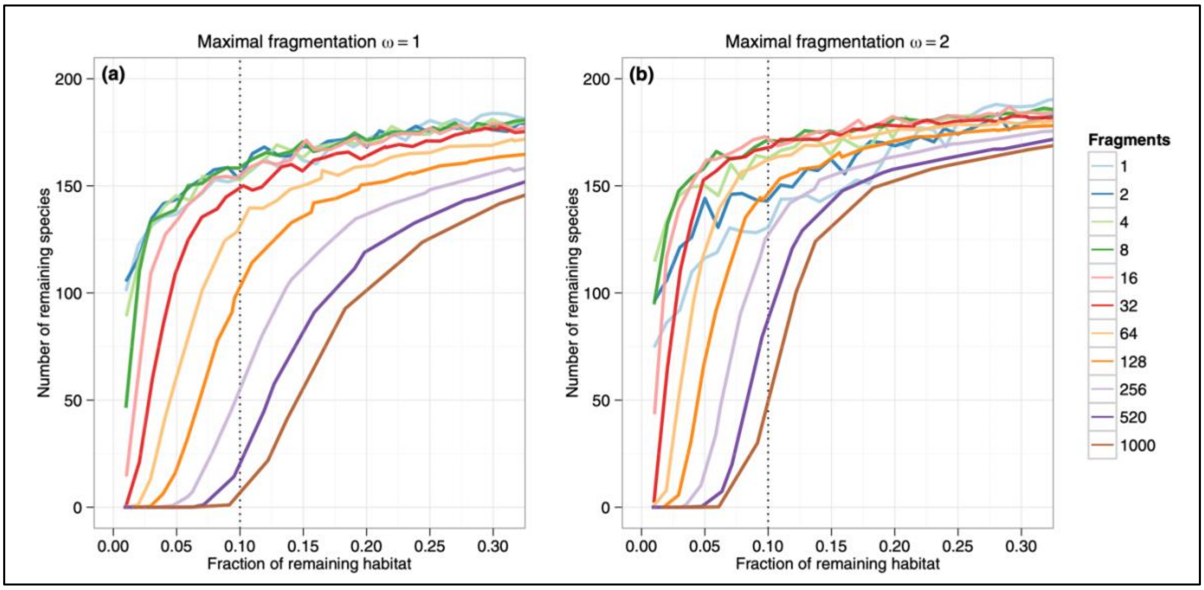


Figure 1.3: The effect of the proportion of the remaining habitat on the number of species. Once the fraction of remaining habitat drops below the 10% threshold (dotted vertical line), biodiversity loss accelerates. The coloured lines represent scenarios based on the number of fragments, and the two graphs exemplify different strengths of correlation (Hanski, 2015).

The *Nature in the City Strategy* acknowledges that ecological restoration supports the health of individuals and brings together communities. It also recognises that restoration enhances cultural and economic values, allowing Māori to connect with nature as an integral component of kaitiakitanga (guardianship and protection) and contributing to economic prosperity by enhancing ecosystem services such as crop pollination and climate regulation (HCC, 2020b).

The strategy supports some of HCC's obligations under the RMA. Three main clauses of the RMA align with this strategy, such as promoting "the sustainable management of natural and physical resources [while] safeguarding the life-supporting capacity of air, water, soil, and ecosystems" (RMA, 1991, p. 70). Additionally, HCC is required to ensure the "protection of areas of significant indigenous vegetation and significant habitats of indigenous fauna" and "the relationship of Māori and their culture and traditions with their ancestral lands, water, sites, waahi tapu [sacred sites], and other taonga [treasures]" (RMA, 1991, pp. 70-71).

Other legislation that requires HCC to conserve and restore indigenous vegetation include the Waikato River Settlement Act 2010 and the Local Government Act (LGA) 2002. The Waikato River Settlement Act urges HCC to protect and improve the health of the Waikato River. The LGA also requires HCC to support the social, environmental, cultural and economic well-being of the city. Restoring gullies and riparian vegetation connected to the Waikato River under the *Nature in the City Strategy* would support the Waikato River Settlement Act 2010 and LGA. The *Nature in the City Strategy* emerged for several reasons, including pressure from the central government to improve the state of biodiversity, the community's desire for a healthy environment and liveable city, and the tangible climate change action of restoration (HCC, 2020b). While the strategy focuses on improving Hamilton City's natural environment, its success would also enhance economic, cultural and social concerns.

The *Nature in the City Strategy* delivered five initial steps to achieve 10% indigenous vegetation cover in Hamilton City by 2050. At the top of the list, HCC intends on restoring the gullies with accessways, pest control, planting indigenous flora and actively managing the sites. Secondly, it aims to establish a holistic monitoring programme across the city, incorporating mātauranga Māori and Western science. It also aims to use an integrated ecological approach to reconnect the city's indigenous patches. The document highlighted the importance of collaborating with neighbouring councils for the project's success. Finally, the strategy prioritised community empowerment and improving individuals to care for the environment (HCC, 2020b).

In November 2021, HCC released additional information on the *Nature in the City Strategy* (HCC, 2021). Over the next decade, its goals include increasing indigenous vegetation cover by three per cent, a 100% increase in the area treated for pests, a 100% increase in community access to natural areas, and an annual increase in volunteer participation by 20%. Between 2022 and 2025, it aims to enhance nature at Donny Park, begin restoration at Te Awa o Katapaki and Mangakotukutuku gully, and initiate a baseline monitoring system. Other goals focus on education and the development of systems to identify optimal restoration sites (HCC, 2021).

Restoring Hamilton's gullies is a prominent focus under HCC's *Nature in the City Strategy* (HCC, 2020b). Hamilton City has a unique network of gullies that extend from the Waikato River into residential areas and comprise about 120-kilometres of streams (Myers, 2017). The sinuous gullies were formed about five thousand years ago when the Waikato River changed course over the Hamilton Basin (Clarkson *et al.,* 2000). Alluvial plains were deposited until around 14 kya as the river excavated its current channels. This process released impermeable silt, which was deposited on the plains and buried by later floods. The seepage of overflowing water from peat swamps travelled along impermeable layers, which arose as springs upon riverbanks, resulting in slips. This geological movement created the main pattern of Hamilton's gully systems.

Previously considered wastelands, the gullies persist because of general neglect and the difficulties associated with developing them (Clarkson *et al.,* 2000). While this neglect has encouraged the dominance of exotic plants, the gullies remain some of the least disturbed environments in the city. Recognition of their potential led to the inception of the Hamilton City Gully Restoration Programme, improving the ecological integrity of gullies noticeably since 2000.

Hamilton City's four main gully systems include the Kirikiriroa, Mangaonua, Mangakotutuku and Waitawhiriwhiri gullies (Clarkson & Downs, 2001). The indigenous vegetation composition of these gullies is intimately related to soil drainage and slope (Clarkson *et al.*, 2000). Two historical indigenous vegetation types have been deduced from Hamilton's gullies, including tōtara-mataī-kōwhai forest on the terrace scarps and gullies sides and kahikatea-pukatea-swamp maire forest on the narrow gully floors (Clarkson *et al.,* 2007). The latter vegetation type has a narrower natural range. Gully restoration offers numerous benefits, including improved water quality and habitat with enhanced shading and decreased water temperatures. It also provides the best opportunity to improve habitat connectivity across the city.

## 1.7 Thesis topic

This thesis spatially assesses ecological data to reveal the ecological integrity of potential restoration sites in Hamilton City, New Zealand. Spatial assessments were conducted by extrapolating data and creating layers and maps in a geographic information system (GIS) to identify the ecological integrity and restoration potential of 3,573 gully and reserve sites across Hamilton City. GIS enables the spatial integration and interpretation of information by merging, manipulating and analysing data. It connects and integrates many disciplines, including ecology, political science, environmental planning, and statistics (Malczewski, 2006; Blaschke & Merschdorf, 2014).

Although numerous studies have examined key sites across the city (Downs *et al.*, 2000; Stevens *et al.*, 2002; McQueen, 2004 & Cornes *et al.*, 2012), this thesis exploits synergies between information and presents novel findings that contribute to ecological restoration in Hamilton City. It provides a more refined representativeness analysis than previous studies and supplies a bespoke site prioritisation tool to identify optimal ecological restoration sites in the city. It also examines the ecological integrity of three kahikatea remnants to identify appropriate restoration strategies that could be used for other restoration projects.

## 1.8 Thesis objectives

The central purpose of this thesis is to support HCC's goal under the *Nature in the City Strategy* to attain a minimum of 10% indigenous vegetation cover in Hamilton City by 2050. Three objectives stem from this purpose. The first objective is to evaluate the representativeness of the landforms and ecological units in Hamilton City. The second objective is to develop a bespoke tool using key ecological principles that prioritises potential restoration sites in Hamilton City. The third objective is to demonstrate how site-specific analyses can direct the selection of appropriate restoration strategies.

## 1.9 Research questions

Chapter 2:

1. What is the state of ecological representativeness in Hamilton City?

Chapter 3:

2. Which gullies and reserves in Hamilton City have the most restoration potential that comprise the area that would need to be restored under HCC's 10% goal?

Chapter 4:

3. How can the age structure, physical conditions and biotic features of the kahikatea remnants at Hillcrest Park, Grove Park and Totara Park guide the selection of restoration strategies?

### 1.10 Thesis overview

Findings from this research are presented in five chapters, including an introduction to the topic (Chapter 1), three main chapters (Chapters 2, 3 and 4) and a synthesis (Chapter 5), which discusses novel findings and provides recommendations for management and further research.

Chapter 2 provides representativeness analyses of Hamilton City's landforms and ecological units (Tables 2.1 & 2.2). The extent of the city's four landforms (Figure 2.2) and eleven ecological units (Figure 2.3) are displayed from QGIS. Using WRC's (2021) Biodiversity Inventory as an estimate of current indigenous vegetation cover, landform and ecological unit representativeness was assessed. Areas are presented that would be required for sufficient representativeness of each landform and ecological unit under HCC's *Nature in the City Strategy* goal to attain 10% indigenous vegetation cover.

Chapter 3 presents an ecological multicriteria tool that prioritises Hamilton City's gullies and reserves using QGIS. Each site was scored on eight ecological criteria, including species composition, natural wetland extent, species richness, ecological connectivity, size, landform representativeness, the presence of naturally regenerating indicator species and total site vegetation cover. Sites with the highest cumulative score, comprising the area that would need to be restored for HCC to achieve 10% indigenous vegetation cover (886 ha), are provided in five prioritisation categories (Figure 3.2).

Chapter 4 describes the ecological integrity of three kahikatea patches in Hamilton City, including Hillcrest Park, Totara Park and Grove Park. It compares these patches with Te Papanui (the reference site). Assessments included kahikatea population age structures from DBH measurements, Green Wheel Assessments, life form analyses and planting zone maps. Ecological restoration strategies are identified based on the physical features and biotic characteristics of each site.

Chapter 5 presents a synthesis of the research and its relevance to HCC’s goal under the *Nature in the City Strategy* to attain a minimum of 10% indigenous vegetation in Hamilton City by 2050. Recommendations for management and further research are also provided.

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# Chapter 2: Ecological representativeness in Hamilton City

## 2.1 Introduction

Ecological representativeness is a concept based on the premise that protected areas should comprise the full suite of species, processes and characteristics of a land unit (Awimbo *et al.*, 1996; Oslon & Dinerstein, 1998). In New Zealand, the Protected Natural Areas Programme (PNAP) was implemented with representativeness as its primary criterion (Myers *et al.*, 1987) because the parks and reserves network does not adequately represent New Zealand's ecological character and biodiversity (Saunders & Norton, 2001). Lowland environments are poorly represented due to their suitability for agricultural practices and other economically valuable activities (Norton, 2000).

Most urban centres in New Zealand contain less than 10% indigenous vegetation (Wallace & Clarkson, 2019). Environments that drop below 10% indigenous vegetation cover may experience a rapid loss of biodiversity, with often less than half the species remaining because of local extinctions (Hanski, 2015). Reconstructing highly degraded environments and assessing representativeness requires historical knowledge such as ecosystem patterns and species composition (Clarkson *et al.*, 2018). This information enables a restoration project to mimic past vegetation patterns, which should maximise its chance of success (Leathwick *et al.*, 2001; Clewell *et al.*, 2004).

Just 1.8% or about 198 hectares (ha) of Hamilton City is covered by indigenous vegetation, which grossly under-represents its natural biota. For example, urban indigenous canopy species characterise less than half those found in Waikato's rural forests (Wallace & Clarkson, 2019). As a part of the *Nature in the City Strategy*, Hamilton City Council (HCC) endeavours to reach 10% indigenous vegetation cover by 2050 (HCC, 2020). This strategy responds to numerous policies such as the Resource Management Act 1991, Waikato-Tainui Raupatu Claims and the Local Government Act 2002. It focuses on restoring gullies which comprise approximately 7% of the city (Table 2.1).

This chapter discusses ecological representativeness globally, nationally, and locally for Hamilton City. It uses existing spatial data and the 10% target to assess the current representativeness of the city's four landforms and eleven ecological units. Here, ecological units are defined as units subject to ecological research that comprise more than one organism (Jax, 2006) and were delineated from soil types. The representativeness analyses identify areas that would need to be restored for each landform and ecological unit to be adequately represented under HCC's 10% goal. However, representativeness is just one of the eight ecological criteria assessed in this thesis, and best practice should incorporate the other criteria for the selection and prioritisation of restoration sites (Chapter 3). The following research questions were addressed:

1. Which climate or landform variable best predicts Hamilton City's landforms and ecological units?
2. What is the state of representativeness for each landform and ecological unit in Hamilton City based on the goal to achieve 10% indigenous vegetation cover?
3. What area of indigenous vegetation would need to be restored for each landform and ecological unit to achieve representativeness under the 10% target?

### 2.1.1 Global representativeness

At least 20% of indigenous species in most terrestrial biomes worldwide have gone extinct since 1990 (International Science-Policy Platform on Biodiversity and Ecosystem Services [IPBES], 2019). The current rate of extinction is tens to hundreds of times greater than the average rate of the past ten million years. A prominent reason for this decline in biodiversity is habitat loss as land-use practices have intensified and natural areas are cleared for agriculture or development. With a growing global population exacerbating the crisis, conservationists must carefully prioritise and justify the protection of natural areas. On a global scale, representativeness aims to protect entire ecosystems or even biomes rather than individual species (Hoekstra *et al.*, 2005). Numerous global representativeness strategies were created to halt biodiversity loss and improve ecological function (Oslon & Dinerstein, 1998; CBD, 2014; Pörtner *et al.*, 2021). The exclusion of representativeness can have dire consequences for biodiversity. For example, the Convention on Biological Diversity's (CBD) Aichi Target did not include representativeness, resulting in nine ecosystems not represented (Sayre *et al.*, 2020).

### 2.1.2 National representativeness

New Zealand's lowland environments are seriously under-represented in the reserve network (Saunders & Norton, 2001). Although the Protected Natural Areas Programme (PNAP) aims to preserve representative samples of New Zealand's natural character (Myers *et al.*, 1987), many assessments have used the current state of ecosystems as a baseline rather than pre-human (or pre-anthropogenic disturbance) vegetation patterns (Awimbo *et al.*, 1996). With about 83 acutely threatened environments represented in New Zealand's urban and peri-urban settings (Clarkson *et al.*, 2018), there is a need to consider representativeness in national policy to protect these environments.

Alongside indigenous dominance and species occupancy, representativeness is a critical component contributing to ecological integrity (Lee *et al.*, 2005). Indigenous dominance is the effect of indigenous species on a community's composition, structure, interactions, biomass, mutualisms and ecosystem processes, including nutrient cycling. Self-perpetuating ecosystems that are shaped by indigenous species can maintain ecological integrity. Likewise, species occupancy refers to the proportion of naturally occurring species in an ecosystem. A restoration project should strive to recuperate the greatest array of species that would have naturally existed and suit the conditions at that site.

It is crucial that national and regional biodiversity planning includes a consistent and systematic representativeness framework to identify vulnerable ecosystems for conservation and restoration (Belbin, 1995). Key ingredients for such a framework include systematic monitoring, robust environmental data, explicit goals and regular progress evaluations (Walker *et al.*, 2008; Belbin, 1995).

### 2.1.3 Representativeness in Hamilton City

At the local scale, the representativeness of sites can be determined using higher-resolution data, which reduces the margin of error and enables accurate monitoring. Ecological representativeness could contribute to HCC's choice of restoration sites under the *Nature in the City Strategy's* goal to achieve 10% indigenous vegetation by 2050 (HCC, 2020). Although reaching 10% indigenous vegetation would be an impressive achievement alone, restoring and reconstructing sites that contain under-represented landforms and ecological units could ensure even better ecological outcomes. For example, restoring under-represented landforms will likely improve the status of vulnerable species in the city and enhance biodiversity by expanding habitat types. The range of ecosystem services that different species provide would also grow, including water purification, microclimate regulation, improved air quality, and recreational activities (Bolund & Hunhammar, 1999).

Hamilton City has four prominent landforms, including alluvial plains, hills, peatlands and gullies. Some of the characteristic indigenous flora that would have occupied each ecological unit have been predicted (Clarkson *et al.*, 2007). For example, two vegetation types dominated Hamilton City's gullies, including tōtara-mataī-kōwhai and kahikatea-pukatea-swamp maire forests. The alluvial plains consisted of three main vegetation types: mixed conifer-broadleaved, kahikatea semi-swamp, and tōtara-mataī-kōwhai forests. The peatlands supported four vegetation types, including submerged and marginal herbaceous vegetation, swamp forest and shrubland, shrub sedgeland, and restiad rushland. Lastly, the hills landform contained three vegetation types: rimu-tawa, kauri-hard beech, and pukatea-kahikatea forest (Clarkson *et al.*, 2007). Although most of these vegetation types have been severely diminished or lost from the city, understanding their natural extent reveals the current state of representativeness for each ecological unit (delineated from soil types). It also enables identifying the area that would be restored to satisfy the representativeness of each ecological unit.

## 2.2 Climate effect on vegetation distribution

Climate plays a significant role in the distribution of vegetation (Hengl *et al.*, 2018; Notaro *et al.*, 2006; Woodward, 1987; Brovkin, 2002). The renowned Köppen climate classification system spatially demonstrates the effect of different climate zones on vegetation types globally. In this study of Hamilton City, climate variables such as temperature, solar radiation and rainfall deficit effect on vegetation are discussed.

Temperature is a significant determinant of the composition and distribution of plants, influencing the physiological processes of photosynthesis and respiration (Leathwick *et al.*, 2003). Temperature changes also signal seasonal cues, catalysing growth and flowering in spring and the shedding of leaves in the autumn (Notaro *et al.*, 2006). In Hamilton City, the mean annual temperature is consistent, with an average of 13.7°C and a range between 13.4 and 13.9°C (Manaaki Whenua, 2020a). As expected, the warmest areas spread across the northern part of the city, whereas the cooler areas are mainly in the southeast (Appendix 2.7).

Hamilton City's mean minimum temperature of the coldest month ranges between 3.3 and 4.1°C (Manaaki Whenua, 2020a). Some of the indigenous flora most suited to Hamilton's climate include *Laurelia novae-zelandiae, Syzygium maire, Cyathea medullaris,* and *Dacrycarpus dacrydioides* (Wardle, 1991).

Plants require different amounts of solar radiation, which contributes to vegetation patterns. Solar radiation provides a plant with energy to carry out photosynthesis; it is the process of converting carbon dioxide and water into carbohydrates, creating energy for the plant and the trophic levels above (Leathwick *et al.*, 2003). Like Hamilton City's temperature, the mean annual solar does not vary significantly. Aside from the east, including Rototuna and Chartwell, the rest of the city receives an annual average of 14.7MJ/day of solar radiation. Similarly, the mean winter solar radiation of the city is consistent. Most of the city receives 5.6MJ/day, whereas the southern areas receive 5.5MJ/day during the winter (Appendix 2.1).

Water deficit also contributes to vegetation distribution (Whitehead *et al.*, 2001; Stephenson, 1990) and refers to the evaporative demand not met by water availability or the difference between potential and actual evapotranspiration (Stephenson, 1990). As a water balance component, water deficit can reveal where plants experience heat stress and metabolic costs that cannot be controlled with transpiration or photosynthesis. More specifically, an inadequate water supply reduces stomatal conductance to limit water loss, which lowers the growth and productivity of plants (Hacke & Sperry, 2001). Hamilton City's average annual water deficit is 37 mm, ranging between 25 and 49 mm. The water deficit increases from west to east of the city, where Rototuna North experiences the highest deficit and Temple View has the lowest deficit. As the climate warms, it is expected that the annual water deficit will increase, creating a more stressful environment for plants (Vicente-Serrano *et al.*, 2013).

These findings highlight Hamilton City's homogenous climate and the weak relationship between climate and vegetation distribution at this scale. Nevertheless, this assessment has examined Hamilton City's macroclimate, and an investigation at the microclimate scale would likely reveal a stronger relationship between climate and vegetation patterns. Microclimate can play a crucial role in vegetation structure, indicating canopy closure and the successional stage of a site. Essential components of microclimate include humidity and soil temperature, which have a prominent effect on Hamilton's gullies, creating environmental gradients that may support a broader range of species than other landforms. For example, the damp, sheltered conditions of canopy-covered gully floors are conducive to functional groups such as epiphytes and lianes (Wallace & Clarkson, 2019).

### 2.3 Landform variables effect on vegetation distribution

Like climate, the relationship between landform attributes and vegetation has been comprehensively studied (Burrough *et al.*, 2001; Deng *et al.*, 2007; Riaño *et al.*, 2003). Landform variables that influence vegetation patterns at the local scale include slope, soil drainage and soil type (Franklin, 1995; Leathwick *et al.*, 1998). The slope is defined as the rate of elevation change and is measured in degrees (Franklin, 1995). A site's slope and aspect influence vegetation distribution via hydrology, soil moisture and development, radiation balance, and nutrient availability (Franklin, 1995). Hamilton has a subdued landscape, so slope indirectly affects plants via the soils and microclimate. Plants that prefer flat to gently sloped sites include *Alectryon excelsus*, *Dacrycarpus dacrydioides* and *Laurelia novae-zelandiae,* while *Beilschmiedia tawa* and *Fuchsia excorticata* are usually found on steeper sites (Leathwick *et al.*, 2003).

Soil drainage modifies the conditions directly surrounding plant roots, contributing to vegetation structures. For example, poorly drained soils have limited oxygen, creating stressful anaerobic conditions for plants. Species including *Dacrycarpus dacrydioides*, *Laurelia novae-zelandiae* and *Syzygium maire* have adapted to these conditions, growing buttress roots for support. Poorly drained soils can accumulate undecomposed plant material or peat, creating acid soils (Leathwick *et al.*, 2003) that support the establishment of species such as *Typha orientalis*, which has adapted to a low-oxygen environment by sending oxygen from their leaves to their roots. In contrast, species such as *Prumnopitys taxifolia*, *Beilschmiedia tawa* and *Podocarpus totara* prefer drier and semi-fertile soils (Wardle, 1991). In Hamilton City, most peat bogs have been drained. However, what is now Innes Common (Lake Rotoroa) was once a restiad bog occupied by species such as *Sporadanthus ferrugineus* (giant cane rush), *Gleichenia* spp. (tangle ferns) and *Empodisma minus* (wire rush) on the dome-like peat structure.

Hamilton City's soil drainage was extrapolated from the Manaaki Whenua (2020a) layer that was created using the New Zealand soil classification system. The city comprises five qualitative classes, from very poor (1) to well-drained (5) soils. Most soils are well-drained, with occasional discrepancies in the north. Well-drained soils may indicate the alluvial plains, although some result from anthropogenic activities, such as the drainage of wetlands for development. The west of the city has some very poorly drained soils, typical of peatlands. Other prominent features are the two areas of poorly drained soils in the east (Appendix 2.1).

The climate and landform analyses of the selected variables demonstrate their limited effect on Hamilton City's vegetation. The results suggest that soils are the best predictor of past vegetation patterns for the highly-modified urban environment (Singers, 2014; Clarkson *et al.*, 2007). Hamilton City's soil types also provide greater variation and detail at this scale than the other variables (Figure 2.1). Soils are connected to vegetation types via the biogeochemical cycle and are also affected by slope and soil drainage, thereby providing a broader perspective than other abiotic variables (Duncan *et al.*, 1990; Cramer *et al.*, 2019; Buri *et al.*, 2017). Consequently, soil type was used to predict the extent of Hamilton City's landforms, ecological units and vegetation types.

