Terrestrial Biodiversity Monitoring in the Waitākere Ranges Heritage Area to 2022

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October 2023 Technical Report 2023/18

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Research and Evaluation Unit RIMU


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Terrestrial Biodiversity Monitoring Programme 20 x 20 metre 'forest plot'
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Executive summary

The Waitākere Ranges Heritage Area Act 2008 recognises the ecological and cultural significance of the Waitākere Ranges which covers approximately 27,000 ha and contains one of the two largest blocks of continuous vegetation in the Auckland region (c. 21,000 ha). The Act requires Auckland Council to monitor and report on the state of the environment within the Heritage Area every five years. This technical report provides empirical analysis on land cover change, and plant and bird biodiversity collected from systematic long-term monitoring of permanent plots in the Heritage Area from 2009 to 2022.

Analysis of land cover, forest canopy cover, and landslides highlight the continued dominance of indigenous vegetation, comprising 81 to 85 per cent (22,000 ha) of the Heritage Area. Forest and scrub/shrubland are the primary land cover classes, occupying 62 per cent and 22 per cent of the land area, respectively. At this broad scale, land cover classes have shown relative stability over a six-year period (2012-2018).

Landslide analysis (of aerial images from 2022) revealed a significant number of landslides (more than 150) in the Waitākere Ranges Regional Park, triggered by intense rainfall in August 2021. These mainly small (average of 0.1 ha) shallow slides and debris flows, have caused vegetation loss, affecting approximately 18 hectares of forest in total. The majority of impacted forest comprises mature kauri-podocarp-broadleaved forest. Satellite images taken after the 2023 Auckland Anniversary Weekend floods and Cyclone Gabrielle show even more extensive landslips throughout the forest but were outside the period of this reporting. They are being analysed for a separate technical report and highlight potential cumulative impacts with increasing rates of intense rainfall triggered multiple-occurrence landslide events in natural forests. Further research and monitoring are necessary to fully understand the causes, ecological processes, and biodiversity impacts of these landslides.

Forest in the Heritage Area continues to recover from widespread earlier disturbance from logging, burning, gum digging and clearance for farming, most of which occurred prior to the 1940s. The most disturbed areas are now in regenerating forest types which make up 42 per cent of the forested area. Areas that were less disturbed or unlogged are classed as warm kauri-podocarp-broadleaved forest and make up 45 per cent of the forest area. Both warm kauri-podocarp-broadleaved forest and regenerating forest are highly diverse, dominated by indigenous plants and following expected successional pathways.

The Heritage Area also supports a diverse range of bird species. The most commonly counted birds were indigenous species, with half of all the birds counted being of endemic New Zealand species. There were significantly fewer introduced species encountered within the Heritage Area compared to many other sites across the region, indicating how important the Waitākere habitat is for supporting indigenous biodiversity. Conspicuousness of indigenous species abundance has increased over the last ~10 years, including rises in the abundance of tauhou, riroriro, pīwakawaka, and korimako.

The high ecological integrity of forest and high percentage of indigenous birds, with notable increases in some species, within the Heritage Area arises partly from the large, unfragmented and continuous characteristics of the forest, and from ongoing management to limit weed and pest pressures. There remain areas of concern, however, arising from the current and potential future impacts of pest animals, plant pathogens, weeds, and climate change. Recent extremes in drought and rainfall events generating wilting of some plant species and progressively weakening soils triggering widespread landslides show how rapidly climate change may impact forest processes and emphasise the need to continue working to protect and support the forest ecosystems to continue their own regeneration.

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List of acronyms and abbreviations

5MBC	First five minutes of 10MBC
10MBC	10-minute bird count
AUP	Auckland Unitary Plan
ANOVA	Analysis of variance
Aotea	Aotea/Great Barrier Island
BMP	Bird Monitoring Programme
CBP	Coastal Bird Programme
CHM	Canopy Height Model
DEM	Digital Elevation Model
DOC	Department of Conservation
ED	Ecological District
Hauturu	Te Hauturu-o-Toi/Little Barrier Island
LAWA	Land Air Water Aotearoa
LCDB	Land Cover Database
LiDAR	Light Detecting and Ranging
MUL	Auckland Council Metropolitan Urban Limit
KMA	Kōkako Management Area
SEA(s)	Significant Ecological Area(s)
SSMRP	Seabird and Shorebird Monitoring and Research Programme
TBMP	Terrestrial Biodiversity Monitoring Programme

1 Introduction

The Waitākere Ranges Heritage Area Act 2008 covers the area known as Te Wao Nui o Tiriwa/Waitākere Ranges and recognises its ecological and cultural significance. The Waitākere Ranges Heritage Area covers approximately 27,000 ha and contains one of the two largest blocks of continuous vegetation in the Auckland region (c. 21,000 ha). The Heritage Area includes all of the Waitākere Ecological District, and small parts of Tāmaki and Kaipara Ecological Districts. The vegetation within the Heritage Area is characterised by a diverse mix of different indigenous ecosystems, which collectively provide extensive habitat for a wide range of indigenous plants, birds, reptiles, and invertebrates. The Heritage Area is of particular significance due to the intact sequences of vegetation from the coast up to the summits of the inland hills, the wild nature of its coastal ecosystems, and distinctive associations of wetland and dune lake systems. Ecosystems within the Heritage Area are home to almost a quarter of New Zealand's indigenous flowering plant species and three-quarters of all indigenous fern species.

While the Waitākere Ranges represent an area of high ecological value as described above, the impacts of past and current pressures are visible with a history of disturbance and regeneration. Arrival of Māori, saw the start of land clearance through burning and from the 1840s, larger areas were cleared for extraction of timber, kauri-gum and farming. Humans brought not only harvesting and disturbance to the Heritage Area, but also hunting, pest animals, plant pathogens, exotic plants, and changing climate. More recently, two plant pathogens have been detected within the Heritage Area, Kauri dieback, caused by the pathogen *Phytophthora agathicida,* and Myrtle rust, caused by the fungal pathogen *Austropuccinia psidii* specific to Myrtaceae (Auckland Council 2020).

Climate change is expected to increase the frequency and severity of drought and storm events in the Auckland region (Pearce et al 2018). There is little knowledge on how changes in climate will impact the ecological integrity of Auckland's forests directly, but it is widely agreed that existing problems with invasive plants and pest animals will be exacerbated (Bishop and Landers 2019, Macinnis-Ng et al 2021).

With regard to drought events, elevated stress from prolonged low soil moisture will impact indigenous forest flora and fauna. There are few predictive traits for drought-induced mortality; but small trees are considered more susceptible than larger trees, and forests on steeper ridges and slopes are more susceptible, which is where the least disturbed forest is more likely to be found (Russo et al 2010, O'Brien et al 2017). In the Auckland region, species such as taraire (*Beilschmiedia taraire)*, kanono (*Coprosma autumnalis*) and māhoe (*Melicytus ramiflorus*) are considered particularly drought sensitive (Bannister 1986, Martin and Ogden 2005, Myers and Court 2013, Wyse et al 2013). Anecdotal evidence suggests taraire showed high dieback and mortality on Auckland's east coast during the droughts of 2012-13 and 2020.

Seedling recruitment of forest species can be particularly sensitive to drought. Within the Waitākere Ranges, seedlings categorised as drought sensitive include whauwhaupaku (*Pseudopanax arboreas*), karamū (*Coprosma robusta*), hangehange (*Geniostoma ligustrifolium* var *ligustrifolium*), māhoe, mapou (*Myrsine australis*), kawakawa (*Piper excelsum*), pūriri (*Vitex lucens*), rewarewa (*Knightia excelsa*), and kōwhai (*Sophora microphylla*) (Seaward et al 2016). Tawa (*Beilschmiedia tawa*) seedling recruitment has also been identified as drought sensitive (Knowles and Beveridge 1982). Drought-related impacts on seedling recruitment can result in failure or compositional changes in forest regeneration (Pozner et al 2022).

Drought may also increase wildfire hazard in Auckland, especially in regenerating forests that contain more fire-prone species or are more prone to drying out due to more exposed structure and potentially change successional trajectories by favouring fire-adapted non-indigenous taxa (Atkinson 2004, Perry et al 2015).

Increasing frequency and severity of drought and high rainfall events causes shrinking and swelling in Auckland's clay-rich soils leading to progressive weakening, and increased likelihood of landslides (Tichavský et al 2020, Brown et al 2003). Landslides are a natural disturbance process that can lead to compositional changes in the vegetation of our indigenous forests. However, landslides are increasing in frequency and scale in response to climate change in Auckland as evidenced by the number and coverage of landslides following extreme storm events in March 2017 (Lee 2020), August 2021 (Section 2 this report) and January 2023 (under analysis) . While landslides may provide opportunities for natural forest regeneration processes, including the regeneration of some species, they also can destroy mature forest and provide opportunities for infestation by exotic plant species and weeds.

1.1 This report

The Waitākere Ranges Heritage Area Act 2008 requires Auckland Council to monitor and report on the state of the environment within the Heritage Area every five years. The third five-yearly report, the *Waitākere Ranges Heritage Area five-year monitoring report 2023,* covers the reporting period 2017-2022. Previous technical reports to support the State of the Waitākere Ranges five-year monitoring report are Bishop et al (2013) for the period 2008-2013 and Landers et al (2018) for the period 2012-2017.

The 2018 report covered a broad range of environmental and biodiversity indicators. In this round of reporting, many of those indicators and findings (including dunes, wetlands, water quality and aquatic biodiversity) have been reported directly into the wider State of the Waitākere Ranges report as they are already published and accessible either on websites or in reports. This technical report provides empirical analysis of new information included in the main State of the Waitākere Ranges report on land cover change and plant and bird biodiversity collected from systematic long-term monitoring of permanent plots in the Heritage Area.

2 Land cover

2.1 Introduction

Understanding the distribution and changes in land cover provides valuable insights into the state and health of ecosystems. In the context of the Waitākere Ranges Heritage Area, a region of significant ecological importance, measuring land cover distribution and change is of importance for sustainable land use planning, biodiversity conservation, and the overall preservation of this unique natural landscape. This area encompasses diverse ecosystems, ranging from indigenous forests and scrublands to rural and urbanised landscapes. The land cover composition and its spatial distribution within the Heritage Area have been influenced by a variety of factors, including historical land use practices, urbanisation, and natural processes.

By analysing land cover data from different time periods, we can quantify rates of land cover change, and assess the impacts of human activities and natural disturbances. In addition, understanding of land cover distribution and change contribute to broader environmental assessments, such as monitoring the impacts of climate change, identifying areas at risk of erosion or landslides, and assessing the resilience of ecosystems to disturbances.

This section aims to provide a detailed analysis of the land cover at different scales (with a focus on the vegetation cover) of the Waitākere Ranges Heritage Area, providing context for the plants and birds sections that follow.

2.1.1 Landslides

Auckland's weak, clay-rich soils are a result of the historical weathering of underlying weak rocks. Within the Waitākere Ranges, the dominant soil types are Waitākere clay soils found on elevated, rolling ridges and plateaus, and Huia stony clay soils on steep bluffy faces (Martindale et al 2018). These soils are associated with the Manukau Group andesite or andesitic breccia, which originated from sea-floor lava flows and lahars during the Miocene epoch, approximately eight to 25 million years ago. The Waitākere Ranges, once a volcanic edifice, have been uplifted from the sea, leaving behind only the eroded eastern flank.

One important factor affecting the soil in Auckland is the seasonal variation in moisture content. The clay-rich soils in Auckland exhibit high "shrink and swell" properties (Brown et al 2003), which gradually weaken the soil over the course of years and decades. As a result, the soil becomes more susceptible to failure during periods of heavy rainfall. Furthermore, preceding dry spells can increase the predisposition of slopes to sliding, particularly in the case of clay-rich soils (Tichavský et al 2019).

The frequency and severity of conditions that trigger landslides in the Waitākere Ranges have been increasing, as evidenced by the number of landslides and size of areas affected in recent years, particularly following weather events like the multiple landslide event triggered by the ‘Tasman Tempest’ storm in the Hunua Ranges in March 2017 (Lee 2020). Despite the high vegetation cover and dense canopy, these events highlight the vulnerability of slopes and shallow soils in the Waitākere Ranges, emphasising the need for a better understanding of the soil properties and their relationship to landslide risk. This report makes a first examination of the potential scale of storm derived landslips in the Heritage Area and discusses potential implications.

2.2 Methods, datasets, and analyses

The distribution of vegetation cover in the Heritage Area and changes to it are described using various datasets. Each dataset varies in scale (spatial and temporal) and purpose and therefore provides different information about the vegetation in the Heritage Area and how it is changing. This includes:

- The Current Ecosystem Extent data describes indigenous terrestrial and wetland ecosystems across Auckland through fine-scale surveys and analysis of aerial imagery. This provides detailed information on the distribution of ecosystem types but as it is not repeated regularly it cannot be used to measure change.
- The New Zealand Land Cover Database (LCDB) provides information on vegetation cover through time using nationally consistent methods and categories. The mapping is based on satellite imagery and is useful for broad-scale change analysis.
- Auckland Council also collects Light Detecting and Ranging (LiDAR)Light for elevation mapping, and this has been used for fine-scale analysis of vegetation canopy. Repeat surveys enable it to identify and measure change, however, LiDAR does not describe vegetation types and ecosystems.
- Various high-resolution aerial and satellite imagery used for mapping landslide extents and validating the canopy cover losses.
- To produce estimates for areas of interest, ancillary geographic boundaries were needed. This includes the WRHA boundary (accessed October 2022), Auckland Unitary Plan (AUP) base zone groups (accessed October 2022) and Significant Ecological Area (SEA) (accessed October 2022).

2.2.1 Current Ecosystem Extent

The Current Ecosystem Extent data describes the current distribution of indigenous terrestrial and wetland ecosystems across Auckland (Singers and Rogers 2014, Singers et al 2017). Knowledge of the current extent is based on ecological surveys of 2000 sites and previous surveys by Auckland Council, Department of Conservation, Crown Research Institutes, and university academics. Auckland Council continues to refine maps of current extent as new data becomes available. As such, these data cannot be used to measure change. Current ecosystem types do not include the built environment.

Analysis of ecosystems is limited to indigenous ecosystem types and excludes exotic ecosystem types mapped in the Heritage Area. Current ecosystem data for the Heritage Area is described using area (ha) or as a percentage (%) of the total area of indigenous ecosystems.

2.2.2 Land cover state and change

Land cover describes the extent of vegetation, built environments, water bodies, and bare natural surfaces across New Zealand. It is an important measure of environmental change and urban development and is used for policy, research, environmental reporting, and decision-making at national and regional level.

Land cover for the Auckland region was measured using the New Zealand Land Cover Database (LCDB) (Landcare Research 2020). The LCDB is based on an analysis of satellite imagery and is funded by central government. The LCDB is suitable for analysis of gross changes in land cover at 5-10-year time scales, and for spatial resolutions of around 1 ha or more. The latest version of the Database is version 5. This contains land cover data as of summer 2018/19 (nominally referred to as 2018) and enables change assessment to be made across five timestamps between 1996 and 2018. These data represent the latest change information available in the LCDB and was not available for inclusion in the 2018 Heritage Area reporting.

Analysis of land cover in the Heritage Area was summarised across the Land, Air, Water Aotearoa (LAWA) 12 medium-level classes and six broad-level classes. The LAWA classes were useful for summarising the LCDB due to the broad scale of the mapping. Where changes existed, lower order classes were used to provide detail.

Current land cover data for the Heritage Area was described using area (ha) or as a percentage (%) of the total land area in the Heritage Area to indicate the relative dominance of each land class. Change over time was presented as both an area changes in hectares (ha) and as a proportional (%) change (the area change expressed as a proportion of the 1996 area) for each land cover class. The trend information showed the extent to which the land cover classes had either increased, decreased, or remained unchanged in an area over the monitoring period (i.e., 1996 to 2018). Trend data was presented for both broad and medium land cover classes.

2.2.3 Canopy cover and losses

We undertook canopy cover current state and change estimates across the Heritage Area drawing on aerial LiDAR survey data from two time periods.

To examine current canopy cover LiDAR data from 2016-2017 (Table 1) was processed from raw LiDAR point clouds to a raster-based canopy height model (CHM) using methods described in Golubiewski et al (2021). To examine losses, LiDAR data from 2013 and 2016-2017 were processed using a modified CHM method.

The key difference was that the former was classified into height classes and was limited to canopy three metres or greater in height, whereas the latter was not classified into height classes and included vegetation below three metres in height.

Table 1: LiDAR datasets and associated acquisition specifications.

Imagery Source	Data Type	Date of capture	Area	Resolution / Horizontal Accuracy	License
Auckland Council Captured by NZ Aerial Mapping & Aerial Surveying Limited	Vertical Aerial LiDAR	17th July 2013 – 23rd November 2013	Urban Auckland + Waitākere Ranges	Data was collected at > 1.5 points/square metre point density. Vertical accuracy specification is +/-0.2m (95% CI) Horizontal accuracy specification is +/- 0.6m (95% CI)	Open
Auckland Council Captured by Aerial Surveys	Vertical Aerial LiDAR	16th August 2016 – 9th August 2018 (mainland 2016-2017)	Auckland Region	Data was collected at > 4 points/square metre point density. Vertical accuracy specification is +/- 0.1m (68% CI). Horizontal accuracy specification is +/- 0.3m (68% CI).	Open

To identify losses, the two CHMs were subtracted from each other, yielding a difference model. This resulted in a detailed output sensitive to small differences in height. Quality control measures such as data filtering, outlier removal, and careful co-registration were used to minimise errors and improve overall accuracy.

The difference model was filtered to only include height reductions five m or greater. This output was then converted from raster to polygon format to form contiguous patches of loss. Another filter was applied to only include loss patches (polygons) of 20 m^2 or greater. The resultant layer was manually reviewed to identify false positive detections, resulting in 56 per cent of all polygons being removed.

These false positive detections were the result of both systematic error and random error. Systematic errors resulted from vertical bias in the height models caused by differences in the positioning and orientation of the LiDAR sensors between the two datasets, leading to an overall shift in the elevation data. This type of error resulted in narrow segments on the edges of the crowns (possibly because of varying sensor viewing angles and lower point density of the 2013 dataset that was less sensitive to detecting crown edges and may have underestimated crown extent). Random errors, on the other hand, were unpredictable and vary from detection to detection. These errors were caused by factors such as complex terrain, noise in the data, atmospheric conditions, and variations in instrument performance.

Analysis of the spatial distribution of current canopy cover (2016-2017) and the changes (losses) between 2013 and 2016-2017, was described by area (in hectares) for the total Waitākere Ranges Heritage Area, as well as the dominant AUP base zone groups and Significant Ecological Areas (SEAs) within the Heritage Area using the Spatial Analyst tools in ArcPro.

2.2.4 Landslide mapping

A torrential downpour event across west Auckland on the night of 30th-31st August 2021 resulted in landslides, flooding and damage to homes and infrastructure. The rainfall was caused by a slow-moving low-pressure system that combined with a ridge of high pressure near the South Island and led to an increased thermal gradient over the Auckland region with persistent rainfall across the Waitakere Ranges (National Institute of Water and Atmospheric Research 2022). Watercare rain gauges in catchments above the Waitākere and Huia dams recorded between 220 mm and 270 mm of rain in a 12-hour period on Monday and Tuesday. These catchments normally receive between 150 mm and 170 mm of rain in the entire month of August.

High-resolution aerial and satellite imagery was used to map landslides in the Waitākere Ranges Regional Park (Table 2). Google Earth Pro (Google n.d.) was used as a preliminary check to determine the timeframe and extent of landslides using the time slider tool. Locally sourced post-event high-resolution imagery (2022) was then used to identify and map visible landslides and reference imagery (2017) was used to view the pre-event conditions.

Table 2: Imagery datasets and associated acquisition specifications.

Imagery Source	Data Type	Date of capture	Area	Resolution / Horizontal Accuracy	License
Auckland Council	Vertical Aerial Imagery	2017 (2016-2017 summer)	Urban Auckland + Waitākere Ranges	0.075 m GSD @ 0.015 m 90% CI	Open
Auckland Council	Vertical Aerial Imagery	January 2022	Rural Auckland incl. Waitākere Ranges	0.075 m GSD @ 0.015 m 95% CI	Open
Google Earth	Satellite Imagery, RGB	August 2021 – March 2022		Various	Open

Landslides in the Heritage Area were initially mapped using points placed at the top (point of highest elevation) of the landslide to record their location. The dataset contained extents of shallow landslide scars visible in the 2022 aerial imagery in the Waitākere ranges. Slips were mapped to include the area of bare soil and debris. Aerial imagery was visually assessed to identify landslides at approx. 1:5000 scale and mapped at approx. 1:2000 scale, therefore many small and narrow slips (<100m^2 and/or 20m width) will not have been captured due to lack of visibility. As a result, the extent of slips will be underrepresented due to canopy overhang, and many small slips missed altogether due to no obvious canopy gaps forming. Ecosystem information used to describe the vegetation lost from landslide areas was extracted from the Current Ecosystem Extent data.

2.3 Results and discussion

2.3.1 Current ecosystems

Since the 2018 report (Auckland Council 2018), there have been no significant updates to the ecosystem extent mapping and therefore the results remained unchanged.

Within the Heritage Area, 30 indigenous ecosystem types were present, covering approximately 21,300 ha of indigenous habitat (approximately 81% of the total Heritage Area). This is one of the largest blocks of contiguous indigenous vegetation remaining in Auckland (Auckland Council 2015).

Forest and scrub ecosystems were the most prevalent indigenous vegetation types, constituting 94 per cent of the total area of indigenous ecosystems. The remaining 6 per cent consisted of non-forest indigenous vegetation, including wetlands, mangroves, and grass and sedge-covered dunes.