## 2.4 Methods

A literature review examined the effect of climate and landform variables on vegetation types. Climate variables that affect the physiological processes of plants were assessed, including temperature, solar radiation and water deficit. Landform variables were also analysed, including soil types, slope and soil drainage (Appendix 2.1). Soil types were selected as the best indicator of landforms, ecological units and vegetation types in Hamilton City, given their intimate connection with biotic attributes and greater variation at this scale.

QGIS (quantum geographic information system) version 3.16.4-Hannover was employed to connect Hamilton City's 36 soil types (Bruce, 1979; Manaaki Whenua, 2020b) with the four landforms (Appendix 2.2) and eleven ecological units and vegetation types (Appendix 2.3). The eleven ecological units represent the broad historical vegetation types (Clarkson *et al.*, 2007). Each layer was created with the clip geoprocessing tool and formatted in the layer properties, style pane and layout manager for presentation (Figures 2.2 & 2.3) (click here for the representativeness GIS layer).

The natural range and current indigenous vegetation cover of each landform and ecological unit were revealed with the open field calculator in QGIS. These areas were exported into Microsoft Excel to quantify current representativeness. The proportional area of each landform and ecological unit were calculated within the city's boundary. Current indigenous vegetation cover for each landform and ecological unit was derived from the Biodiversity Inventory (WRC, 2021) and identified by overlaying these layers using the intersection geoprocessing tool in QGIS. Based on the area that would need to be restored for Hamilton City to achieve 10% indigenous vegetation cover (886 ha), the current representativeness of each landform (Table 2.1) and ecological unit (Table 2.2) was presented. Opportunities to satisfy the representativeness of each landform and ecological unit were quantified by comparing areas not dominated by indigenous vegetation on public land with the areas required to achieve representativeness under the 10% goal. Finally, the capacity to adequately represent each landform and ecological unit was calculated from the area not dominated by indigenous vegetation that is publicly owned.

## 2.5 Results

### 2.5.1 Soil types

Hamilton City's soils developed from a combination of accumulation, pedogenic mixing and weathering processes. The soils range from deep organic peat (Kaipaki and Rukuhia soils) to mineral soils of the dominant alluvial plains (Horotiu, Te Kowhia and Te Rapa soils), the porous river margin and lower terrace soils (Tamahere and Waikato soils) and thicker clay soils of the aged hills (Hamilton and Kainui soils) that bulge through the wash of alluvium. These soil classes also have inter-grades.

Yellow-brown Horotiu soils dominate Hamilton City and developed on gravelly rhyolitic alluvium with occasional tephric alluvium (Bruce, 1979). The well-drained soils are highly versatile. Tamahere soils were formed by early Māori who added gravel and sand to create free-draining soils for growing kumara. These soil classes contribute to the alluvial plains, spreading throughout the city's centre from Te Rapa to Peacocke (Figure 2.1).

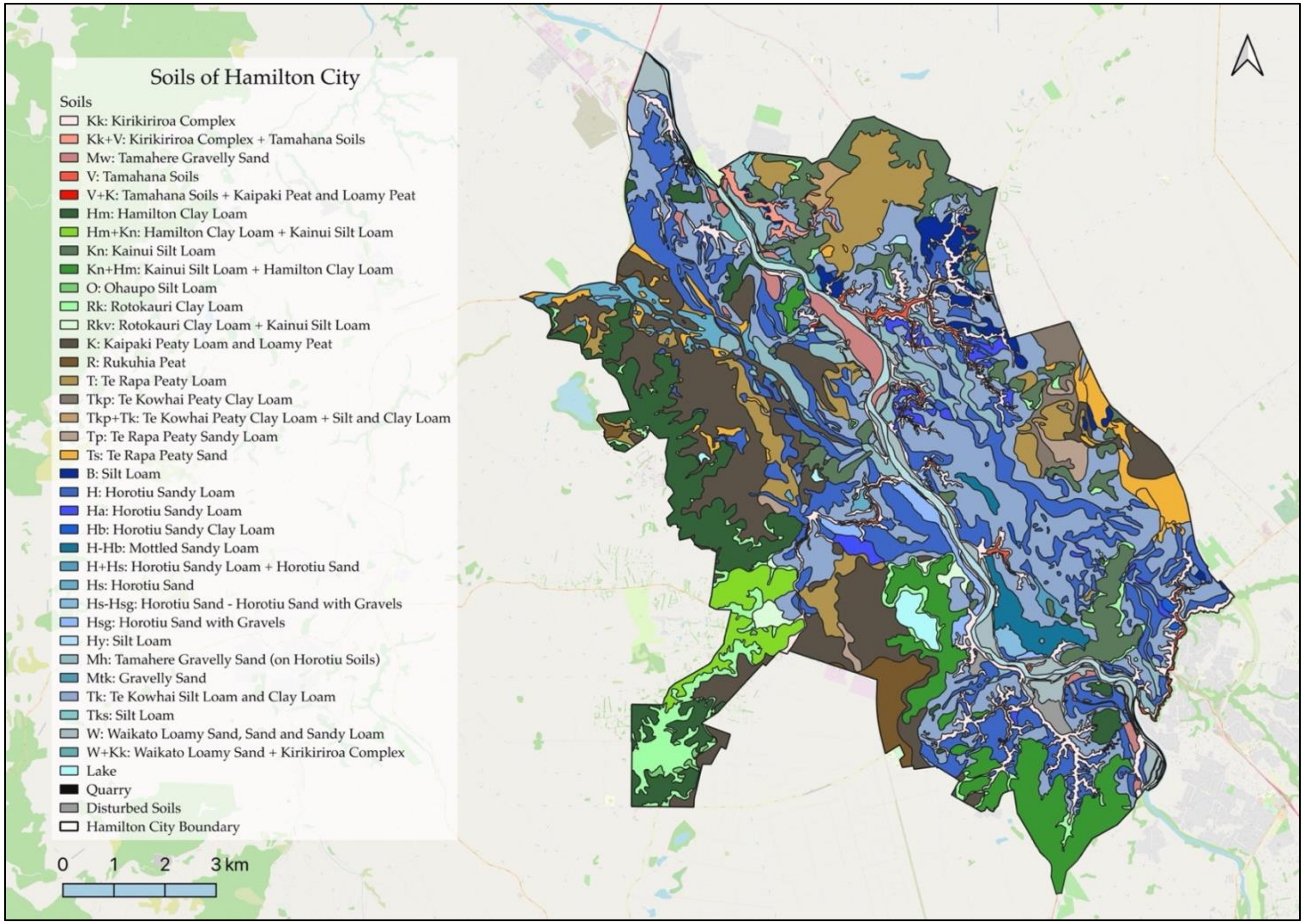


Figure 2.1: Soils of Hamilton City: deep organic peat, mineral soils, river margin soils and clay soils (Bruce, 1979; Manaaki Whenua, 2020b). The red shaded soils represent the gullies, the green soils represent the hills, the brown soils represent the peatlands, and the blue soils represent the alluvial plains.

Hamilton City's low rolling hills comprise four soil classes: Kainui, Hamilton, Ohaupo and Rotokauri soils (Bruce, 1979). Yellow-brown Kainui soil developed on weathered tephric silts above highly weathered tephra and dominate this landform. Similarly, brown, granular Hamilton soils were established on strongly weathered tephra. The Ohaupo and Rotokauri soil classes occur in the city's southern section, especially in Temple View. Yellow-brown Ohaupo soils exist from weakly weathered, younger Mairoa ash beds and are well-drained. Lastly, the imperfectly drained Rotokauri soils developed on colluvium resulting from tephra (Bruce, 1979). The four soils are primarily found on the western and northeast edges of the city.

Te Kowhai, Te Rapa, Rukuhia and Kaipaki soil classes form the peatlands landform. Te Kowhai soils are widely spread across the city, mixing with soils of the plain. These poorly to imperfectly drained soils have developed on fine-textured alluvium that accumulated in depressions of the plain. Poorly to imperfectly drained Te Rapa soils are found in low-lying sites formed on thin peat and overlying alluvium. The Rukuhia soils occur in the city's southwest on Rukuhia's domed peat, with very poor drainage. Most Rukuhia peat is well decomposed, with about 15 cm of loamy peat. Finally, the Kaipaki soils exist in deeper depressions and developed on peat above alluvium. These soils are very poorly drained, with the water table sitting close to the surface (Bruce, 1979); they form intricate patterns within the city's east and west.

Young and weakly developed gully soils include Kirkikiriroa, Tamahere, Tamahana and Waikato soil classes (Bruce, 1979). The Kirikiriroa complex formed steep terraces and gully sides from various Hinuera sediments. Like the alluvial plains, the synthetically created, well-drained Tamahere soils also contribute to the gully landform. The poorly drained Tamahana series dominates the gully bottoms, which developed on alluvium that cut into the Hinuera Formation. The Waikato soils formed with rhyolitic alluvium deposits from the Taupo eruption in 130 AD and are highly drained soils that dry out quickly without constant rainfall (Bruce, 1979). The young gully soils weave throughout the city and are prominent in the city's northeast and southwest (Figure 2.1).

### 2.5.2 Landform representativeness

Hamilton City covers about 10,854 ha if its water bodies are excluded. The alluvial plains extend over 5,011 ha or about 46% of Hamilton City's terrestrial land, occupying a central zone on either side of the Waikato River. Peatlands are the second biggest landform and cover about 2,548 ha or 23% of the city and are commonly between the plains and hills. The low rolling hills cover approximately 2,527 ha or 23% and are primarily around the city's edges. Finally, the gullies are the smallest landform, encompassing about 767 ha or seven per cent of the city (Table 2.1). The representativeness results from this study are based on the proportional area each landform would need for adequate representation under HCC's goal to achieve 10% indigenous vegetation cover.

Based on the 1,085 ha that should be covered by indigenous vegetation to satisfy the 10% target, all landforms are under-represented except for the gullies. The gully landform's natural extent covers seven per cent of the city, so just 76 ha of the gullies would need to be covered by indigenous vegetation for adequate representation. Nevertheless, about 86 ha of gullies are already dominated by indigenous vegetation, so no other gullies would need to be restored based on the representativeness criterion alone. As the gully landform has exceeded its representative area, targets to achieve representativeness for the other three landforms are presented (Table 2.1).

Currently, peatlands are the least represented landform in Hamilton City. Only about seven hectares of peatlands are covered by native vegetation in the city, constituting roughly three per cent of the required area for peatlands to be adequately represented. A further 229 ha of peatlands would need to be restored to represent this landform adequately. However, the public reserves comprise only 189 ha of peatlands, so it would be necessary to restore an additional 40 ha of peatlands to satisfy representativeness.

The alluvial plains are the second least represented landform in Hamilton City. Despite its natural range covering almost half the city, only 58 ha are dominated by indigenous vegetation. Consequently, the alluvial plains dominated by native vegetation only comprise 12% of the area required for representation. A further 430 ha would need to be restored for this landform to be adequately represented. Nearly 450 ha of the public reserves comprise alluvial plains, providing sufficient area and opportunity for this landform to be amply represented under the 10% goal.

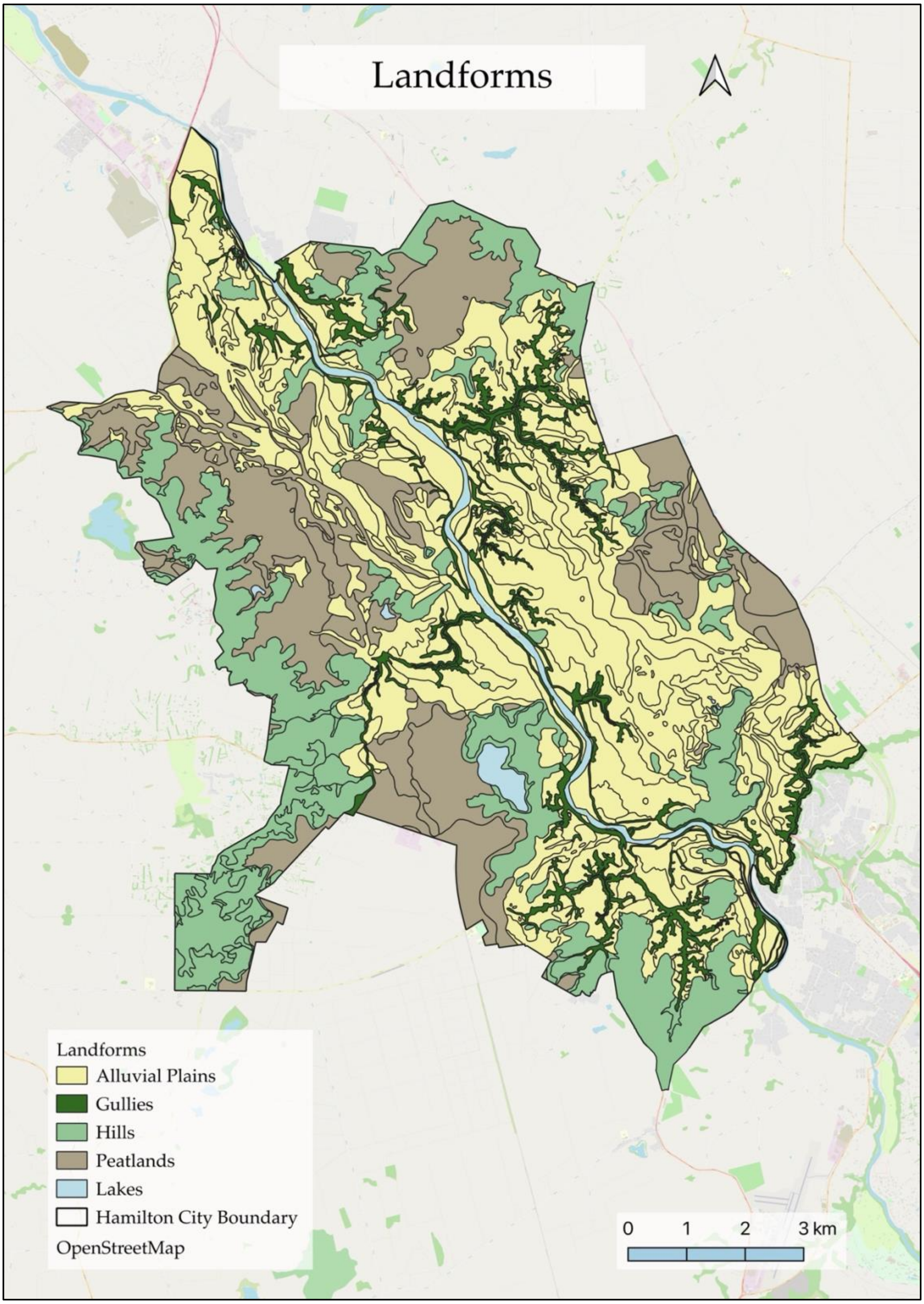


Figure 2.2: Hamilton City's four dominant landforms: the alluvial plains, hills, peatlands and gullies. The landform boundaries were identified by linking soil types (Bruce, 1979; Manaaki Whenua, 2020b) with generalised parent material and vegetation types (Clarkson *et al.*, 2007).

Hills make up more than a fifth of the city, although only 46 ha of this landform are covered by indigenous vegetation, which comprises 18% of the area needed for its representation. About 227 ha would need to be restored to represent this landform adequately (Table 2.1). However, Hamilton City's public reserves comprise only 52 ha, so another 175 ha outside the reserves would need to be restored to represent it sufficiently.

Table 2.1: The representativeness of Hamilton City's four landforms. The representative area of 10% provides the areas that would need to be restored to represent Hamilton City's four landforms adequately. The current representativeness column divides the current indigenous vegetation cover by the appropriate cover at 10% (found in the adjacent column) for each ecological unit. The representativeness capacity was calculated by dividing the combined current and unrestored site areas by the representativeness at 10% area. 'Unrestored' refers to areas not dominated by indigenous vegetation.

| Landform | Area (ha) | Current indigenous vegetation area (ha) | Current representativeness (%) | Representative area of 10% (ha) | To satisfy representativeness at 10% (ha) | Unrestored, publicly owned sites (ha) | Representativeness capacity (%) |
|---|---|---|---|---|---|---|---|
| Hills | 2,527.6 (23.3%) | 46.2 | 18.3 | 252.8 | 206.6 | 52.0 | 38.8 |
| Alluvial Plains | 5,010.9 (46.2%) | 58.2 | 11.6 | 501.1 | 442.9 | 449.8 | 114.6 |
| Peatlands | 2,548.7 (23.5%) | 7.4 | 2.9 | 254.9 | 247.5 | 189.2 | 77.1 |
| Gullies | 767.3 (7%) | 86.6 | 113.9 | 76.7 | 0.0 | 548.9 | 836.2 |
| **Total** | **10,854.5** | **198.4** | | **1,085.5** | **897.7** | **1239.9** | |

### 2.5.3 Ecological unit representativeness

Defining ecological boundaries reveals invaluable information for restoration planning and management, such as vegetation types that existed before anthropogenic disturbance. This section spatially and quantitatively presents the distribution of Hamilton City's eleven ecological units. It also identifies highly degraded ecological units that require the most attention. Like the city's landforms, the ecological units and vegetation types were predicted using the soil types (Figure 2.3). The representativeness results from this analysis are based on the proportional area that would need to be restored for the adequate representation of each ecological unit under HCC's goal to achieve 10% indigenous vegetation cover.

Hamilton City is dominated by alluvial plains, which spread throughout the city's centre. The three ecological units of the alluvial plains are the low mounds or ridges, the shallow depressions or swales and the low terraces. The low mounds or ridges ecological unit consists of mixed conifer-broadleaved forest and is the second least represented, requiring another 221 ha of native vegetation cover for adequate representation. One example of a low mound site is Donny Park in Chartwell (Appendix 2.4), with alluvium soils dominated by rhyolitic sand, silt and gravel. Restoring this park is one of the first goals under the *Nature in the City Strategy* (HCC, 2021).

The shallow depressions or swales ecological unit was naturally occupied by kahikatea semi-swamp forest and would require the restoration of another 235 ha to satisfy the representativeness criterion. The kahikatea forest remnant at Te Papanui (Claudelands Bush/ Jubilee Park) is one example of the natural vegetation of the shallow depressions ecological unit (Appendix 2.4).

Finally, the low terraces adjacent to the Waikato River previously supported tōtara-mātai-kōwhai forest (Clarkson *et al.*, 2007). Some examples of this ecological unit include Memorial Park in Hamilton East and Munro's Walkway north of the Pukete Bridge. This ecological unit would require another 19 ha for sufficient representativeness.

Hamilton's peatlands comprise three ecological units: peatland margins, peat bogs and peat domes with the vegetation types of swamp forest and shrubland, shrub sedgeland and restiad "rushland", respectively. The peat depth and vegetation type differentiate the three ecological units. Peatlands margins have shallow peat less than 0.4 metres or between 0.4 and one metre deep. With only about 14 ha of peatland margins dominated by indigenous vegetation, another 100 ha would need to be restored to represent this ecological unit. However, the city's reserves contain only 25 ha of peatland margins that could be restored. One example of peatland margin vegetation to the northeast of Hamilton City is the Kopuatai Peat Dome on the Hauraki Plains (Appendix 2.4).

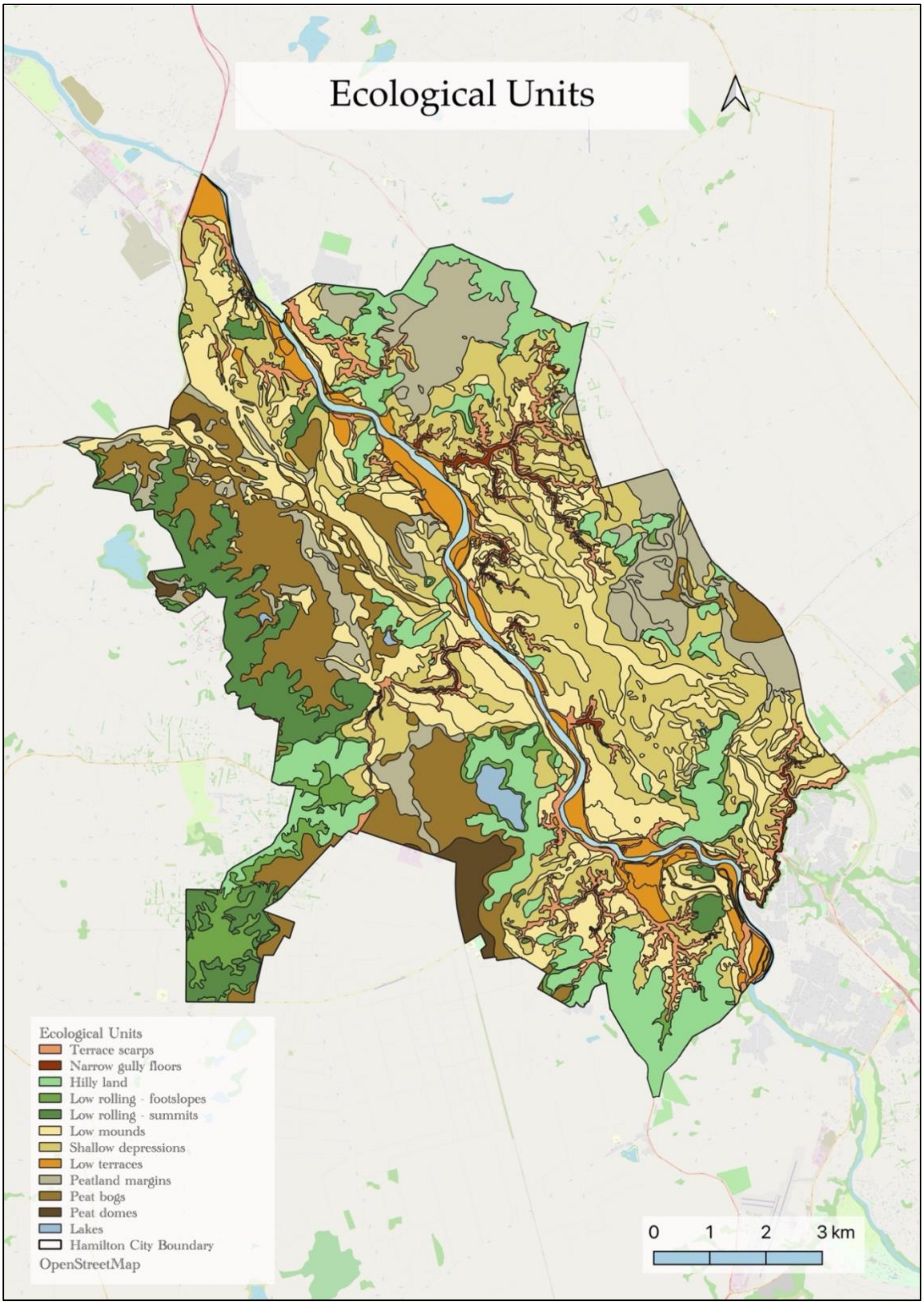


Figure 2.3: Hamilton City's eleven ecological units were derived from soil types (Bruce, 1979; Manaaki Whenua, 2020b). The four landforms were split into ecological units to identify vegetation types (Clarkson *et al.*, 2007).

Peat bogs and peat domes are classified as having similar peat depths of greater than one metre but differ in vegetation type (Bruce, 1979). The peat bogs ecological unit is severely under-represented, needing another 127 ha of indigenous vegetation for sufficient representation. Hamilton City's reserves comprise about 137 ha of peat bogs, so they could adequately represent this ecological unit. An example of a reserve dominated by peat bogs includes Minogue Park next to Lake Rotokaeo (Appendix 2.4).

Of the 136 ha that peat domes naturally cover, none are dominated by indigenous vegetation, so about 14 ha would need to be restored to represent this ecological unit amply. Hamilton City's public reserves comprise about 27 ha of peat domes, which could sufficiently represent the ecological unit. One site naturally dominated by the peat dome ecological unit is Lake Rotokauri which sits on the north-western boundary of the city. Although just under five hectares out of the 18 ha of Lake Rotokauri lies within the Hamilton City boundary, several restoration activities have occurred over the past decade, such as native plantings and pest control efforts (HCC, 2002).

The hills are the third-largest landform in the city and are mostly found on the western, northeastern and southwestern edges. This landform comprises three ecological units: hilly land, low rolling hills (footslopes), and low rolling hills (summits). The natural vegetation of these ecological units included rimu or tawa, kauri-hard beech, and pukatea-kahikatea forest. About six per cent of the hilly land needed for representation is covered by indigenous vegetation, necessitating the restoration of a further 140 ha (Table 2.2). However, only 31 ha of public reserves comprise hilly land, so more than 100 ha of additional land would need to be restored to achieve representation. The most prominent hilly land site in Hamilton City is a section of Hamilton Gardens to the east of the Hamilton East Cemetery with a slope up to 14 degrees. Another example of hilly land in Hamilton City is Till's Lookout, with a slope up to seven degrees. Native species have been planted at Till's Lookout, such as *Dacrycarpus dacrydioides*, *Melicytus ramiflorus* and *Blechnum parrisiae.*

The western hills range includes the low rolling hills (summits) ecological unit, with 43% of its desired representativeness area covered by indigenous flora. Like the hilly land ecological unit, the low rolling hills (summit) require another 72 ha to be restored, although the city's reserves contain just six hectares of this ecological unit. One example of this ecological unit is Bremworth Park in Dinsdale, which supports a small patch of indigenous vegetation, including *Dacrycarpus dacrydioides*.

Finally, about nine per cent of low rolling hills (footslopes) desired area for representation is covered by native vegetation, requiring the restoration of another 41 ha. However, the public reserves only contain 15 ha of low rolling hills (footlslopes), so a further 25 ha would need to be restored for representativeness. One example of this ecological unit is Brymer Park in Nawton, which has been partially restored with native flora since 2002 but also hosts exotic plants (Appendix 2.4).

Table 2.2: The representativeness of Hamilton City's eleven ecological units. The current representativeness column divides the current cover by the appropriate cover at 10% (found in the adjacent column) for each ecological unit. The representativeness capacity was calculated by dividing the combined current and unrestored site areas by the representation at 10% area. 'Unrestored' refers to the area not dominated by indigenous vegetation.

| Landform | Area (ha) | Ecological unit | Area (ha) | Current cover (ha) | Current representativeness (%) | To achieve representativeness at 10% (ha) | Unrestored, publicly owned sites (ha) | Representativeness capacity of reserves and gullies (%) |
|---|---|---|---|---|---|---|---|---|
| Hills | 2527.6 (23.3%) | Hilly land | 1400.7 | 9.0 | 6.4 | 140.1 | 30.6 | 28.3 |
| | | Low rolling - footslopes | 408.7 | 3.8 | 9.3 | 40.9 | 15.3 | 46.6 |
| | | Low rolling - summits | 718.2 | 31.2 | 43.4 | 71.8 | 6.1 | 51.9 |
| Alluvial plains | 5010.9 (46.2%) | Low mounds | 2214.4 | 9.2 | 4.1 | 221.4 | 73.7 | 37.4 |
| | | Low terraces | 447.8 | 11.5 | 25.7 | 44.8 | 129.7 | 315.2 |
| | | Shallow depressions | 2348.8 | 21.9 | 9.3 | 234.9 | 246.8 | 114.4 |
| Peatlands | 2548.7 (23.5%) | Peat bogs | 1274.0 | 9.5 | 7.5 | 127.4 | 137.2 | 115.2 |
| | | Peat domes | 136.4 | 0.0 | 0.0 | 13.6 | 27.2 | 199.6 |
| | | Peatland margins | 1138.3 | 13.8 | 12.2 | 113.8 | 24.8 | 33.9 |
| Gullies | 767.3 (7%) | Narrow gully floors | 65.8 | 9.2 | 140.3 | 6.6 | 51.0 | 915.5 |
| | | Terrace scarps | 701.5 | 79.3 | 113.0 | 70.2 | 497.9 | 822.7 |
| **Total** | **10854.5** | | **10854.5** | **198.4** | | **1085.5** | **1240.2** | |

The gullies cover the smallest area of the four landforms in Hamilton City. Still, they encompass most indigenous vegetation with a web-like structure that weaves throughout the city, extending from the central Waikato River out towards the boundary. During the city's development, the gullies were often used as rubbish dumps (Lowe, 2021; Clarkson &

Bylsma, 2016). This neglect explains how they came to comprise most of the city's biota. The gullies contain two ecological units, including terrace scarps and gully sides and narrow gully floors. The terrace scarps are predicted to have originally supported tōtara-mātai-kōwhai forest. This ecological unit is adequately represented with about 113% of the area that would be required for representativeness under HCC's 10% target. One example of the terrace scarps ecological unit is the Mangaiti gully in the northeast of the city (Appendix 2.4).

The gully floors supported kahikatea-pukatea-swamp maire forest before anthropogenic disturbance. The gully floors exist centrally in the gully systems, with the more extensive terrace scarp ecological unit fitting around them (Figure 2.3). With a natural range of just 65 ha, the nine hectares of narrow gully floors dominated by indigenous vegetation exceed the six hectares that would need to be restored for sufficient representativeness. An example of the narrow gully floor ecological unit is the central section of the Mangaonua Esplanade in Riverlea (Appendix 2.4). A community-led restoration group controls the troublesome weeds and has planted native species.

**2.6 Discussion**

Climate and landform variables significantly influence vegetation distribution (Hengl *et al.*, 2018; Woodward & Williams, 1987; Deng *et al.*, 2007). Abiotic variables including temperature, solar radiation, water deficit, soil drainage, slope and soil type are intimately linked with biotic features. However, soil type was selected as the best predictor of landforms and ecological units for Hamilton City due to its intimate connection to vegetation via the biogeochemical scale and the greater detail it provides at this scale. Identifying the distribution of landforms and ecological units elucidated representativeness gaps across current indigenous vegetation cover in the city. Most indigenous vegetation is found in the city's gullies because they have been at the forefront of restoration since 1975 and contain land that is not suitable for development (MacKay *et al.*, 2011).

Under the goal to restore 10% indigenous vegetation cover in Hamilton City, the gullies are the only adequately represented landform alongside its two ecological units of narrow gully floors and terrace scarps. Despite gullies satisfying the representativeness criterion, they provide more significant opportunities to improve the city's biodiversity than the other landforms. For example, gullies contain complex environmental gradients and microclimates that likely suit a wider range of species.

The results demonstrate that extant indigenous vegetation severely under-represents peatlands, alluvial plains and hills. Nine of Hamilton City's ecological units are inadequately represented within the peatlands, alluvial plains and hills. In order of increasing representativeness, these ecological units include peat domes, low mounds, hilly land, peat bogs, low rolling hills (footslopes), shallow depressions, peatland margins, low terraces and low rolling hills (summits). No native vegetation exists on peat domes. However, its natural range covers about 136 ha, so only 14 ha would need to be restored to achieve representation. Other opportunities to rapidly improve representativeness include the low rolling hills (footlslopes), low terraces, and low rolling hills (summits), requiring another 37 ha, 33 ha, and 41 ha of indigenous vegetation. Amply representing the shallow depressions and low mounds would necessitate restoring more than 200 ha, given their extensive natural range. Adequately representing the peatland margins, peat bogs, and hilly land would require restoration of more than 100 ha for each ecological unit.

Information provided in this chapter may support the prioritisation of restoration sites in Hamilton City. Selecting sites based on ecological representativeness encourages the conservation or restoration of the complete natural range of species, traits, processes and ecosystem services (Clarkson *et al.*, 2018). Although they are adequately represented, gully restoration is at the forefront of HCC's *Nature in the City Strategy* and is practically the best chance of achieving a minimum of 10% indigenous vegetation cover by 2050. The city's gullies provide a rare opportunity for restoration where socially and economically, they are not suitable for development. As the gullies extend across more than 750 ha or about seven per cent of the city, their complete restoration would certainly be a significant ecological achievement. In addition, gully restoration improves indigenous dominance and connectivity, which contribute to ecological integrity.

The public reserves examined in this study do not provide enough land to represent the hills three ecological units amply, should they undergo ecological restoration. There is also not enough public land for the low mounds and peatland margins. Nevertheless, restoration planning can improve landform representativeness by prioritising reserve sites, which mainly consist of peatlands, alluvial plains and hills. Despite the biotic features at some reserves which endorse their restoration, it may not be feasible to restore them if they are sports parks or contain extensive infrastructures, such as Waikato Stadium or Hamilton Gardens. The reserves also comprise monetarily valuable, flat and fertile land. However, several reserves provide valuable restoration opportunities with kahikatea patches, connection to nearby gullies, and existing vegetation cover. A multicriteria tool that examines representativeness among other relevant ecological criteria is needed to prioritise potential gully and reserve restoration sites in the city (Chapter 3). Targeting sites with ideal physical properties and biotic features could accelerate the progress of HCC's city-wide project.

### 2.6.1 Conclusion

This study found that the gullies are the only sufficiently represented landform under the goal to attain 10% indigenous vegetation. Most of the city's restoration activities incorporate the gullies as they contain land that is not desirable for development. Nevertheless, Hamilton's gullies comprise more complex microclimates that can support more diversity than the peatlands, hills, or alluvial plains, so restoring them may provide greater biodiversity rewards. Improving the representativeness of alluvial plains in the city may pose the most significant challenge. It would require the restoration of an additional 370 ha of highly sought-after fertile land. The under-represented peatlands, alluvial plains and hills contribute significantly to the city's character, so restoring them could enhance the suite of native flora and improve Hamilton City's ecological integrity. This research has provided a more refined representativeness analysis than previous studies and elucidated possible gaps in vegetation types across the city, providing the area that would need to be restored to represent each landform and ecological unit adequately. Given the level of modification of urban centres, representativeness may be more appropriately used to support projects at the regional or national scale. The results from this study only consider one ecological criterion and should be used in tandem with other criteria to select and prioritise the restoration of sites in Hamilton City (Chapter 3).

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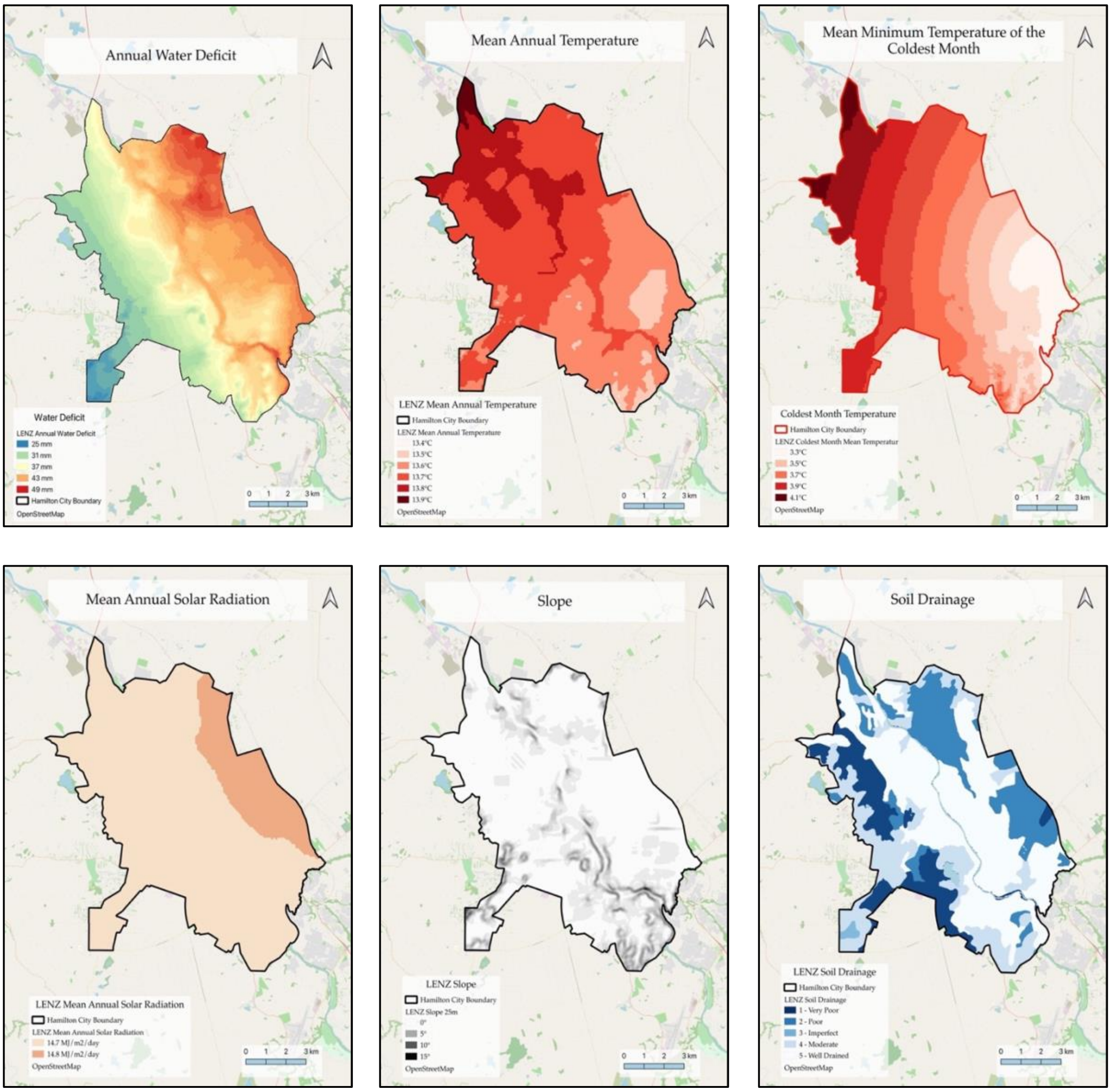
**Appendices**

Appendix 2.1: Climate and landform variation across Hamilton City, including annual water deficit, mean annual temperature, mean minimum temperature of the coldest month, mean annual solar radiation, slope and soil drainage (Manaaki Whenua, 2020a).



Appendix 2.2: Hamilton City's soil types (Bruce, 1979; Manaaki Whenua, 2020b) categorised into each of the four main landforms.

| Soils physiographic location | Soils map code | Description |
|---|---|---|
| Gullies | V | Tamhana soils |
| | Kk | Kirikiriroa complex |
| | V+K | Tamahana soils + Kaipaki peat and loamy peat |
| | V+Kk | Waikato loamy sand + Kirikiriroa complex |
| | Kk+V | Kirikiriroa complex + Tamahana soils |
| Hills | Kn | Kainui silt loam |
| | O | Ohaupo silt loam |
| | Rk | Rotokauri clay loam |
| | Rkv | Rotokauri clay loam, very gently sloping phase |
| | Hm+Kn | Hamilton clay loam + Kainui silt loam |
| | Kn+Hm | Kainui silt loam + Hamilton clay loam |
| | Hm | Hamilton clay loam |
| Alluvial plains | Tk | Te Kowhai silt loam and clay loam |
| | Ha | Horotiu mottled sandy loam |
| | H | Horotiu sandy loam |
| | Hb | Horortiu sandy clay loam |
| | Hsg | Horotiu sand with gravels |
| | Hs | Horotiu sand |
| | B+Tk | Silt loam + Te Kowhai silt loam |
| | H-Hb | Mottled sandy loam |
| | Hs-Hsg | Horotiu sand - Horotiu sand with gravels |
| | B | Silt loam |
| | Tks | Silt loam |
| | Hy | Silt loam |
| | Mb | Gravelly sand |
| | Mh | Tamahere gravelly sand (on Horotiu soils) |
| | Mtk | Gravelly sand |
| | Mw | Tamahere gravelly sand |
| | W | Waikato loamy sand, sand and sandy loam |
| Peatlands | Tkp | Te Kowhai peaty clay loam |
| | T | Te Rapa peaty loam |
| | Ts | Te Rapa peaty sand |
| | Tp | Te Rapa peaty sandy loam |
| | Tkp+Tk | Te Kowhai peaty clay loam + silt and clay loam |
| | K | Kaipaki peaty loam and loamy peat |
| | R | Rukuhia peat |

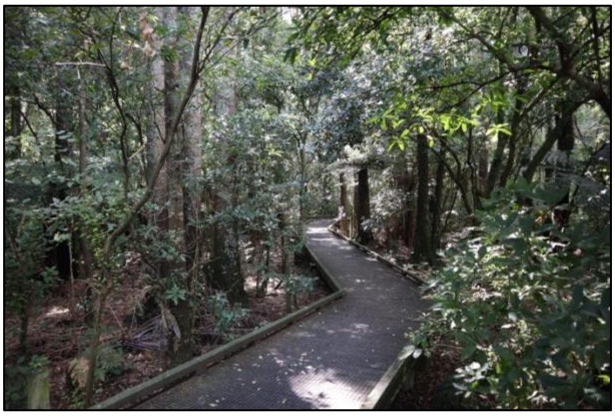
Appendix 2.3: Hamilton City's soil types (Bruce, 1979; Manaaki Whenua, 2020b) categorised into each of the eleven ecological units and their vegetation types (Clarkson *et al.*, 2007).

| Soils physiographic location | | Vegetation type | Description | Soils map code |
|---|---|---|---|---|
| Gullies | Terrace scarps and gully sides | Tōtara-mātai-kōwhai forest | Loose, mainly rhyolitic sand and gravel (Hinuera Formation) | Kk, V+K, Kk+V, V+Kk |
| | Narrow gully floors | Kahikatea-pukatea-swamp maire forest | Colluvium, mainly rhyolitic sand, silt and gravel (Hinuera Formation), occasional organic material | V |
| Hills | Hilly land and foothills of ranges at margins of Hamilton Ecological District | Rimu/tawa forest | Late Quaternary, composite rhyolitic and andesitic tephras (>1 m thick in south, <1 m thick in north), usually well drained, over weathered Hamilton Ash or colluvium where easy rolling to rolling; underlying units (mainly weathered sedimentary rocks or basalt) exposed on steepland | Kn, Kn+Hm, Hm+Kn |
| | Low rolling hills – summits, shoulders, backslopes | Kauri-hard beech forest | North of Hamilton City: Thin (<0.5 m) late Quaternary, composite rhyolitic and andesitic tephras on weathered Hamilton Ash, moderately well drained (non-allophanic) | Hm |
| | | | South of Hamilton City: Thick (> 1.0 m) late Quaternary, composite rhyolitic and andesitic tephras, well drained (allophanic) | O |
| | Low rolling hills - footslopes | Pukatea-kahikatea forest | Colluvium derived from Hamilton Ash and other deposits | Rk, Rkv |
| Alluvial plains | Low mounds or ridges | Mixed conifer-broadleaved forest | Alluvium, mainly rhyolitic sand and gravel (Hinuera Formation) | Ha, H, Hb, Hsg, Hs, H-Hb, H+Hs, Hs-Hsg, Hy, Mh, Mtk |
| | Shallow depressions or swales | Kahikatea semi-swamp forest | Alluvium, mainly pumiceous silt and clay, sand in places (Hinuera Formation) | Tk, B+Tk, B, Tks, Mb |
| | Low terraces adjacent to the Waikato River | Tōtara-mataī-kōwhai forest | Alluvium, pumiceous to non-pumiceous silt, sand and gravel (Taupo Pumice Alluvium) | W, Mw, W+Kk |
| Peatlands | Peatland margins | Swamp forest and shrubland | Shallow peat (<0.4 m) on alluvium | T, Tkp, Ts, Tp, Tkp+Tk |
| | Peatland margins Peat bogs | Swamp forest and shrubland Shrub sedgeland | Moderately deep peat (0.4-1.0 m) | |
| | | | Deep peat (> 1.0 m) | K |
| | Peat domes | Restiad "rushland" | Very deep peat (>1.0 m) | R |

Appendix 2.4: Examples of Hamilton City's eleven ecological units from the city and the Waikato region. The peatland margins ecological unit is the only example outside Hamilton City (Kopuatai Peat Dome on the Hauraki Plains) due to the lack of examples.

Mangaonua Esplanade – Narrow gully floors

Mangaiti Gully – Terrace scarps and gully sides



Te Papanui – Shallow depressions or swales

Donny Park – Low mounds or ridges

Munro’s Walkway – Low terraces

Kopuatai Peat Dome – Peatland margins (images supplied by B.D. Clarkson)

Minogue Park – Peat bogs

Lake Rotokauri – Peat domes

Till’s Lookout – Hilly land


Brymer Park – Low rolling hills (summits)


Bremworth Park – Low rolling hills (footslopes)

## Chapter 3: Prioritising ecological restoration sites in Hamilton City

### 3.1 Introduction

Ecological restoration is crucial for biodiversity conservation, especially in highly-modified urban environments (Wilson *et al*., 2011; Carroll *et al*., 2004). Urban restoration poses unique constraints and opportunities where social and environmental factors meet. In New Zealand, more than 86% of the population lives in urban centres (World Bank, 2018). As the population of these areas grow, anthropogenic pressures result in the loss of native vegetation cover. However, the practice of restoration also depends on people, so urban restoration has an advantage where larger communities can accelerate progress while reconnecting with nature (Standish *et al.*, 2013). Also, urban centres are primarily within lowland environments, where indigenous biodiversity is most threatened (Walker *et al.*, 2008), so restoring and reconstructing habitats within them could significantly improve local and regional indigenous biodiversity (Clarkson *et al.*, 2007b).

Before Europeans arrived, Hamilton City was dominated by indigenous forests, with peat lakes and bogs (Leathwick *et al.*, 1995). It is now one of the country's most modified cities, with about 1.8% of indigenous vegetation cover. Between 2000 and 2011, indigenous vegetation increased by 0.2%, primarily from restoration at Waiwhakareke Natural Heritage Park (Myers, 2017). A significant improvement in the city's ecological integrity would require the inception of many more restoration projects. The main components that contribute to ecological integrity include indigenous dominance, species occupancy and representativeness. Ecological integrity is regained once the full range of naturally occurring biota and major ecosystem processes that support ecosystem functioning are restored (Karr & Chu, 1995).

Under Hamilton City Council's (HCC) *Nature in the City Strategy*, increasing indigenous vegetation cover to 10% by 2050 could significantly improve ecological integrity. Healthy ecosystems and viable populations are estimated to require at least 10% indigenous habitat (Hanski, 2015; McIntyre & Hobbs, 1999; Clarkson *et al.*, 2007b). Achieving 10% indigenous cover would require the restoration of about 886 hectares (ha) and conservation of the existing 198 ha. This equates to restoring approximately 32 ha per year until 2050. Such an ambitious target necessitates careful yet comprehensive planning and site prioritisation that employs ecological principles. Practical considerations for prioritising sites may include conserving existing vegetation alongside restoration projects (Myers & Bazely, 2003) and restoring sites with native remnants that act as nuclei. Successful restoration projects also typically consider connectivity, the extension of buffers, weed and pest control, eco-sourcing, mimicking natural succession and enrichment planting when choosing sites (Clarkson & McQueen, 2004).

Prioritising restoration sites is especially important for efficient and successful restoration at the landscape scale (Mostert *et al.*, 2018; Wilson *et al.*, 2011). For example, protecting and restoring sites with higher ecological integrity will likely be easier and less costly (Van Haveren *et al.*, 1997). Ongoing protection of high-quality fragments in the city, including Te Papanui (Claudelands Bush/Jubilee Park) and Hammond Park, should positively affect nearby sites. Restoration prioritisation frameworks may focus on valuing ecosystem services (Li *et al.*, 2017; Weeks *et al.*, 2014) or cost-effectiveness (Wilson *et al.*, 2011; Crossman *et al.*, 2011). However, standard ecological criteria commonly include habitat size, connectivity, climate, species richness and composition (Orsi *et al.*, 2011; Dymond *et al.*, 2013).

This study presents a bespoke ecological multicriteria tool that prioritises restoration sites, focusing on Hamilton City's gullies and reserves. The gullies are ideal targets for restoration, covering about 767 ha (seven per cent) of the city and providing the best opportunity to enhance connectivity. Restoring the reserves, which comprise the under-represented peatlands, hills and alluvial plains, would also improve the city's landform representativeness. Hamilton City's gullies and reserves were prioritised using eight filters: species composition, species richness, natural wetland extent, connectivity, size, landform representativeness, the presence of naturally regenerating indicator species and total vegetation cover. These criteria elucidate the ecological integrity of each site, using key ecological principles to highlight restoration sites that may provide the best biodiversity rewards. The following questions are addressed in this chapter:

1. Which ecological criteria should contribute to the selection and prioritisation of restoration sites?
2. What are the most ecologically intact gully and reserve sites in Hamilton City that fulfil the area (886 ha) that would need to be restored to reach 10% indigenous vegetation?