The dominant forest type within the Heritage Area was kauri-podocarp-broadleaf forest, which contributed nearly 45 per cent of all indigenous ecosystems (Table 3, Fig. 1). This diverse forest type exhibits a variety of canopy and sub-canopy species, with kauri primarily found on ridge-crests and slopes, and broadleaved species more abundant in gullies. Podocarp species like rimu, tōtara, miro, kahikatea, and tānekaha are widespread. Other significant forest and scrub types included manuka-kanuka scrub (17% of total), broad-leaved scrub and forest (13% of total), and kanuka scrub and forest (12% of total) (Table 3, Fig. 1). Collectively, these four dominant ecosystems accounted for over 88 per cent of the indigenous ecosystems in the Heritage Area. Five additional indigenous ecosystems each covered one to 3 per cent of the total indigenous ecosystem area, encompassing less common forest types, as well as duneland and cliff ecosystems (Table 3, Fig. 1). The remaining 21 ecosystem types comprised less than 1 per cent of the total area each and consisted of rare forest types and wetland ecosystems (Table 3, Fig. 1).

Table 3: Description and approximate area of indigenous ecosystem types (Singers er al 2017) in the Waitākere Ranges Heritage Area. These ecosystems are mapped in Figure 1.

Ecosystem name (code)	Approx. total area (ha)	Per cent of total indigenous ecosystem area
Kauri, podocarp, broadleaved forest (WF11)	9,695	45.5%
Mānuka, kānuka scrub (VS3)	3,639	17.1%
Broadleaved scrub/forest (VS5)	2,861	13.4%
Kānuka scrub/forest (VS2)	2,644	12.4%
Tawa, kohekohe, rewarewa, hīnau podocarp forest (WF13)	617	2.9%
Coastal broadleaved forest (WF4)	536	2.5%
Spinifex, pīngao grassland/sedgeland (DN2)	314	1.5%
Dune plains (DN5)	256	1.2%
Kauri forest (WF10)	207	1.0%
Pōhutukawa treeland/flaxland/rockland (CL1)	196	0.9%
Raupō reedland (WL19)	72	0.3%
Mānuka dominated scrub (VS3.2)	60	0.3%
Taraire, tawa, podocarp forest (WF9)	59	0.3%
Treeland (TL)	39	0.2%
Machaerina sedgeland (WL11)	32	0.2%
Hebe, wharariki, flaxland/rockland (CL6)	28	0.1%
Planted vegetation (PL)	19	0.1%
Gumland (WL1)	12	0.1%
Coastal turf [Herbfield] (SA5)	**8**	**<0.1%**
Kahikatea, pukatea forest (WF8)	**5**	**<0.1%**
Fire induced gumland heath (WL1.2)	**2**	<0.1%
Mangrove forest and scrub (SA1.2)	**2**	<0.1%
Oioi restiad rushland/reedland (WL10)	**1**	<0.1%
Flaxland (WL18)	**1**	<0.1%
Dune slack [Herbfield] (DN5.2)	**<1**	<0.1%
Kahikatea forest (MF4)	**<1**	<0.1%
Mangrove forest scrub (SA1)	**<1**	<0.1%
Mānuka, tangle fern, scrub, fernland (WL12)	**<1**	<0.1%
Saltmarsh – Sea rush oioi (SA1.3)	**<1**	<0.1%
Coastal lakeshore turf [Herbfield] (WL15.1)	**<1**	**<0.1%**

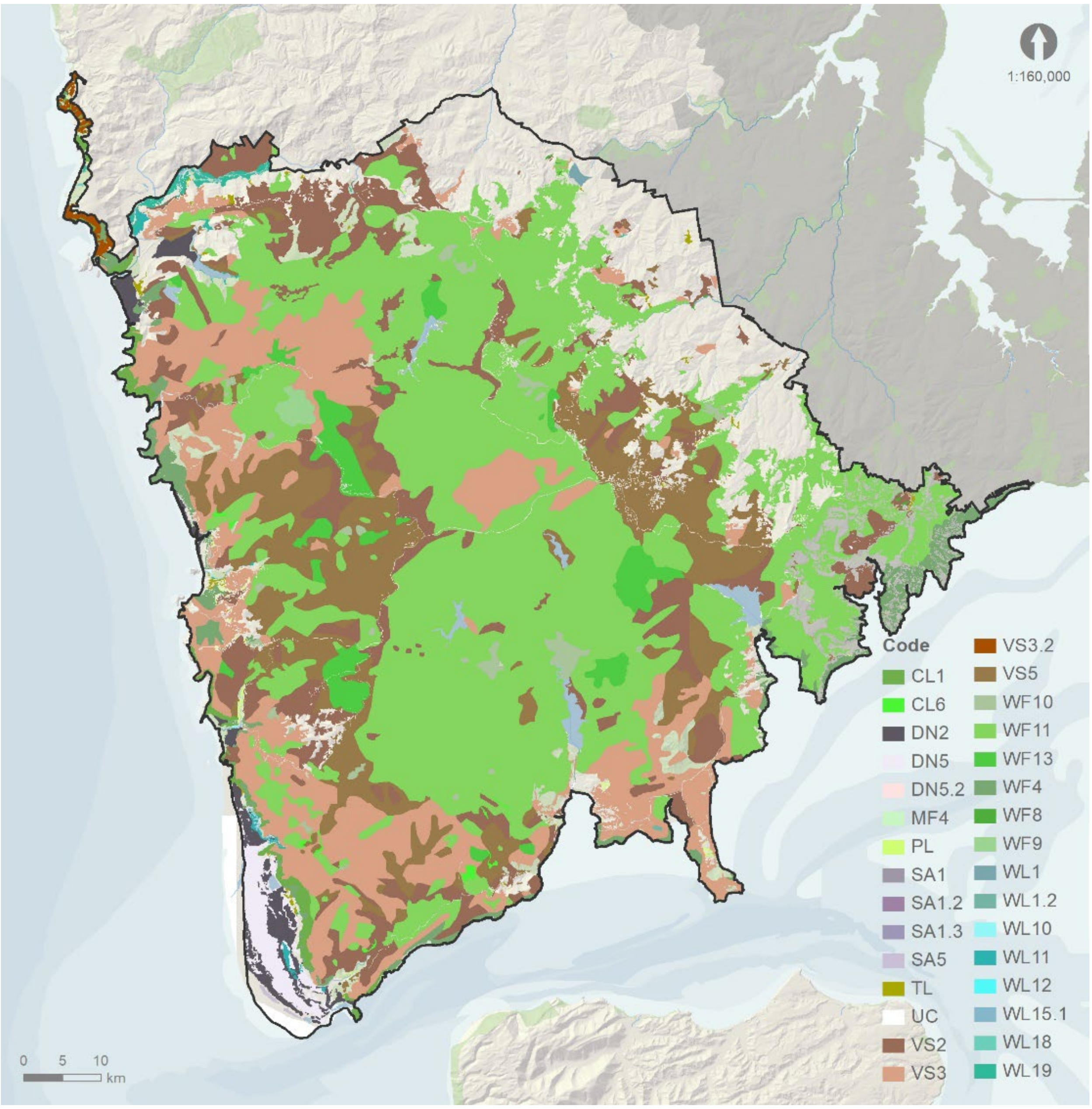

Figure 1: Vegetation map of current indigenous ecosystem extent distribution in the Heritage Area (excluding exotic ecosystem types), based on Singers et al (2017).

2.3.2 Land cover state (2018) and change (2012 to 2018) based on LCDB

Over 85 per cent, or 22,000 hectares, of the land cover in the Heritage Area was indigenous vegetation (including indigenous forest, indigenous scrub/shrubland, and other herbaceous vegetation classes) as mapped in the LCDB in 2018. The remaining land cover was associated with rural production (12% of total) and urbanised areas (3% of total) (Figure 2).

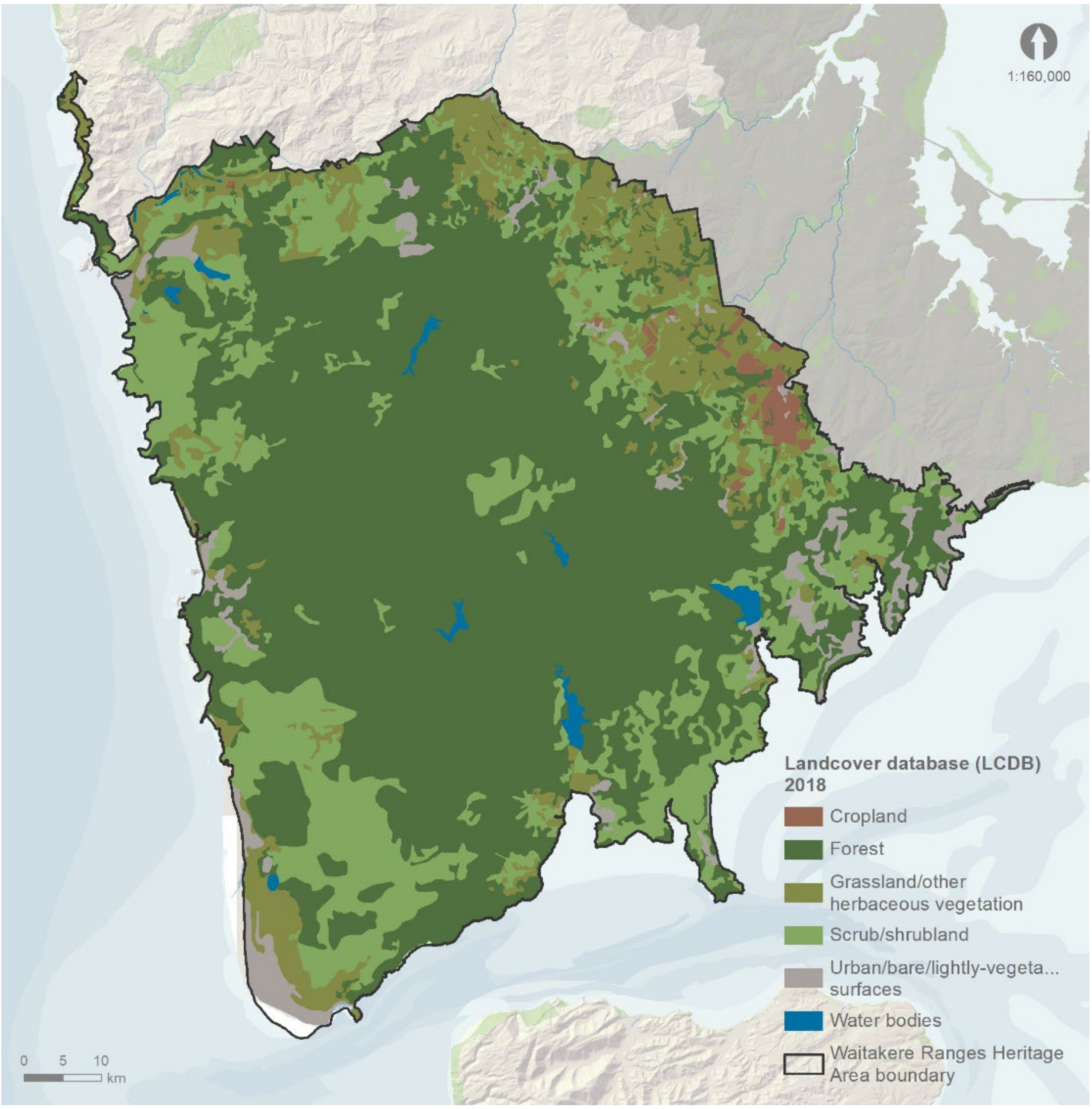

Figure 2: Land cover distribution in the Waitākere Ranges Heritage Area based on the LCDB (Landcare Research, 2020). Land cover is shown in the broad class level as used in the LAWA (Land Air Water Aotearoa, 2021) reporting.

Using the broad land cover classes (Table 4), the land cover in the Heritage Area was dominated by forest (62% of land area), and scrub/shrubland (22% of land area). Grassland/other herbaceous vegetation, occupied 11 per cent of the Heritage Area land area. Urban/bare/lightly-vegetated surfaces, which include urban areas, and cropland occupied four and 1 per cent of the Heritage Area, respectively.

The medium land cover classes, provide a more detailed picture of the land cover in the area (Table 4). In the Heritage Area, Indigenous Forest (60% of the land area) accounts for almost the entire area of forest, the remaining area is occupied by exotic forest (1% of the land area) (Table 4). Similarly, the area of scrub/shrubland cover in the Heritage Area is predominantly indigenous scrub/shrubland (22% of land area) (Table 4). Exotic grassland (10% of land area) accounts for most of the area of grassland/other herbaceous vegetation (Table 4). The area of urban/bare/lightly vegetated surfaces is almost entirely comprised of urban area (3% of the land area) (Table 4).

Table 4: Land cover state in the Heritage Area (2018) based on LCDB (Landcare Research, 2020). Land cover is summarised using the LAWA Broad and Medium class levels. Area is expressed in hectares and as expressed as a proportion of the total Heritage Area.

Land cover class, Broad and Medium	Area	
	ha	Per cent
Cropland	**223**	**1%**
Cropping/horticulture	223	1%
Forest	**16,064**	**62%**
Exotic Forest	296	1%
Indigenous forest	15,768	60%
Grassland/other herbaceous vegetation	**2,805**	**11%**
Exotic grassland	2,534	10%
Other herbaceous vegetation	271	1%
Scrub/shrubland	**5,765**	**22%**
Exotic scrub/shrubland	12	0%
Indigenous scrub/shrubland	5,753	22%
Urban/bare/lightly-vegetated surfaces	**1,027**	**4%**
Artificial bare surfaces	19	0%
Natural bare/lightly-vegetated surfaces	332	1%
Urban area	676	3%
Water bodies	**213**	**1%**
Water bodies	213	1%

Areas of the dominant land cover classes in the Heritage Area have been relatively stable between 2012 and 2018 (6 years) (Table 5). Using the broad land cover classes, changes comprised a total of less than one ha. This change was the result of a decrease in scrub/shrubland (0.61 ha) and cropland

(0.03 ha) and area accounted for in the increase in area of urban/bare/lightly-vegetated surface (0.64 ha).

There were slightly more changes in area of broad land cover types detected by the LCDB from 1996 to 2018 (22 years) (Table 5). The greatest of these was an increase in cropland by 11.6 ha and an increase in water bodies of 5.9 ha. The distribution of other land cover types, however, has not changed by more than 2 per cent over this time period (Table 5).,

Table 5: Land cover change in the Heritage Area between 2012 and 2018, and 1996 and 2018 based on LCDB (Landcare Research, 2020) using the LAWA broad class levels. Change is expressed as a proportion of the initial reference area.

Broad land cover	2012 to 2018		1996 to 2018	
	ha	Per cent	ha	Per cent
Cropland	-0.03	0%	11.6	5%
Forest	-	0%	-24.9	0%
Grassland/other herbaceous vegetation	-	0%	-14.3	-1%
Scrub/shrubland	-0.61	0%	2.5	0%
Urban/bare/lightly-vegetated surfaces	0.64	0%	19.2	2%
Water bodies	-	0%	5.9	3%

2.3.3 Current canopy cover 2016-2017

The most recent canopy cover estimate in the Heritage Area is 76 per cent (derived from 2016-2017 LiDAR data) (Fig. 3).

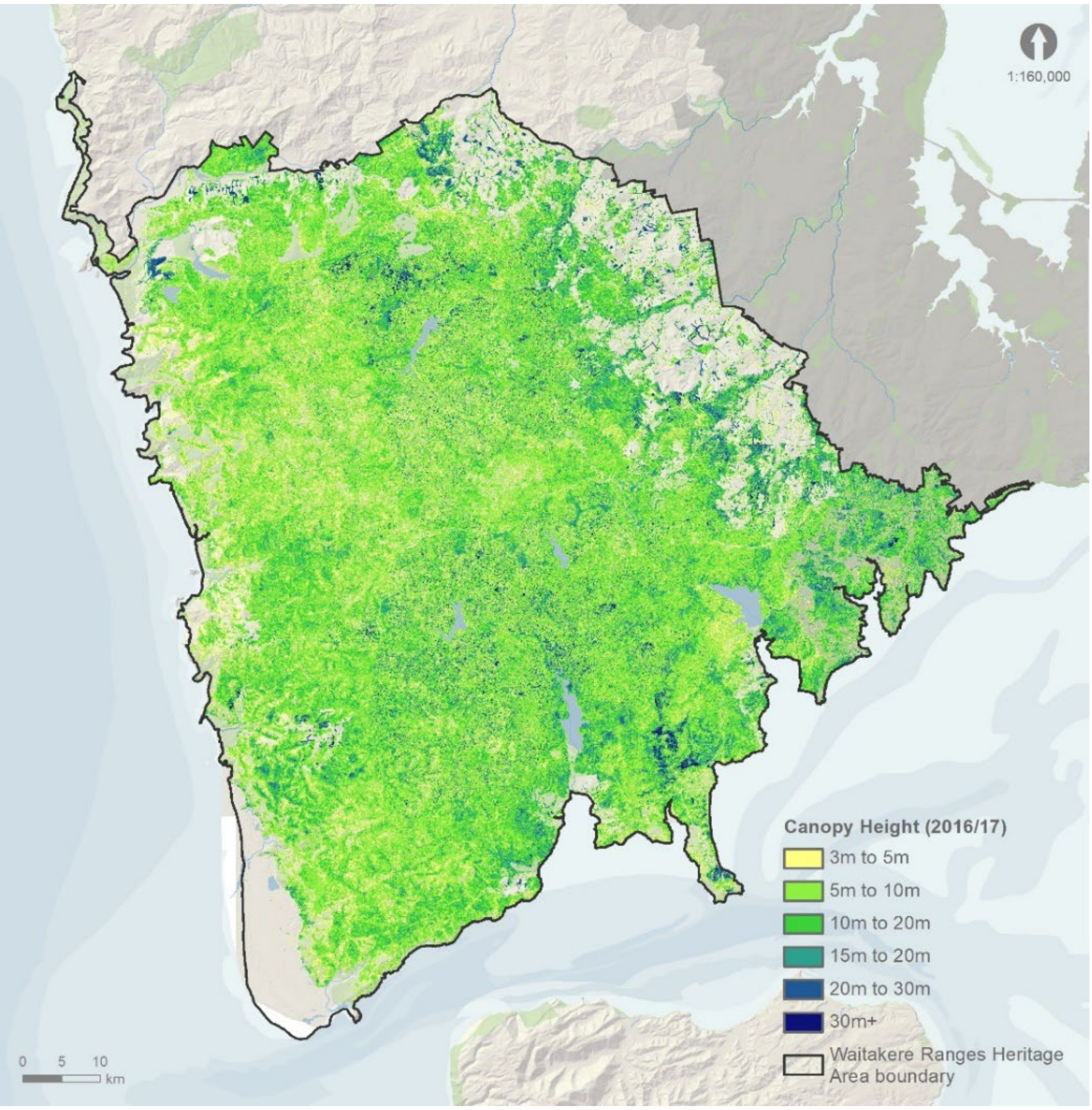

Figure 3: Current canopy distribution in the Heritage Area. Map shows the 2016-2017 Canopy Height Model derived from LiDAR.

Canopy cover varies by the underlying Auckland Unitary Plan zoning across the Heritage Area. The dominant zones (>99% of total land area) in the Heritage Area are Public Open Space (68%), Rural (24%), Residential (4%) and General (3%) zones. All other zones only make up 0.4 per cent of the Heritage Area. The canopy cover across the zone groups ranges from 56 per cent in general zones (such as roads and water) to 84 per cent in Public Open Space (which includes the Waitākere Ranges

Regional Parks and various reserves), while Residential and Rural zones have 59 per cent and 69 per cent canopy cover respectively (Figure 4).

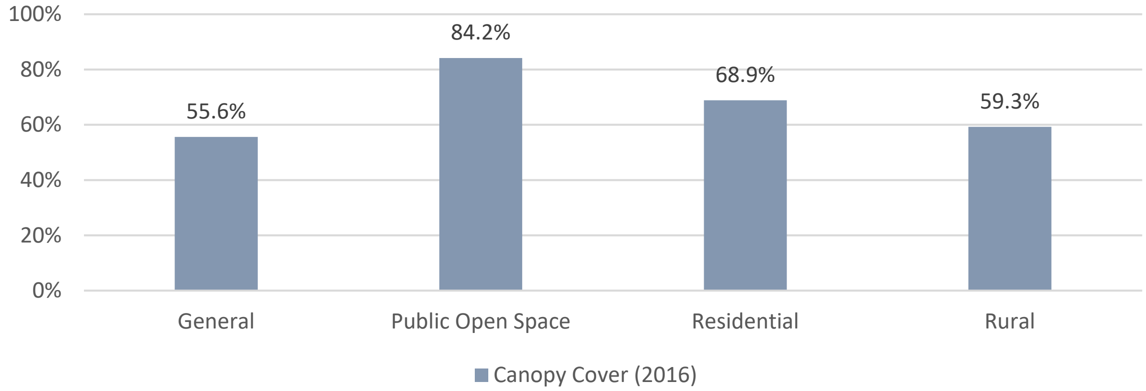

Figure 4: Canopy cover 3 m in height or greater (2016-2017) by Auckland Unitary Plan (AUP) base zone groups in the Heritage Area.

The estimated distribution of canopy height also varies among the zones (Figure 5). All zones follow the same general pattern, whereby the canopy surface is skewed toward the lower height classes (3 m to 5 m and 5 m to 10 m) comprising 60 per cent of the canopy surface area; this tapers off towards the higher height classes (Figure 5). However, there are some height classes that diverge more than others. The greatest difference in proportions of the canopy among height classes is in the 5 to 10 m class. Public Open Space and General zones have higher proportions in the 5 m to 10 m, indicative of lower stature regenerating forest types common in the Heritage Area (see Section 3.2.1). It is important to note that the height distribution describes only the canopy surface area on a per-pixel basis; it does not describe the height classes of crowns or individual trees. While it does describe the height of the tree canopy overall (akin to a blanket that would lie across the top surface of all the trees), it is not an accurate substitute for forest structure or height class distribution, as high height classes are underestimated (i.e., tall trees have area present in the lower height classes in addition to their maxima) and low height classes are overestimated (i.e., some of the area present in lower height classes actually belongs to tall trees).