## 3.2 Key ecological concepts

Species richness and composition contribute significantly to ecological integrity. Species richness, or the number of species per unit area (Brown *et al*., 2007), is a measure of diversity and is generally coupled with ecosystem functioning (Grime, 1998). Species composition identifies which species are present, commonly focusing on rare, characteristic or indicator species. It is widely agreed that both of these components of biodiversity are correlated with ecosystem functioning (Naeem *et al.*, 1994; Hector *et al.*, 1999; Hooper *et al.*, 2012). Biodiversity is associated with ecosystem stability or resilience to disturbance, fertility and the state of regulatory processes such as decomposition and production (Millennium Ecosystem Assessment, 2005). Therefore, it would be practical to prioritise sites with greater diversity.

Another concept that contributes to ecological integrity is representativeness. Ecological representativeness was constructed to preserve samples of all classes of natural landscapes that contribute to its character, encouraging the restoration of the most degraded environments to prevent the loss of diversity. Incorporating representativeness in restoration plans promotes the preservation of diversity and the aesthetic quality of landscapes (Molloy, 1980; Norton & Roper-Lindsay, 2004; Reza & Abdullah, 2011). In New Zealand, representativeness is measured by comparing an environment with what likely existed before European settlement in 1840 (Norton & Roper-Lindsay, 2004). Classification systems, including Land Environments New Zealand (LENZ), have been used to define ecosystem patterns and representativeness at different scales (Norton & Roper-Lindsay, 2004). Despite ongoing discussions (Coad *et al.*, 2009; Cao *et al.*, 2002), protected natural areas in New Zealand seriously under-represent the full range of natural ecosystems, particularly lowland and coastal environments (Awimbo *et al.*, 1996; Saunders & Norton, 2001). Given the scale of this study and limited resources available under the *Nature in the City Strategy*, the representativeness criterion considers landforms rather than ecological units. In Hamilton City, indigenous vegetation cover is mainly found in gullies, the only adequately represented landform under the 10% goal. In contrast, peatlands, alluvial plains and hills are severely under-represented (Chapter 2).

Connectivity also contributes to ecological integrity and is employed in restoration projects to reverse the effects of fragmentation (LaPoint *et al.*, 2015; McRae *et al.*, 2012). Sites that improve connectivity through green (terrestrial) or blue (aquatic) corridors are positively associated with dispersal, gene flow, diversity, ecosystem stability and climate change mitigation (Rudd *et al.*, 2002; LaPoint *et al.*, 2015). Scattered native vegetation fragments in cities are particularly crucial for connectivity, providing havens for remaining biodiversity to travel between metapopulations (Ignatieva *et al.*, 2011; Rudd *et al.*, 2002). In Hamilton City, the gully systems form a network and connect existing vegetation to the Waikato River, which flows through the centre of the city. The restoration of reserves that abut the gullies would further enhance connectivity.

### 3.3 Indicator species

The presence of naturally regenerating indicator species also signifies the ecological integrity of a site. Indicator species have been defined as the most characteristic species commonly found across the sites of interest (Dufrêne & Legendre, 1997). The identification of species with high fidelity to a specific set of sites has been broadly accepted by ecologists to draw attention to biodiversity 'hotspots' and high-functioning ecosystems worthy of conservation. However, the methods of selecting these indicator species vary significantly, depending on their application. For example, the analysis of common species can reveal distinct distribution patterns considering their larger databases, although rare or satellite species often mark biodiversity hotspots (Lehmann *et al.*, 2002). Studies of indicator species have primarily focused on the abundance of species (Dufrêne & Legendre, 1997; Diekmann, 2003). Nevertheless, sites with high species richness do not necessarily have greater ecological value because rare species may be excluded (Dufrêne & Legendre, 1997). Consequently, some ecologists have modelled species that functionally represent an ecosystem (Ricotta *et al.*, 2020; Azeria *et al.*, 2020) or species combinations rather than the effect of individual indicator species (De Cáceres *et al.*, 2012).

In this study, indicator species distinguish native vegetation patches on a natural successional trajectory, signalling superior health and performance. Succession is the natural change in species composition, which ecological restoration practitioners manipulate to attain the best biodiversity outcomes (Walker *et al.*, 2007). Sensitive species were also selected that prefer damp, shaded sites or indicate biotic complexity as a part of less common forest tiers. Various attributes were used to determine these species, including life forms, habitat and frequency in Hamilton City (Appendix 3.2). As a foundation, plants considered characteristic species of numerous ecological units in Hamilton were noted (Clarkson *et al*., 2007a). Species were selected to represent dominant life forms in Hamilton City, including ferns, fern allies, tree ferns, shrubs, trees and lianes. While many of these groups are not abundant in the city, they are important indicators of forest health, signalling the presence of more complex vegetation structures (Baars *et al.*, 1998). Additionally, the distribution and frequency of identified species across Hamilton City were considered using iNaturalist NZ (hereafter iNaturalist). Ferns such as *Blechnum filiforme* and tree ferns, such as *Dicksonia fibrosa,* were also included due to their critical role in forest succession and health (Overdyck & Clarkson, 2012).

Chosen indicator species include *Leptopteris hymenophylloides*, *Blechnum chambersii*, *Blechnum filiforme*, *Trichomanes venosum*, *Tmesipteris elongata*, *Dicksonia fibrosa*, *Coprosma autumnalis*, *Fuchsia excorticata*, *Melicytus ramiflorus* and *Passiflora tetrandra*. The ferns *Leptopteris hymenophylloides* and *Blechnum chambersii* are found throughout New Zealand, from lowland to montane forest, preferring damp, shaded banks alongside streams. As native seeds only persist in the seed bank for a few years, New Zealand's urban forests are commonly dominated by wind-dispersed species such as ferns (Overdyck & Clarkson, 2012). *Blechnum filiforme* is found in the North and South Islands of New Zealand, common in wet lowland and coastal forests on the ground as a juvenile and eventually as an epiphyte. It is one of few high climbing ferns, indicating forest complexity. *Trichomanes venosum* is found throughout New Zealand as an epiphyte, typically in wet forests. The fern ally *Tmesipteris elongata* has a wide distribution throughout New Zealand, from lowland to montane environments, especially on tree ferns (Brownsey & Smith-Dodsworth, 2000). These epiphytes indicate overall ecological integrity and productivity due to their sensitivity to environmental stress, role in nutrient cycles, provision of shade and food sources for other organisms (Bartels & Chen, 2012).

*Dicksonia fibrosa* is found across the country but mainly in the sub-canopy of lowland forests in the North Island's central districts. This tree fern is tolerant of frost and temperatures as low as -8°C (Warrington & Stanley, 1987), highlighting cooler sites in the city with desirable conditions such as shade and shelter. Tree ferns are a conspicuous feature of New Zealand forests and have an essential role in forest dynamics and function, influencing nutrient cycling and preventing the establishment of shade-intolerant seedlings (Brock *et al.*, 2016). *Coprosma autumnalis* is an endemic shrub found throughout the North and South Islands in sheltered, shady sites with high rainfall (de Lange, 2021). *Fuchsia excorticata* occurs throughout the country in damp, disturbed lowland to mid-montane environments such as forest margins, on slips and along streams (Dawson & Lucas, 2016). This endemic tree provides an essential nectar reservoir for birds, including tūī, bellbirds and silvereyes. *Melicytus ramiflorus* is abundant across New Zealand, mainly in the understory of lowland forests on moist soils. Finally, *Passiflora tetrandra* is an endemic liane found in lowland forest across the North Island, down to Banks Peninsula. This liane climbs up to ten metres, connecting tiers, indicating forest complexity and ecological integrity. Lianes can signify forest maturity as they require a significant basal area for colonisation and stable humidity (Baars *et al.*, 1998).

### 3.4 Methods

Optimal ecological restoration sites of Hamilton City were spatially assessed and prioritised using QGIS (quantum geographic information system) version 3.16.4-Hannover. QGIS was employed as a spatial platform to amalgamate key information and determine the ecological condition of sites for prioritisation. All layers were manipulated in QGIS with geoprocessing tools, including clipping, symmetrical difference and intersection tools. Data was collated from numerous databases to assess eight ecological criteria at each gully and reserve site. The eight criteria selected for this study included species composition, natural wetland extent, species richness, ecological connectivity, size, landform representativeness, the presence of naturally regenerating indicator species and total site vegetation cover.

The city's current indigenous vegetation cover and the total vegetation cover of each site were extracted from WRC's Biodiversity Inventory (2021). Areas dominated by indigenous vegetation were removed from potential sites using the Biodiversity Inventory to identify gully and reserve areas that could be restored. For the landform representativeness criterion, soil classes (Bruce, 1979; Manaaki Whenua, 2020) were split into landforms. The gullies and reserves layers were provided by HCC for the connectivity and size criteria.

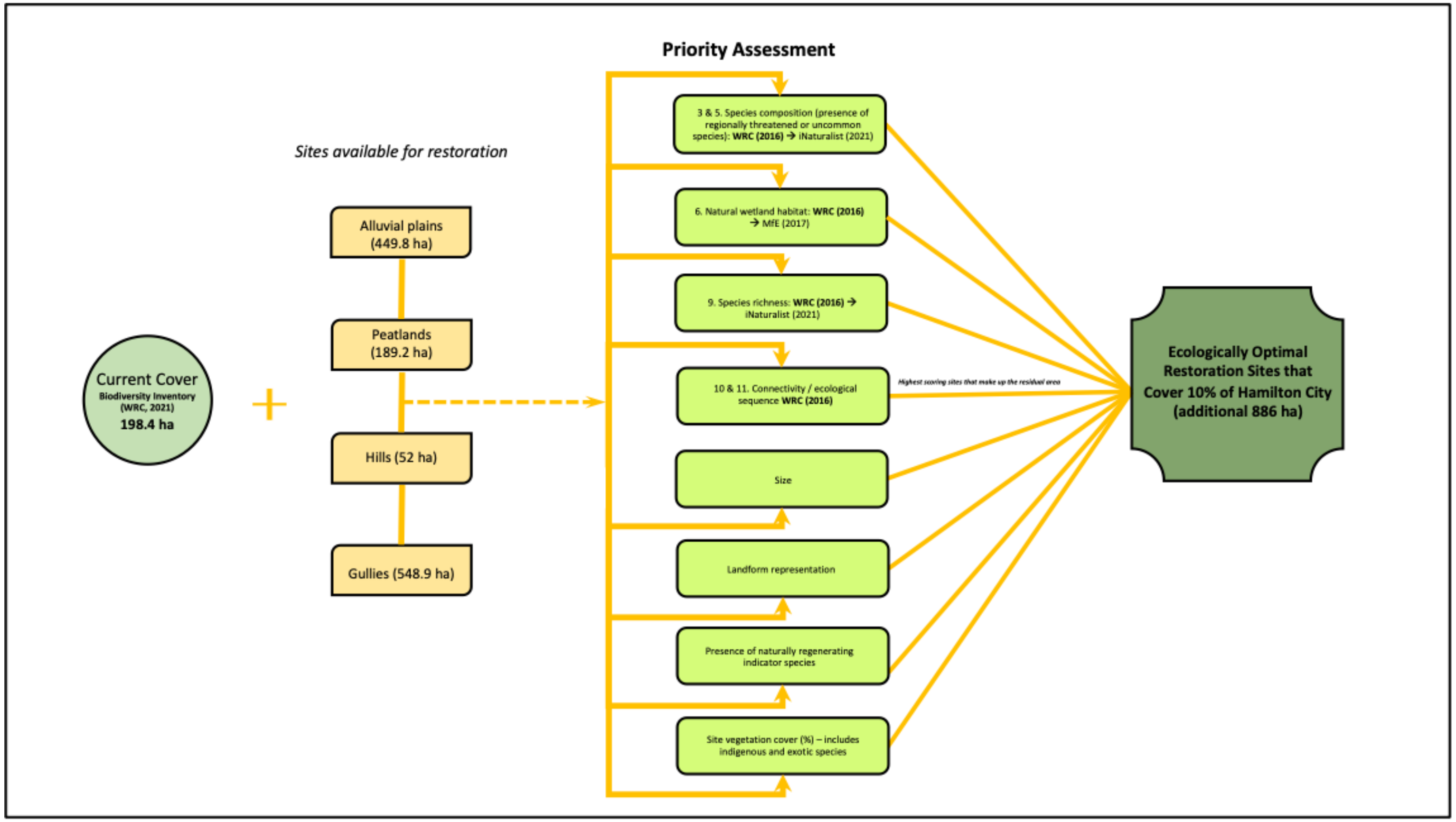



Figure 3.1: A prioritisation framework for the potential gully and reserve restoration sites in Hamilton City using eight ecological criteria. Gully and reserve sites not dominated by indigenous vegetation of all four landforms were scored on each ecological criteria; those with the highest total score were prioritised (Appendix 3.1). Species richness, natural wetland extent and connectivity criteria were derived from WRC's (2016) significant natural areas (SNAs) assessment, where the numbers ascribed to the first four criteria align with the SNA documentation. The size and landform representativeness criteria were modified from WRC's (2018) LIBS document. Species composition, the presence of naturally regenerating indicator species and total vegetation cover criteria were added independently.

The property tiles layer from Land Information New Zealand (LINZ, 2021) split the gullies into publicly and privately-owned properties by overlaying the two layers with the clip tool in QGIS. Data from iNaturalist was employed for the species richness, composition and the presence of naturally regenerating indicator species criteria. Research-grade observation data points were assembled as layers using the delimited text setting in QGIS. Species richness was calculated with a vector analysis tool that counts points (native vascular species) in each polygon (site), and species per ha for each site was found with the open field calculator. The presence of uncommon and indicator species was manually added to each site by overlaying the iNaturalist point data with the gullies and reserves. The natural wetland extent of each possible restoration site was acquired from the Ministry for the Environment's 2017 layer and calculated with a vector analysis tool. The property tiles and natural wetland extent layers were downloaded from Koordinates, while the rest were provided separately by the respective organisations.

Prioritisation of the city's potential restoration sites was conducted with the simultaneous assessment of eight criteria (Figure 3.1). Each criterion was assigned a standardised scoring system (Appendix 3.1) modified from similar regional assessments (WRC, 2018; WRC, 2016); sites with higher total scores were prioritised. Half of the criteria in the tool, including species composition and richness, natural wetland extent and ecological connectivity, were obtained from WRC's (2016) criteria for determining SNAs. Other criteria, including size, landform representativeness, presence of naturally regenerating indicator species and the total vegetation cover of a site, were added independently. Some of the data, including the presence of indicator species, required assortment and manipulation to ensure that each data point represented a naturally regenerated individual. Indicator species, species richness and composition data were downloaded from iNaturalist on 01.12.21.

Another layer was created in QGIS from the assessment of the eight criteria, constituting sites with the highest scores in Hamilton City, satisfying the area required to achieve the 10% goal (886 ha). The 873 sites representing the 886 ha were divided into five prioritisation categories, with a similar area for each category, to suggest a staged approach for implementing restoration projects. The prioritisation map was formatted in the attribute table, layer properties, style pane and layout manager of QGIS for presentation (Figure 3.2).

### 3.4.1 Criteria selection

Eight ecological (physical and biotic) criteria were selected to prioritise possible restoration sites from Hamilton City's reserves and gullies. The criteria selected include vascular plant species richness, vascular plant species composition, vascular plant indicator species, vegetation cover, patch size, ecological connectivity, landform representativeness and natural wetland extent. Each criterion is defined, the data source described, its use is justified, and the score range is provided below.

Species richness is the number of vascular species recorded at a site per hectare. The data was sourced from iNaturalist on 01.12.21. Species richness is often used as a selection criterion because it indicates diversity and can support biodiversity conservation (Pearman & Weber, 2007). In this assessment, species richness ranged between 0-85 species per ha. About 3,365 sites (94%) are depauperate, with no observed indigenous plants in the iNaturalist data. For this criterion, the greater the number of observed species, the higher the site's score (range of 1-5).

Species composition examines the prevalence of certain species at each site. The data for this criterion was sourced from iNaturalist on 01.12.21. The 25 uncommon species selected for Hamilton City were *Arthropteris tenella, Asplenium gracillimum, Astelia grandis, Blechnum colensoi, Coprosma rhamnoides, Coprosma rigida, Cranfillia fluviatilis, Dianella haematica, Dianella nigra, Elaeocarpus hookerianus, Elatostema rugosum, Gleichenia microphylla, Leptopteris hymenophylloides, Melicope simplex, Melicytus micranthus, Metrosideros fulgens, Mida salicifolia, Nestegis lanceolata, Olearia rani, Pellaea rotundifolia, Phlegmariurus varius, Rhabdothamnus solandri, Sparganium subglobosum, Syzygium maire* and *Typha orientalis*. These species were selected as they are native to Hamilton but locally uncommon. They provide opportunities to conserve species that may otherwise become locally extinct. Approximately 33 sites (0.9%) had one or more iNaturalist observations of these species. Sites hosting more of these species received a higher score for this criterion (range of 1-5).

Indicator species are the most characteristic species commonly found across the sites of interest (Dufrêne & Legendre, 1997). The data for this criterion was collected from iNaturalist on 29.11.21. The selected vascular plant species include *Leptopteris* *hymenophylloides, Blechnum chambersii, Blechnum filiforme, Trichomanes venosum, Tmesipteris elongata, Coprosma autumnalis, Dicksonia fibrosa, Fuchsia excorticata, Melicytus ramiflorus* and *Passiflora tetrandra*. In this study, indicator species were chosen to identify sites on a desired successional trajectory towards indigenous vegetation dominance, typically preferring cool, humid or damp and shaded conditions (Appendix 3.1). Scores for this criterion were based on sites supporting between 0 and 10 indicator species; the more indicator species observed at a site, the higher its score (range of 1-5).

The total vegetation cover criterion examined the proportion of woody vegetation at each site, including native and exotic species. The data for this criterion was obtained from the Biodiversity Inventory (WRC, 2021). Vegetation cover inclusive of exotic species provides favourable conditions for native plants to establish, such as cooler, shaded sites that can retain moisture. For example, Totara Park in St Andrews maintains greater native diversity than other open or exposed sites like Tauhara Park in Rototuna. Sites with a higher proportion of vegetation cover received a higher score for this criterion (range of 1-5).

The size criterion determined the area of each site not dominated by native vegetation to signal its restoration potential. The data for this criterion was sourced from HCC's gully and reserves layers. Restoration benefits multiply with the size of a site (Chazdon & Guariguata, 2016). The size scoring used in this study was adjusted to fit the sites examined in Hamilton City. These areas ranged from 0.001 ha to more than 100 ha, although most sites were less than one hectare. Larger sites received a higher score for this criterion (range of 1-5).

Ecological connectivity is the connection of sites that enables the unimpeded movement of species (Beier *et al.*, 2011). The data for this criterion was manually created in QGIS using HCC's gully and reserve layers to identify whether a site is connected to another. Ecological connectivity was included in this assessment as it is crucial for maintaining floral diversity in urban environments (such as Hamilton City) where native vegetation is rare and fragmented (Yu *et al.*, 2012; Bierwagen, 2007). Without ecological corridors, isolation and the gradual loss of diversity are imminent (Rudd *et al.*, 2002). About 471 sites (13%) were connected to either a gully or reserve. Sites adjoining another reserve or gully received a higher score for this criterion (range of 1-2).

Landform representativeness is a concept employed to preserve samples of all classes of natural landscapes that contribute to their character (Molloy, 1980). The data employed for this criterion was sourced from the previous representativeness analysis (Chapter 2). Improving landform representativeness in Hamilton City could halt local extinctions, gradually enlarge the range of ecological units, and encourage the reinstatement of species they naturally host. The least represented landforms in Hamilton City received higher scores for this criterion. Therefore, sites received increasing scores for comprising landforms in the following order: gullies, hills, alluvial plains, and peatlands (range of 1-4).

The natural wetland extent criterion represented the proportion of each site likely dominated by wetland vegetation before humans arrived. The data for this criterion was taken from the Ministry for the Environment's 2017 layer in Koordinates. Although wetlands constituted about 13% of Hamilton City before European settlement in 1840, less than one per cent of those wetlands remain (Leathwick *et al.*, 1995). These systems provide invaluable ecosystem services, including water purification, habitat for native fauna, carbon sequestration and the mitigation of floods and drought (Mitsch *et al.*, 2015). Hence, sites that would have naturally comprised a higher proportion of wetlands obtained a higher score for this criterion (range of 1-3).

### 3.5 Results

This assessment identified 873 sites with the most intact ecological integrity that constitute the remaining area to restore for Hamilton City to reach a minimum of 10% indigenous vegetation cover (886 ha). Prioritised sites were split into five categories of a similar area (Figure 3.2). Most sites that received high ecological scores were found in the city's east, such as the Mangaonua and Kirikiriroa gullies. Although the total area of each category is similar, the number of sites varies significantly. The highest priority category (red) supports just 11 sites, whereas the lowest (blue) contains 321 sites. The proportion of gullies to reserves differs across the categories, ranging from the second category (orange) entailing sites that are 67% gullies and the fourth category (green) containing 91%. The number of gullies exceeds reserves across all categories. However, the second, fourth and fifth (blue) categories include a larger area of reserves than gullies (click here for the list of prioritised sites and GIS layers).

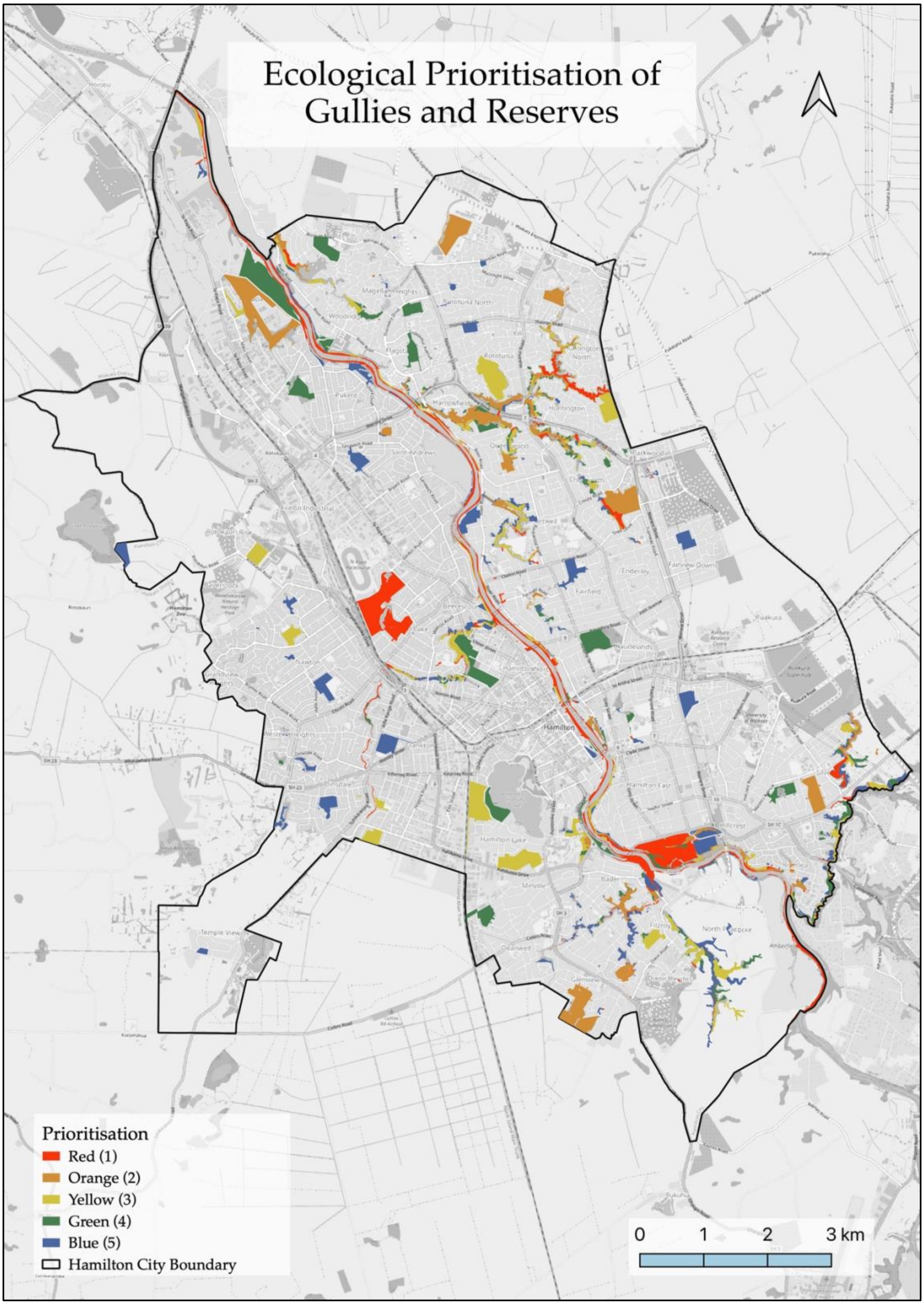



Figure 3.2: The prioritisation of potential gully and reserve restoration sites in Hamilton City. Site prioritisation was conducted using eight ecological criteria (physical and biotic) and split by a similar area into five prioritisation categories. Areas dominated by indigenous vegetation were excluded from the sites using the Biodiversity Inventory (WRC, 2021).