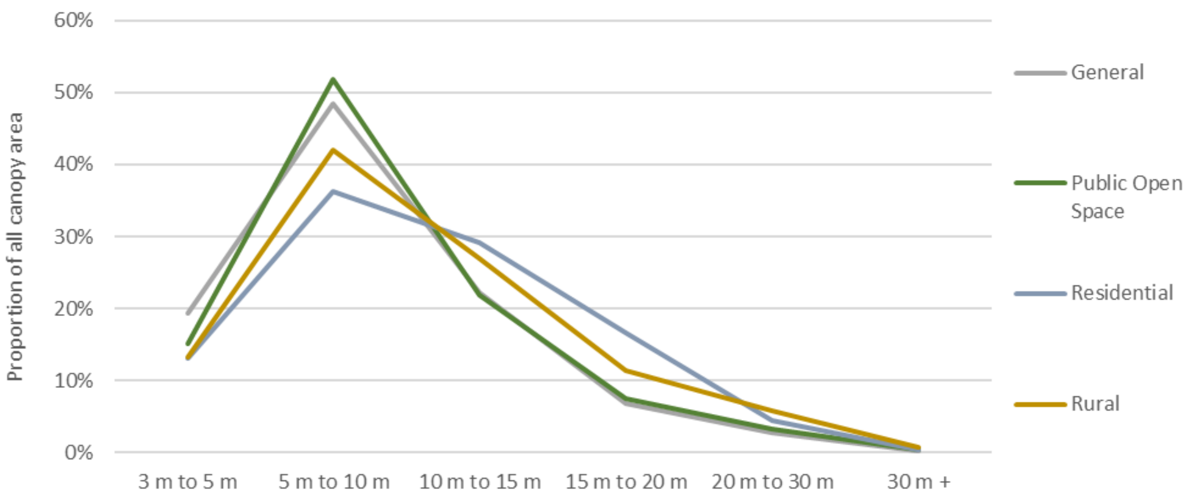

Figure 5: Canopy area height distribution (2016-2017) by Auckland Unitary Plan (AUP) base zone groups in the Heritage Area.

2.3.4 Canopy losses 2013 to 2016-2017

Comparison of the CHMs developed for 2013 and 2016-2017 detected thousands of small canopy loss events across the Heritage Area (Figure 6). This totalled 50 hectares of canopy loss (with no vegetation 3 m or over remaining), equivalent to 0.2 per cent of the total land area in the Heritage Area reducing in canopy cover.

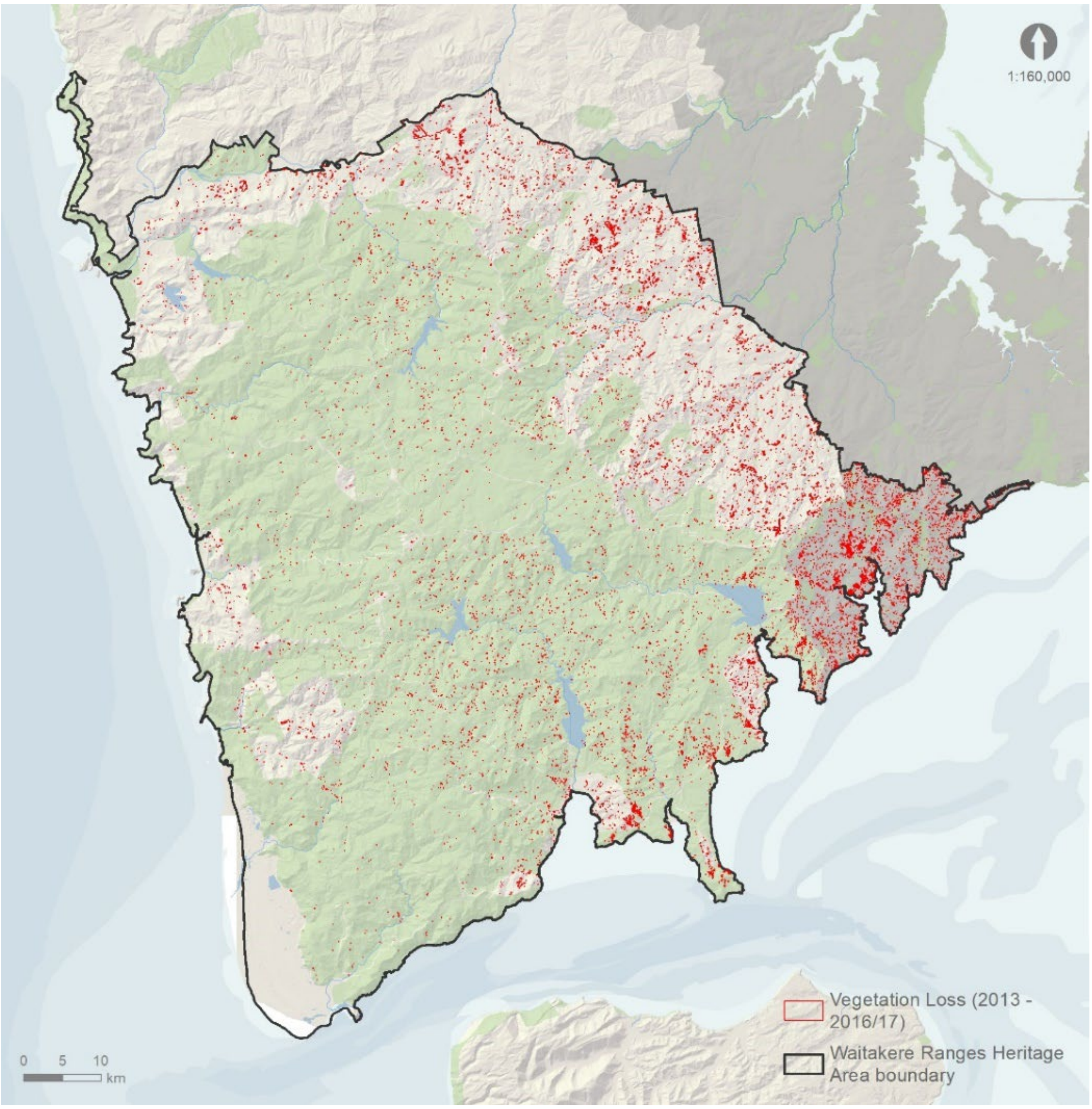

Figure 6: Spatial distribution of canopy losses between 2013 and 2016-2017 in the Heritage Area.

As with canopy cover and height class distributions, canopy loss (with no vegetation 3 m or over remaining) varies across the Heritage Area by zone (Figure 7). Despite making up a quarter of the total land area in the Heritage Area, a large share of the total losses was identified in Rural zones (31 ha) (Figure 7). The remaining losses were found in Residential (9 ha), Public Open Space (8 ha), and General zones (2 ha). As a proportion of the total land area in each zone Residential zones experienced the most significant loss (0.8%), followed by Rural (0.5%), General (0.3%) and Public Open Space (0.05%) (Figure 7).

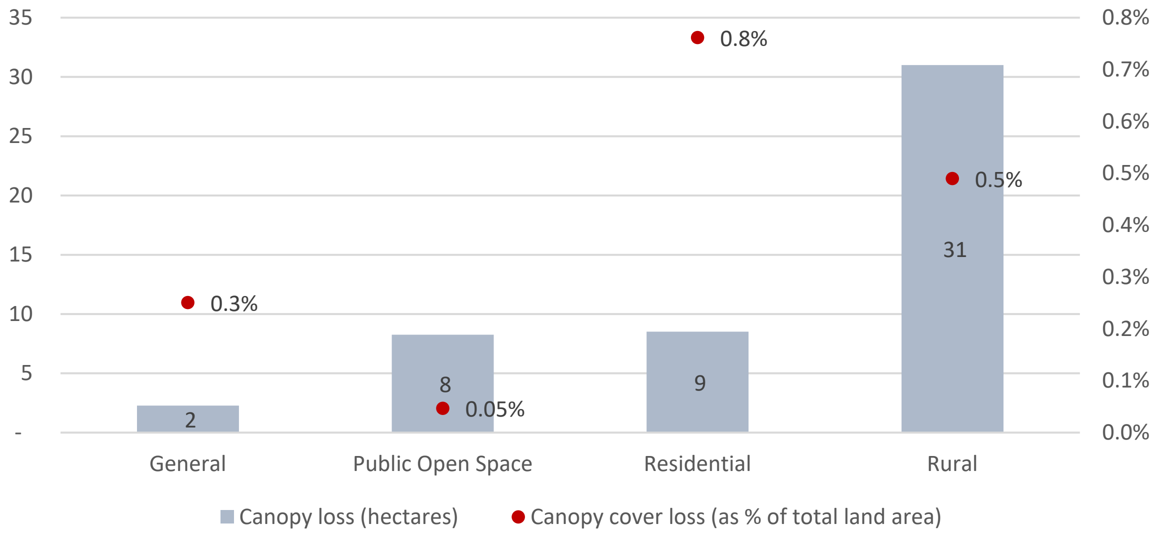

Figure 7: Canopy loss between 2013 and 2016-2017 measured in hectares across the dominant Auckland Unitary Plan (AUP) zone groups in the Heritage Area.

The AUP Significant Ecological Overlay is designed to protect ecological areas through requirement of resource consent to permit vegetation clearance. Most of the regional parkland (designated as public open space) in the Heritage Area is under SEA protection and therefore it is no surprise that most losses (96%) here are in SEAs (Figure 8).

Typical examples of canopy loss in residential zones were deliberate vegetation clearance associated with developments and property maintenance (landscaping, powerline maintenance, etc), whereas losses in rural zones were associated with harvesting plantation forests, removal of dead or dying trees, removal of shelter belts, and various other maintenance activities. It is not known if the losses are more prevalent in indigenous or exotic vegetation for each zone.

However, comparison of losses with aerial imagery indicated that canopy loss in the Heritage Area (particularly the public open space) was not solely a result of human activities and land use changes. Natural succession and competition, disturbances, senescence (aging), and disease also contributed to the loss of canopy cover. Further research is needed to quantify and understand the causes and legality of losses.

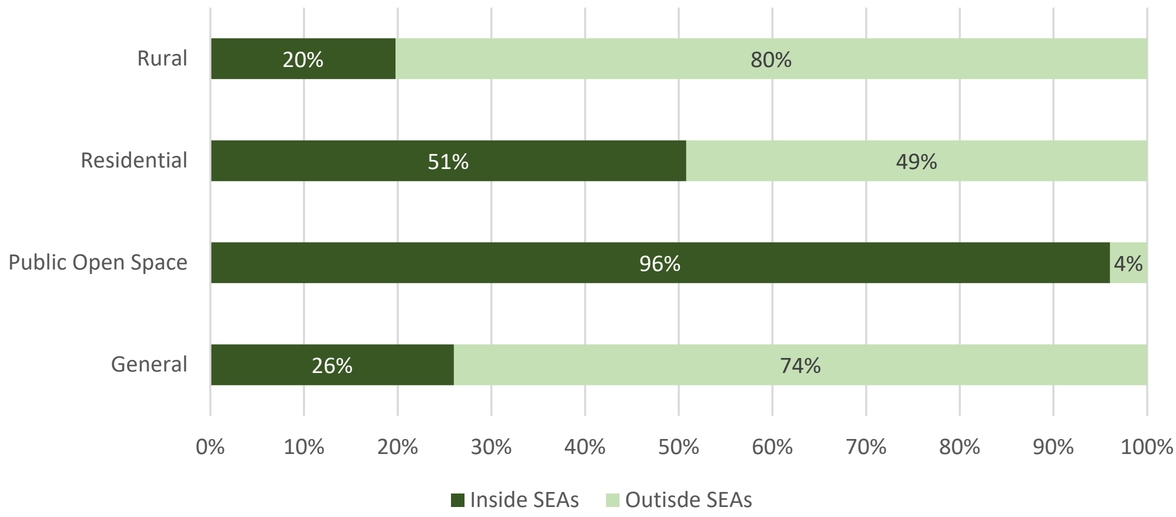

Figure 8: Proportion of complete canopy loss (understory 3 m or over remains) inside and outside Auckland Unitary Plan Significant Ecological Areas (AUP SEAs) inside the Heritage Area.

2.3.5 Landslides

We identified a substantial number of landslides (exceeding 150) across the Waitākere Ranges Heritage Area triggered by the August 2021 rainfall event. The average area of these landslides (mapped from 2022 aerial imagery) was 0.1 ha and the largest measured 1.8 ha. Most landslides were small shallow slides and flows in dense indigenous forests. The landslides were not evenly distributed across the study area, with the majority located in the south-facing catchments, around the Upper Huia and Upper Nihotupu Reservoirs (Figure 9). A preliminary assessment of the Auckland Council aerial image catalogue dating back to the early 2000s showed no evidence of other multiple-occurrence shallow landslide events prior to 2021, which had been uncommon until recently.

Although further research and monitoring will be necessary to discern the causes and overall impacts on biodiversity of these landslides, it is apparent that a significant amount of vegetation loss has occurred, with approximately 18 ha of forest being affected, predominantly consisting of mature kauri-podocarp-broadleaved forest (75%).

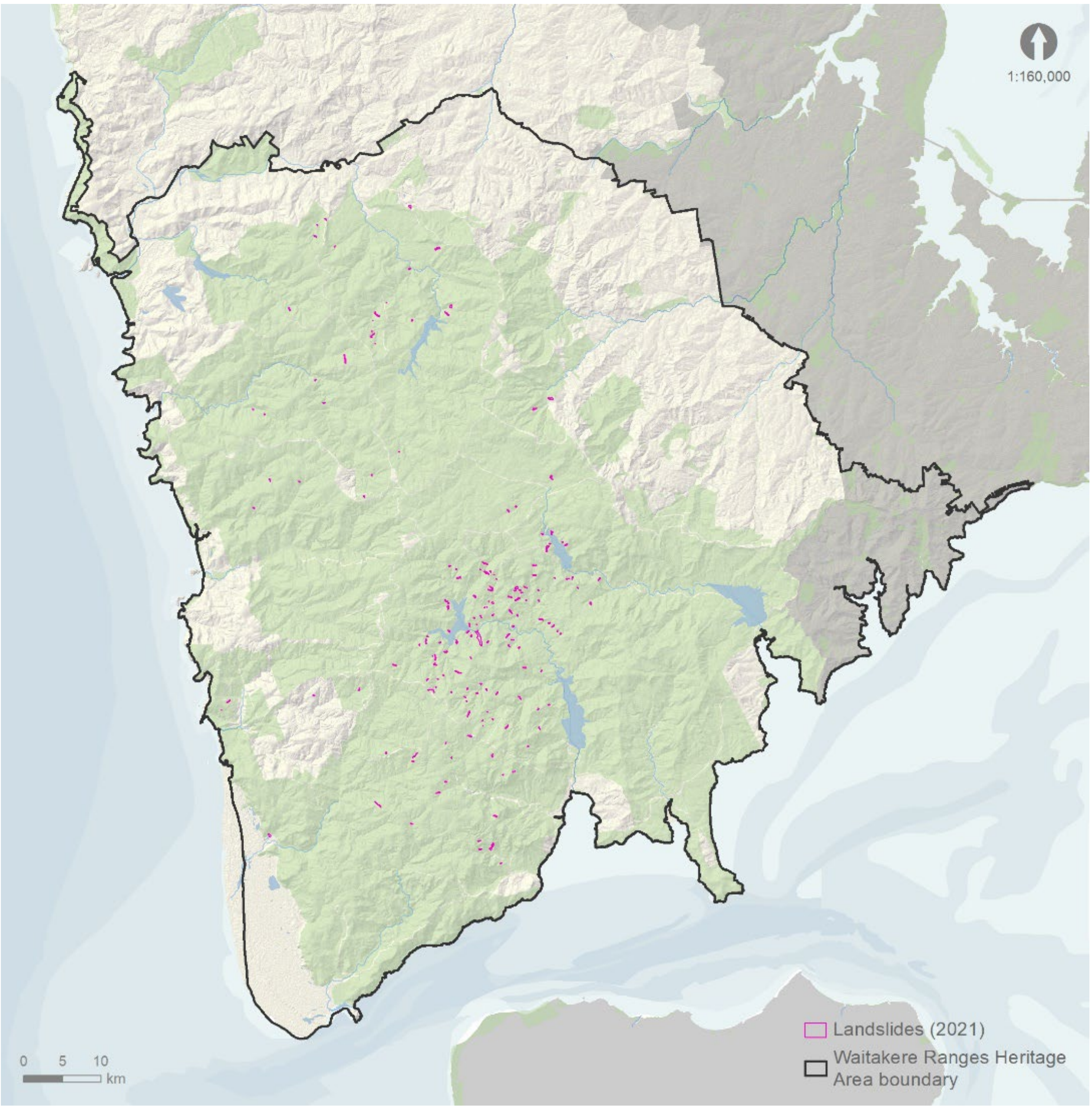

Figure 9: Map showing the distribution of landslides triggered by rainfall in August 2021 in the Heritage Area.

3 Plants

3.1 Introduction

3.1.1 Heritage Area history and pressures

Prior to human arrival the Heritage Area was covered in forest, dominated by kauri (*Agathis australis*), podocarp, and broadleaved canopy species. In addition, pōhutukawa (*Metrosideros excelsa*) were common in coastal areas, emergent northern rātā (*Metrosideros robusta*) frequent in kauri forest and kahikatea (*Dacrycarpus dacrydioides*) clustered in wetter areas (Esler 1983). Forests of the Heritage Area probably formed a shifting mosaic of patches resulting from asynchronous but regular disturbance events (Coomes and Allen 2007) over timescales of hundreds to thousands of years.

The recent history of the Heritage Area is one of disturbance and regeneration. With the arrival of Māori, forest along the west and south coast of the Heritage Area was repeatedly burnt up to one kilometre inland (Esler 1983). From the 1840s, colonising pākeha used the Heritage Area for extraction of timber and kauri-gum and cleared and burnt forest for farming. These anthropogenic activities produced a mosaic of unlogged, selectively logged, burnt, and cleared patches across the Heritage Area (Esler and Astridge 1974, Esler 1983). There are no data quantifying areas of land converted to pasture or subjected to different levels of logging, burning, or clearing from that time. Aerial imagery from the 1940s shows numerous large patches of pasture and thinned forest. Gradually, and especially since the 1940s when farming was largely abandoned, logging stopped and increasing areas of the Heritage Area protected, allowing widespread forest regeneration (Denyer et al 1993).

Humans brought not only harvesting and disturbance to the Heritage Area, but also hunting, pest animals, plant pathogens, exotic plants, and changing climate (Denyer et al 1993, National Institute of Water and Atmospheric Research 2017). Consequently, forest regeneration has occurred in an altered environment; one in which the dispersal of seeds of many broadleaved canopy and emergent conifers is more limited because of reductions in the populations of their bird dispersers, where pest animals consume seeds, seedlings, flowers, buds, leaves, stems and new growth of palatable plant species, where plant pathogens causing kauri dieback and myrtle rust threaten some of the most iconic and abundant tree species, where indigenous plant species must compete with exotic species, and where weather patterns have been shifting towards more droughts and more intense rainfall events. Given the scale of anthropogenic influence, it is not clear that forest regeneration can follow the expected successional pathways of forest types previously dominant in the Heritage Area (Wyse et al 2018). Arrested successional pathways are frequently attributed to the absence of seed sources of fleshy-fruited broadleaved canopy and conifer species, absence or low frequency of bird mediated seed-dispersal and/or the consumption of palatable seedlings by introduced mammalian herbivores.

Analysis of forest plots in Te Urewera (250km south-east of the Heritage Area) concluded that successional processes were arrested in fire-induced communities dominated by kānuka (*Kunzea* species), treeferns, rewarewa (*Knightia excelsa*) and kāmahi (*Weinmannia racemosa*) which all showed minimal compositional change over 30 years, especially of canopy species (Payton et al 1984, Richardson et al 2014). This arrested succession was attributed to deer grazing on palatable broadleaved canopy species.

Deer and goats are absent from the Heritage Area but brushtail possum (*Trichosurus vulpecula*), feral pig (*Sus scrofa*), ship rat (*Rattus rattus*) and Norway rat (*Rattus norvegicus*) are present, and all consume plants to varying degrees (Fitzgerald 1976, Thomson and Challies 1988, Daniel 1973, Sweetapple and Nugent 2007). By the 1990s, populations of possum were high enough to have caused significant damage to canopy and seedling populations of northern rātā and other species in the Heritage Area (Denyer et al 1993, Buddenhagen et al 1995). Since then, multiple operations, but notably Operation Forest Save, have annually suppressed possum numbers to between 0.6 and 6.6 per cent residual trap catch (the number of possums caught per 100 trap nights, Lovegrove and Parker *in review*). For feral pigs in podocarp-tawa forest in Te Urewera, plant material composed 72 per cent of their diet, with the fleshy fruits of tawa and hīnau (*Elaeocarpus dentatus*) forming a large component of their diet (Thomson and Challies 1988). Plant matter, including seeds, fruit and leaves, form more than 70 per cent of ship rat diet, with seeds of nīkau (*Rhopalostylis sapida*), hīnau and miro (*Podocarpus ferrugineus*) commonly consumed (Daniel 1973, Sweetapple and Nugent 2007).

Within the Heritage Area are two plant pathogens with the potential to disrupt forest composition, structure and ecosystem function (Jo et al 2022). Kauri dieback, caused by the pathogen *Phytophthora agathicida*, is a lethal soil-borne root rot disease of kauri (*Agathis australis*). Kauri dieback was first detected in the Heritage Area in 2006 and as of 2021, *P. agathicida* is distributed around the periphery of the Waitakere Ranges, with two areas of elevated detection in the north and mid-west of the Heritage Area (Froud et al 2022). Myrtle rust, caused by the fungal pathogen *Austropuccinia psidii* specific to Myrtaceae, arrived in New Zealand in 2017 and has so far infected 17 native myrtaceous species and killed adult trees of one species (Manaaki Whenua Landcare Research 2020).