Sites in the first category with the best ecological integrity, comprising the top 190 ha, include three reserves and eight gullies. It entails the smallest number of sites but the largest area of the categories. The reserves include Hamilton Gardens (29 ha) and Hammond Park (0.6 ha) in Hillcrest, and Minogue Park (39 ha) in Forest Lake. Although small, the Hammond Park section supports locally uncommon species such as *Astelia grandis* and *Syzygium maire*, with more than 21 native species per hectare, is connected to the nearby gully and Waikato River and hosts uncommon *Fuchsia excorticata, Trichomanes venosum*, *Tmesipteris elongata*, *Blechnum filiforme*, *Passiflora tetrandra*, *Blechnum chambersii* and *Dicksonia fibrosa.* The eight publicly owned gullies include the major riverside gully system (102 ha), the River Road north gully (two hectares), two Puketaha Astelia gullies (two hectares each), the Kirikiriroa gully Huntington arm (six hectares), Porritt Stadium (three hectares), Mangaonua (four hectares) and the gully north of the Pukete bridge (0.3 ha).

The second category includes about 180 ha with 33 gullies and 16 reserves. Eleven of these gullies are privately owned, encompassing nearly seven hectares, with all except two sites less than one hectare. The Kirikiriroa and Manganoua gullies are central features of this category. For example, the Kirikiriroa gully section near Rototuna School has high native richness with indicator species such as *Blechnum chambersii* and *Blechnum filiforme*. Other significant sites include the 1.8 ha River Road north gully, which supports uncommon *Blechnum colensoi* and a privately owned 14 ha gully in Mangaonua gully. The size of the reserves ranges from 0.06 ha (Munro's Walkway) to 22 ha (Resthills Park). Totara Park is the highest-scoring site, with more than 20 native species per hectare, five indicator species, one uncommon species (*Phlegmariurus varius*), and significant vegetation cover. Another noteworthy reserve includes Graham Park, which is part of the alluvial plains, hosts uncommon *Dianella nigra* and one indicator species (*Blechnum chambersii*).

The third category includes 170 sites with 149 gullies and 21 reserves. It is dominated by Mangaonua gully and Kirikiriroa gully sites, although the Waitawhiriwhiri gully is also more prominent in this category. Higher ranking reserves include Mangaiti Sports Park, Fitzroy Park and Edgecumbe Park. Mangaiti Sports Park received the highest score in this category. It is connected to the Kirikiriroa gully, is a part of the alluvial plains landform, supports two indicator species (*Tmesipteris elongata* and *Dicksonia fibrosa*), and contains some mixed vegetation. Fitzroy Park covers more than four hectares, hosts uncommon *Coprosma rigida* and is partially covered by vegetation. Edgecumbe Park only covers 0.4 ha, although approximately 90% of its area comprises mixed vegetation. A Mangaonua gully section (three hectares) and Waitawhiriwhiri gully site (two hectares) received the highest scores as gullies. Although these sites have a high total vegetation cover, they are dominated by exotic species and support relatively poor native diversity.

The fourth category consists of 322 sites, including 293 gullies and 29 reserves. It has the highest proportion of gullies to reserves, comprising 273 small, privately owned gullies. Some of the best scoring reserves in this category are Ashurst Park (eight hectares), Ferrybank (0.4 ha), Jansen Park (11 ha) and Hillcrest Park (six hectares). Ashurst Park is prioritised because of its size and landform (peatlands). However, Ferrybank and Jansen Park support marginally higher species richness and are part of the alluvial plains. Hillcrest Park provides an exceptional opportunity to restore 5.6 ha surrounding a rare 1.5 ha 120-year-old kahikatea forest remnant (Chapter 4). Another important site in this category is Claudelands Park, adjacent to the largest kahikatea remnant in the city (Te Papanui). Claudelands Park provides an opportunity to expand and protect the adjoined bush, which is the largest indigenous vegetation patch in the city (Wallace & Clarkson, 2019), despite receiving a relatively low score due to its lack of native species. The highest scoring gullies in this category include a Mangaonua segment in Riverlea and a privately owned gully in Silverdale (eight hectares), with the latter supporting one indicator species (*Fuchsia excorticata*).

Similarly, the fifth category contains 321 sites with 278 gullies and 43 reserves. The highest-ranking gullies of this category consist of two Mangakotukutuku gully segments and the Waitwawhiriwhiri gully in Edgecumbe Park. The Mangakotukutuku gully sections are partially covered by vegetation, and one is connected with a nearby reserve. The Edgecumbe Park gully has a slightly higher species richness and supports one indicator species (*Coprosma autumnalis*). Key reserves include Bremworth Park, Caernarvon Park and St Andrews Park. Bremworth Park is a part of the hills landform, supports *Coprosma rigida,* and is partially covered by mixed vegetation. Caernarvon Park is also on hills with moderate species richness of more than nine species per hectare. St Andrews Park (six hectares) is dominated by the peatlands landform, but no native plants have been observed here, so it received a reasonably low score.

### 3.6 Discussion

Hamilton City's native habitat has been highly degraded since European settlement in 1840, with less than two per cent of the city covered by indigenous vegetation. Under HCC's *Nature in the City Strategy,* increasing native vegetation cover to 10% by 2050 would improve its ecological integrity markedly. Some restoration benefits include providing habitat for vulnerable species, reducing local extinctions, enhancing connectivity among isolated fragments, and improving landform representativeness. Indigenous vegetation also supplies a surplus of ecosystem services such as climate regulation, water purification and improved air quality, which enhance the well-being of urban dwellers (Mark *et al.*, 2013).

The results suggest an order of priority for restoring gully and reserve sites in Hamilton City. The eight criteria illuminate potential restoration sites with advantageous biotic and abiotic features that could provide the greatest biodiversity rewards. Priority sites constituting 886 ha that would need to be restored for Hamilton City to reach 10% indigenous vegetation cover are displayed (Figure 3.2). Given the significant number of sites that would need to be restored to achieve the 10% goal, five prioritisation categories are provided to assist a staged restoration approach at the landscape scale.

One key finding is that Hamilton City's gullies present a unique restoration opportunity to achieve the 10% target as they comprise a significant proportion (seven per cent) of the city. Restoring the gullies would also result in a significant improvement in ecological connectivity, and as they are not suitable for development, their restoration is more feasible than the reserves. Of the 3,573 examined sites, more than 3,200 were gullies with about 3,000 small, privately owned sections. The gullies typically received high scores for naturally regenerating indicator species, species richness and composition that suggest their superior health. The restoration of the Kirkiriroa and Mangaonua gullies may provide the best 'value for money', as they entail favourable conditions for a broad range of species. Restoring whole systems rather than fragmented sites at the landscape scale is expected to produce greater biodiversity rewards (Chazdon, 2017). The major gully on either side of the Waikato River also presents an opportunity to enhance connectivity between blue and green corridors throughout the city, enabling the movement of species between native fragments. The size of this gully (102 ha) would contribute significantly to the land that would need to be restored for Hamilton City to reach 10% indigenous vegetation cover (886 ha).

Another result was that more ecologically valuable sites generally occur in the city's east, suggesting that restoration projects on this side could generate greater biodiversity rewards and ecosystem services. This difference may result from the industrial centre in the northwest and the comparably smaller Waitawhiriwhiri gully. However, the city's west supports precious peat lakes, including Horseshoe Lake, Lake Rotoroa, Lake Rotokaeo and the fringes of Lake Rotokauri. Vegetation surrounding these lakes comprises a significant portion of extant native vegetation in the city. On a larger scale, restoring native vegetation throughout the city (rather than just on the eastern side) would enhance connectivity between these fragments and regional native reservoirs like Pirongia Forest Park, the Kaimai-Mamaku Forest and Sanctuary Mountain Maungatautari (Clarkson & McQueen, 2004).

Initially, restoring sites in the first category may be sensible, targeting those with the richest diversity and most characteristic features of Hamilton City. There are only eleven sites in the first category, although most cover a large area and are near SNAs with superior ecological health. For example, the two publicly owned Puketaha Astelia gullies lie adjacent to a privately owned SNA, presenting key opportunities to expand and buffer the *Dicksonia squarrosa* forest.

### 3.6.1 Conclusion

This study prioritised gully and reserve sites in Hamilton City, using eight ecological criteria to elucidate the ecological integrity of sites. Selecting the highest scoring sites that satisfy this area would be pragmatic to provide the richest biodiversity rewards and improve ecological integrity. Restoring whole systems, such as the Kirikiriroa and Mangaonua gullies, rather than many fragmented sites would also maximise the benefits of restoration. With 198 ha (1.8%) of current indigenous vegetation, about 886 ha would need to be restored to attain 10% in Hamilton City by 2050. This equates to restoring approximately 32 ha a year. Achieving this target may require a strategy that incrementally establishes restoration projects in the city over the next thirty years. The results from this chapter could inform such a phased strategy. Further studies may combine scoring from social, cultural and economic criteria with these ecological results to support the selection of restoration sites in Hamilton City. Social and economic factors would likely alter the order of priority presented here, and sites not presented from this ecological assessment may still offer significant restoration opportunities.

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# Appendices

Appendix 3.1: The ten indicator species for Hamilton City selected to highlight vegetation patches on the right successional trajectory. The species were chosen based on their life form, habitat and number of research-grade observations in iNaturalist NZ (extracted 29.11.21). Species that prefer shaded, damp and cool microclimates were targeted.

| Indicator Species | Life Form | Habitat Description | Research-Grade iNaturalist Observations in Hamilton City |
|---|---|---|---|
| *Leptopteris hymenophylloides* | Fern | Prefers damp, dark shady places in cooler forest. | 10 |
| *Blechnum chambersii* | Fern | Grows in damp, shaded areas, typically along rivers and streams in lowland forest. | 42 |
| *Blechnum filiforme* | Fern | Commonly grows near gullies in damp, lowland forest on the ground or as an epiphyte. | 80 |
| *Trichomanes venosum* | Fern | Prefers shaded forest with damp conditions and is prone to desiccation (characteristic epiphyte of *Dicksonia squarrosa* and *Cyathea dealbata*). | 45 |
| *Tmesipteris elongata* | Fern ally | Epiphyte on tree ferns (particularly *Dicksonia squarrosa*) | 32 |
| *Coprosma autumnalis* | Shrub | Prefers a shaded site in damp soil. | 21 |
| *Dicksonia fibrosa* | Tree fern | Suited to cold sites. | 40 |
| *Fuchsia excorticata* | Tree | Prefers damp, sheltered sites. | 26 |
| *Melicytus ramiflorus* | Tree | Found in the forest understory, on damp soil. | 68 |
| *Passiflora tetrandra* | Liane | Requires well-drained soil with sufficient moisture in the growing season. | 20 |

Appendix 3.2: Ecological restoration priority scoring framework for Hamilton City's reserves and gullies. Species richness, natural wetland extent and connectivity criteria were sourced from WRC's (2016) significant natural areas (SNAs) assessment, the size and landform representativeness criteria were modified from WRC's (2018) LIBS document.

| Criteria | Description | Score |
|---|---|---|
| Species composition (iNaturalist, 2021) | 1. 0 uncommon species<br>2. 1 uncommon species<br>3. 2 uncommon species<br>4. 3 uncommon species<br>5. 4-5 uncommon species | 1-5 |
| Catchment services: Originally Wetland Habitat (MfE, 2017) | 1. Site had no or only minor wetland cover before the arrival of humans (0-10%)<br>2. Site was partly a wetland before humans arrived (20-80%)<br>3. Site would have been initially a wetland before the arrival of humans (100%) | 1-3 |
| Species richness (iNaturalist, 2021) | 1. Few or no native species present (0-7/ha)<br>2. Insignificant number of native species present (8-14/ha)<br>3. Moderate number of species present (15-21/ha)<br>4. Significant number of native species present 22-29/ha)<br>5. High native species richness (30-36/ha) | 1-5 |
| Connectivity to a gully or reserve | 1. Not connected<br>2. Connected | 1-2 |
| Size | 1. < 0.1 ha<br>2. 0.1 - 1 ha<br>3. 1 - 5 ha<br>4. 5 – 10 ha<br>5. > 10 ha | 1-5 |
| Landform representation | 1. Gullies<br>2. Peatlands<br>3. Hills<br>4. Alluvial Plains | 1-4 |
| Presence of naturally regenerating indicator species | 1. 0-2 species<br>2. 3-5 species<br>3. 6-8 species<br>4. 9-11 species<br>5. 12-15 species | 1-5 |
| Site vegetation cover (%) including indigenous and exotic species | 1. 0-20% cover<br>2. 21-40% cover<br>3. 41-60% cover<br>4. 61-80% cover<br>5. 81-100% cover | 1-5 |
| **Total score** | | Between 8-34. The higher the score, the higher the priority. |

## Chapter 4: Ecological integrity of three kahikatea remnants in Hamilton City

### 4.1 Introduction

*Dacrycarpus dacrydioides* (kahikatea, white pine) is an endemic podocarp found in the lowlands of the North, South and Stewart Islands of New Zealand, reaching up to 600 metres elevation (Dawson & Lucas, 2016). Kahikatea forest typically develops on poorly drained gley and organic soils and can tolerate waterlogging. Kahikatea display several distinct features throughout their lifespan. Juvenile trees have an abundance of short shoots from their leaf axils along the trunk and branches with subdistichous, small, dark green leaves and are shade-intolerant (Philipson & Molloy, 1990). Kahikatea grow up to 60 metres as the tallest tree in New Zealand and can have a trunk as large as two metres in diameter. They shed their lower branches with maturity while the smooth bark flakes off to form thick, black, round segments. Large buttress roots support kahikatea in its preferred swamp environment with a limited supply of oxygen. Male trees have narrow cones, while females produce cones with black seeds 4-5 millimetres long and fruit that ripen from green to red. Kahikatea relies on birds such as *Prosthemadera novaeseelandiae* (tūī) and *Hemiphaga novaeseelandiae* (kererū) for dispersal (Dawson & Lucas, 2016). They provide a range of services, including habitat for vulnerable native fauna, such as the nationally critical long-tailed bat.

#### 4.1.1 Kahikatea forest in New Zealand

Kahikatea forest was once ubiquitous in the lowland basins and a distinct feature of New Zealand (Griffiths & McAlpine, 2017; Wardle, 1974). The natural range of kahikatea forest spreads across most of the North Island and the west and southern areas of the South Island (Singers *et al.*, 2018). Although common across New Zealand, its range has shrunk because of agricultural and forestry pressures on the lowland environment; the west coast of the South Island contains the largest intact section of kahikatea forest (Wilcox, 2010). It is estimated that more than 98% of pre-European kahikatea forest has been lost (Waikato Regional Council [WRC], 2021a; Ausseil *et al.*, 2007; Leathwick *et al.*, 1995; McGlone, 1989). Such lowland forests contain some of the richest assemblages of species in the country despite being seriously under-represented (Dingwall, 1982). Wetlands, including semi-swamp kahikatea forest, are vulnerable to disturbances such as the invasion of *Salix cinerea* (grey willow) and artificial drainage (Griffiths & McAlpine, 2017). The effective management of kahikatea fragments across New Zealand is essential for conservation as they support rich biodiversity and contribute to ecological connectivity.

### 4.1.2 Kahikatea forest in the Waikato region

About one per cent of the original extent of kahikatea forest remains in the Waikato region (WRC, 2019), and just 13% are legally protected (WRC, 2021a). The kahikatea-dominated fragments scattered throughout the dairy landscape in central Waikato only constitute 0.2% of the area (Smale *et al.*, 2005). These remnants demonstrate similar size and age structures, commonly having a core of 350-450 year-old trees surrounded by 80-120 year-old trees (Burns *et al.*, 1999). With a life span of about 450 years and relatively young fragments in the Waikato region, kahikatea are expected to dominate the canopy of these stands for at least another three centuries (Smale *et al.*, 2005).

Kahikatea forest typically grows on flat, fertile land ideal for agriculture and face several threats, including clearance, grazing, the invasion of exotic plants, edge effects and drainage. Half of the remaining kahikatea forests in Waikato are not fenced off from stock (WRC, 2021a). Heavily grazed kahikatea fragments require at least 15-20 years of fencing for major functional groups to recover, and 40 to 50 years of protection may steer a site towards its natural state (Smale *et al.*, 2005). Persistent forest clearance exacerbates edge effects, which increases the vulnerability of fragments to weed invasion and unfavourable microclimatic conditions, including prevailing winds. Kahikatea are also threatened by drainage, which encourages its replacement with other dry land species such as *Podocarpus totara*, *Prumnopitys taxifolia*, *Alectryon excelsus* and *Beilschmiedia tawa* (Bryan, 2012; de Lange, 2014). Despite most kahikatea stands covering less than one hectare in the Waikato, they are some of the region’s last reservoirs of indigenous diversity.

### 4.1.3 Kahikatea forest in Hamilton City

Once a prominent feature of Hamilton City, kahikatea forest has been reduced to just 15 ha (WRC, 2021b). This area constitutes about 17 sites, with the largest remnants including Te Papanui (5.5 ha), Burbush Road (1.8 ha), Hillcrest Park (1.5 ha) and Southwell (1.2 ha). The remaining area resides in patches of less than one hectare (WRC, 2021b). In the city, kahikatea forest is commonly found on recent fertile alluvial soils, such as Te Kowhai silt loam (Smale *et al.*, 2005). They also prefer waterlogged soils of the low rolling hills (footslopes), shallow depressions or swales and narrow gully floors (Clarkson *et al.*, 2007). Protecting these sites is crucial for the conservation of kahikatea forest in the city.

This chapter assesses the state of three kahikatea remnants in Hamilton City, including Hillcrest Park, Totara Park and Grove Park. It suggests site-specific ecological restoration strategies based on the conditions of each site and differences from the reference site (Te Papanui). The objective of this study is to demonstrate how the characteristics of a site can guide the selection of appropriate restoration strategies that direct a site towards its natural state. The following questions were asked:

1. What is the age structure of the kahikatea population at Te Papanui, Grove Park, Hillcrest Park and Totara Park?
2. How does the ecological integrity of these patches, regarding physical and biotic conditions, compare with Te Papanui as the reference site?
3. Which restoration strategy would be appropriate for each site based on its features?

### 4.2 Characteristic species of kahikatea forest

Most restoration projects strive to assist a site's recovery or return it to its original state (Clewell *et al.*, 2004). Therefore, determining characteristic species of specific environments provides crucial information for successful restoration. Six characteristic species lists have been developed for semi-swamp kahikatea forest (Cockayne & Turner, 1958; Burns *et al.*, 1999; Clarkson *et al.*, 2007; Cornes & Clarkson, 2010; WRC, 2019; Landcare, 2019). Canopy species mentioned in most sources include *Dacrycarpus dacrydioides* and *Laurelia novae-zelandiae* with less frequent *Beilschmiedia tawa, Dacrydium cupressinum* and *Prumnopitys taxifolia*. Species in lower forest tiers (ground cover and understory) typically include *Asplenium bulbiferum, Freycinetia banksii, Streblus heterophyllus, Coprosma areolata, Ripogonum scandens, Cyathea dealbata, Dicksonia squarrosa, Melicytus micranthus, Microlaena avenacea* and *Myrsine australis* (Appendix 4.1). The species found within kahikatea forest also reflect the age, seed sources and historical disturbances, including clearance, drainage, grazing, and edge effects (Wilcox, 2010). The natural disturbance regimes responsible for the development of kahikatea forest, like regular flooding, have been irreversibly altered at many sites. Maintaining kahikatea forest in such modified environments requires active management (Hamilton City Council [HCC], 1993), including planting kahikatea itself.

Some native plants are sparsely mentioned in the characteristic species lists despite acknowledgement of their presence in past kahikatea forest (Cockayne & Turner, 1958) and preference for swamp conditions (de Lange, 2014; Clarkson *et al.*, 2007). The evolution of these lists may align with kahikatea forest composition changes caused by anthropogenic activities over the last century. For example, forest clearance and drainage have considerably altered remaining kahikatea forest conditions and species assemblages. With the visible modification of New Zealand's natural environment and extinction of frugivorous birds, including *Dinornis* spp. (moa), *Turnagra capensis* (piopio) and *Heteralocha acutirostris* (huia), many heavy-seeded plants, have become entirely dependent on kererū for dispersal (Clout & Hay, 1989; McEwan, 1978). The combination of habitat modification, habitat loss and species extinction has restricted the distribution and depleted the full range of kahikatea forest characteristic species.

One species thought to have been abundant in kahikatea semi-swamp forests (Cockayne & Turner, 1958; de Lange, 1989; de Lange, 2014) but is rarely mentioned as a characteristic species is *Elaeocarpus hookerianus* (pokaka) (WRC, 2019; Burns *et al.*, 1999; Landcare, 2019). Pokaka is a cold-tolerant species often found in alluvial forests, on valley floors, and in damp, well-draining soils. Like kahikatea and *Laurelia novae-zelandiae,* it is also tolerant of flooding and shade (Peters & Clarkson, 2010). Based on its habitat, pokaka was likely once a characteristic species of kahikatea forest. Most of its population has been lost, and it seldom regenerates in Hamilton's highly modified environment. As pokaka produces heavy fruit that relies on large birds (predominantly kererū) for dispersal, its distribution has been restricted. By defining characteristic species as those abundant in current fragments (WRC, 2019), characteristic species of kahikatea forest before anthropogenic disturbances may be excluded. Future studies should carefully consider the selection of characteristic species to ensure a restoration site follows the desired trajectory towards as full species occupancy as practicable.

## 4.3 Methods

### 4.3.1 Site selection

Based on their existing features and restoration potential, three sites were selected, including Hillcrest Park, Totara Park and Grove Park. Some of the initial requirements of the sites were that they are publicly owned and include a kahikatea remnant because restoring sites with existing vegetation as nuclei is sensible (Clarkson & Downs, 2001). All three sites also comprise soils suitable for kahikatea semi-swamp forest (Clarkson *et al.*, 2007), are significant natural areas (SNAs) (Cornes *et al.*, 2012) and adjoin areas without indigenous vegetation, thereby providing restoration opportunities. Te Papanui, formally known as Jubilee Park and commonly known as Claudelands Bush (hereafter Te Papanui), was chosen as the notional reference site because it is the largest indigenous vegetation patch and most ecologically intact remnant of semi-swamp kahikatea forest in the city (Cornes *et al.*, 2012).

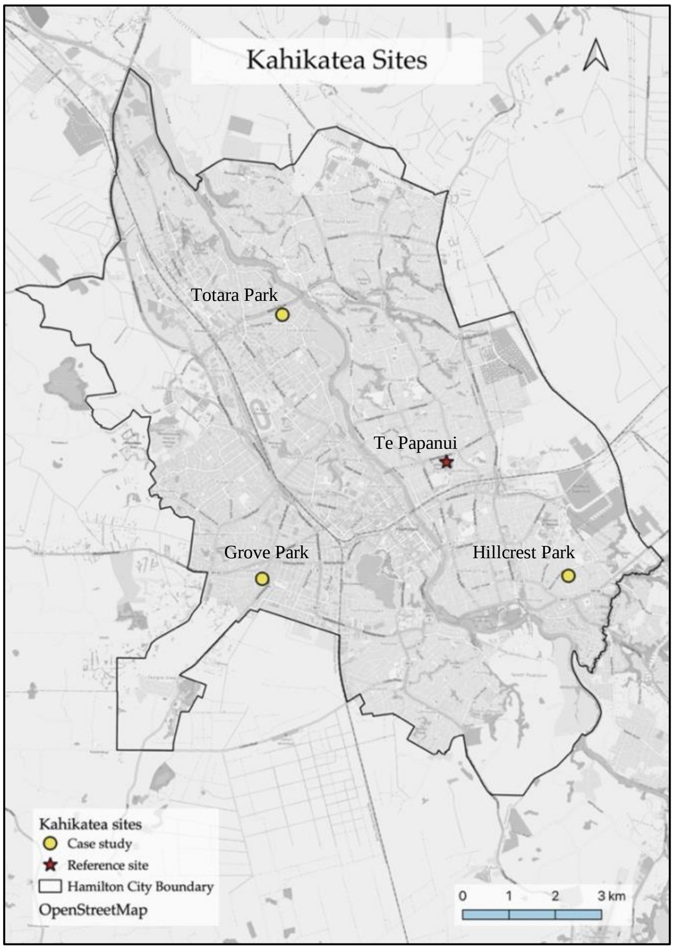


Figure 4.1: Location of the three kahikatea case studies and reference site. Totara Park is in the northwest, Grove Park is in the southwest, and Hillcrest Park is in the southeast of Hamilton City. Te Papanui is the reference site in the central-eastern side of the city.

### 4.3.2 Site descriptions

Te Papanui (the reference site) is the largest indigenous vegetation remnant in Hamilton City at about 5.2 hectares (ha). It is dominated by the shallow depressions ecological unit, which suits semi-swamp kahikatea forest. The kahikatea stand has endured significant threats, including clearance, drainage, invasive plant species and grazing (Whaley *et al.*, 1997), although it continues to lose native species. Active management of the patch, including a windbreak on the western boundary, removal of exotic plants, construction of a raised boardwalk and planting of native species, has slowed local extinctions (Cornes & Clarkson, 2010).

Hillcrest Park supports the third largest kahikatea remnant in Hamilton City, after Te Papanui and Burbush Road (de Lange, 2014). The 7.1 ha site includes a 1.5 ha kahikatea patch surrounded by 5.6 ha of open grass on the east and west. The nearest indigenous vegetation includes the University of Waikato kahikatea stands and Mangaonua Esplanade, which are over a kilometre away (Cornes *et al.*, 2011). The park comprises four soil types: Te Kowhai silt loam in the centre, Kainui silt loam and Rotokauri clay loam on the western side, and Horotiu sandy loam on the eastern side. It also contains three under-represented ecological units: shallow depressions, low mounds and low rolling hills (footslopes). The remnant has been severely degraded with the loss of most understory species by 1972 and drainage since 1977 (de Lange, 2014). Canopy species in the 1980s included *Cordyline australis*, *Laurelia novae-zelandiae*, *Nestegis lanceolata*, *Dacrycarpus dacrydioides*, *Elaeocarpus hookerianus* and one *Elaeocarpus dentatus*. By 1994, Hamilton City Council (HCC) and Hillcrest High School initiated planting, fenced off the remnant and constructed a raised walkway for recreation and educational activities. A scout hall is sited in the south-western side of the forest, and a sports hall sits on the eastern edge. Although the ground cover is sparse, abundant native plants occupy the mid-tier, and the canopy is healthy with few gaps. The east and west boundaries of Hillcrest Park have the widest buffers with *Kunzea ericoides*, *Pittosporum tenuifolium*, *Myrsine australis* and *Podocarpus totara*. Kahikatea have also been planted in the patch, occasionally close to the forest edge.

Grove Park was established as a reserve in 1975 (Kelly, 1997; unpublished manuscript). It is the third-largest kahikatea forest remnant on the western side of the city in Dinsdale, supporting a rare secondary stand of about sixty trees. The site is isolated, with the nearest indigenous vegetation patches 500 metres (Bremworth Park) and over a kilometre away (Till's Landing). Additionally, the park's flat setting, encircled by residential properties, has resulted in its drainage and the unlikely return of a high-water table. The site is only 0.3 ha, with 0.1 ha of grass on its east and west that could be restored. Its Te Kowhai silt loam soil supports kahikatea forest (Smale *et al.*, 2005), and the shallow depressions ecological unit of the alluvial plains is severely under-represented in Hamilton City. The ground cover primarily consists of leaf litter. Also, the understory is mostly bare amid some native plantings that began in 2003, such as *Podocarpus totara*, *Myrsine australis*, *Coprosma autumnalis*, *Carpodetus serratus*, *Blechnum parrisiae*, *Piper excelsum*, *Artistotelia serrata*, *Geniostoma ligustrifolium*, *Alectryon excelsus* and *Melicytus micranthus*.

Totara Park is in the northwest suburb of St Andrews in Hamilton City. Surrounded by residential properties and roads, the park is more than 500 metres away from any indigenous forest (Cornes *et al.*, 2011). It is a grey willow and kahikatea forest, hosting the best-regenerating kahikatea swamp forest in the city. In 1969, the site was mined for sand, clearing most vegetation and enduring substantial modification (Coleman, 2010). Eventually, HCC altered the drainage system and enabled a functional flooding regime with small pipes that supported the development of the wetland. The canopy is dominated by grey willow with emergent kahikatea in the central gully bottom or wetter sections of the park that retains a high water table for most of the year (Downs *et al.*, 2000). The 2.7 ha site comprises two distinct environments: a gully (terrace scarps) and a depauperate grassy park with peaty soils. The vegetated section of the park is comprised of Tamahana, Kaipaki peat and Kirikiriroa complex soils, whereas the open side of the park is dominated by Kaipaki peaty loam.

### 4.3.3 Data collection

All 84 research-grade kahikatea observations within Hamilton City were downloaded from iNaturalist NZ (hereafter iNaturalist) on 05.11.21. The observations were carefully assessed to determine if the individuals established naturally or were planted. A conservative approach was taken to which observations were retained based on the descriptive notes and photographs provided for each plant. The use of research-grade iNaturalist data also meant species were identified by a minimum of two contributors and have been subject to wider scrutiny.

The diameter at breast height (DBH, 1.35 m) of the kahikatea stems at each site were measured. The size and number of naturally regenerating individuals at these remnants was somewhat limited, so an attempt was made to measure all kahikatea present at each site rather than using a quadrat sampling technique. Species richness and composition were also recorded by observations uploaded to iNaturalist. Again, a quadrat sampling method was not employed as many of the understory species at Hillcrest Park and Grove Park were planted and have not naturally regenerated. However, Totara Park's well-established kahikatea saplings demonstrating recruitment were recorded by laterally traversing across the park with a sampling intensity of approximately 40% (Appendix 4.2).

Kahikatea Green Wheels (WRC, 2019) were used to identify differences in conditions and species assemblages between Te Papanui and the case studies. Most of the 31 attributes in the tool were examined with site visits besides the extraneous indicator animals and mammalian predator attributes. Research-grade observations of indigenous vascular plant species were employed from iNaturalist to complete a Kahikatea Green Wheel (KGW) for each site. The data was cleaned by carefully removing cultivated plants. Waikato Regional Council's (WRC) official spreadsheet was used to generate the KGW diagrams (Appendix 4.3).

#### 4.3.4 Data analysis

The diameter measurements and counts of saplings were used to construct population structure histograms for each site. The DBH data were extracted from Whaley *et al.* (1997) for Te Papanui and Coleman (2010) for Totara Park. Age midpoints were predicted using the DBH classes from Whaley *et al.* (1997) and two existing regression equations. For Te Papanui, Hillcrest Park and Grove Park, the J.R. Leathwick (unpublished) regression equation for Berkley, Hamilton was used for most of the size classes encountered. However, the D.A. McLean (unpublished) regression equation was used for the age midpoint of the youngest size class at Te Papanui, Hillcrest Park and Grove Park as it more accurately predicts the age of smaller trees. For Totara Park, the D.A. McLean (unpublished) regression equation was applied to reveal the midpoint of all size classes because it was developed from the park's data and is better suited to its larger population size and smaller age range. Then, the age midpoints were used to compare each kahikatea population structure (Figure 4.2e). Three kahikatea at Hillcrest Park, Grove Park and Totara Park were cored using standard methodology (Norton, 1998) to verify the fit of the DBH-age relationship from the equations.

On average, the estimated age of the kahikatea using the coring methodology was six years older than the DBH measurements suggested, with a margin of error less than 10% (Appendix 4.4).

- Hillcrest and Grove Park Kahikatea Age Equation (J.R. Leathwick, unpublished):
  $y = 55.127 \ln(x) - 132.240$
- Totara Park Kahikatea Age Equation (D.A. McLean, unpublished):
  $y = 0.4262x + 24.693$
    - Where y (age) is measured in years and x (DBH) is in cm

Life form and epiphyte assessments were conducted for the four sites from research-grade iNaturalist data (Appendix 4.5). Native, exotic and naturalised plant species lists were compiled on 03.02.22 (Appendix 4.6). The official life forms were acquired from a previous assessment of Te Papanui (Cornes & Clarkson, 2010). Finally, planting zone maps based on ecological units were supplied for Hillcrest Park, Grove Park and Totara Park (Appendix 4.7). The ecological unit data layer was extracted from the previous analysis (Chapter 2) and manipulated to fit these sites in QGIS (quantum geographic information system) version 3.16.4-Hannover. The geoprocessing clipping tool was used for the boundary of each site, and the ecological units were differentiated from the properties and formatted for presentation in the print layout pane.

## 4.4 Results

### 4.4.1 Age structure of kahikatea remnants

The DBH of Te Papanui's 371 kahikatea ranged from two to 100 centimetres (cm). The average age was about 60 years, which is younger than Hillcrest Park and Grove Park. Most kahikatea were between 71 and 92 years. Te Papanui's kahikatea structure demonstrated a wider range of ages than Totara Park but a similar structure to Hillcrest Park and Grove Park (Figure 4.2a).

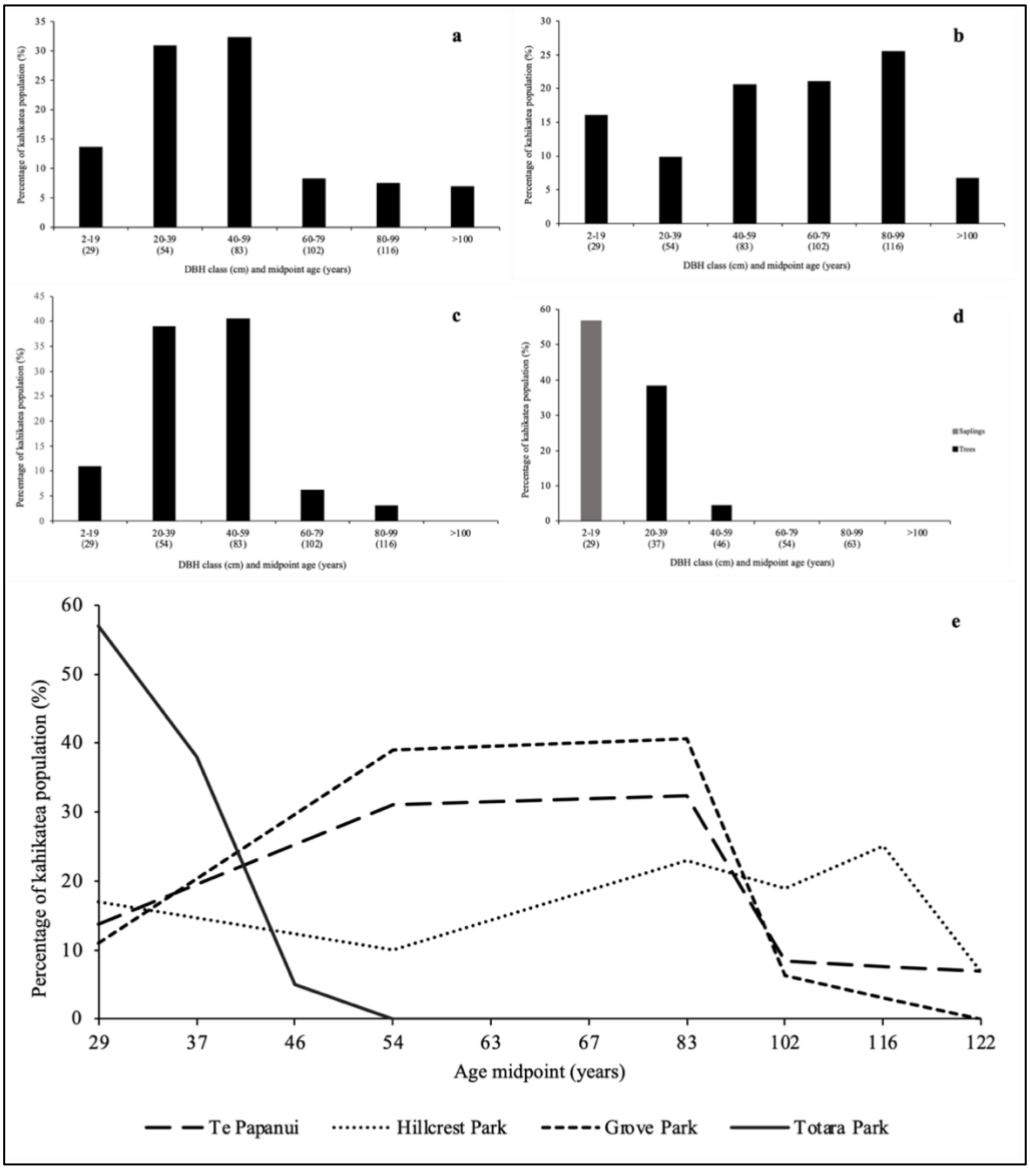


Figure 4.2: Kahikatea stand DBH classes (percentage of population) and predicted midpoint age of Te Papanui n = 371 (a), Hillcrest Park n = 223 (b), Grove Park n = 64 (c) and Totara Park n = 65 (d). Size class data for Te Papanui (the reference site) was sourced from Whaley *et al.* (1997). Ages were predicted from the J.R. Leathwick (unpublished) regression equation for Te Papanui, Hillcrest Park and Grove Park, although the midpoint age of their smallest size class was calculated from the D.A. McLean (unpublished) regression equation because it is a better predictor of the age of small kahikatea. Data was used from Coleman (2010) for Totara Park's age structure, and ages were predicted using the D.A. McLean (unpublished) regression equation. The percentage of kahikatea at each age midpoint for the four remnants is also presented (e). Totara Park is represented by younger age midpoints (29, 37, 46, 54, 63 and 67 years) than Te Papanui, Hillcrest Park and Grove Park (29, 54, 83, 102, 116 and 122 years) due to the use of different DBH-age regression equations.

The DBH of Hillcrest Park's 223 kahikatea ranged between four and 127 cm. The average age was 82 years, which is older than Grove Park and Totara Park. The maximum age was estimated to be 135 years. The age structure of this patch shows that most trees are between 80 and 120 years, and the most common age is 118 years (Figure 4.2b).

The DBH of Grove Park's 64 kahikatea ranged between 14 and 83 cm, with a mean diameter of 42 cm. The average age was 70 years, approximately 12 years younger than Hillcrest Park but 38 years older than Totara Park's kahikatea. From these measurements, the youngest kahikatea was about 19 years, and the maximum age was 130 years. Almost 70% of the kahikatea are predicted to be 60 to 100 years, with the 60 to 70-year age class containing the most trees (Figure 4.2c).

Comprehensive data collected by Don McLean and Emma Coleman at Totara Park (Coleman, 2010) found that the DBH of these kahikatea were between three and 47 cm. Totara Park has the youngest population of the three sites, with an average age of 32 years. The minimum age was approximately 26 years, and the maximum was 45 years, representing a narrower age range than the other case studies. Fieldwork also identified 25 well-established kahikatea saplings demonstrating recruitment (grey bar in Figure 4.2d), defined as individuals taller than 135 cm with a DBH less than four centimetres (Champion, 1988). Hundreds of smaller kahikatea seedlings (<135 cm) were also encountered.

### 4.4.2 Kahikatea Green Wheels

There is a constant need for restoration management standards as planners, managers, and practitioners depend on them to achieve restoration goals. In an attempt to protect the region's kahikatea forest stands, WRC adapted the KGW from the Australasian Ecosystem Recovery Wheel (McDonald *et al.*, 2016). The Ecosystem Recovery Wheel was created to characterise an ecosystem's condition before degradation to support its recovery. It provides standards, using fundamental principles, that land managers can apply to restore ecosystems anywhere in the world. Similarly, the KGW tool uses a five-star rating system to rank a range of attributes relevant to kahikatea forest health and functioning (WRC, 2019). Although this tool used critical concepts from the Ecosystem Recovery Wheel (McDonald *et al.*, 2016), it was specifically modified for kahikatea remnants.

In principle, the KGW was designed for rural kahikatea fragments, so threat attributes including stock access, feral ungulates and agricultural nutrient inputs were not relevant to this study. Instead, the greatest threats to urban kahikatea patches examined in the KGW include exotic plants, local exposure and drainage. For example, Totara Park has abundant exotic plants in the canopy, shrub and ground cover tiers, while the other case studies have very few. However, Totara Park has the most extensive buffer, Hillcrest Park has a moderate buffer despite gaps often revealing the kahikatea, and Grove Park is most exposed to environmental fluctuations with a few *Melicytus ramiflorus* on its edges. Totara Park is the largest of the remnants, followed by Hillcrest Park and Grove Park.

Reference sites provide a model of optimal ecological integrity that have endured minimal degradation for similar sites while planning and evaluating restoration projects (Clewell *et al.*, 2004; Gann *et al.*, 2019). Although no two sites are identical, information about a reference site, such as historical and current species composition, threats, and solutions, can guide the restoration of similar sites towards their natural state. However, a reference site depicts a single state of an ecosystem and may inadequately represent other biophysical conditions specific to a restoration site. In this study, Te Papanui was chosen as the notional reference site as it is the largest indigenous vegetation patch and semi-swamp kahikatea remnant in Hamilton City (Cornes *et al.*, 2012). Its species composition should indicate species gaps in similar local patches. The ecological integrity of Te Papanui was compared with the three case studies using the KGW to identify opportunities to improve their condition.

Most of Hamilton City's primary forest has been lost, leaving small secondary forest patches. Primary forests are defined as "mature natural forests… that retain their natural composition and structure, and have not been completely cleared and re-planted in recent history" (Margono *et al.*, 2014, p. 730). Te Papanui is the only kahikatea remnant in Hamilton City that partly includes primary forest. Alternatively, secondary forests "are forests regenerating largely through natural processes after significant human and natural disturbance of the original forest vegetation… displaying a major difference in forest structure and canopy species composition with respect to nearby primary forests on similar sites" (Chokkalingam & De Jong, 2001, p. 21). The kahikatea remnants at Grove Park, Totara Park, and Hillcrest Park are secondary forest patches.

Te Papanui supports the healthiest kahikatea patch with all three forest tiers intact, hosting rich native flora. It is almost entirely dominated by native plants, and according to the WRC (2019) KGW, it contains 35 characteristic species with three regional pest species and 14 adventive species. Characteristic species found at Te Papanui but not at the other kahikatea remnants include *Oplismenus hirtellus*, *Carpodetus serratus*, *Astelia hastata*, *Asplenium bulbiferum* and *Nestegis lanceolata*. The health of the emergent kahikatea across all sites is excellent, with minimal yellowing or defoliating. Hillcrest Park has two intact tiers, Grove Park has a healthy canopy, and Totara Park is not dominated by native plants in any of its tiers. Based on the KGW, Totara Park supports approximately 19 characteristic species, four pests and 22 other adventive species. About 12 characteristic species were found at Hillcrest Park, followed by five at Totara Park under the KGW. Native plant recruitment is scarce for all sites, although Totara Park supports the best example of regenerating kahikatea in the city. Ecological connectivity is also poor across the sites, with the nearest healthy patch of indigenous vegetation often up to several kilometres away.

Data collected from iNaturalist suggest that Hillcrest Park has about 15 native plant species, including the canopy species of *Dacrycarpus dacrydioides*, *Laurelia novae-zelandiae*, *Cordyline australis*, *Beilschmiedia tawa*, *Nestegis lanceolata* and *Elaeocarpus hookerianus*. Most of the indigenous species in Hillcrest Park's understory were likely planted. No kahikatea seedlings (< 135 cm tall) or saplings (> 135 cm tall, with a DBH < four centimetres) were found during the site assessments suggesting that the kahikatea are not regenerating. A few problematic weeds exist in Hillcrest Park, including *Euonymus japonicus*, *Hedera helix* and *Ligustrum lucidum*.

Grove Park has also faced severe disturbances, including drainage and clearance; it is now a depauperate kahikatea remnant with sixty kahikatea, one mature *Prumnopitys taxifolia* and a handful of planted native species. According to iNaturalist data, there are about eight native plant species and one naturalised species (*Pseudopanax crassifolius x lessonii*). There was no evidence that any native species are regenerating, with no established saplings found during site assessments. The few introduced species include *Laurus nobilis*, *Berberis glaucocarpa* and *Euonymus japonicus*.

Totara Park was found to support 61 plant species, including 41 native and 20 exotic species. The gully's edge conditions, including increased light and well-drained soils, have enabled the establishment of *Melicytus ramiflorus* and *Cyathea dealbata*. Other common native species at Totara Park include *Dacrycarpus dacrydioides*, *Cordyline australis*, *Dicksonia squarrosa* and *Geniostoma ligustrifolium*. The site also contains numerous problematic exotic plants, including *Salix cinerea*, *Zantedeschia aethiopica*, *Lonicera japonica* and *Ligustrum sinense*. A mature *Laurelia novae-zelandiae* in the patch signals suitable habitat and an opportunity to reintroduce more individuals (click here for the KGW spreadsheets).

### 4.4.3 Life forms and epiphytes

The life form analyses using iNaturalist data found that Te Papanui hosts the most groups, followed by Totara Park, Grove Park and Hillcrest Park (Appendix 4.5). The selected life forms included 13 categories: ferns and fern allies, gymnosperm trees, dicot trees, dicot shrubs, dicot lianes, dicot herbs, monocot trees, orchids, grasses, sedges, rushes, monocot herbs and monocot lianes (Cornes & Clarkson, 2010). Te Papanui supports species of all life forms except dicot herbs and rushes, also absent from the case studies. The dominant life forms at Te Papanui were ferns and fern allies, and dicot trees. This trend is primarily consistent with the other sites. Totara Park's native flora includes eight life forms, not including monocot herbs, grasses, monocot lianes, dicot herbs or rushes. Grove Park's assessment identified six life forms but lacked dicot lianes, orchids, grasses, monocot lianes, sedges, dicot herbs and rushes. Finally, Hillcrest Park supported five life forms, but it lacked dicot lianes, monocot herbs, orchids, dicot shrubs, monocot lianes, sedges, dicot herbs and rushes.

While epiphytes have already been accounted for in the life form analysis, they are considered separately here because epiphytes play a prominent role in ecosystem functioning via biomass and nutrient partitioning (Hofstede *et al.*, 2001) and are influenced by stand density and microclimate (Hietz, 1999; Wallace *et al.*, 2017). An epiphyte is a plant growing upon a host that is unconnected to soils and is not parasitic (Moffett, 2000). Life forms that commonly contain epiphytes include ferns and fern allies, shrubs, herbs and orchids. Totara Park hosted the most epiphytes (nine), followed by Te Papanui (six), Hillcrest Park (one), and none were observed at Grove Park. The nine native epiphytes at Totara Park included eight ferns and fern allies (*Asplenium flaccidum, Asplenium polyodon, Asplenium oblongifolium, Microsorum pustulatum, Phlegmariurus varius, Pyrrosia eleagnifolia, Tmesipteris elongata* and *Tmesipteris lanceolata*) and one orchid (*Earina mucronata*). Comparably, the epiphytes at Te Papanui included four ferns (*Arthropteris tenella, Blechnum filiforme, Microsorum scandens* and *Pyrrosia eleagnifolia*), one monocot herb (*Astelia hastata*) and one orchid (*Earina mucronata*). The fern *Pyrrosia eleagnifolia* was the only epiphyte found at Hillcrest Park.