Climate change is expected to elevate temperatures and increase the frequency and severity of drought and storm events in the Auckland region (National Institute of Water and Atmospheric Research 2017). There is little knowledge on how changes in climate will impact the ecological integrity of Auckland's forests directly, but it is widely agreed that existing problems with invasive plants and pest animals will be exacerbated (Bishop and Landers 2019, Macinnis-Ng et al 2021). With regard to drought events, elevated stress from prolonged low soil moisture will impact indigenous forest flora and fauna. There are few predictive traits for drought-induced mortality; but small trees are considered more susceptible than larger trees, and forests on steeper ridges and slopes are more susceptible, which is where the least disturbed forest is more likely to be found (Russo et al 2010, O'Brien et al 2017). In the Auckland region, species such as taraire (*Beilschmiedia taraire)*, kanono (*Coprosma autumnalis*) and māhoe (*Melicytus ramiflorus*) are considered particularly drought sensitive (Bannister 1986, Martin and Ogden 2005, Myers and Court 2013, Wyse et al 2013). Anecdotal evidence suggests taraire showed high dieback and mortality on Auckland's east coast during the droughts of 2012-13 and 2020. Seedling recruitment of forest species can be particularly sensitive to drought resulting in failure or compositional changes in forest regeneration (Pozner et al 2022).

Droughts also may increase wildfire hazard (Pearce 2011), especially in regenerating forests that contain more fire-prone species, maybe dry out more due to physical exposure of structure, and potentially change successional trajectories by favouring fire-adapted non-indigenous taxa (Perry et al 2015, Kitzberger et al 2016).

Increasing frequency and severity of drought and high rainfall events may cause shrinking and swelling in Auckland's clay-rich soils leading to progressive weakening, and increased likelihood of landslides (Tichavský et al 2019, Brown et al 2003). Landslides are a natural disturbance process that can lead to compositional changes in the vegetation of our indigenous forests. However, landslides are increasing in frequency and scale in response to climate change as evidenced by the number and coverage of landslides following extreme storm events in March 2017 (Lee 2020), September 2020 (Section 2) and January 2023 (under analysis). While landslides may provide opportunities for natural forest regeneration processes, including the regeneration of other species, they also can destroy mature forest and provide opportunities for infestation by exotic plant species and weeds.

3.1.2 Forest composition and successional dynamics

Following disturbance, regenerating forest typical of the Heritage Area goes through several developmental stages (Wyse et al 2018). Early successional stages are defined by seedling recruitment, followed by a building phase characterised by a high density of small tree stems. Once the sub-canopy closes, mid-successional stages are defined by a period of intense competition for light during which there is high mortality (competitive thinning) of smaller tree stems. This maturing forest supports a stand basal area (the summed cross-sectional area of trees at 1.35m height per unit forest area) that remains stable (Weiner and Freckleton 2010). With increasing tree growth, this constant stand basal area leads to self-thinning. In late-successional stages, mature forest is characterised by high structural complexity with understorey, sub-canopy, canopy, and emergent trees. Emergent trees are typically kauri or podocarp conifers and the hemi-epiphytic northern rātā. Once forest stands mature, senescence leads to canopy thinning, providing light for seedlings and saplings to establish. Age estimates from broadleaved-podocarp forest in Mamaku Plateau, Waikato, give 80-100 years to reach canopy closure, an average broadleaved canopy turnover time of 200-270 years, while cohorts of conifers are recruited, mature and senesce over longer time frames of > 400 years (Smale et al 1997).

In the Heritage Area, logging, clearance of the original forest for pasture and repeated burning created eroded soils that were typically colonised by light-demanding, wind-dispersed species such as bracken, mānuka (*Leptospermum scoparium)* and kānuka (*Kunzea robusta*) or in coastal areas pōhutukawa. Mānuka is more salt-tolerant and grows well in coastal areas but has a shorter stature than kānuka and will eventually be shaded out in areas where kānuka grows well (Stephens et al 2005). Pōhutukawa dominated communities can persist for several centuries, while kānuka/mānuka dominated communities can progress to more diverse later successional stages over a shorter time period so long as seed is available and herbivore and weed pressures are low (Atkinson et al 2004).

Following the establishment of these early pioneer species, succession proceeds with the arrival and establishment of bird-dispersed secondary migrants including mapou (*Myrsine australis*), mahoe (*Melicytus ramiflorus*), kohekohe (*Didymocheton spectabilis*), karaka (*Corynocarpus laevigatus*), pūriri (*Vitex lucens*), whauwhaupaku (*Pseudopanax arboreus*, tānekaha (*Phyllocladus trichomanoides*) and porokaiwhiri (*Hedycarya arborea*, Atkinson et al 2004). Also common are the wind-dispersed rangiora (*Brachyglottis repanda*), akepiro (*Olearia furfuracea*) and rewarewa (*Knightia excelsa*). Later successional stages are indicated by the arrival of broadleaved canopy species such as tawa and taraire (*Beilschmiedia tarairi*) with their large bird-dispersed seeds.

Kauri and podocarp species often form similar aged cohorts following landscape-scale disturbance (Wyse et al 2018). In the absence of landscape-scale disturbance, more light-demanding species of conifers such as kauri and rimu (*Dacrydium cupressinum*) will enter the successional pathway by colonising areas after minor disturbances such as landslides or treefalls (Adams & Norton 1991). In the absence of disturbance there may be a compositional shift towards more shade-tolerant conifers such as miro (*Prumnopitys ferruginea*). Drier sites will favour the light-demanding and drought-tolerant tōtara while moister sites will favour kahikatea (*Dacrydium dacrydioides*). Although light-demanding podocarps and kauri follow similar successional pathways, their communities often differ driven by the ecosystem engineering effects of kauri. The acidic and nutrient poor soils under kauri favour more stress-tolerant species, including their own seedlings, to create a compositionally and structurally distinct plant community compared to podocarp conifer forest (Wyse 2012, Wyse and Burns 2013, Wyse et al 2018). Tree-ferns (mostly ponga, *Cyathea dealbata*), mamaku (*Cyathea medullaris*) and *Dicksonia squarrosa* in the Heritage Area can be common throughout all successional stages but are more likely to dominate the basal area in younger forest (Smale et al 1997, Brock et al 2017).

Using the classifications of Singers et al (2017), Warm Forest (WF) comprises 52 per cent of indigenous vegetation in the Heritage Area (Table 3). This is composed predominately of Kauri, podocarp, broadleaved forest (WF11), Tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13) and Kauri forest (WF10). There is also some Pōhutukawa, pūriri, broadleaved forest (WF4) on the coastal fringe. Regenerating forest (VS) comprises 42 per cent of indigenous vegetation in the Heritage Area, composed predominately of Kānuka scrub/forest (VS2), Mānuka/kānuka scrub (VS3) and Broadleaved species scrub/forest (VS5). Warm forest (kauri-podocarp-broadleaved forest) broadly occurs where forest was less intensively logged, and in a few places, unlogged (Esler 1983, Denyer et al 1993). Regenerating forest broadly occurs where forest was cleared for pasture, burnt or intensively logged with removal of large trees (including kauri, kahikatea, rimu, pūriri, miro, totara and matai, Denyer et al 1993).

3.1.3 This study

Here we report on the ecological integrity of forest in the Heritage Area using 14 years of data (2009-2022) from Auckland Council's Terrestrial Biodiversity Monitoring Programme (TBMP) forest plot network. Ecosystems have ecological integrity when all the indigenous plants and animals typical of a region are present, together with the key major ecosystem processes (Lee et al 2005, McGlone et al 2020). We describe the ecological integrity by examining the state and trends in plant species composition and structure from 26 permanent forest plots in the Heritage Area in the context of forest successional dynamics and novel pressures. We examine whether forest is regenerating following expected successional pathways, the presence of Threatened and At Risk plant species, whether we can detect changes in the abundance of those plants vulnerable to pressures including herbivory, plant pathogens and/or climate change, and the relative abundance of indigenous to exotic species.

3.2 Methods

3.2.1 Forest plot network and protocol

The Terrestrial Biodiversity Monitoring Programme (TBMP) established a network of permanent 20 m x 20 m plots across Tāmaki Makaurau to monitor forest biodiversity using a systematic sampling approach and national protocols (Griffiths et al 2021). Plots were established in alternate 4 km grid squares to measure the state and trends in forest ecological integrity regionally (Tier 1 Regional), in areas of high conservation value (Tier 2, e.g., Waitākere Ranges), and in areas of high conservation intervention (Tier 3, e.g., Ark in the Park). The majority of plots were established between 2009 and 2013 and they were measured every five years, with rotation 1 in 2009-2013, rotation 2 in 2014-2018, and rotation 3 in 2019-2022. Plot visits took place between October to December annually. At each permanent plot, data collection follows the national 20 m x 20 m permanent plot protocol (Hurst et al 2022) with some adaptations (Griffiths et al 2021). Using the national method ensures our forest monitoring follows best practice and is comparable with forest data across New Zealand. For each plot rotation, abundance data was collected for woody species in three size-classes: trees (>1.35m height and >2.5cm diameter at 1.35m height or DBH), saplings (>1.35m height and <2.5cm DBH) and seedlings (<1.35m height and <2.5cm DBH). The presence of all other species >15 cm tall was recorded. The aim of the protocol was to capture as complete a snapshot of the forest composition and structure as is feasible, given limited resources.

There were 26 TBMP plots located within the Heritage Area boundaries with three complete rotations taken between 2009 and 2022 (Figure 10). Of the 26 plots, 17 were located in forest mapped as warm forest types (WF) that experienced little past disturbance, nine were located in forest mapped as regenerating forest types (VS) that experienced disturbance including logging, burning and clearance (Table 6). To examine the current state of forest composition and structure, the latest rotations (2019-2022) were compared between warm (WF) and regenerating (VS) forest types (Table 7). We were unable to examine individual forest types (e.g., WF4, WF10, WF11, etc) due to insufficient plot numbers. To examine trends in forest composition and structure, data from all plots was compared between the first (2009-2013), second (2014-2018) and third (2019-2022) rotations. We also compared the latest TBMP plot data (2019-2022) between the Heritage Area and regional forest plots; for this we used data from 25 Heritage Area plots and 58 regional plots (for this comparison it was necessary to exclude Tier 1 plots from the Heritage Area sample as these are part of the regional forest network, but we were able to include Heritage Area plots that were only sampled in the third rotation (2019-2022)).

Table 6: Number of TBMP plots in each warm (WF) and regenerating (VS) forest type mapped according to Singers et al 2017.

Forest type	Forest ecosystem	Code	Number of TBMP plots
Warm forest (WF)	Pōhutukawa, pūriri, broadleaved forest (Coastal forest)	WF4	1
	Kauri forest	WF10	0
	Kauri, podocarp, broadleaved forest	WF11	15
	Tawa, kohekohe, rewarewa, hīnau, podocarp forest	WF13	1
Regenerating forest (VS)	Kānuka scrub/forest	VS2	2
	Mānuka, kānuka scrub	VS3	4
	Broadleaved species scrub/forest	VS5	3

Table 7: Numbers of TBMP plots used for analyses of state and trends in the Heritage Area and comparison with regional forests.

Analysis	Location	Rotation	Number of plots			
			Tier 1	Tier 2	Tier 3	Total
State	WRHA	3	5	17	4	26
Trends	WRHA	1, 2, 3	5	17	4	26
WRHA vs Regional	WRHA	3	0	21	4	25
	Regional	3	58	0	0	58

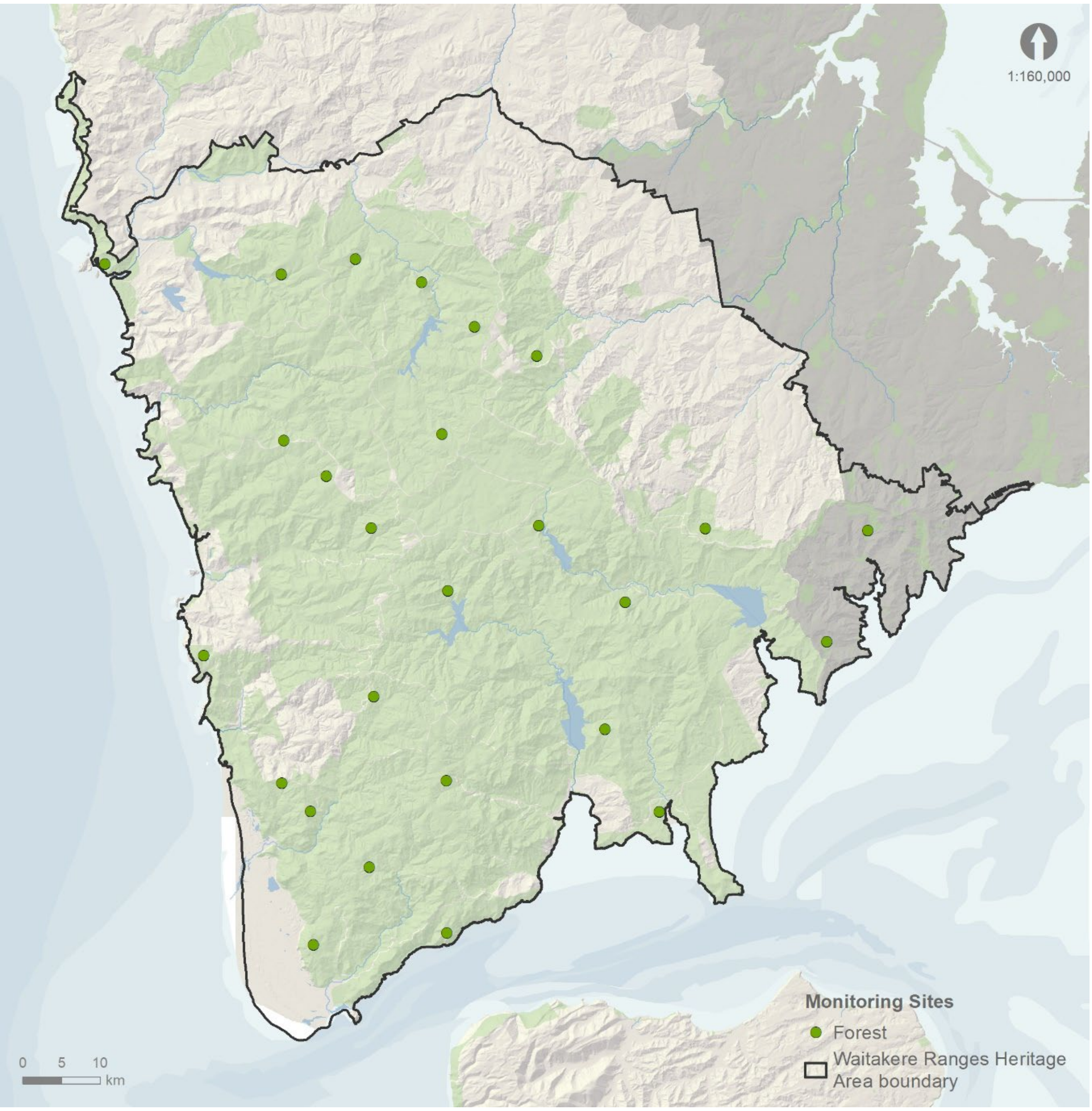

Figure 10: Map of the TBMP forest monitoring plots within the Heritage Area.

3.2.2 Analyses

For the 26 TBMP plots in the Heritage Area, state and trends in forest composition and structure were examined in the context of forest succession using measures of woody species abundance (basal area and density) structured by size-class and tree-type (Schlesselmann et al 2022).

The woody species data collected in three size-classes (trees, saplings and seedlings) was used to calculate four abundance metrics:

1. Basal area or the summed cross-sectional area of trees at 1.35m height (m^2ha^{-1})

2. Density of tree stems (ha^{-1})
3. Density of sapling stems (ha^{-1})
4. Density of seedling stems (ha^{-1})

Stand basal area (ha^{-1}) was calculated for all woody species in a plot. This is a key structural parameter of forests. Stand basal area typically increases during the building phase of forest regeneration after which it remains relatively stable (Weiner and Freckleton 2010). As trees continue to grow in maturing forest, this constant stand basal area leads to self-thinning. Basal area was also calculated for each tree type, where woody species were categorised according to their habit and form within a mature forest (Appendix):

1. Conifer – Gymnosperm trees that do not have flowers. Most conifers reproduce using woody cones, but in the podocarp family (e.g., rimu, kahikatea, miro) the seeds are surrounded by fleshy tissue, and they are dispersed by birds. Many conifers will become emergent trees above the canopy in mature forest.
2. Canopy broadleaf – Angiosperm trees that produce flowers and seeds, many are fleshy-fruited and are dispersed by birds. They have high stature, and many will form the canopy in mature forest.
3. Sub-canopy broadleaf – Angiosperm trees that produce flowers and seeds and have medium stature, often forming a sub-canopy in early forest succession.
4. Shrub – Woody species with low stature, often growing below the level of the sub-canopy.
5. Monocot tree – Predominately nīkau and some cabbage tree species such as tī kouka
6. Tree fern – Tree-like ferns with a trunk, elevating fronds above the ground.

Densities (ha^{-1}) for each size-class (trees, saplings, seedlings) were also calculated for all woody species and for each tree type.

Non-metric multidimensional scaling (NMDS) using the metaMDS function in the package *vegan* (Oksanen et al 2022) was used to describe the relationship between plots in ordination space using tree species basal area per plot. Default settings were used and stress levels <0.2 (suitable for small data sets, Dexter et al 2018). Procrustes analyses were performed to examine the rotation required to map NMDS ordinations from the first (2009-2013) and third (2019-2022) plot rotations (Peres-Neto and Jackson 2001). Procrustes residuals were used to identify plots with greater than expected change in composition.

To calculate species richness, we included all species recorded inside the plot including trees, saplings, woody seedlings, non-woody seedlings, vines, climbers and any additional species. Species richness and turnover are calculated assuming an additive relationship between mean species richness (alpha, a), turnover or heterogeneity between plots (beta, b) and overall species richness (gamma, g, Lande 1996). Measures of percentage canopy cover were estimated on each plot rotation.

Using data from the latest rotation (2019-2022) of the 26 plots, we list species that are classified as Threatened, At Risk or Data Deficient in the National and Regional Threat Classification for plants (de Lange et al 2018, Simpkins et al 2022). Threat classifications are based on a range of criteria but generally, threatened species will have a small population size, occupy a small area or have a high predicted risk of decline (Townsend et al 2008). Species classified as At Risk will be declining, scarce, recovering from a previous Threatened status or survive only in relictual populations (Townsend et al 2008). For woody species only, we calculate the percentage basal area and tree numbers of Threatened, At Risk and Data Deficient species relative to Not Threatened species per plot.

We used the relative abundances of sensitive species to assess whether the impact of pressures can be detected in the forest composition and structure. Plant species disproportionately sensitive to kauri dieback, herbivory by feral pigs, possum, ship rat and Norway rat, and climate change (drought and temperature change) were identified from the literature (Table 8). The abundance of sensitive species was calculated relative to more resilient species (Bellingham et al 2016) for four abundance metrics across three size-classes (basal area, tree, sapling and seedling densities). Generally, a community-wide approach is advocated, with indicator statistics reported by aggregating species in sensitive and resilient functional groups (MacLeod et al 2016). The condition of the single species northern rātā has also been used and recommended as an indicator of possum control due to the high preference of possum for this species (Crisp 2001).

The use of functional plant groupings to assess pressures does not demonstrate causal effects. Plant species vary in their abundance and distribution patterns while pest animals vary regionally in their plant species preferences (Allen et al 2002). Furthermore, consumption of fruits and seeds of palatable plants may result in seed dispersal, and even favour regeneration processes in palatable species. Functional group data are indicative only and no substitute for more rigorous and targeted investigation.

Table 8: Plant species cited in the literature as sensitive to different pressures: kauri dieback, herbivory to feral pigs, possums and rats, and climate change (drought and temperature change)

Pressures	Plant species		Reference
Kauri dieback	*Agathis australis*	Kauri	Froud et al 2022
Feral pig	*Prumnopitys taxifolia*	Mataī	O'Connor & Kelly 2012
Feral pig / Possum / Rat / Climate	*Beilschmiedia tawa*	Tawa	Thomson & Challies 1988 / DOC 2014 / Innes 1977 / Clendon et al 2023
Feral pig / Possum / Rat	*Elaeocarpus dentatus var dentatus*	Hīnau	Sweetapple and Nugent 2007; Daniel 1973 / Fitzgerald 1976 / Thomson & Challies 1988
Possum	*Cyathea medullaris*	Mamaku	DOC 2014
Possum	*Didymocheton spectabilis*	Kohekohe	DOC 2014; Denyer et al 1993
Possum	*Metrosideros excelsa*	Pōhutukawa	DOC 2014; Denyer et al 1993
Possum	*Metrosideros robusta*	Northern rātā	DOC 2014; Crisp 2001; Denyer et al 1993
Possum	*Podocarpus laetus*	Tōtara-kiri-kotukutuku	DOC 2014; Denyer et al 1993
Possum	*Podocarpus totara var totara*	Tōtara	DOC 2014
Possum	*Pseudopanax crassifolius*	Horoeka	DOC 2014
Possum	*Raukaua edgerleyi*	Raukawa	DOC 2014
Possum / Climate	*Pseudopanax arboreus*	Whauwhaupaku	DOC 2014 / Seward et al 2016
Possum / Rat	*Alectryon excelsus*	Tītoki	DOC 2014 / Innes 1977
Possum / Rat	*Myrsine salicina*	Toro	DOC 2014 / Sweetapple and Nugent 2007
Possum / Rat	*Schefflera digitata*	Patē	DOC 2014 / Sweetapple and Nugent 2007; Daniel 1973
Possum / Rat / Climate	*Melicytus ramiflorus*	Māhoe	DOC 2014 / Innes 1977; Daniel 1973 / Seward et al 2016; Wyse et al 2013; Bannister 1986
Rat	*Aristotelia serrata*	Makomako	Sweetapple and Nugent 2007
Rat	*Coprosma lucida*	Shining karamū	Innes 1977; Daniel 1973
Rat	*Corynocarpus laevigatus*	Karaka	Innes 1977; Daniel 1973
Rat	*Dacryidium cupressinum*	Rimu	Sweetapple and Nugent 2007; Daniel 1973
Rat	*Freycinetia banksii*	Kiekie	Innes 1977
Rat	*Hedycarya arborea*	Porokaiwhiri	Innes 1977; Daniel 1973
Rat	*Macropiper excelsum*	Kawakawa	Innes 1977; Daniel 1973
Rat	*Pectinopitys ferruginea*	Miro	Sweetapple and Nugent 2007; Daniel 1973
Rat	*Pittosporum crassifolium*	Karo	Moors 1985
Rat	*Podocarpus dacrydioides*	Kahikatea	Daniel 1973
Rat	*Pseudowintera axillaris*	Horopito	Daniel 1973
Rat	*Rhopalostylis sapida*	Nīkau	Sweetapple and Nugent 2007; Innes 1977; Daniel 1973
Rat / Climate	*Coprosma robusta*	Karamū	Daniel 1973 / Seward et al 2016; Bannister 1986
Rat / Climate	*Vitex lucens*	Pūriri	Innes 1977 / Seward et al 2016
Climate	*Beilschmiedia tarairi*	Taraire	Seward et al 2016; Myers & Court 2013
Climate	*Coprosma autumnalis*	Kanono	Wyse et al 2013; Martin & Ogden 2005; Bannister 1986
Climate	*Geniostoma ligustrifolium var ligustrifolium*	Hangehange	Seward et al 2016
Climate	*Knightia excelsa*	Rewarewa	Seward et al 2016
Climate	*Myrsine australis*	Red mapou	Seward et al 2016
Climate	*Piper excelsum*	Kawakawa	Seward et al 2016
Climate	*Sophora microphylla*	Kōwhai	Seward et al 2016

Mean annual indices of the NZ Drought index (NZDI) and Soil Moisture Deficit Anomaly (SMDA) for the Auckland region were compared against seedling densities. NZDI is a climate-based indicator of drought based on four drought indicators, with high values indicating drought. SMDA describes the moisture available in the soil compared to normal conditions and is calculated using daily rainfall, daily potential evapotranspiration and a fixed available water capacity or the amount of water in the soil that plants can use, with high values indicating higher than normal soil moisture deficit.