Totara Park and Te Papanui support different epiphytic species aside from *Earina mucronata* and *Pyrrosia eleagnifolia*, which grow on a wide range of hosts. One explanation for the different assemblage of epiphytes at Te Papanui may be the loss of *Dicksonia squarrosa* (wheкī), which was abundant in the mid-1900s (Whaley *et al.*, 1997). Wheкī is a ubiquitous tree fern found throughout New Zealand which provides a prominent microsite for epiphytes (Brock & Burns, 2021; Page & Brownsey, 1986). For example, *Asplenium flaccidum*, *A. oblongifolium*, *Phlegmariurus varius*, *Tmesipteris elongata* and *Tmesipteris lanceolata* were all found growing on wheкī in Totara Park. The damp, cool microclimate of Totara Park also sets it apart from the other sites. Furthermore, epiphytes such as *Arthropteris tenella*, *Blechnum filiforme,* and *Microsorum scandens* that were not seen at Totara Park have colonised lower forest tiers in Te Papanui. The limited presence of epiphytic species at Hillcrest Park and Grove Park is likely due to their drainage and low humidity, which are not conducive to epiphytes (Oliver, 1930).

**4.5 Discussion**

All three case studies provide unique opportunities where mature kahikatea can act as nuclei for extending and connecting patches. The assortment of features at each site should guide the restoration strategy and its application over time. For example, Hillcrest Park encompasses the oldest kahikatea and has the largest area available to restore, covering three different ecological units. Grove Park supports a secondary stand of kahikatea, with the smallest available restoration area of the three case studies. However, it contains the severely under-represented alluvial plains and is a key feature of the western side of the city. Totara Park is the best example of regenerating kahikatea in Hamilton City and offers a considerable area for restoration. The persistence of locally uncommon species in this remnant necessitates a sustained manipulation restoration strategy.

The kahikatea at Hillcrest Park are in reasonable condition, with plantings in the understory and a narrow buffer. The canopy layer is in the best state, with healthy kahikatea. Only one mature *Laurelia novae-zelandiae*, *Nestegis lanceolata*, and *Elaeocarpus hookerianus* still exist in the stand. The dense *Freycinetia banksii* understory in the 1960s (de Lange, 2014) has been completely eradicated. The liane *Ripogonum scandens* has also been lost since the 1990s (Clarkson, 1993; unpublished data). Community groups have restricted exotic plants from establishing and enabled native plants to dominate with an intact canopy tier. However, naturalised native plants, including *Pseudopanax crassifolius x lessonii* and *Hoheria populnea* (de Lange, 2014), have established, and *Asplenium* × *lucrosum* has also been planted.

Hillcrest Park's ground cover has been severely degraded with clearance exacerbating unfavourable conditions like prevailing winds and enhanced light penetration. The shrub layer also lacks several species, with a scarce dicot shrub life form aside from a few mature *Melicytus ramiflorus*. For example, absent characteristic small-leaved species include *Coprosma propinqua*, *Coprosma rotundifolia* and *Coprosma rhamnoides*. Further dicot shrubs typical of kahikatea forest that could be planted at Hillcrest Park include *Coprosma tenuicaulis* and *Melicytus micranthus*. Another characteristic species, *Teucridium parvifolium*, is an at-risk shrub species that would suit the dry kahikatea patch (Burns *et al.*, 1999). The re-establishment of missing life forms at Hillcrest Park, such as lianes and orchids, would necessitate improved semi-swamp conditions. Some lianes found in Te Papanui characteristic of kahikatea forest include *Freycinetia banksii*, *Metrosideros perforata, Parsonsia heterophylla, Passiflora tetrandra* and *Ripogonum scandens*. Orchids were not included in the characteristic species lists, although *Earina mucronata* and *Microtis unifolia* were found in Te Papanui. Only one epiphyte (*Pyrrosia eleagnifolia*) was found at Hillcrest Park.

Modest plantings at Grove Park since 2003 and the control of exotics have contributed significantly to its health. However, artificial drainage has also markedly modified the physical conditions of the park from its original state. Like Te Papanui and Hillcrest Park, it is unlikely that a high-water table will be re-established at Grove Park, given its proximity to residential properties.

Grove Park's canopy is intact with a healthy kahikatea population, one *Prumnopitys taxifolia*, and planted *Carpodetus serratus, Aristotelia serrata* and *Alectryon excelsus*. However, there is minimal ground cover with just one native fern (*Blechnum parrisiae*). The shrub tier comprises a few planted species like *Coprosma robusta*, *Melicytus micranthus* and *Geniostoma ligustrifolium*. Life forms missing from this stand include grasses, sedges, herbs and rushes from the ground cover tier and lianes and orchids from the shrub and canopy tiers.

Characteristic ground cover species of kahikatea forests that may be planted in Grove Park include sedges like *Carex uncinata*, *Carex dissita* and *Carex lambertiana*. Typical epiphytes of kahikatea forest include *Astelia hastata* and ferns like *Pyrrosia eleagnifolia* and *Blechnum filiforme*. Further planting appropriate shrub species such as *Coprosma areolata*, *Coprosma tenuicaulis*, *Melicytus micranthus* and *Melicytus ramiflorus* should improve its ecological integrity. *Teucridium parvifolium,* a characteristic species that grows in dry conditions, has already been planted at Grove Park. Planting additional individuals could improve its population viability while contributing to the stand's diversity. Restoring Grove Park would provide numerous benefits, including strengthened ecological linkages from the southwest of the city to other native patches and the gullies. Extending Grove Park's buffer and planting native species in its ground cover and shrub layers would reduce the edge effects, increase its diversity and improve its ecological health.

Totara Park provides an exceptional example of the effect of a (reinstated) flooding regime on the persistence of native species otherwise rare throughout the city. In contrast to Te Papanui, Totara Park supports species like *Tmesipteris lanceolata*, *Tmesipteris elongata, Dicksonia fibrosa* and *Rhopalostylis sapida*, which prefer its sheltered, damp and cool microclimate. Its richer epiphytic diversity than the other case studies, and Te Papanui highlight the value of restoring Totara Park to protect these species and encourage the establishment of others. Epiphytes such as *Griselinia lucida*, *Pittosporum cornifolium* and *Astelia solandri* could be reintroduced to the site and protected while carefully managing the profusion of troublesome weeds at Totara Park.

Optimising the ecological potential of Totara Park requires the adoption of a manipulative restoration strategy to progressively release native plants from the competition of abundant exotic species. Some of the troublesome weeds include grey willow, *Lonicera japonica*, *Ligustrum sinense*, *Tradescantia fluminensis*, and *Euonymus japonicus*. Suddenly removing all exotic species could alter the cool, damp and sheltered conditions that have enabled the locally rare native species to persist. The adoption of this restoration strategy would be labour-intensive, demanding the careful control of exotics. However, planting native species while removing exotic species would allow kahikatea to dominate the canopy gradually. It would also encourage the persistence of uncommon native species in the other forest tiers.

Regardless of the abundance of exotic plants in Totara Park, the grey willow-kahikatea patch supports the most native species per forest tier of the three case studies. Its native dicot trees include *Aristotelia serrata* and *Schefflera digitata*. The natural establishment of mature *Melicytus ramiflorus* on the northern edge and one *Laurelia novae-zelandiae* suggest it may be practical to plant more individuals of these species. Another characteristic tree that would likely thrive in this environment is *Syzygium maire*. The shrub layer currently includes *Coprosma robusta*, *Coprosma autumnalis* and *Geniostoma ligustrifolium,* which could be enriched to include species such as *Coprosma areolata*, *Coprosma tenuicaulis* and *Melicytus micranthus*. The orchid *Earina mucronata* persists in the patch, and if restored, epiphytes currently at Te Papanui such as *Arthropteris tenella, Astelia hastata*, *Blechnum filiforme,* and *Microsorum scandens* may eventually establish (see Appendix 4.7 for planting zone maps for each case study).

### 4.5.1 Conclusion

This chapter examined three case studies and one reference site (Te Papanui) that support kahikatea remnants in Hamilton City and provide unique restoration opportunities. Kahikatea forest was once ubiquitous in the lowland basins of New Zealand. With less than two per cent of its original extent remaining nationally, one per cent in the Waikato region and only 15 ha in Hamilton City, it urgently needs to be protected. Characteristic species should be based on ecosystems that have experienced minimal anthropogenic disturbance to achieve as full a species occupancy as practicable. Planting species from the missing life forms could fill functional gaps at each site. The leading threat these patches face is artificial drainage, which continues to modify Hillcrest Park and Grove Park. As seen at Totara Park, reinstating a flooding regime can substantially enhance the health of kahikatea forest. Plant pest control will be vital for the successful restoration of Totara Park, requiring a labour-intensive manipulation strategy. Extending the buffer at each small patch would likely mitigate forest edge effects by reducing light intensity and air temperature and increasing the humidity. Despite the limited size of these patches, they provide some of the last opportunities to conserve kahikatea semi-swamp forest in Hamilton City.

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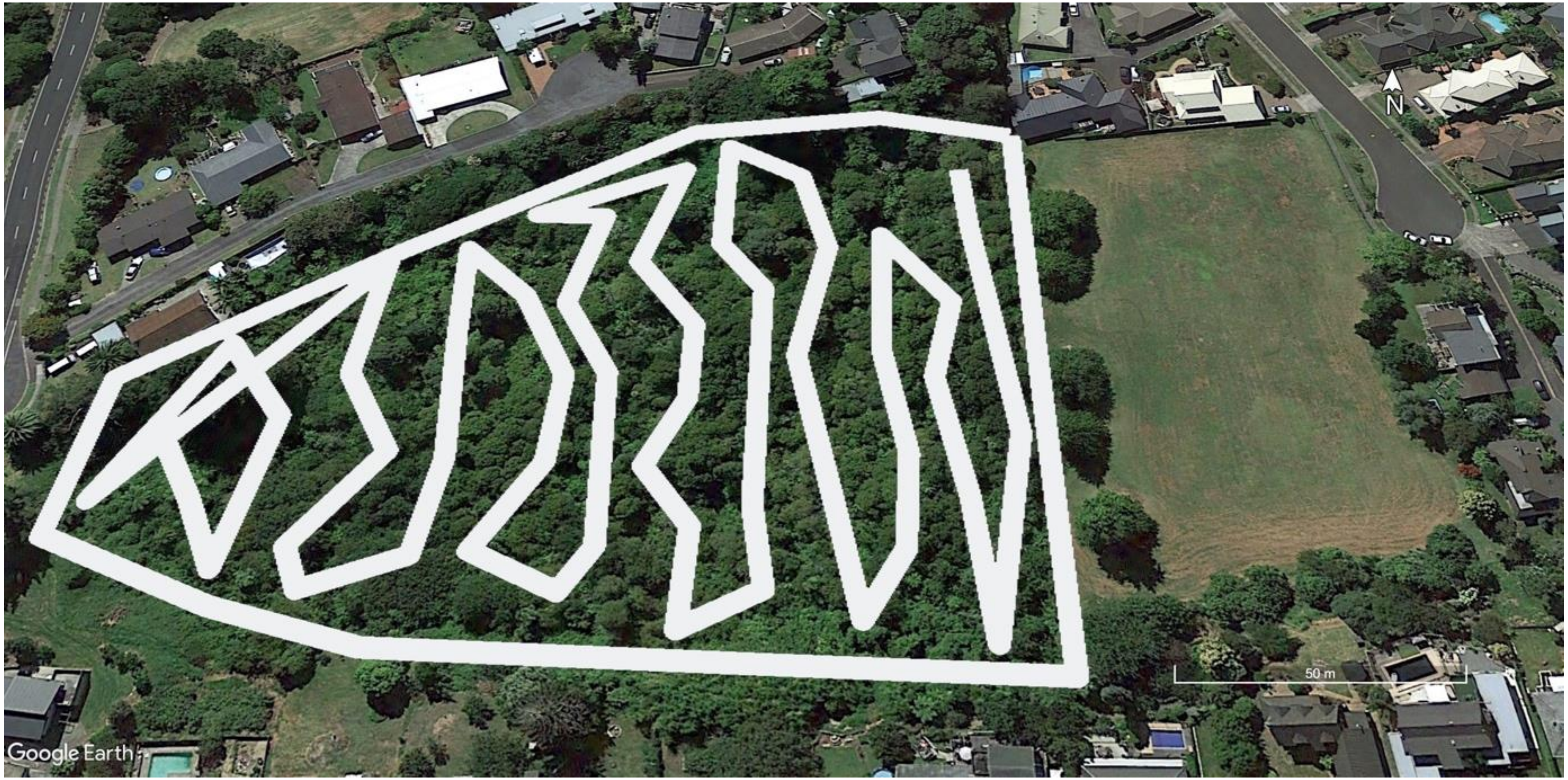
# Appendices

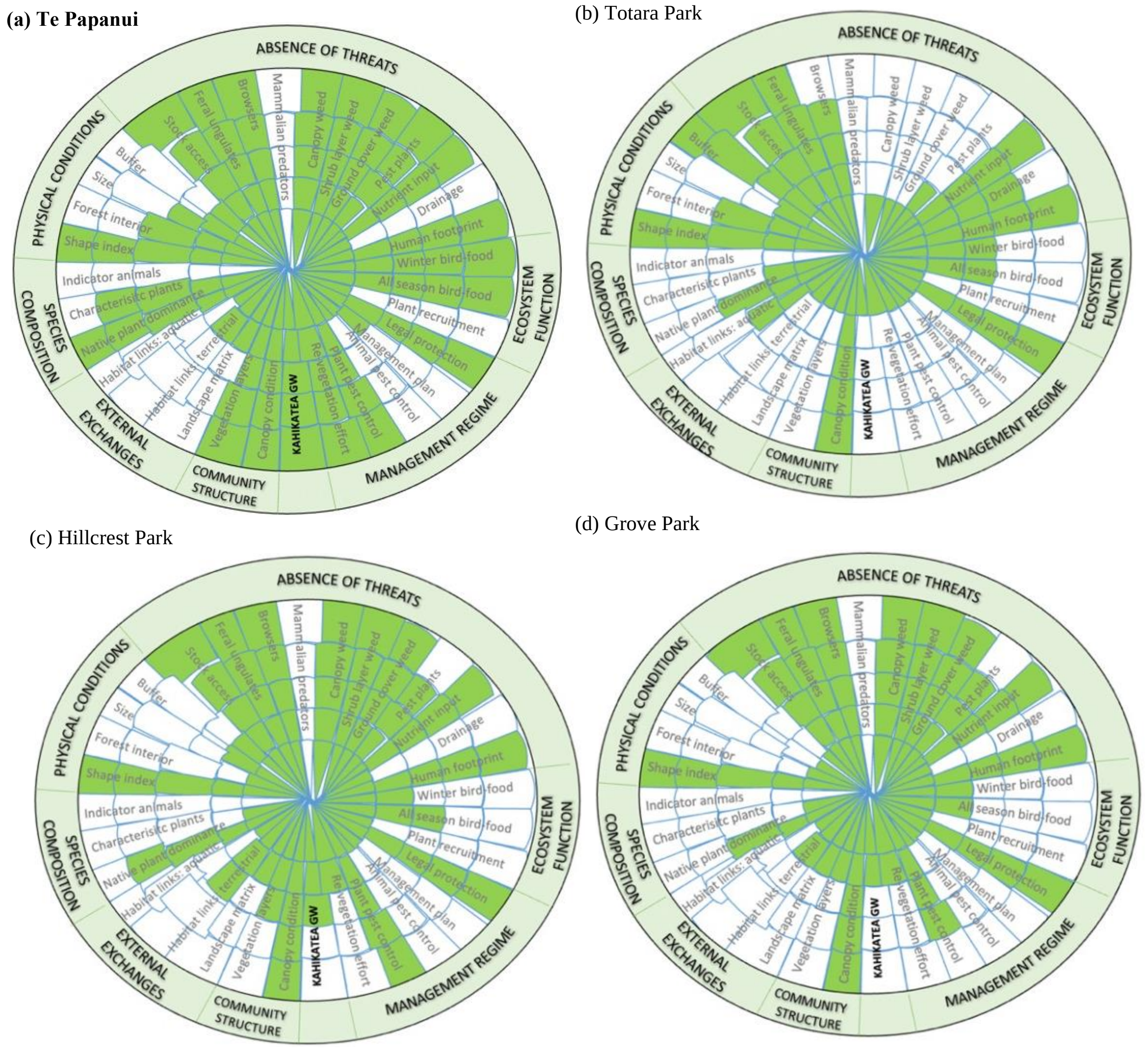
Appendix 4.1: Species considered characteristic of kahikatea forest categorised by the number of times listed from the six sources (Burns *et al.*, 1999; Clarkson *et al.*, 2007; Cockayne & Turner, 1958; Cornes & Clarkson, 2010; Landcare, 2019 & WRC, 2019).

| Times listed | Species |
|---|---|
| 1 | *Acaena anserinifolia, Adiantum cunninghamii, Alseuosmia quercifolia, Austroderia fulvida, Loxogramme dictyopteris, Arthropteris tenella, Asplenium bulbiferum subsp. bulbiferum, Asplenium bulbiferum subsp. gracillimum, Asplenium bulbiferum x flaccidum, Asplenium flaccidum subsp. flaccidum, Asplenium oblongifolium x polyodon, Astelia grandis, Astelia solandri, Blechnum discolor, Blechnum procerum, Brachyglottis repanda var. repanda, Calystegia sepium subsp. roseata, Carex banksiana, Carex comans, Carex lectissima, Carex secta, Carex solandri, Clematis paniculata, Coprosma lucida, Coprosma propinqua, Coprosma propinqua x C. robusta, Coprosma repens, Coprosma rhamnoides, Coprosma rigida, Coprosma spathulata, Corybas trilobus, Corynocarpus laevigatus, Cyathea colensoi, Cyathea cunninghamii, Cyperus ustulatus, Doodia media, Earina mucronata, Elaeocarpus dentatus, Elatostema rugosum, Fuchsia excorticata, Griselinia littoralis, Haloragis erecta, Hoheria populnea, Hymenophyllum revolutum, Hypolepis ambigua, Hypolepis rufobarbata, Lastreopsis hispida, Leptopteris hymenophylloides, Leucopogon fasciculatus, Litsea calicaris, Lygodium articulatum, Melicytus ramiflorus, Metrosideros robusta, Mida salicifolia, Neomyrtus pedunculata, Nestegis cunninghamii, Nestegis montana, Notogrammitis billardierei, Olearia rani, Paesia scaberula, Parsonsia capsularis, Pennantia corymbosa, Piper excelsum, Pittosporum cornifolium, Pittosporum eugenioides, Plagianthus regius, Polystichum richardii, Polystichum vestitum, Pseudopanax crassifolium var. unifoliolatum, Pseudowintera axillaris, Pterostylis banksii, Raukaua anomalus, Rubus squarrosus, Rumohra adiantiformis, Solanum aviculare, Sophora microphylla, Veronica stricta, Vitex lucens.* |
| 2 | *Asplenium flaccidum, Astelia fragrans, Astelia nervosa var. grandis, Carex virgata, Coprosma autumnalis, Coprosma robusta, Coprosma rotundifolia, Cranfillia fluviatilis, Cyathea smithii, Blechnum parrisiae, Elaeocarpus hookerianus, Gahnia xanthocarpa, Hymenophyllum demissum, Leptospermum scoparium, Lophomyrtus bullata, Melicope simplex, Melicytus lanceolatus, Muehlenbeckia complexa, Myrsine divaricata, Oplismenus hirtellus subsp. imbecillis, Oplismenus imbecillis, Parablechnum novae-zelandiae, Pseudowintera colorata, Rhopalostylis sapida, Rubus schmidelioides.* |
| 3 | *Aristotelia serrata, Asplenium oblongifolium, Asplenium polyodon, Blechnum chambersii, Blechnum filiforme, Carex uncinata, Cyathea medullaris, Deparia petersenii, Dicksonia fibrosa, Diplazium australe, Histiopteris incisa, Metrosideros diffusa, Metrosideros perforata, Microlaena stipoides, Microsorum pustulatum subsp. pustulatum, Muehlenbeckia australis, Nestegis lanceolata, Parapolystichum glabellum, Parapolystichum microsorum subsp. pentangulare, Parsonsia heterophylla, Passiflora tetrandra, Pellaea rotundifolia, Podocarpus totara var. totara, Pseudopanax crassifolius, Pteridium esculentum, Pteris macilenta, Pteris tremula, Pyrrosia eleagnifolia.* |
| 4 | *Alectryon excelsus var. excelsus, Astelia hastata, Carex dissita, Carex lambertiana, Carpodetus serratus, Coprosma tenuicaulis, Cordyline australis, Hedycarya arborea, Knightia excelsa, Melicytus ramiflorus subsp. ramiflorus, Microsorum scandens, Pneumatopteris pennigera, Schefflera digitata, Syzygium maire.* |
| 5 | *Asplenium bulbiferum, Beilschmiedia tawa, Coprosma areolata, Cyathea dealbata, Dacrydium cupressinum, Dicksonia squarrosa, Freycinetia banksii, Melicytus micranthus, Microlaena avenacea, Myrsine australis, Prumnopitys taxifolia.* |
| 6 | *Dacrycarpus dacrydioides, Geniostoma ligustrifolium, Laurelia novae-zelandiae, Ripogonum scandens, Streblus heterophyllus.* |

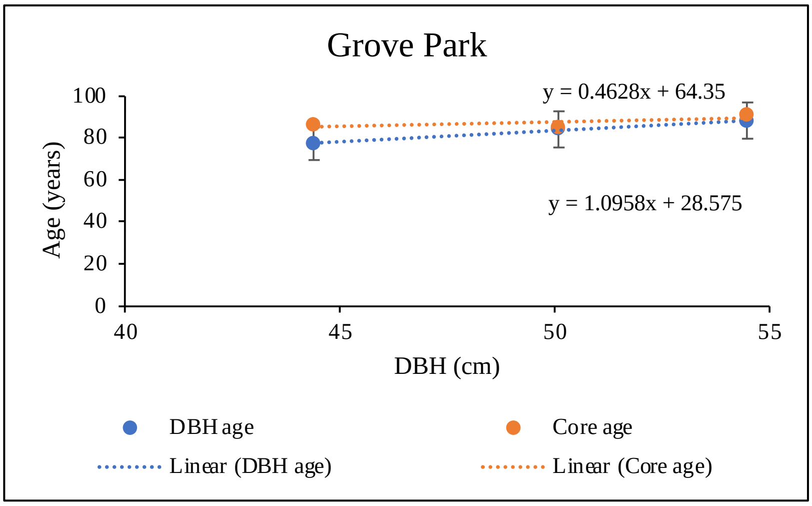
Appendix 4.2: The area traversed across Totara Park while collecting sapling data. The wetland's circumference is about 530 m and the internal distance traversed was 1,214 m. With a two-metre buffer on each side of the track, the area covered was about 0.68 ha (40%) of the total 1.71 ha. The map was created in Google Earth using a vector layer created in QGIS that connected point observations to estimate the area traversed.

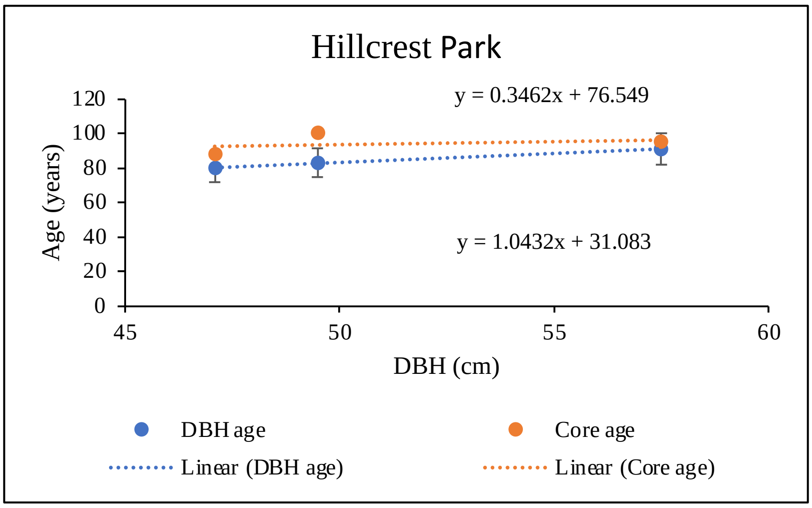


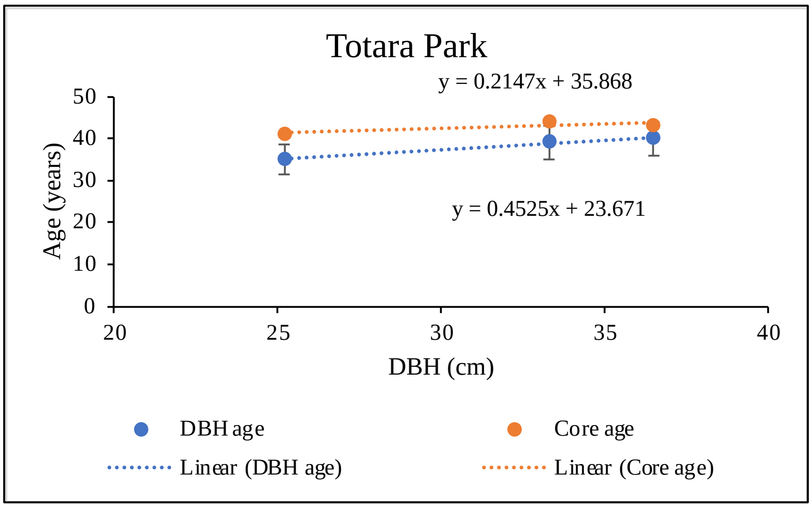
Appendix 4.3: Kahikatea Green Wheel Assessments of Te Papanui (a), Totara Park (b), Hillcrest Park (c) and Grove Park (d). Te Papanui was used as a reference site for comparison with the three case studies. The greener the wheel and higher the score, the healthier the native remnant. Some attributes, including indicator animals and mammalian predators, were not assessed. The wheels were created from the official spreadsheet (WRC, 2019).