The species richness and abundance of exotic species was calculated for the most recent rotation (2019-2022) of the 26 plots in the Heritage Area. Relative (%) species richness and abundance of exotic was compared between the Heritage Area (using 25 TBMP forest plots) and regional forests (using 58 TBMP forest plots). Exotic species listed as weeds in Auckland Council's Regional Pest Management Plan (Auckland Council 2020) are considered capable of having serious adverse effects on the environment or people.

We tested for differences between regenerating forest (VS) and warm forest (WF), between plot rotations, and between Heritage Area and regional forest plots using one of three models depending on the metric used (Schlesselmann et al 2022). Generalised linear models with poisson errors were used for basal area and species richness. Generalised linear models with negative binomial errors were used for densities of trees, saplings, and seedlings. Generalised linear models with binomial errors were used for proportions of indigenous and Threatened species. Generalised linear models were analysed using the lme4 package in R (Bates et al 2015).

Prior to starting analyses, data were checked for outliers or species inconsistencies. In 17 plots there were one or two species that could not be identified to species level and these were omitted from subsequent analyses (Jo et al 2023). All statistical analyses were conducted using the R software for statistical computing version 4.2.2 (R Core Team 2022).

3.2.3 Data caveats

When the Terrestrial Biodiversity Monitoring Programme was established, trees were not tagged as a cost-saving alteration to the national 20 m x 20m forest plot protocol (Hurst et al 2022). This means we were unable to measure recruitment, growth or mortality of trees in the plot. It also means there is more error associated with the re-measure of plots if they are not re-laid in precisely the same location. Since 2018 Auckland Council has changed its protocol and now tags trees in all remeasured plots. We continue to omit the forest reconnaissance (RECCE) methodology (measuring percentage cover of plants in the 20 m x 20 m plot) from our plot protocol due to concerns around its subjectivity.

Forest plot locations were determined systematically using a grid-based approach and so the distribution of plots was not designed to test differences in regenerating and warm forest types. Furthermore, the current ecosystem mapping layer (Singers et al 2017) is based on large-scale patterns in biotic and abiotic characteristics which do not always translate directly to patterns of forest composition and structure observed in 20 m x 20 m plots, especially given the heterogeneity of forest in the Heritage Area.

The proportion of forest covered by the 26 TBMP plots in the Heritage Area (1.04 ha) is small compared to the 27,000 ha covered by the Heritage Area. The spatially distributed systematic allocation of plot locations intends to sample forest representatively but given the heterogeneity of landscape and forest in the Heritage Area, the TBMP plot network will only capture the dominant plant composition and structure, and broad changes over time. The TBMP plot network is not designed to capture uncommon or highly localised species. Furthermore, while plots capture some data on exotic species, the plot network was not designed to measure the pressure from exotic species that tends to be concentrated in buffer zones and areas of high human activity. There are more plant species, Threatened or At Risk plants, and exotic plant species growing across the Heritage Area than are sampled in these forest plots.

3.3 Results

3.3.1 Forest composition and structure – state

Across all 26 forest plots measured in the Heritage Area in 2019-2022, 239 indigenous vascular plant species were recorded. The mean (± standard error) indigenous species richness per plot was 49.6 (± 2.0) species. This compares with the mean species richness of regional forest plots of 34.2 (± 1.3) species. The turnover of species between plots was 152.4 species, demonstrating the high level of forest heterogeneity between plots, where turnover accounts for 75 per cent of the overall species pool. Indigenous species included 13 canopy broadleaf species, eight conifer species, 35 sub-canopy broadleaf species, 28 species of shrub, five tree fern species, three monocot tree species including nīkau (*Rhopalostylis sapida*), tī kōuka (*Cordyline australis*) and tī ngahere (*Cordyline banksii*), and 110 vine, epiphyte and understorey species.

Stand basal area (the cross-sectional area of a tree at 1.35m height per plot) ranged from 25.7 m^2 ha^{-1} to 136 m^2 ha^{-1}, while tree stem densities ranged from 1250 stems ha^{-1} to 7600 stems ha^{-1}.

Summed across all 26 plots, ponga (C*yathea dealbata*) dominated the forest by basal area and had the second highest stem density (Table 9). Ponga, kauri, nīkau, kānuka and northern rātā were the most abundant tree species by basal area. The highest stem density tree species were (in descending order) horoeka (*Pseudopanax crassifolius*), ponga, hangehange (*Geniostoma ligustrifolium var. ligustrifolium*), wheki (*Dicksonia squarrosa*) and māmāngi (*Coprosma arborea*).

No species were common to all 26 plots. Two species occurred in 25 plots: ponga and hangehange. Other common species, occurring in 22 to 23 out of 26 plots, were kanono (*Coprosma autumnalis*), porokaiwhiri (*Hedycarya arborea*), karamū (*Coprosma lucida*), rewarewa, and mahoe; several of which are common, bird-dispersed species. There were 61 species that occurred in only one or two of the 26 TBMP plots.

Table 9: Total tree species abundance across all 26 plots, ranked by basal area (m^2 ha^{-1}) and tree stem density (ha^{-1}).

Plant species		Basal area (m^2 ha^{-1})	Plant species		Tree stems (ha^{-1})
Ponga	*Cyathea dealbata*	9.8	Horoeka	*Pseudopanax crassifolius*	375.0
Kauri	*Agathis australis*	5.6	Ponga	*Cyathea dealbata*	373.1
Nīkau	*Rhopalostylis sapida*	4.6	Hangehange	*Geniostoma ligustrifolium var. ligustrifolium*	325.0
Kānuka	*Kunzea robusta*	4.2	Wheki	*Dicksonia squarrosa*	234.6
Northern rātā	*Metrosideros robusta*	3.9	Māmāngi	*Coprosma arborea*	227.9
Pūriri	*Vitex lucens*	2.7	Nīkau	*Rhopalostylis sapida*	219.2
Wheki	*Dicksonia squarrosa*	2.2	Kānuka	*Kunzea robusta*	200.0
Pōhutukawa	*Metrosideros excelsa*	2.0	Māhoe	*Melicytus ramiflorus*	198.1
Kahikatea	*Dacrycarpus dacrydioides*	2.0	Kanono	*Coprosma autumnalis*	187.5
Rewarewa	*Knightia excelsa*	1.8	Porokaiwhiri	*Hedycarya arborea*	171.2
Horoeka	*Pseudopanax crassifolius*	1.6	Heketara	*Olearia rani*	152.9
Heketara	*Olearia rani*	1.5	Red mapou	*Myrsine australis*	135.6
Miro	*Pectinopitys ferruginea*	1.5	Mānuka	*Leptospermum scoparium*	129.8
Rimu	*Dacrydium cupressinum*	1.5	Tanekaha	*Phyllocladus trichomanoides*	103.8
Mānuka	*Leptospermum scoparium*	1.2	Karamū	*Coprosma lucida*	102.9
Tawa	*Beilschmiedia tawa*	1.2	Kohekohe	*Didymocheton spectabilis*	85.6
Taraire	*Beilschmiedia tarairi*	1.2	Mingimingi	*Leucopogon fasciculatus*	75.0
Tanekaha	*Phyllocladus trichomanoides*	1.0	Rewarewa	*Knightia excelsa*	72.1
Māmāngi	*Coprosma arborea*	0.8	Tawa	*Beilschmiedia tawa*	68.3
Porokaiwhiri	*Hedycarya arborea*	0.8	Houhere	*Hoheria populnea*	59.6

Multivariate analyses (NMDS) of species basal area for each plot were used to examine patterns of forest tree composition. One plot (CF40AA) clearly separated from the others based on the dominance of pōhutukawa (METEXC) and paucity of other tree or understorey species. Pōhutukawa made up 99 per cent of the tree basal area and 93 per cent of tree numbers. Species richness was low in this plot, with only 21 indigenous species and one exotic species, the veldt grass *Ehrharta erecta*.

For the remaining plots, those located in regenerating (yellow text) forest were clustered near the centre of the ordination space, while plots in warm forest (green text) were more dispersed across the ordination space (Figure 11a). The clustered distribution reflects the fact that regenerating forest plots were all dominated in basal area by a few tree fern and early successional species, namely ponga (CYADEA), kānuka (KUNROB), mānuka (LEPSCO) and horoeka (PSECRA). One regenerating plot also had a large relict northern rātā (METROB). Broadleaved canopy species present within regenerating forest plots included tawa, pūriri, white maire (*Nestegis lanceolata*) and karaka (*Corynocarpus laevigatus*). Kauri, all relatively small (<10 cm DBH), were numerous in one regenerating forest plot, but otherwise conifer trees were infrequent, with just one rimu and one tōtara-kiri-kōtukutuku (*Podocarpus laetus*). More canopy broadleaf and conifer species were present as saplings and seedlings including taraire, kahikatea, miro, and kohekohe. One regenerating forest plot (CF41A) had no broadleaf canopy or conifer species.

In the plot ordination (Figure 11a), the dispersed distribution of warm forest plots (green text) reflects greater differentiation among plots. When examining the three most abundant species by basal area per plot, no two plots were the same. This variation underpins the high heterogeneity or beta-diversity across the Heritage Area. Dominant species within different plots included rewarewa (KNIEXC), tawa (BEITAW), taraire (BEITAR), pūriri (VITLUC), rimu (DACCUP), kauri (AGAAUS), kahikatea (DACDAC), miro (PRUFER), nīkau (RHOSAP), heketara (OLERAN) and tanekaha (PHYTRI).

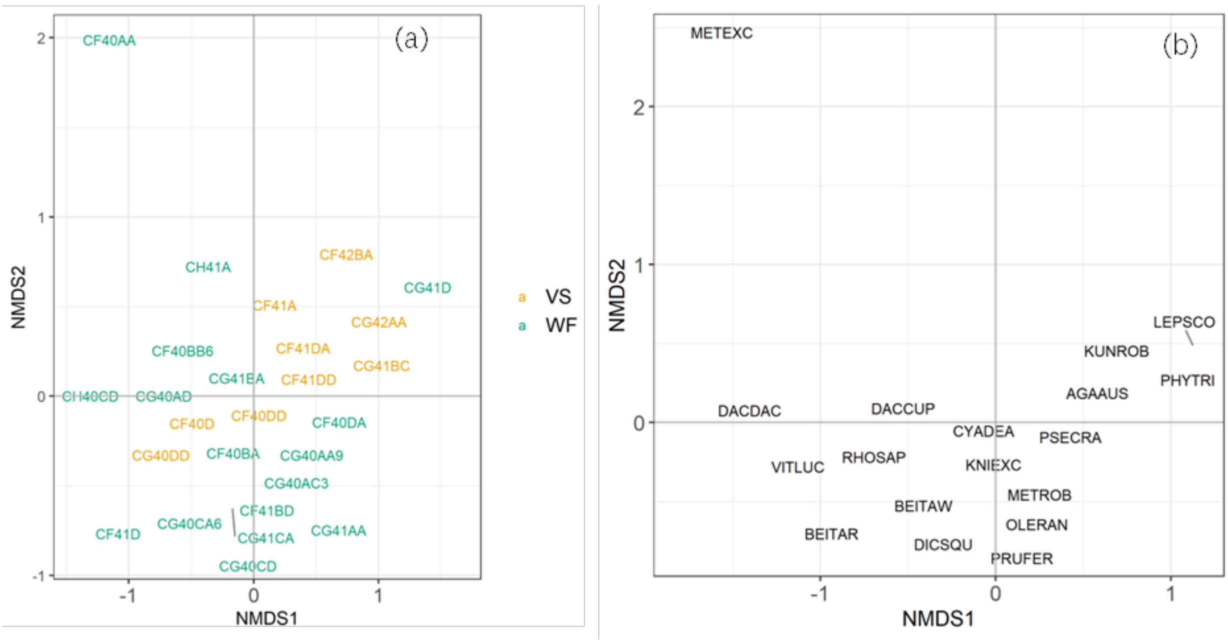

Figure 11: Non-metric multi-dimensional scaling (NMDS) of tree species basal area showing plots (a) and species (b). Forest plots (Figure 11a) are shown with regenerating forest types (VS) in yellow and warm forest types (WF) in green. The species ordination (Figure 11b) shows only the most abundant species (> 1m² basal area). Species 6-letter codes were: AGAAUS *Agathis australis*, BEITAR *Beilschmiedia tarairi*, BEITAW *B. tawa*, CYADEA *Cyathea dealbata*, DACCUP *Dacrydium cupressinum*, DACDAC *Dacrycarpus dacrydioides*, DICSQU *Dicksonia squarrosa*, KNIEXC *Knightia excelsa*, KUNROB *Kunzea robusta*, LEPSCO *Leptospermum scoparium*, METROB *Metrosideros robusta*, OLERAN *Olearia rani*, PHYTRI *Phyllocladus trichomanoides*, PRUFER *Pectinopitys ferruginea*, PSECRA *Pseudopanax crassifolius*, RHOSAP *Rhopalostylis sapida*, VITLUC *Vitex lucens*.

Across all warm forest plots, kauri and ponga had highest basal area; kauri from fewer large trees, ponga from ubiquitous and numerous trees (Table 10). Nīkau (RHOSAP) was common to all warm forest plots, but only occurred in half the regenerating forest plots.

There were no differences in tree canopy cover or indigenous species richness between warm and regenerating forest types (Table 10). Regenerating forest plots had lower basal area but a higher density of trees and saplings than warm forest plots. In regenerating forest plots, species composition was dominated by sub-canopy broadleaved species with 39 per cent of basal area, 61 per cent of tree stems, 49 per cent of saplings and 38 per cent of seedlings. In contrast, warm forest plots were characterised by a higher basal area that was dominated by conifers (28%) and canopy broadleaved species (28%). Densities of trees and saplings were lower in warm forest, and species composition was more broadly distributed across sub-canopy broadleaved species (41%), tree ferns (21%), canopy broadleaved species (14%), shrubs (14%), monocot trees (7%) and conifers (3%).

While conifer species made up a large proportion of the basal area in warm forest plots (28%), they composed only 6 per cent of basal area in regenerating forest plots, and less than 6 per cent of trees, saplings and seedlings in both warm and regenerating plots (Table 10). Broadleaved canopy species represented 28 per cent of the basal area in warm forest plots but only 16 per cent in regenerating forests. Broadleaved canopy species had higher densities in warm forest compared to regenerating forest for all size classes, but these species were still well represented in regenerating forest. There were no discernible differences in seedling densities between regenerating and warm forest plots due to the high variation in seedling numbers among plots.

Table 10: Comparison of canopy cover, species richness, and abundance measures between regenerating forest (VS) and warm forest (WF). Abundance measures were calculated for all indigenous woody species, canopy broadleaf, conifer, sub-canopy broadleaf, shrub, treefern and monocot tree species. Abundance metrics were basal area (m^2 ha^{-1}), tree stem density (ha^{-1}), sapling density (ha^{-1}), and seedling density (ha^{-1}). Basal area was tested using a general linear model with normal errors. Densities of tree stems, saplings and seedlings were tested with general linear models with negative binomial errors. s.e. = standard error.

		Regenerating forest (VS)		Warm forest (WF)		Test stat	P value
		mean	s.e.	mean	s.e.		
Canopy cover (%)		70.0	4.0	66.0	4.5		n.s.
Indigenous species richness		52.4	3.0	48.1	2.5		n.s.
All woody species	Stand basal area (m^2 ha^{-1})	50.5	8.2	60.6	7.6	10.8	<0.01
	Tree stems (ha^{-1})	5,414.0	476.0	3,551.0	329.0	7.7	<0.01
	Saplings stems (ha^{-1})	6,064.0	1,107.0	3,904.0	444.0	4	<0.05
	Seedling stems (ha^{-1})	22,099.0	4,394.0	21,405.0	2,982.0		n.s.
Canopy broadleaf	Basal area (m^2 ha^{-1})	8.1	5.4	17.0	4.5	37.1	<0.001
	Tree stems (ha^{-1})	275.0	94.3	513.0	117.0		n.s.
	Saplings stems (ha^{-1})	214.0	78.1	416.0	131.0		n.s.
	Seedling stems (ha^{-1})	2,408.0	1,174.0	4,314.0	1,732.0		n.s.
Conifer	Basal area (m^2 ha^{-1})	2.8	1.5	17.0	7.5	124	<0.001
	Tree stems (ha^{-1})	264.0	198.0	124.0	65.3		n.s.
	Saplings stems (ha^{-1})	333.0	254.0	153.0	107.0		n.s.
	Seedling stems (ha^{-1})	988.0	584.0	719.0	308.0		n.s.
Sub-canopy Broadleaf	Basal area (m^2 ha^{-1})	19.5	2.7	8.6	1.5	53.2	<0.001
	Tree stems (ha^{-1})	3,292.0	574.0	1,434.0	221.0	5.1	<0.05
	Saplings stems (ha^{-1})	2,992.0	709.0	1,731.0	186.0		n.s.
	Seedling stems (ha^{-1})	8,334.0	2,091.0	5,589.0	1,039.0		n.s.
Shrub	Basal area (m^2 ha^{-1})	1.7	0.4	0.9	0.2		n.s.
	Tree stems (ha^{-1})	811.0	182.0	481.0	106.0		n.s.
	Saplings stems (ha^{-1})	1,747.0	353.0	1,163.0	206.0		n.s.
	Seedling stems (ha^{-1})	8,457.0	2,881.0	5,752.0	1,386.0		n.s.
Tree fern	Basal area (m^2 ha^{-1})	13.1	4.1	12.7	2.6		n.s.
	Tree stems (ha^{-1})	467.0	136.0	734.0	237.0		n.s.
	Saplings stems (ha^{-1})	450.0	122.0	276.0	98.0		n.s.
	Seedling stems (ha^{-1})	494.0	313.0	558.0	397.0		n.s.
Monocot tree	Basal area (m^2 ha^{-1})	5.4	4.4	4.3	1.5		n.s.
	Tree stems (ha^{-1})	300.0	197.0	218.0	72.0		n.s.
	Saplings stems (ha^{-1})	75.0	27.3	116.0	41.2		n.s.
	Seedling stems (ha^{-1})	1,173.0	631.0	2,974.0	990.0		n.s.

3.3.2 Forest composition and structure – trends

Procrustes analyses (Procrustes correlation 0.94, m2 = 0.12, P = 0.001 on 999 permutations) showed species basal area compositions were similar between plot rotation 1 (2009-2013) and rotation 3 (2019-2022), indicating that the composition of plots has not changed greatly over this time period (Figure 12a). Inspection of residuals showed a higher level of change in plots CG41D (WF), CF42BA (VS) and CF41D (WF) which all had low basal area (25.3, 27.0 and 48.8 m^2 ha^{-1} respectively) and therefore greater potential for change (Figure 12b).

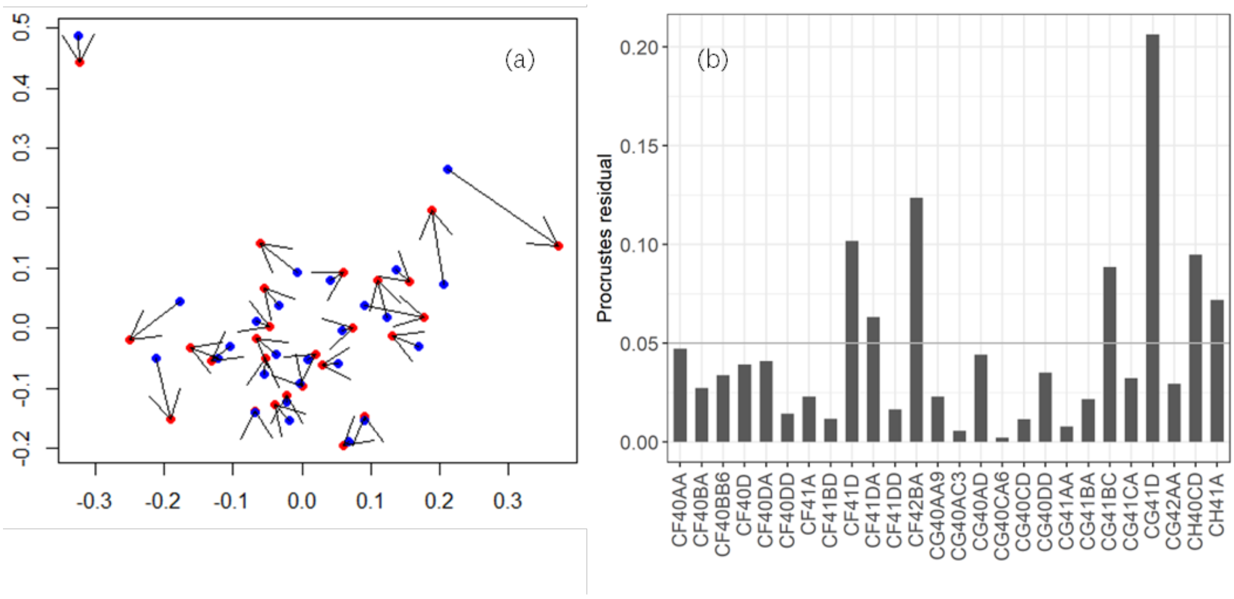

Figure 12: Procrustes analyses examining change between sampling rotation 1 (2009-2013) and rotation 3 (2019-2022) in the NMDS ordination of tree species basal area for all Heritage Area plots. The species basal area compositions for both rotations were similar and significantly correlated (correlation = 0.94, m^2 = 0.12, P<0.001 based on 999 permutations). Figure 12a shows the amount of movement required by each plot to align the two NMDS ordinations. Figure 12b shows the individual plot residuals of the procrustes analysis.

For the warm forest plot CG41D, there were small reductions in the basal area of the most abundant species kānuka, tānekaha (*Phyllocladus trichomanoides*) and mānuka and arrival of five new species as seedlings and saplings including tōtara and rimu, indicative of a maturing forest stand. Between plot rotations 1 and 3, the regenerating forest plot CF42BA, changed from one dominated by mānuka (3.5 m^2 ha^{-1}) to one dominated by kānuka (15.0 m^2 ha^{-1}) and māmāngi (*Coprosma arborea*, 4.7 m^2 ha^{-1}), with mānuka declining in abundance (1.0 m^2 ha^{-1}). The taller stature of kānuka means this species typically overtops and shades out mānuka where these species co-occur in mid-successional forest. For the warm forest plot CF41D there was a decline in the basal area of taraire and ponga, an increase in basal area of nīkau, rewarewa and hangehange, and the arrival of mamaku and porokaiwhiri as seedlings and saplings. With the exception of decline in taraire basal area, these patterns are consistent with typical of mid-successional forest.

Across the three rotations, there were small but significant increases in indigenous species richness (Table 11). Stand basal area and the basal area of canopy broadleaf species showed a consistent but non-significant increase, while conifer basal area showed a consistent but non-significant decrease. There was a significant decline in seedling numbers of all woody species, with a large proportion of this decline contributed by nīkau seedlings, and sub-canopy broadleaf species.

Table 11: Comparison of canopy cover, indigenous species richness, and abundance in plot rotation 1 (2009-2013), rotation 2 (2014-2018) and rotation 3 (2019-2022). Abundance was calculated for all indigenous woody species, canopy broadleaf, conifer, sub-canopy broadleaf, shrub, treefern and monocot tree species. Abundance metrics are basal area (m^2 ha^{-1}), tree stem density (ha^{-1}), sapling density (ha^{-1}) and seedling density (ha^{-1}). Species richness and basal area were tested using generalised linear model with poisson errors. Tree stem, sapling and seedling densities were tested with generalised linear models with negative binomial errors. s.e. = standard error.

		Measurement 1		Measurement 2		Measurement 3		Test stat	P value
		2009 - 2013		2014 - 2018		2019 - 2022			
		mean	s.e.	mean	s.e.	mean	s.e.		
Canopy cover (%)		58	3.8	62	2.6	67	3.2		n.s.
Indigenous species richness		44.0	2.8	49.3	1.7	49.6	2.0	10.7	<0.01
All woody species	Stand basal area (m^2 ha^{-1})	55.3	5.7	56.9	5.7	57.1	5.7		n.s.
	Tree stems (ha^{-1})	4,428	435	4,365	367	4,183	320		n.s.
	Saplings stems (ha^{-1})	5,542	803	5,498	748	4,652	510		n.s.
	Seedling stems (ha^{-1})	39,918	5,675	41,414	5,724	21,647	2,422	10.9	<0.01
Canopy broadleaf	Basal area (m^2 ha^{-1})	11.9	3.2	12.7	3.5	13.9	3.5		n.s.
	Tree stems (ha^{-1})	358	68.9	403	89.1	431	85.2		n.s.
	Saplings stems (ha^{-1})	360	112	329	93.7	346	90.9		n.s.
	Seedling stems (ha^{-1})	5,385	2,154	4,573	1,713	3,654	1,200		n.s.
Conifer	Basal area (m^2 ha^{-1})	12.8	5.4	12.6	5.3	12.1	5.1		n.s.
	Tree stems (ha^{-1})	165	75.1	162	79.5	172	79.5		n.s.
	Saplings stems (ha^{-1})	211	114	226	120	215	110		n.s.
	Seedling stems (ha^{-1})	1,047	426	1,047	413	812	279		n.s.
Sub-canopy Broadleaf	Basal area (m^2 ha^{-1})	8.8	1.3	8.8	1.3	12.4	1.7	21.3	<0.001
	Tree stems (ha^{-1})	2,174	392	2,038	307	2,077	297		n.s.
	Saplings stems (ha^{-1})	2,752	572	2,694	512	2,167	291		n.s.
	Seedling stems (ha^{-1})	11,689	1,743	10,770	1,687	6,539	1,002	7	<0.05
Shrub	Basal area (m^2 ha^{-1})	1.1	0.2	1.2	0.2	1.2	0.2		n.s.
	Tree stems (ha^{-1})	601	104	620	106	595	96.7		n.s.
	Saplings stems (ha^{-1})	1,692	256	1,656	243	1,365	186		n.s.
	Seedling stems (ha^{-1})	9,402	1,859	9,103	1,728	6,689	1,338		n.s.
Tree fern	Basal area (m^2 ha^{-1})	12.8	2.0	13.5	2.1	12.9	2.2		n.s.

		Measurement 1		Measurement 2		Measurement 3		Test stat	P value
		2009 - 2013		2014 - 2018		2019 - 2022			
		mean	s.e.	mean	s.e.	mean	s.e.		
	Tree stems (ha^{-1})	639	148	639	155	641	162		n.s.
	Saplings stems (ha^{-1})	302	77.4	312	61.7	337	77.1		n.s.
	Seedling stems (ha^{-1})	833	301	620	253	556	277		n.s.
Monocot tree	Basal area (m^2 ha^{-1})	4.1	1.4	4.1	1.5	4.7	1.7		n.s.
	Tree stems (ha^{-1})	253	78	241	70.4	246	80.7		n.s.
	Saplings stems (ha^{-1})	122	37.4	125	33.5	102	28.5		n.s.
	Seedling stems (ha^{-1})	11,454	3,523	14,809	5,214	2,351	696	9.8	<0.01

3.3.3 Threatened and at risk species

In the latest plot sampling rotation (2019-2022), 42 species recorded in the Heritage Area forest plots are classified as Threatened, At Risk or Data Deficient based on the combined regional and national threat classification assessments (de Lange et al 2018, Simpkins et al 2022). Of these, nine are nationally Threatened species and three nationally At Risk species (Table 12). Threatened, At Risk or Data Deficient species make up 40.1 per cent of basal area and 14.5 per cent of tree numbers in the Heritage Area (as a percentage of total basal area or total tree numbers per plot). Most of this abundance was contributed by the myrtaceous species including kānuka, mānuka, pōhutukawa, northern rātā, climbing rātā (*Metrosideros fulgens*), carmine rātā (*Metrosideros difffusa*), akatea (*Metrosideros perforata*) and ramarama (*Lophomyrtus bullata*). These are naturally widespread but are susceptible to the plant pathogen myrtle rust (*Austropuccinia psidii*, Beresford et al 2019). Kauri is also widespread but susceptible to the plant pathogen *Phytophthora agathidicida* that causes kauri dieback.

Table 12: Species categorised as Threatened, At Risk or Data Deficient in the national and regional threat classification (de Lange et al 2017, Simpkins et al 2022) and recorded within at least one of the 26 Heritage Area forest plots in the third rotation (2019-2022).

National threat classification (2017)	Regional threat classification (2022)	Number of species	Species
Threatened Nationally Critical	Threatened Regionally Vulnerable	1	ramarama (*Lophomyrtus bullata*)
Threatened Nationally Vulnerable	Threatened Regionally Vulnerable	1	kohurangi (*Brachyglottis kirkii* var. *Kirkii*)
Threatened Nationally Vulnerable	At Risk Declining	7	kauri (*Agathis australis*); kānuka (*Kunzea robusta*); carmine rātā (*Metrosideros diffusa*); pōhutukawa (*Metrosideros excelsa*); climbing rātā (*Metrosideros fulgens*); akatea (*Metrosideros perforata*); northern rātā (*Metrosideros robusta*).
At Risk Naturally Uncommon	At Risk Declining	1	*Pittosporum ellipticum*
At Risk Naturally Uncommon	At Risk Naturally Uncommon	1	kōwhai (*Sophora fulvida*)
Not Threatened	Data Deficient	2	*Clematis foetida;* tarata (*Pittosporum eugenioides*)
Not Threatened	Threatened Regionally Endangered	2	kāpuka (*Griselinia littoralis*); black maire (*Nestegis cunninghamii*)
Not Threatened	Threatened Regionally Vulnerable	5	*Coprosma crassifolia*; korokio (*Corokia cotoneaster*); mairehau (*Leionema nudum*); narrow-leaved maire (*Nestegis montana*); raukawa (*Raukaua edgerleyi*).
Not Threatened	At Risk Declining	13	toetoe (*Austroderia splendens*); kohurangi (*Brachyglottis kirkii var. angustior*); *Carex ochrosaccus*; *Carmichaelia australis*; *Dracophyllum sinclairii*; *Gleichenia microphylla*; *Helichrysum lanceolatum*; *Hiya distans*; kawaka (*Libocedrus plumosa*); mangeao (*Litsea calicaris*); toro (*Myrsine salicina*); tāwhiri karo (*Pittosporum cornifolium*); toru
Not Threatened	At Risk Naturally Uncommon	8	*Cyathea cunninghamii*; *Hymenophyllum lyallii*; tawari (*Ixerba brexioides*); large-leaved māhoe (*Melicytus macrophyllus*); *Pseudopanax discolor*; tāwheowheo (*Quintinia serrata*); *Raukaua anomalus*; *Tmesipteris sigmatifolia*.

3.3.4 Pressures – pest animals and drought

Over the 14 years covered by the TBMP plot rotations, there were no changes in the relative abundances (basal area and densities of trees, saplings and seedlings) of kauri, or woody species palatable to feral pigs or possum (Table 13). Seedling densities were low compared to the basal area for these groups. More data is required to understand the role of feral pigs as consumers or dispersers of tree seeds in the Heritage Area. In addition, tawa seed production may be influenced by temperature change driven by climate change (Clendon et al 2023).

For several species palatable to possum, including the highly preferred northern rātā, pōhutukawa, whauwhaupaku and mamaku there were no saplings or seedlings recorded. In 2021 we started to collect epiphyte data as part of our standard plot protocol. No northern rātā epiphytes were recorded in Heritage Area plots suggesting that epiphytic regeneration of this species is not common either.

Between plot rotation 2 (2014-2018) and plot rotation 3 (2019-2022) there was a significant decline in seedling density for species palatable to rats or sensitive to climate change. These functional groups overlap, both containing nīkau which showed a significant decline, and which contributes a large proportion of forest seedlings. Between 2019 and 2022 there was a spike in rat numbers in the Heritage Area (reported by Forest & Bird for Ark in the Park) as well as a severe drought in 2020. It is not possible to differentiate their individual effects and both pressures may be interacting to reduce seedling recruitment. Seedling numbers showed a negative relationship with mean indices of the NZ Drought Index (NZDI, LRT = 10.6_1, P<0.01, 11.7% deviation explained) and the Soil Moisture Deficit Anomaly (SMDA, LRT = 10.7_1, P<0.01, 11.8% deviation explained), but the plant data available to make this comparison are sparse (Figure 13).

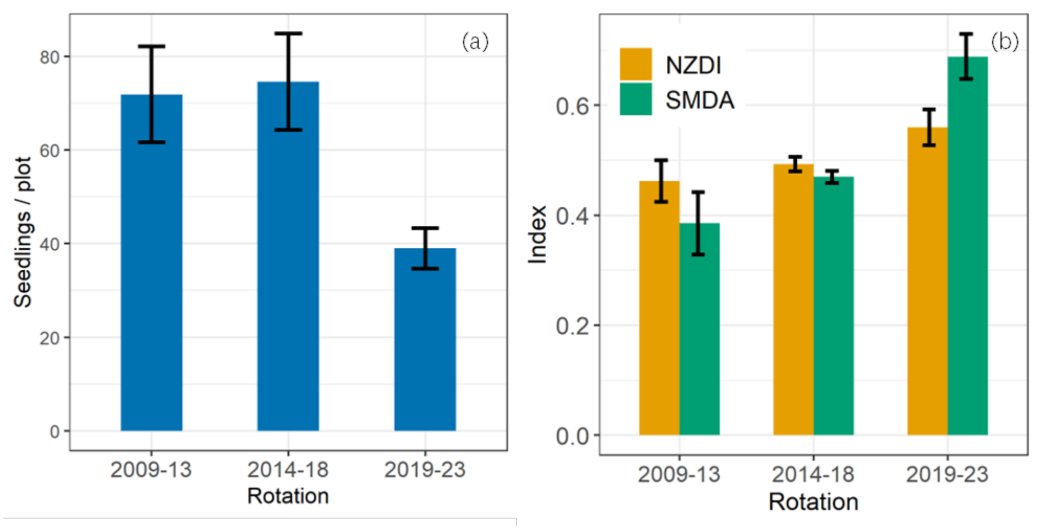

Figure 13: Means (± s.e.) per plot rotation for (a) seedling numbers (plot^{-1}) for all woody species and (b) two indices of drought, the NZ Drought Index (NZDI) and the Soil Moisture Deficit Anomaly (SMDA).

Table 13: Percentage abundance of plant species functional groups for each rotation and size-class. Plant species functional groups were: woody species vulnerable to kauri dieback (kauri); woody species palatable to feral pigs (hinau, tawa, mataī); woody species palatable to possum (mamaku, kohekohe, pōhutukawa, northern rātā, tōtara-kiri-kotukutuku, tōtara, horoeka, raukawa, whauwhaupaku, tawa, tītoki, toro, patē, māhoe, hīnau); northern rātā (indicator of possum control, Crisp 2001), woody species palatable to rats (tītoki, toro, patē, māhoe, hīnau, makomako, shining karamū, karaka, rimu, kiekie, porokaiwhiri, kawakawa, miro, karo, kahikatea, horopito, nīkau, karamū, pūriri); and woody species vulnerable to climate change (taraire, kanono, hangehange, rewarewa, red mapou, kawakawa, kōwhai, whauwhaupaku, tawa, māhoe, karamū, pūriri).

Pressure	Abundance metric	Measurement 1 2009 - 2013	Measurement 2 2014 - 2018	Measurement 3 2019 - 2023	df	Test stat	P value
			% palatable / vulnerable				
Woody species vulnerable to kauri dieback (*Agathis australis*)	Basal area (m^2 ha^{-1})	12.2	11.6	11.3			n.s.
	Tree stems (ha^{-1})	0.7	0.7	0.8			n.s.
	Saplings stems (ha^{-1})	0.5	0.5	0.7			n.s.
	Seedling stems (ha^{-1})	0.6	0.5	1.0			n.s.
Woody species palatable to feral pigs	Basal area (m^2 ha^{-1})	3.2	2.5	2.3			n.s.
	Tree stems (ha^{-1})	1.7	1.8	1.9			n.s.
	Saplings stems (ha^{-1})	1.1	1.0	1.3			n.s.
	Seedling stems (ha^{-1})	0.5	0.7	1.0			n.s.
Woody species palatable to possum	Basal area (m^2 ha^{-1})	22.0	24.8	23.7			n.s.
	Tree stems (ha^{-1})	22.9	23.9	25.7			n.s.
	Saplings stems (ha^{-1})	12.7	11.9	11.5			n.s.
	Seedling stems (ha^{-1})	4.9	3.5	5.5			n.s.
Northern rātā (*Metrosideros robusta*)	Basal area (m^2 ha^{-1})	4.9	5.8	5.5			n.s.
	Tree stems (ha^{-1})	0.0	0.2	0.3			n.s.
	Saplings stems (ha^{-1})	0.0	0.0	0.0			n.s.
	Seedling stems (ha^{-1})	0.0	0.0	0.0			n.s.
Woody species palatable to rats	Basal area (m^2 ha^{-1})	21.4	22.7	26.4			n.s.
	Tree stems (ha^{-1})	23.3	23.9	27.0			n.s.
	Saplings stems (ha^{-1})	23.1	22.4	24.1			n.s.
	Seedling stems (ha^{-1})	82.8	106.2	43.5		11.1	<0.01
Nīkau (*Ropalostylis sapida*)	Basal area (m^2 ha^{-1})	7.6	7.4	8.6			n.s.
	Tree stems (ha^{-1})	5.0	4.8	5.5			n.s.
	Saplings stems (ha^{-1})	1.9	2.0	2.0			n.s.
	Seedling stems (ha^{-1})	40.1	55.5	12.2		9.2	<0.01
Woody species vulnerable to climate	Basal area (m^2 ha^{-1})	27.2	25.6	29.0			n.s.
	Tree stems (ha^{-1})	28.4	27.3	30.2			n.s.
	Saplings stems (ha^{-1})	31.9	28.6	28.9			n.s.
	Seedling stems (ha^{-1})	72.8	86.9	34.7		14.7	<0.001

3.3.5 Indigenous species dominance

In the most recent plot rotation (2019-2022), 7.4 per cent of species recorded in plots in the Heritage Area were introduced species, this contrasts strongly with the regional TBMP forest plot network in which 36.1 per cent of species are exotic. For those exotic species where abundance was recorded, exotic species in the Heritage Area plots composed 0.1 per cent of basal area, 0.5 per cent of tree stem density, 0.4 per cent of sapling density and 0.7 per cent of seedling density. This was far below abundances for exotic species recorded in the regional forest plot network (Table 14).

In the latest plot rotation (2019-2022), fifteen exotic species were recorded in nine of the 26 Heritage Area forest plots, including four regenerating and five warm forest plots (Table 14). Nine of these species are weeds listed in Auckland Council's Regional Pest Management Plan (Auckland Council 2020) and considered capable of having serious adverse effects on the environment or people. Wild ginger (*Hedychium gardnerianum*) was the most widespread weed occurring in four plots. Prickly hakea (*Hakea sericea*) was the most abundant weed by basal area (1.73 m^2 ha^{-1}) and the most numerous tree, with all found in a single warm forest plot. High seedling numbers were observed for loquat (*Rhaphiolepsis bibas*) and gorse (*Ulex europaeus*), with gorse present as trees, saplings, and seedlings in three regenerating plots. Other weed species were recorded as present in a plot, but no abundance data was available.

Table 14: Exotic and weed species (listed in the Regional Pest Management Plan 2020); the number of plots in which they occur and total abundances. Species without abundance measures were only recorded as present in the plot.

Exotic species		Weed (RPMP 2020)	Number of plots	Basal area (m^2 ha^{-1})	Tree stems (ha^{-1})	Saplings stems (ha^{-1})	Seedling stems (ha^{-1})
Black wattle	*Acacia mearnsii*	Weed	1				
Sheep's bur	*Acaena agnipila*	Weed	1			25	
Climbing asparagus	*Asparagus scandens*	Weed	3				
Centaury	*Centaurium erythraea*		1				
Pampas grass	*Cortaderia selloana*	Weed	2				
Cocksfoot	*Dactylis glomerata*		1				
Veldt grass	*Ehrharta erecta*		2				
Prickly hakea	*Hakea sericea*	Weed	1	1.73	475	75	
Wild ginger	*Hedychium gardnerianum*	Weed	4				
Catsear	*Hypochaeris radicata*		1				
Harestail	*Lagurus ovatus*		1				
Loquat	*Rhaphiolepis bibas*		1				556
African clubmoss	*Selaginella kraussiana*	Weed	1				
Monkey apple	*Syzygium smithii*	Weed	1				
Gorse	*Ulex europaeus*	Weed	3	0.02	25	425	3333
% exotic abundance in TBMP Heritage Area plots				0.1	0.5	0.4	0.7
% exotic abundance in TBMP Regional plots				10.0	6.3	4.9	1.7

3.4 Discussion and conclusions

Prior to human arrival the Heritage Area was vegetated in forest, dominated by warm forest types. Since human arrival, there has been widespread disturbance from logging, burning, gum digging and clearance for farming which was largely complete by the 1940s (Froud et al 2022). The largest kānuka in the regenerating plots had a modelled age of 88-90 years taking the recruitment date to 1933-1935 (based on diameter-age relationships in Payton et al (1984)). In addition to forest disturbance, humans brought hunting, pest animals, pathogens, exotic plants, and induced climate change. The Heritage Area is now vegetated in 52 per cent warm forest and 42 per cent regenerating forest types. Although regenerating forest lacks the structural complexity of warm forest, for both forest types indigenous plant diversity is high and appear to be regenerating following expected successional pathways.

In warm forest (WF, largely kauri-podocarp-broadleaved WF11) patterns of plant species composition and structure were consistent with late successional maturing forest. Warm forest (WF) had higher structural complexity and supported a wide range of conifer and canopy broadleaved tree species including rewarewa, tawa, rimu, kohekohe, kauri, white maire, tōtara, kahikatea, northern rātā, miro, and coastal pōhutukawa. Warm forest had higher woody species basal area dominated by conifer and canopy broadleaved species and a lower density of stems. For regenerating forest (VS), patterns of species composition and structure were consistent with mid-successional forest following sub-canopy closure by early successional species, and with late successional broadleaved canopy and conifer species growing up under the sub-canopy. Regenerating forest had a low basal area of conifer and canopy broadleaved species, but good canopy closure and a high stem density, especially of sub-canopy broadleaved species typical of mid-successional regenerating forest including ponga, kānuka, mānuka and horoeka.