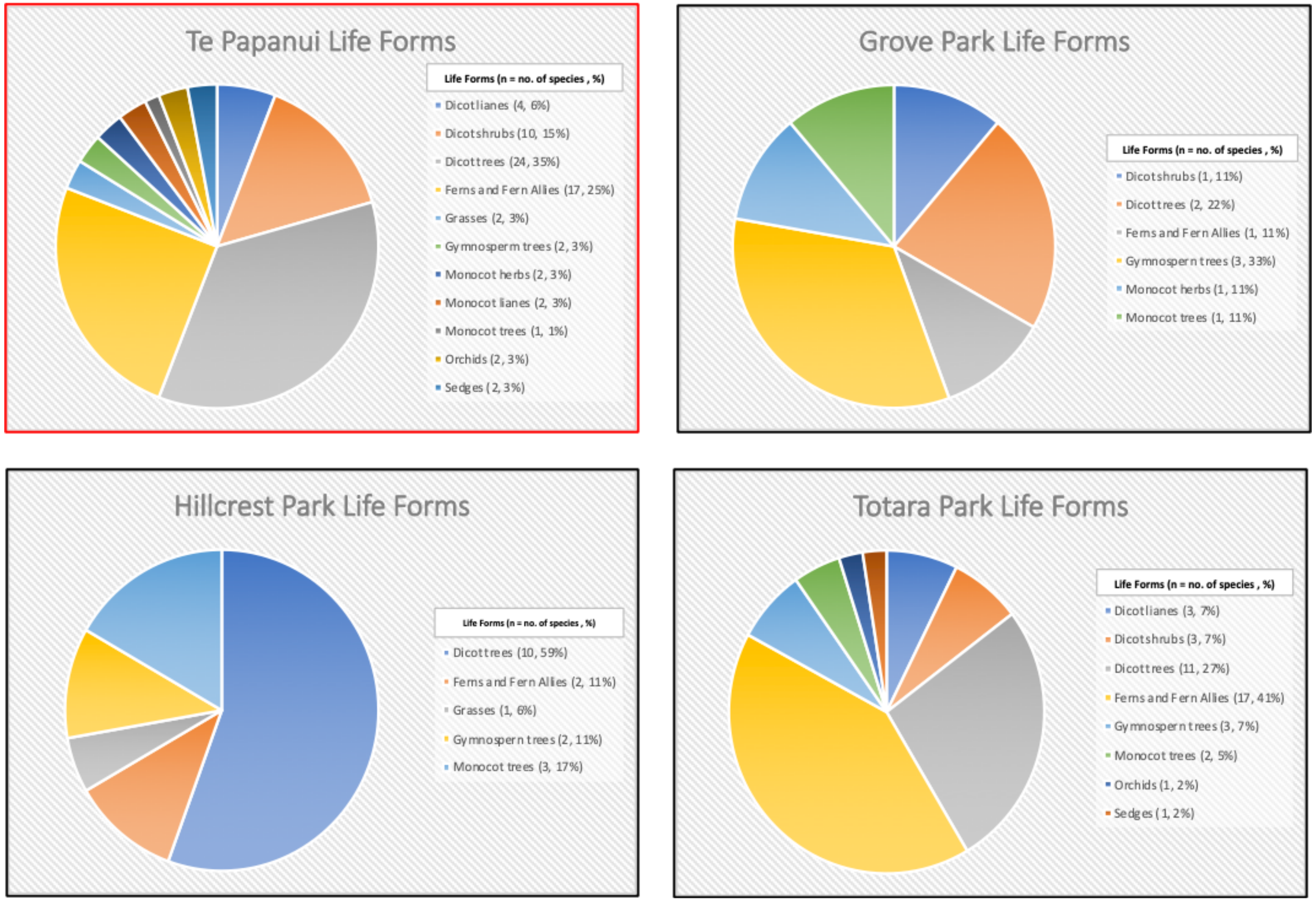
Appendix 4.4: Kahikatea age from DBH measurements versus coring technique; the margin of error represents 10%. The three cores taken from Grove Park, Hillcrest Park and Totara Park were used to validate the DBH-age equations adopted for each site. While the J.R. Leathwick (unpublished) regression equation was used for Grove Park and Hillcrest Park, the D.A. McLean (unpublished) regression equation was employed for Totara Park.



Appendix 4.5: Life form analyses of Te Papanui (the reference site) and three kahikatea remnants, including Grove Park, Hillcrest Park and Totara Park. Research-grade observational data was sourced from iNaturalist to determine the life forms at each site. The life forms considered in this analysis included ferns and fern allies, gymnosperm trees, dicot trees, dicot shrubs, dicot lianes, dicot herbs, monocot trees, orchids, grasses, sedges, rushes, monocot herbs and monocot lianes (Cornes & Clarkson, 2010).

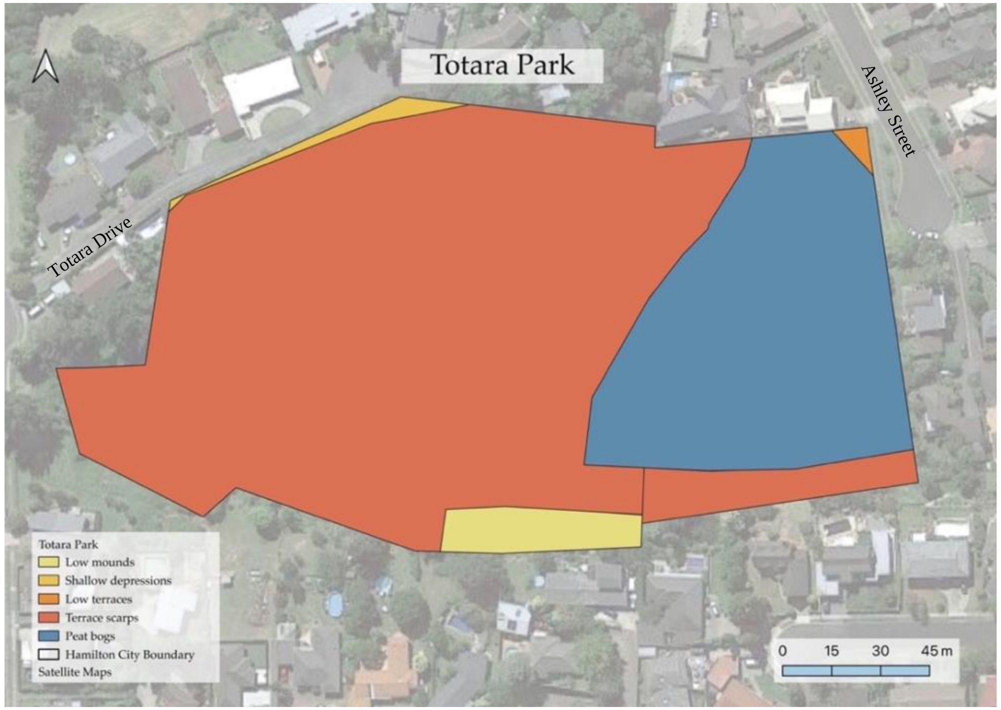


Appendix 4.6: Vascular plant species recorded in Te Papanui (reference site) and the case study kahikatea remnants, including Hillcrest Park, Grove Park and Totara Park (data was downloaded from iNaturalist NZ on 03.02.22).

| Park | Native | Exotic | Naturalised |
|---|---|---|---|
| **Te Papanui** | *Adiantum cunninghamii, Alectryon excelsus, Alseuosmia quercifolia, Aristotelia serrata, Arthropteris tenella, Asplenium bulbiferum, Asplenium oblongifolium, Astelia hastata, Beilschmiedia tawa, Blechnum filiforme, Blechnum parrisiae, Carex uncinata, Carpodetus serratus, Coprosma areolata, Coprosma autumnalis, Coprosma lucida, Coprosma rigida, Coprosma robusta, Cordyline australis, Corynocarpus laevigatus, Cyathea dealbata, Cyathea medullaris, Cyperus ustulatus, Dacrycarpus dacrydioides, Diplazium australe, Earina mucronata, Elaeocarpus hookerianus, Freycinetia banksii, Geniostoma ligustrifolium, Hedycarya arborea, Histiopteris incisa, Knightia excelsa, Laurelia novae-zelandiae, Litsea calicaris, Lomaria discolor, Melicytus ramiflorus, Metrosideros perforata, Microlaena avenacea, Microsorum scandens, Microtis unifolia, Mida salicifolia, Muehlenbeckia australis, Myrsine australis, Nestegis cunninghamii, Nestegis lanceolata, Oplismenus hirtellus subsp. imbecillis, Parapolystichum microsorum, Parsonsia heterophylla, Passiflora tetrandra, Pellaea rotundifolia, Phormium tenax, Piper excelsum, Pittosporum tenuifolium, Prumnopitys taxifolia, Pseudopanax arboreus, Pseudopanax crassifolius, Pteris macilenta, Pteris tremula, Pyrrosia eleagnifolia, Ripogonum scandens, Schefflera digitata, Solanum laciniatum, Streblus heterophyllus, Veronica stricta.* | *Araujia sericifera, Archontophoenix cunninghamiana, Asplenium x lucrosum, Crocosmia x crocosmiiflora, Ehrharta erecta, Iris foetidissima, Ligustrum sinense, Maytenus boaria, Oxalis incarnata, Persea americana, Phoenix canariensis, Prunus serrulata, Pteris cretica, Solanum mauritianum, Solanum pseudocapsicum, Trachycarpus fortunei.* | *Hoheria populnea, Pseudopanax crassifolius x lessonii, Pseudopanax lessonii, Vitex lucens.* |

| | | | |
|---|---|---|---|
| Hillcrest Park | *Alectryon excelsus, Beilschmiedia tawa, Cordyline australis, Cordyline banksii, Cyathea dealbata, Dacrycarpus dacrydioides, Elaeocarpus hookerianus, Hedycarya arborea, Laurelia novae-zelandiae, Melicytus ramiflorus, Microlaena avenacea, Myrsine australis, Nestegis lanceolata, Podocarpus totara, Pyrrosia eleagnifolia, Rhopalostylis sapida, Streblus heterophyllus.* | *Aphanes arvensis, Asplenium x lucrosum, Bromus catharticus, Datura stramonium, Eleusine indica, Euonymus japonicus, Galium aparine, Hedera helix, Ligustrum lucidum, Malva sylvestris, Plantago major, Solanum chenopodioides, Solanum lycopersicum, Trifolium subterraneum.* | *Pseudopanax crassifolius x lessonii.* |
| Grove Park | *Blechnum parrisiae, Coprosma robusta, Cordyline australis, Dacrycarpus dacrydioides, Dianella nigra, Myrsine australis, Podocarpus totara, Prumnopitys taxifolia.* | *Asplenium x lucrosum, Berberis glaucocarpa, Borago officinalis, Echium vulgare, Laurus nobilis, Ligustrum sinense, Myosotis sylvatica, Zantedeschia aethiopica.* | *Pseudopanax crassifolius x lessonii.* |
| Totara Park | *Aristotelia serrata, Asplenium flaccidum, Asplenium oblongifolium, Asplenium polyodon, Blechnum chambersii, Blechnum novae-zelandiae, Calystegia sepium, Calystegia tuguriorum, Carex secta, Coprosma autumnalis, Coprosma robusta, Cordyline australis, Cyathea dealbata, Cyathea medullaris, Dacrycarpus dacrydioides, Dacrydium cupressinum, Dicksonia fibrosa, Dicksonia squarrosa, Diplazium australe, Earina mucronata, Geniostoma ligustrifolium, Laurelia novae-zelandiae, Melicytus ramiflorus, Microsorum pustulatum subsp. pustulatum, Muehlenbeckia australis, Myrsine australis, Pittosporum eugenioides, Pittosporum tenuifolium, Pneumatopteris pennigera, Podocarpus totara, Pseudopanax crassifolius, Pyrrosia eleagnifolia, Rhopalostylis sapida, Schefflera digitata, Tmesipteris elongata, Tmesipteris lanceolata.* | *Allium triquetrum, Archontophoenix cunninghamiana, Calystegia sylvatica, Eriobotrya japonica, Euonymus japonicus, Fatsia japonica, Jasminum polyanthum, Ligustrum sinense, Lonicera japonica, Oxalis incarnata, Persea americana, Potentilla indica, Pteris cretica, Ranunculus repens, Roldana petasitis, Salix cinerea, Solanum mauritianum, Tradescantia fluminensis, Verbascum virgatum, Zantedeschia aethiopica.* | *Hoheria populnea, Pseudopanax crassifolius x lessonii, Pseudopanax lessonii.* |

Appendix 4.7: Planting zone maps for the three kahikatea remnant case studies: Totara Park, Hillcrest Park and Grove Park. The most characteristic vascular plants of each ecological unit were extracted from Clarkson *et al*. (2007).




Totara Park's planting zones. Low mounds (mixed conifer-broadleaf forest); shallow depressions (kahikatea semi-swamp forest); low terraces (tōtara-mataī-kōwhai forest); terrace scarps (tōtara-mataī-kōwhai forest) and peat bogs (shrub sedgeland). In the terrace scarps ecological unit, appropriate species that could be planted include *Blechnum chambersii*, *Dacrydium cupressinum*, *Podocarpus totara*, *Prumnopitys taxifolia*, *Olearia rani* and *Knightia excelsa* (Clarkson *et al.*, 2007). Restoration of the open grassy area to the east of the grey willow-kahikatea patch would require less effort. The space can be planted with suitable species for the shrub sedgeland ecological unit, including *Leptospermum scoparium*, *Cordyline australis*, *Coprosma propinqua*, *Machaerina teretifolia*, *M. rubiginosa*, *Phormium tenax* and *Carex secta* (Clarkson *et al.*, 2007).


Hillcrest Park's planting zones. Hilly land (rimu/tawa forest); low rolling hills – footslopes (pukatea-kahikatea forest); low mounds (mixed conifer-broadleaf forest) and shallow depressions (kahikatea semi-swamp forest). Pioneer species of the alluvial plains include *Cordyline australis*, *Melicytus ramiflorus*, and *Myrsine australis*. Alternatively, pioneer species of the hills include *Hedycarya arborea*, *Podocarpus totara* and *Alectryon excelsus* (Clarkson *et al*., 2007).


Grove Park's planting zone. The shallow depressions ecological unit suggests that planting kahikatea semi-swamp forest species around the remnant could be appropriate. Some of the appropriate species for planting the grassy areas of this shallow depressions ecological unit include *Cordyline australis*, *Myrsine australis*, and *Melicytus ramiflorus*. Species suited to the understory of this ecological unit include *Beilschmiedia tawa*, *Syzygium maire* and *Laurelia novae-zelandiae* (Clarkson *et al.*, 2007).

# Chapter 5: Synthesis

## 5.1 Discussion

This thesis contributes to our knowledge of Hamilton City's indigenous vegetation and the opportunities to restore gullies and reserves at the landscape and site-specific scale. It has analysed ecological representativeness, one important criterion, across the city's four landforms and eleven ecological units (Chapter 2). It has also prioritised the city's gullies and reserves for restoration using eight ecological criteria (Chapter 3). Finally, it assessed the composition and structure of three kahikatea forest remnants, including Hillcrest Park, Totara Park and Grove Park, as examples for determining appropriate restoration strategies (Chapter 4). The findings are summarised below with reference to the research questions of this thesis presented in Chapter 1.

1. What is the state of ecological representativeness in Hamilton City?

Current indigenous vegetation cover in Hamilton City was found to severely under-represent the hills, alluvial plains and peatlands and their respective ecological units based on the area that would need to be restored to achieve at least 10% cover. In comparison, the gullies are already sufficiently represented because most of the city's restoration projects incorporate them. Despite its adequate representation, additional gully restoration would provide a myriad of opportunities and is at the forefront of HCC's *Nature in the City Strategy* because it utilises land not suitable for subdivision development. While the inadequate representation of most landforms is not a new finding, the ecological unit analysis provides refined information that is available on a GIS platform.

This study found that ecological representativeness is more appropriately used alongside other criteria for the selection of restoration projects in highly-modified urban environments such as Hamilton City. Restoration projects should aim to reinstate natural vegetation that existed before European settlement where feasible. Nonetheless, dramatic shifts in the city's biophysical conditions necessitate planting native species most suited to the modified environment. Exploiting extant indigenous vegetation rather than just attempting to recreate past ecological communities may accelerate the progress of the city-wide project. For example, restoring complex peat bogs and domes that have been almost completely lost from the city would require substantially more effort and resources than gullies with existing vegetation cover and more conducive conditions. A focus on the representativeness criterion is more relevant on a larger scale like the Waikato region, where there are more extensive remnants of indigenous vegetation. The use of additional ecological criteria also supports a more robust assessment of the ecological integrity of sites (Chapter 3).

2. Which gullies and reserves in Hamilton City have the most restoration potential that comprise the area that would need to be restored under HCC’s 10% goal?

To answer this research question, a novel approach was taken by developing a prioritisation framework that identified 873 gully and reserve sites with the most intact ecological integrity that satisfy the area (886 hectares (ha)) that would need to be restored for Hamilton City to attain 10% indigenous vegetation cover. Sites with the highest potential included sections of Hamilton Gardens, Hammond Park, Minogue Park, Kirikiriroa gully, the major riverside gully and Mangaonua gully. This study suggests that initially restoring these high ranking sites may provide the greatest biodiversity rewards. The copious number of privately owned gullies (almost three-quarters of prioritised sites) highlights the importance of appropriate and yet transparent consultation and communication between the council and landowners. The assessment also revealed that more high-ranking sites occur in the city’s east. However, implementing restoration projects throughout the city would enhance connectivity at the regional scale, connecting native biodiversity reservoirs like Pirongia Forest Park with the city. As the inclusion of social, economic and cultural criteria was outside the scope of this study, their future addition will likely alter the prioritisation of sites.

Besides the practical option of adopting existing vegetation patches as nuclei for restoration, restoring a few large areas would also require significantly fewer resources than it would to restore many very small fragments. Small isolated patches are significantly more exposed to edge conditions such as prevailing winds and solar radiation and more vulnerable to the invasion of exotic plants. Within the city’s current boundary, this approach may encourage restoring whole gully systems like the Kirikiriroa and Mangaonua gullies. If Hamilton City’s boundary continues to expand, restoring large areas would also provide a pragmatic route to reaching 10% indigenous vegetation. For example, if subdivisions are extended to include Rukuhia, which abuts Temple View and supports precious peat lakes such as Lake Mangahia and Lake Koromatua, development which incorporates substantial restoration would provide many biodiversity benefits and contribute significantly to the 10% target.

3. How can the age structure, physical conditions and biotic features of the kahikatea remnants at Hillcrest Park, Grove Park and Totara Park guide the selection of restoration strategies?

Hillcrest Park was found to support the oldest population of kahikatea of the three case studies with an average age of 82 years, followed by Grove Park (70 years) and Totara Park (32 years). Te Papanui supports a kahikatea remnant with an average age of approximately 60 years as the reference site. Hillcrest Park is comprised of three ecological units and provides the largest area that could be restored (5.6 ha) of the case studies. Grove Park is the smallest site, only presenting 0.1 ha that could be restored, but it is a key feature of the city's west and is dominated by the under-represented shallow depressions ecological unit. Totara Park provides an invaluable opportunity as the best example of regenerating swamp forest in the city, offering about 2.7 ha that could be restored. Unlike Hillcrest Park and Grove Park, restoring Totara Park would require a cautious and persistent manipulation technique, simultaneously removing exotics and planting and releasing native species.

This study found numerous gaps between the species composition of Te Papanui, as the notional reference site, and the three selected kahikatea patches. Planting species found in Te Papanui absent from the other sites would significantly enhance the life forms they support and overall health. The study also signalled the importance of the physical conditions of the remnants, such as a high water table. For example, while many troublesome weeds dominate Totara Park, its reinstated flooding regime supports the best regenerating kahikatea forest and numerous locally rare species. It was also found to host more epiphytes than Te Papanui, Hillcrest Park or Grove Park due to its sheltered and damp conditions and a wider range of host species. For example, the loss of a significant host (*Dicksonia squarrosa*, wheki̅) from Te Papanui has likely contributed to its reduced epiphytic diversity. In comparison, improving the health of kahikatea remnants such as Hillcrest Park and Grove Park, where it may not be feasible to reinstate a flooding regime, should include buffer extensions and ongoing understory native plantings with a gradual shift towards dry land species. Restoration of these valuable remnants alongside a regional restoration plan should be considered to avoid the further loss and fragmentation of semi-swamp kahikatea forest.

## 5.2 Recommendations for management

This research has identified the following recommendations for urban restoration management in Hamilton City:

- Landform representativeness could be improved using the results from Chapter 2 to restore a wider range of environments. It would be practical to target landforms or ecological units requiring the smallest restoration area to meet representativeness thresholds.
- Restoring 886 ha to achieve a minimum of 10% indigenous vegetation by 2050 requires comprehensive planning and monitoring procedures to track progress. The city-wide restoration implementation plan underpinning the *Nature in the City Strategy* should adopt a staged approach, prioritising the restoration of sites with the most intact ecological integrity (Chapter 3). Extant indigenous vegetation must be conserved in conjunction with any restoration planting (*reconstruction*) efforts to ensure the target is met.
- The restoration of whole gully systems like the Kirikiriroa and Mangaonua gullies rather than many small fragments would necessitate fewer resources and provide more benefits like enhanced ecological connectivity (Chapter 3). Successfully restorating whole gully systems depends heavily on effective cooperation and collaboration between the council and landowners. Additional consultation efforts associated with restoring private gullies should be factored into the city-wide plan as their restoration is crucial for enhanced connectivity.
- Consistent planning processes to identify restoration strategies adopted for each site should be in tune with its biotic and physical features (Chapter 4). For example, buffer and understory native plant species lists for each of the *Nature in the City* sites could be created based on analyses of the main vegetation types prior to European settlement, as well as the physical conditions and biotic features. Given the city's highly-modified environment, it would be practical to plant species found in kahikatea forest that has experienced minimal anthropogenic disturbance that also suit drier conditions, such as *Teucrium parvifolium, Prumnopitys taxifolia, Beilschmiedia tawa* and *Podocarpus totara*.

## 5.3 Recommendations for further research

This research has identified the following areas for future research:

- Long-term monitoring of native vegetation changes at specific sites and across Hamilton City would provide valuable information for restoration planning and future prioritisation tools.
- A representativeness study of the Waikato region would provide greater context across territorial local authorities, offering information on environmental gaps and threatened species that may steer the selection of restoration sites and protected natural areas.
- The inclusion of social, economic and cultural criteria alongside ecological criteria to prioritise sites would enable a holistic, multifaceted approach when selecting optimal restoration sites in urban environments like Hamilton City. Updating the data periodically over the next thirty years would also support the prioritisation of restoration sites to achieve the 10% goal by 2050.
- Similar analyses conducted at the three kahikatea remnants in this study could be completed for other sites throughout the city supporting indigenous vegetation patches to identify bespoke restoration strategies for prioritised sites.
- A detailed investigation of environmental gradients and the change in microclimatic conditions across a Hamilton gully could reveal critical insights for future restoration projects.