Conifer and canopy broadleaved species occupy all size-classes in both warm and regenerating forest types. Densities of conifer trees, saplings and seedlings were generally lower than canopy broadleaved species; this may reflect their tendency to regenerate in cohorts following infrequent landscape level disturbance (Wyse et al 2018). The broad similarity in conifer tree, sapling and seedling densities between warm and regenerating forest provides some reassurance that regenerating forests are not seed limited for conifers despite the mature conifers being limited to only a few regenerating forest plots. Tree ferns were common to both regenerating and warm forest and these tend to reduce numerically as forest matures (apart from in tree fall gaps, Smale et al 1997). Nīkau were more ubiquitous in warm forest.

Across all 26 forest plots (total = 1.04 ha), 239 indigenous vascular plant species were recorded, but this is low compared to the 542 species recorded in the Protected Natural Area Programme survey report for the Waitākere Ranges Ecological District (ca. 20,000ha, Denyer et al 1993). This is not to suggest that species richness is declining, indeed the number of species per plot increased significantly over the 14 years of the TBMP. The difference in species richness between the two studies results from differences in sampling effort and reflects the primary intent of the TBMP forest plot network which is to describe the dominant forest characteristics rather than to document all species as in the protected natural area survey.

Few changes over time were detected in the abundance of plants vulnerable to pressures including herbivory, plant pathogens and/or climate change. The seedling densities of all woody species declined by almost a half between rotation 2 (2014-18) and rotation 3 (2019-23), and this was particularly apparent in nīkau and sub-canopy broadleaf species. As a result, species vulnerable to climate change (drought) and rat predation showed significant declines in seedling density. Seedling densities across the three rotations showed a negative relationship with mean indices of the NZ Drought Index and the Soil Moisture Deficit Anomaly. In the summer of 2019-20, when sampling started for the third rotation of forest plots, Auckland experienced one of the most extreme drought events since 1993/94. At the same time, however, Forest and Bird reported a spike in rat numbers in the Heritage Area. It is possible that both pressures contributed to seedling decline, and this highlights how climate change can exacerbate existing pressures. More research is required to understand the cause of seedling declines and determine whether the decline will impact forest regeneration patterns longer term. Use of plant indicator groups to detect change from herbivory would be improved with knowledge of herbivore plant preferences in the Heritage Area relative to plant abundance (Bellingham et al 2016).

Tree species palatable to possum showed signs of poor regeneration, with several species having few or no saplings or seedlings (northern rātā, pōhutukawa, tōtara-kiri-kotukutuku, patē and whauwhaupaku). Further investigation is required to understand the cause of this absence in the Heritage Area. It is possible that northern rātā and other palatable species are unable to regenerate under current possum populations despite long-term and effective population suppression (Lovegrove and Parker *in review*). All of these species, however, also require high light conditions to regenerate which is not possible without some canopy disturbance so an intact canopy may also contribute.

Kauri and Myrtaceous species, vulnerable to kauri dieback and myrtle rust, contribute considerable abundance to forest in the Heritage Area. In fact, Myrtaceous species were estimated to be the second most important woody family across New Zealand in terms of forest cover, basal area and species richness (Jo et al 2023). As myrtle rust is a wind-dispersed pathogen, it is almost impossible to control its spread (Beresford et al 2019). It is still too early to say how virulent myrtle rust will be to New Zealand's indigenous forest species. Early evidence suggests that *Lophomyrtus* species such as ramarama are highly susceptible, with new shoots, reproductive structures, and seedlings all impacted (Beresford et al 2019). *Metrosideros* species are less susceptible, but have little resistance, while kānuka and mānuka are least susceptible and have some resistance (Beresford et al 2019). Auckland Council introduced surveillance of myrtle rust to the TBMP forest plot protocol in 2020, and myrtle rust symptoms were observed on several pōhutukawa, carmine rātā, ramarama and maire tawake (*Syzygium maire*) within regional plots. Myrtle rust was not detected in plots inside the Heritage Area in the 2019-2022 rotation period, although the timing of forest monitoring in October/November is too early to detect maximum disease symptoms of *A. psidii*. Seasonal epidemics of *A. psidii* typically start in late spring or early summer (November/December) with disease severity increasing rapidly in December/January and reaching a maximum in early autumn (March/April, Beresford et al 2019). It is likely that the most immediate impact of myrtle rust will be on species that are both highly susceptible and already have reduced populations, notably ramarama and maire tawake. Although L*ophomyrtus* species can continue to produce new growth at temperatures too low for *A. psidii* infection (10° C) which may provide some potential for these species to survive *A. psidii* infection (Beresford et al 2019).

Kauri dieback has not yet been detected in the 26 TBMP plots in the Heritage Area and measures of kauri abundance showed no signs of decline. In fact there was a small but insignificant increase in the density of kauri trees and saplings in the Heritage Area plots over the 14 years of plot rotation. While *P. agathicida* remains on the periphery of the Heritage Area, it has not yet reached its full potential range (Froud et al 2022). Evidence from the Waitākere Ranges Kauri Dieback Surveillance support continued vector management through isolation, hygiene and treatment (Froud et al 2022).

The TBMP data showed that indigenous dominance of the forest interior in the Heritage Area was high, especially compared to regional forest plots. The plot data however, did not capture areas of the Heritage Area with high weed pressure. Weeds and exotic species tend to arrive first on the forest edges or in areas of high human activity. Residential areas adjacent to the forest, roadways and tracks are all likely to support a higher proportion of exotic species than measured in these forest plots. Lower weed prevalence in the Heritage Area compared to regional forest may result from its large, continuous forested area with good connectivity to indigenous habitat, and little adjacent rural and urban land, characteristics associated with higher indigenous dominance (Griffiths et al 2021).

The most abundant weeds in plots in the forest interior were pyrophytic, fire adapted species (hakea and gorse) which readily colonise regenerating forest. Regenerating forests, which cover 42 per cent of the Heritage Area, tend to be more flammable than later successional forests, due to the flammability of early successional *Leptospermum* and *Kunzea* species (Wyse et al 2016), as well as differences in the microclimate and structure of these low-stature forests (Tepley et al 2016, Kitzberger et al 2016). The presence of invasive pyrophytic species can make these regenerating forests more flammable (Andersen and Andersen 2010), and potentially alter fire frequency (Perry et al 2015). Increased drought frequency and severity as a result of climate change is predicted to increase the risk of wildfires (Pearce et al 2011). Later successional forests are less flammable than early successional forests so as regenerating forest matures towards warm forest (WF) types, the risks of wildfires will reduce (Kitzberger et al 2016). Successful forest regeneration will not only reduce wildfire risks but will also support greater carbon sequestration and storage (Paul et al 2021).

More recently, less expected impacts of climate change have become evident with the increased number of land slips in response to extreme rainfall events in August 2021 and January 2023. Ultimately, these slips may provide canopy gaps favouring conifer and broadleaved canopy species, but they may also provide disturbed ground suitable for weed or exotic plant invasion. We recommend future research aims to monitor plant regeneration patterns at land slip locations.

In our assessment of forest ecological integrity in the Heritage Area we have made some comparisons with regional forest data to understand the benefits of large continuous forested areas and broad management activities (Griffiths et al 2021). It would also be valuable to compare the state and trends for forest in the Heritage Area with that of more pristine forest to identify potential impacts on ecosystem processes (Wurtzebach and Schultz 2016). For example, resampling of plots on offshore islands such as Te Hauturu-o-Toi may provide one example of what warm forest typical of the

Auckland region could look like with limited past disturbance, no pest animals, few weeds but with impacts of climate change and plant pathogens.

Overall, forest in the Heritage Area has high ecological integrity, is recovering well from past disturbance and following expected forest successional pathways. The forest is highly diverse and dominated by indigenous plants. Many of these benefits arise in part from the large, unfragmented and continuous characteristics of the Heritage Area, and ongoing management to limit weed and pest populations. There remain areas of concern however, especially from the current and potential future impacts of plant pathogens, weeds and climate change. The recent extremes in drought and rainfall events generating widespread land slips show how rapidly climate change may impact forest processes.

4 Birds

4.1 Introduction

Birds, although only a small proportion of total biodiversity, are commonly used as indicators for monitoring the status and trends of ecosystem integrity and its inherent biodiversity (Temple and Wiens 1989, Furness and Greenwood 1993, Browder et al 2002, Carignan and Villard 2002, Gill 2006, Monks et al 2013). There are a several reasons for this utility:

- Birds are often high on food chains and thus must rely on the health of multiple trophic levels below them to survive (MacLeod 2014);
- Different bird species interact with particular habitats, and populations are affected by disturbance in these areas relatively quickly with many species short-lived (Browder et al 2002);
- Many birds have relatively large home ranges, especially in comparison to other taxa, allowing the integration of conditions over the landscape (Rolando 2002); and
- Birds are also important to monitor given the significant ecological roles they play, namely as predators, pollinators, and seed dispersers (Clout and Hay 1989, Kelly et al 2010, Young et al 2012).

New Zealand’s diurnal land birds are particularly useful indicators because many are conspicuous and easy to identify (Landers et al 2021), with New Zealanders tending to have an interest in hearing about how the birds are faring (Galbraith et al 2014, Brandt et al 2020). Many species need monitoring given the huge declines that have occurred from anthropogenic effects since humans arrived in New Zealand (Worthy and Holdaway 2002, Tennyson and Martinson 2006, Innes et al 2010, Robertson et al 2021). New Zealand birds may also have added pressure as a result of climate change from the predicted increased extreme weather events and pest animals, as well as other habitat changes (Pearce et al 2018, Bishop and Landers 2019, Auckland Council 2020).

Here we report on the state and trends in bird species populations and communities in the Heritage Area using 14 years (2009-2022) of bird count data from Auckland Council’s Terrestrial Biodiversity Monitoring Programme (TBMP) forest plot network (described in Section 3.2.1).

4.2 Methods

As part of the forest plot network used to monitor biodiversity, bird surveys were carried out at the corner of each plot on the same days the plants were surveyed. On these days, three 10-minute bird counts (10MBC) were performed between 7am and 1pm (for details, see Landers et al 2021).

Bird data for this report included the full set of Tier 1 and 2 plots within the Heritage Area (Heritage Area Tier 1 plots were generally at similar distances/spatial scale to Tier 2 plots) to a) establish the current state using sampling rotation (here after referred to as rotation) 3 (2019-2022), noting all plots used were sampled by the end of 2022; n = 26), and b) examine trends using plots which had been surveyed in all three rotations (rotation 1 2009-13, rotation 2 2014-18, rotation 3 2019-22, n = 22,

Table 15). For context, results were compared to regional data using bird surveys conducted at Tier 1 plots (Table 15).

Table 15: The number of bird survey plots used for Repeated Measures ANOVA analyses ('state' and 'trends') by Terrestrial Biodiversity Monitoring Programme tier category and sampling rotation (1 2009-13, 2 2014-18, 3 2019-2022).

<table>
<tr><th rowspan="2">State or trend</th><th rowspan="2">Comparison</th><th rowspan="2">Location</th><th rowspan="2">Rotation</th><th colspan="3">Number of plots</th></tr>
<tr><th>Tier 1</th><th>Tier 2</th><th>Total</th></tr>
<tr><td rowspan="5">Current state</td><td>Heritage area</td><td>Heritage area</td><td>3</td><td>5</td><td>21</td><td>26</td></tr>
<tr><td rowspan="2">Rotation 3

(Rotation 2 provided for context only)</td><td>Heritage area</td><td>2</td><td>5</td><td>24</td><td>29</td></tr>
<tr><td>Heritage area</td><td>3</td><td>5</td><td>21</td><td>26</td></tr>
<tr><td rowspan="2">Heritage area vs Regional</td><td>Heritage area</td><td>3</td><td>5</td><td>17</td><td>22</td></tr>
<tr><td>Regional</td><td>3</td><td>37</td><td>0</td><td>37</td></tr>
<tr><td rowspan="3">Trends</td><td>Heritage area</td><td>Heritage area</td><td>1, 2, 3</td><td>5</td><td>17</td><td>22</td></tr>
<tr><td rowspan="2">Heritage area vs Regional</td><td>Heritage area</td><td>1, 2, 3</td><td>5</td><td>17</td><td>22</td></tr>
<tr><td>Regional</td><td>1, 2, 3</td><td>37</td><td>0</td><td>37</td></tr>
</table>

Only counted birds which had full species identifications were used in analyses. Three main dependent variables were used for most analyses in this study: Naturalness (proportion of indigenous individuals of total individuals counted), Indigenous (individuals of indigenous species only) and Introduced (individuals of introduced species only). We also calculated these three variables for species richness rather than number of individuals. Hence, a total of six main variables were calculated for all analyses.

Abundance variables were calculated using the first five minutes of the 10MBC (hereafter called 5MBC) and richness variables using the full 10MBC. All variables are means per count, calculated by averaging the totals from each of the three bird counts conducted at each plot on the same day. In the 'Total species summary' section Total Species Richness (total number of species from all counts using the full 10MBC) and Mean Species Abundance (mean number of individuals per 5MBC) were also calculated for all species counted in the Heritage Area in rotation 3 to give the 'state' (Table 18). To provide some context to the 'state' of birds (Total Species values) we also provide the 'state' for rotation 2.

To analyse for 'state' and 'trend' differences in abundances and species richness within the Heritage Area and in comparison to regional plots, we ran six two-way Repeated Measures ANOVAs (RM-

ANOVA) using the Naturalness, Indigenous and Introduced variables (Table 2) using the factors Location (Heritage Area vs regional) and time period. The assumptions for ANOVA (independent observations, normality, homogeneity via Levene's Test and inspecting histograms) were checked for all data and any data failing these were transformed as required. For all significant RM-ANOVAs, post-hoc tests were run to determine which factor pairs were significant (Tukey HSD tests for ANOVAs).

4.3 Results

4.3.1 Current state of Waitākere Ranges Heritage Area 2018-2022

Total species summary

In total, 78 bird counts were completed at 26 forest plots within the Waitākere Ranges Heritage Area (Heritage Area) over 2018-22 (rotation 3), during which 1,364 individual birds were counted (Table 16). The majority of these were endemic (indigenous found only in New Zealand) and indigenous species, with only about one quarter of all birds counted being introduced species (Table 16). Only a small percentage (<3%) of total birds counted were Threatened or At Risk species (Table 17, Robertson et al 2021). Total Species Richness comprised 66 species, and the top four of the five most abundant species were indigenous (i.e., tauhou/silvereye, riroriro/grey warbler, tūī, and pīwakawaka/North Island fantail – manu pango/Eurasian blackbird was the 5th most abundant species) (Table 18).

In comparison to the previous survey conducted over 2014 and 2018 (rotation 2), there were increases in the abundance of tauhou, riroriro, and pīwakawaka, which were all approximately twice as abundant in the rotation 3 survey (Table 18). Korimako/bellbird, although relatively uncommon, was another species which appears to be increasing in the Heritage Area. The most common introduced species were manu pango (5th most common), pahirini/chaffinch (6th), Eastern rosella (7th), common myna (8th), and tiu/house sparrow (10th). Generally, these introduced species were counted at similar levels as in the previous survey rotation, but one notable outlier was the increase of tūī, which was almost six times more abundant in rotation 3.

Table 16: Status of species counted at 26 forest plots (78 total bird counts conducted from 2018-2022 [rotation 3]) in the Waitākere Ranges Heritage Area.

Status	Count	Percentage of total birds
Endemic	676	49.5%
Indigenous	348	25.6%
Introduced	340	24.9%
TOTAL	1,364	

Table 17: Conservation status (Robertson et al 2021) of indigenous species counted at 26 forest plots (78 total bird counts from 2018-2022 [rotation 3]) in the Waitākere Ranges Heritage Area.

Conservation Status	Count	Percentage of total birds
Threatened	0	0.0%
At Risk	26	2.5%
Not Threatened	998	97.5%
TOTAL	1.024	

Table 18: Mean Abundance (± s.e.) of all bird species counted at forest plots in the Waitākere Ranges Heritage Area from 2019-2022 (rotation 3) and 2014-18 (rotation 2). Abundance ordered by most abundant to least abundant in rotation 3. *indigenous, **endemic.

Species			Abundance	
			Rotation 2 2014-18 n = 29	Rotation 3 2019-22 n = 26
Silvereye	tauhou	*Zosterops lateralis lateralis**	2.45 ± 0.28	4.06 ± 0.42
Grey warbler	riroriro	*Gerygone igata***	1.93 ± 0.22	2.97 ± 0.48
Tui	tūī	*Prosthemadera novaeseelandiae novaeseelandiae***	2.08 ± 0.19	2.51 ± 0.29
North Island fantail	pīwakawaka	*Rhipidura fuliginosa placabilis***	0.72 ± 0.11	1.36 ± 0.19
Eurasian blackbird	manu pango	*Turdus merula*	1.43 ± 0.16	0.95 ± 0.15
Chaffinch	pahirini	*Fringilla coelebs*	0.56 ± 0.15	0.91 ± 0.23
Eastern rosella		*Platycercus eximius*	0.72 ± 0.14	0.71 ± 0.17
Common myna		*Acridotheres tristis*	0.48 ± 0.13	0.58 ± 0.18
Sacred kingfisher	kōtare	*Todiramphus sanctus vagans**	0.44 ± 0.09	0.54 ± 0.12
House sparrow	tiu	*Passer domesticus*	0.09 ± 0.09	0.53 ± 0.41
New Zealand pigeon	kererū	*Hemiphaga novaeseelandiae***	0.32 ± 0.08	0.44 ± 0.12
North Island tomtit	miromiro	*Petroica macrocephala toitoi***	0.36 ± 0.10	0.42 ± 0.13
Variable oystercatcher	tōrea pango	*Haematopus unicolor***	<0.01	0.22 ± 0.22
Song thrush		*Turdus philomelos*	0.09 ± 0.08	0.17 ± 0.07
Welcome swallow	warou	*Hirundo neoxena neoxena**	0.06 ± 0.02	0.15 ± 0.09
Australian magpie	makipae	*Gymnorhina tibicen*	0.01 ± 0.01	0.12 ± 0.08
Shining cuckoo	pīpīwharauroa	*Chrysococcyx lucidus**	0.11 ± 0.05	0.12 ± 0.05
Eurasian skylark	kaireka	*Alauda arvensis*	0.01 ± 0.01	0.09 ± 0.08
Red-billed gull	tarapunga	*Larus novaehollandiae scopulinus**	<0.01	0.09 ± 0.09

Species			Abundance	
			Rotation 2 2014-18 n = 29	Rotation 3 2019-22 n = 26
European goldfinch		*Carduelis carduelis*	0.09 ± 0.06	0.08 ± 0.03
Bellbird	korimako	*Anthornis melanura melanura***	<0.01	0.06 ± 0.04
Common pheasant	peihana	*Phasianus colchicus*	0.03 ± 0.02	0.05 ± 0.04
Pukeko	pūkeko	*Porphyrio melanotus melanotus**	0.02 ± 0.02	0.05 ± 0.04
Southern black-backed gull	karoro	*Larus dominicanus dominicanus**	<0.01	0.05 ± 0.04
Common starling	taringi	*Sturnus vulgaris*	0.01 ± 0.01	0.05 ± 0.04
Spotted dove		*Streptopelia chinensis tigrina*	0.05 ± 0.05	0.05 ± 0.04
Dunnock		*Prunella modularis*	0.05 ± 0.05	0.04 ± 0.04
Pied Shag	karuhiruhi	*Phalacrocorax varius varius***	<0.01	0.03 ± 0.03
Spur-winged plover		*Vanellus miles novaehollandiae**	<0.01	0.03 ± 0.02
California quail		*Callipepla californica*	<0.01	0.03 ± 0.02
European greenfinch		*Carduelis chloris*	0.03 ± 0.02	0.01 ± 0.01
Paradise shelduck	pūtangitangi	*Tadorna variegata***	<0.01	0.01 ± 0.01
Mallard		*Anas platyrhynchos*	<0.01	0.01 ± 0.01
Morepork	ruru	*Ninox novaeseelandiae novaeseelandiae**	<0.01	0.01 ± 0.01
Australasian gannet	tākapu	*Morus serrator**	<0.01	<0.01
Barbary dove		*Streptopelia risoria*	<0.01	<0.01
Black shag	kawau	*Phalacrocorax carbo novaehollandiae**	<0.01	<0.01
Black swan	kakianau	*Cygnus atratus*	<0.01	<0.01
Brown quail	kuera	*Coturnix ypsilophora*	<0.01	<0.01
Canada goose		*Branta canadensis*	<0.01	<0.01
Caspian tern	taranui	*Hydroprogne caspia**	<0.01	<0.01
Chicken		*Gallus gallus domesticus*	<0.01	<0.01
Long-tailed cuckoo	koekoeā	*Eudynamys taitensis***	<0.01	<0.01
North Island fernbird	mātātā	*Bowdleria punctata vealeae***	<0.01	<0.01
North Island kaka	kākā	*Nestor meridionalis septentrionalis***	<0.01	<0.01
North Island kokako	kōkako	*Callaeas wilsoni***	<0.01	<0.01
North Island rifleman	titipounamu	*Acanthisitta chloris granti***	<0.01	<0.01
North Island robin	toutouwai	*Petroica longipes***	<0.01	<0.01
North Island saddleback	tīeke	*Philesturnus rufusater***	<0.01	<0.01

Species			Abundance	
			Rotation 2 2014-18 n = 29	Rotation 3 2019-22 n = 26
North Island weka	weka	*Gallirallus australis greyi***	<0.01	<0.01
Northern New Zealand dotterel	tūturiwhatu	*Charadrius obscurus aquilonius***	<0.01	<0.01
Peafowl		*Pavo cristatus*	<0.01	<0.01
Pied stilt	poaka	*Himantopus himantopus leucocephalus**	<0.01	<0.01
Red-crowned parakeet	kākāriki	*Cyanoramphus novaezelandiae novaezelandiae***	<0.01	<0.01
Rock pigeon		*Columba livia*	0.01 ± 0.01	<0.01
South Island pied oystercatcher	tōrea	*Haematopus finschi***	<0.01	<0.01
Spotless crake	pūweto	*Porzana tabuensis tabuensis**	<0.01	<0.01
Stitchbird	hihi	*Notiomystis cincta***	<0.01	<0.01
Sulphur-crested cockatoo		*Cacatua galerita*	<0.01	<0.01
Swamp harrier	kāhu	*Circus approximans**	0.01 ± 0.01	<0.01
White-faced heron	matuku moana	*Egretta novaehollandiae novaehollandiae**	<0.01	<0.01
White-fronted tern	tara	*Sterna striata striata**	<0.01	<0.01
Whitehead	pōpokatea	*Mohoua albicilla***	<0.01	<0.01
Wild turkey		*Meleagris gallopavo*	<0.01	<0.01
Yellow-crowned parakeet	kākāriki	*Cyanoramphus auriceps***	<0.01	<0.01
Yellowhammer		*Emberiza citrinella*	0.02 ± 0.02	<0.01

Heritage Area compared with the Auckland region for rotation 3 (2018 to 2022)

The overall results of the six RM-ANOVA models run for each of the variables are summarised in Table 19 below: four of the six models (Naturalness and Introduced Species for both Abundance and Richness) were significant, with three requiring transformation of data to fulfil assumptions.

The mean percentage of indigenous individuals (Naturalness for Abundance) in the Heritage Area in rotation 3 was 76 per cent, which was significantly higher than the regional mean of 67 per cent ($P<0.001$, Figure 14, Table 20). Although there was no significant difference in the number of individual indigenous birds counted in rotation 3 (~13 birds in both Heritage Area and regional plots, $P=0.14$), there was a trend for fewer introduced birds to be counted in Heritage Area plots (4.41) in comparison to regional plots (6.67, $P=0.06$, Figure 14, Table 22).

Similarly to the abundance data, the mean percentage of indigenous species of total species counted (Naturalness for Richness) was higher in the Heritage Area (67%) over rotation 3 compared to the regional mean (57%, $P<0.05$, Figure 15, Table 23). Introduced Richness was lower in the Heritage Area (2.89 species) compared to an average in regional plots of 4.36 introduced species encountered per count (P<0.05, Figure 15, Table 24). Approximately five indigenous species were counted per 10MBC in both Heritage Area and regional plots (P=0.99, Figure 15).

4.3.2 Trends in Waitākere Ranges Heritage Area 2009-2022

The overall results of the six RM-ANOVA models run for each of the variables when looking for time effects (trends) are summarised in Table 25. The only time effects found for plots within the Heritage Area over the three rotations (2009-22) were for Indigenous and Introduced Abundances. More indigenous birds were counted in rotation 3 in comparison to both rotation 1 (P<0.05) and 2 (P<0.001, Figure 14, Table 21). Introduced birds varied less over time, however there were more introduced birds counted in the third rotation in comparison to the first (P<0.05, Figure 14, Table 22).

A similar time effect was found in the regional plot network for Indigenous Abundance, with more indigenous birds counted in rotation 3 in comparison to rotation 1 (P<0.001, Figure 14, Table 21), however introduced species remained constant across the three rotations in contrast to the increase seen within the Heritage Area.

Table 19: Repeated Measures ANOVA model results for bird surveys conducted at Terrestrial Biodiversity Monitoring Programme plots in the Heritage Area compared with regional plots across Auckland region.

Variable group	Variable name	df	F value	Transformation applied	P value	η^2
Abundance	Naturalness	1, 57	21.50		**<0.001**	0.27
	Indigenous	1, 57	0.41	Log	0.522	0.01
	Introduced	1, 57	27.73	Log	**<0.001**	0.33
Richness	Naturalness	1, 57	39.78		**<0.001**	0.41
	Indigenous	1, 57	0.02		0.898	<0.01
	Introduced	1, 57	35.55	Square root	**<0.001**	0.38

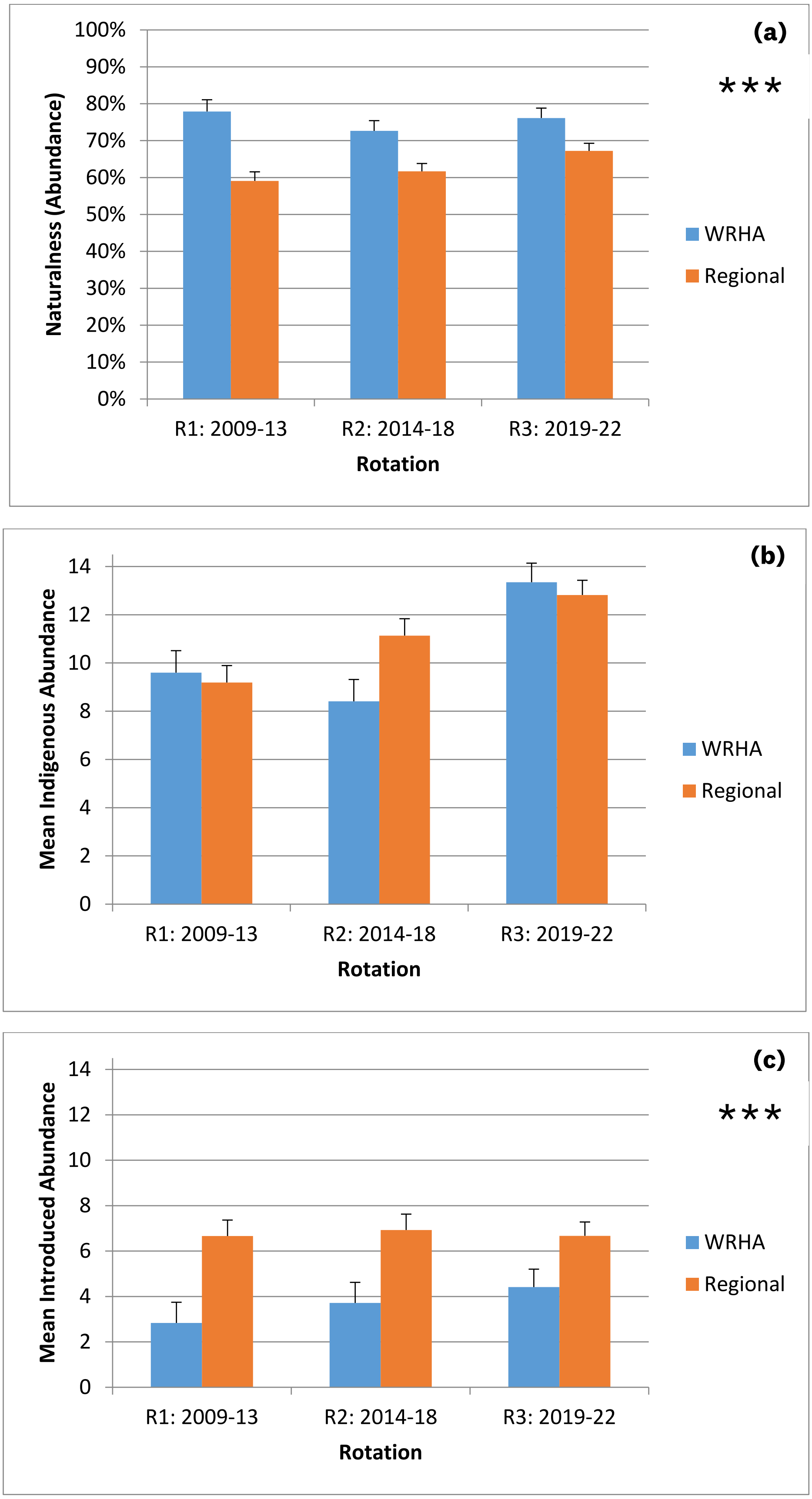

Figure 14: (a) Naturalness (Abundance), (b) Indigenous and (c) Introduced Mean Abundance for birds counted at forest plots by location (within the Heritage Area vs regional Tier 1 plots) and rotation. Bars = standard error. Overall Repeated Measures ANOVA: ***P<0.001.

Table 20: Post-hoc comparisons using Tukey HSD test of Naturalness (Abundance) for birds counted at forest sites by Area (within the Heritage Area vs regional Tier 1 plots) and rotation (R1 = rotation 1, R2 = rotation 2, R3 = rotation 3), n = number of bird survey plots.

Area - Rotation	n	P values				
		Heritage Area - R1	Heritage Area - R2	Heritage Area - R3	Regional - R1	Regional- R2
Heritage Area - R1	22					
Heritage Area - R2	22	0.582				
Heritage Area - R3	22	0.994	0.888			
Regional - R1	37	P<0.001	P<0.01	P<0.001		
Regional - R2	37	P<0.001	P<0.05	P<0.01	0.905	
Regional - R3	37	P<0.05	P<0.01	P<0.001	P<0.05	0.235

Table 21: Post-hoc comparisons using Tukey HSD test of Indigenous Abundance for birds counted at forest plots by Area (within the Heritage Area vs regional Tier 1 plots) and Rotation (R1 = Rotation 1, R2 = Rotation 2, R3 = Rotation 3), n = number of bird survey plots.

Area - Rotation	n	P values				
		Heritage Area - R1	Heritage Area - R2	Heritage Area - R3	Regional - R1	Regional - R2
Heritage Area - R1	22					
Heritage Area - R2	22	0.978				
Heritage Area - R3	22	P<0.05	P<0.001			
Regional - R1	37	0.998	0.999	P<0.001		
Regional - R2	37	0.718	0.275	0.235	0.132	
Regional - R3	37	P<0.05	P<0.001	0.999	P<0.001	0.119

Table 22: Post-hoc comparisons using Tukey HSD test of Introduced Abundance for birds counted at forest plots by Area (within the Heritage Area vs regional Tier 1 plots) and Rotation. (R1 = Rotation 1, R2 = Rotation 2, R3 = Rotation 3).

Area - Rotation	n	P values				
		Heritage Area - R1	Heritage Area - R2	Heritage Area - R3	Regional - R1	Regional - R2
Heritage Area - R1	22					
Heritage Area - R2	22	0.343				
Heritage Area - R3	22	P<0.05	0.884			
Regional - R1	37	P<0.001	P<0.01	0.110		
Regional - R2	37	P<0.001	P<0.001	P<0.05	0.969	
Regional - R3	37	P<0.001	P<0.01	0.063	0.999	0.997

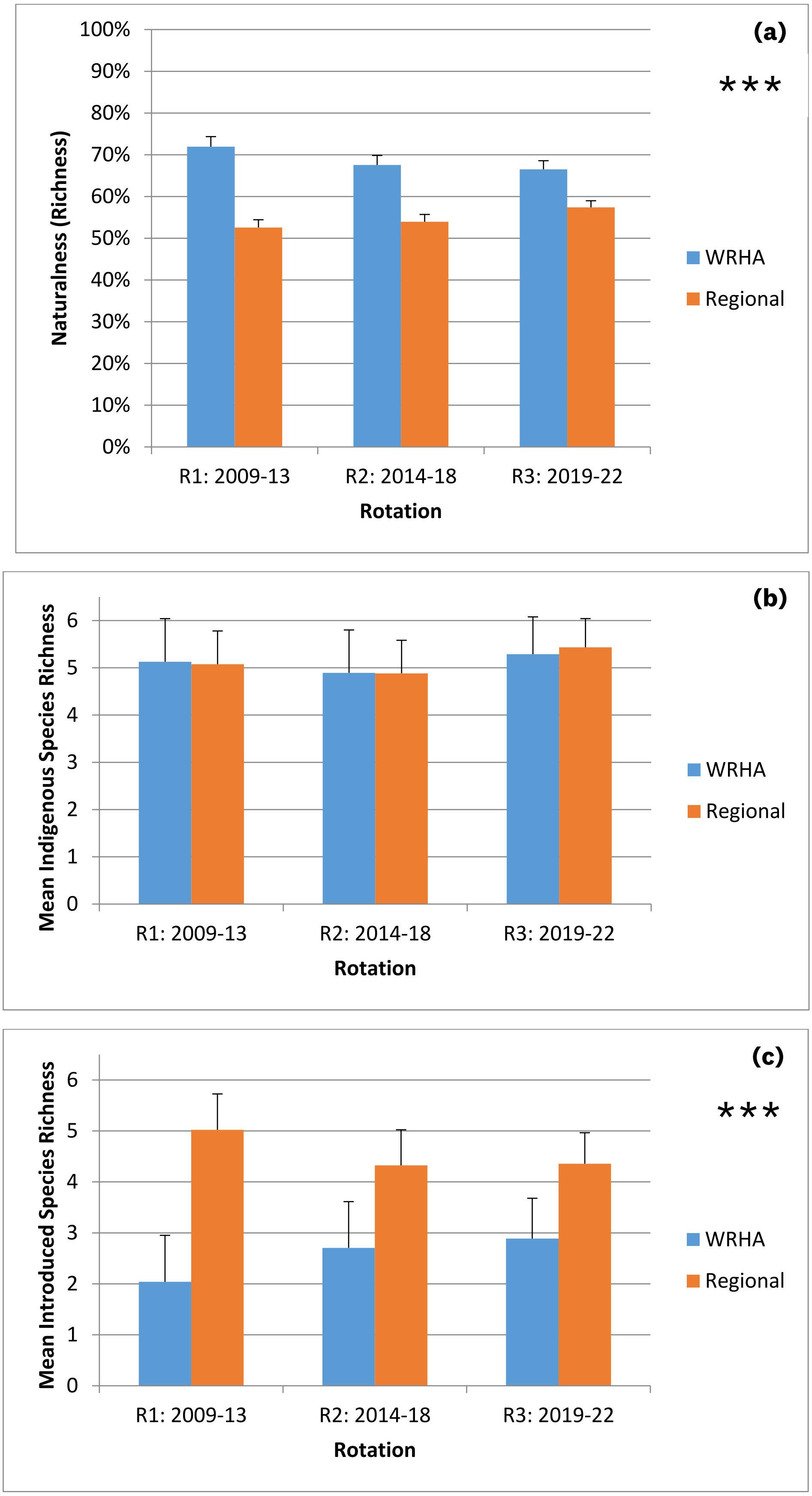

Figure 15: (a) Naturalness (Richness), (b) Indigenous and (c) Introduced Abundance for birds counted at forest plots by area (within the Heritage Area vs regional Tier 1 plots) and Rotation. Bars = standard error. Overall Repeated Measures ANOVA: ***P<0.001.

Table 23: Post-hoc comparisons using Tukey HSD test of Naturalness (Richness) for birds counted at forest plots by Area (within the Heritage Area vs regional Tier 1 plots) and Rotation. (R1 = Rotation 1, R2 = Rotation 2, R3 = Rotation 3).

Area - Rotation	n	P values				
		Heritage Area - R1	Heritage Area - R2	Heritage Area - R3	Regional - R1	Regional - R2
Heritage Area - R1	22					
Heritage Area - R2	22	0.477				
Heritage Area - R3	22	0.238	0.998			
Regional - R1	37	P<0.001	P<0.001	P<0.001		
Regional - R2	37	P<0.001	P<0.001	P<0.001	0.977	
Regional - R3	37	P<0.001	P<0.01	P<0.05	0.114	0.446

Table 24: Post-hoc comparisons using Tukey HSD test of Introduced Richness for birds counted at forest plots by Area (within the Heritage Area vs regional Tier 1 plots) and Rotation. (R1 = Rotation 1, R2 = Rotation 2, R3 = Rotation 3).

Area - Rotation	n	P values				
		Heritage Area - R1	Heritage Area - R2	Heritage Area - R3	Regional - R1	Regional - R2
Heritage Area - R1	22					
Heritage Area - R2	22	0.808				
Heritage Area - R3	22	0.252	0.938			
Regional - R1	37	P<0.001	P<0.001	P<0.001		
Regional - R2	37	P<0.001	P<0.001	P<0.01	0.656	
Regional - R3	37	P<0.001	P<0.001	P<0.05	0.499	0.999

Table 25: Repeated Measures ANOVA model results for time effects (trends) for bird surveys conducted at Terrestrial Biodiversity Monitoring Programme plots in the Heritage Area and at regional plots across Auckland region over rotations 1 (2009-2013), 2 (2014-2018) and 3 (2019-2022).

Variable group	Variable name	df	F value	Transformation applied	P value	η^2
Abundance	Naturalness	2, 114	2.59		0.079	0.04
	Indigenous Species	2, 114	21.16	Log	<0.001	0.27
	Introduced Species	2, 114	3.89	Log	<0.05	0.06
Richness	Naturalness	2, 114	0.53		0.589	0.01
	Indigenous Species	2, 114	2.49		0.087	<0.01
	Introduced Species	2, 114	0.26	Square root	0.769	<0.01

4.4 Discussion and conclusions

4.4.1 Limitations of this study

This 14-year study focussed on forest birds within the Heritage Area, has revealed significant variation both when comparing within the Heritage Area over time, as well as within the Heritage Area compared to the regional forest plot network. As discussed in Landers et al (2021), the caveat must be applied that point counts, although very useful for monitoring, disproportionately detect more conspicuous birds that are more easily heard and seen compared to more cryptic, quieter birds (Hartley 2012). Given we were most focussed on understanding large scale changes across the Heritage Area and any detectable trends over the three rotations, the consistently applied 10MBC method with good sample sizes has meant robust inferences are able to be made.

This study is the first attempt at looking at trends within the forest plot network, which has been made possible with the availability of data from three rotations.

4.4.2 Heritage Area state and trend

This study has shown the diverse community of birds and its high ecological integrity that exists within the Heritage Area. We encountered 66 different bird species over rotation 3, with approximately 75 per cent of all individual birds counted indigenous. When comparing the Heritage Area to the regional means over the last five years, the Naturalness variables were both significantly higher in the Heritage Area for Abundance (76% vs 67%, $P<0.001$, Figure 14) and Richness (67% vs 57%, $P<0.05$, Figure 15).

The main driver for the higher Naturalness of the Heritage Area in comparison to the region is the lower number of introduced species, with surveys counting on average less than three introduced species at plots compared to greater than four throughout the regional plot network ($P<0.05$). The higher variation in introduced birds, in contrast to indigenous birds which were more stable throughout the Heritage Area and the region, was also a key finding found in a recent 10-year bird study that looked at both regional averages as well as other highly managed areas in Auckland (Landers et al 2021). These latest 'state' data further confirm this trend and remind us that the Heritage Area is an important ecological area that is maintaining good ratios of indigenous to introduced birds (i.e., has high ecological integrity). Thus, we need to continue to protect the Heritage Area given there are few locations like it on our mainland. The Heritage Area 76 per cent Naturalness (Abundance) is close to the high levels found only in other highly managed areas in Auckland such as at Tāwharanui (~78%) and on islands like on Aotea (~80%, Landers et al 2021).

Indigenous species were counted more often within the Heritage Area in comparison to introduced species (four out the five most abundant species were indigenous). In terms of individual species, tauhou/silvereye was the most commonly counted bird over the last five years, but riroriro/grey warbler, tūī, and pīwakawaka/fantail were also very abundant, as were the introduced species manu pango/blackbird and pahirini/chaffinch (Table 18). Abundance of tauhou, riroriro, and pīwakawaka doubled in comparison to the five years prior, a trend also seen in the latest Garden Bird Survey for tauhou and pīwakawaka (Hayman et al 2022). Similarly, Lovegrove and Parker's 22-year study (*in review*) in the Heritage Area also found increased tauhou, as well as riroriro and korimako/bellbird, but not pīwakawaka which appeared to have stable populations. The lack of change in pīwakawaka abundance detected by Lovegrove and Parker in contrast to our survey results could relate to the different methodology used, which was to conduct 5MBCs at bird stations located along specific walking tracks. Our survey plot network in the Heritage Area covered a broader area across the Ranges given the plots were established based on a sample grid, whereas the locations of Lovegrove and Parker's walking-track stations were not spread as evenly across the Heritage Area.

Our first trend analysis of bird data from the forest plot network revealed that more indigenous birds are being counted both within the Heritage Area and across the region over the last 14 years: from approximately nine per count in earlier surveys to approximately 13 individuals per count in more recent counts ($P<0.001$, Figure 14, Table 21). Introduced birds also slightly increased within the Heritage Area: from approximately three per count in early surveys to approximately four individuals in more recent counts ($P<0.05$, Figure 14, Table 22). Lovegrove and Parker (*in review*) found a similar general trend across their 22 year study, which they discuss as potentially related to pest management efforts in the Waitākere Ranges given there are a number of studies documenting increased indigenous bird numbers in areas where management is carried out (Lovegrove 1988, Veltman 2000, Byrom et al 2016, Ruffell and Didham 2017, Miskelly 2018, Fitzgerald et al 2019, Lovegrove and Parker (*in review*)).

The increase in both indigenous species and individual birds identified in this study is difficult to pinpoint, especially with this trend also being seen across the region (with the indigenous birds). This general increase may relate to a combination of factors relating to forest condition (e.g., habitat quality/management success; see next section), and also to environmental changes, such as more extreme and variable weather patterns that have been predicted to occur in Auckland as a result of climate change (Pearce et al 2018). The recent cycling of wet and dry years, as well as the variation of east coast and west coast weather conditions relating to El Niño-Southern Oscillation (Trenberth 2023), are likely to have significant effects on the ecology and breeding biology of avifauna in Auckland (Grosbois et al 2008, Bishop and Landers 2019), however these changes are yet to be understood, particularly on sub-regional scales. Drought will likely have costly effects on birds, whereas increases in rain may benefit birds though the increases in plants and lower trophic fauna (i.e. increased food availability). Further remeasures from the TBMP will help elucidate these effects.

4.4.3 Management implications

The state and preliminary trends seen in this study within the Heritage Area support the long-established understanding that it is of high ecological value for birds as well as other terrestrial biodiversity, which is related to the extensive high-quality forest habitat that exists there (Griffiths et al 2021, Landers et al 2021 and references within), but also the success of implemented management. Bird communities are known to vary across the landscape with the highest degree of naturalness (percentage of indigenous species) tending to be concentrated in more highly managed areas and where large indigenous forests exist (Landers et al 2021). The higher degree of naturalness and increasing abundance of indigenous birds found in this study compared to the region in general support the identification of the Heritage Area as a management priority in the region that needs prolonged and continued efforts to both protect and continue to enhance its significant biodiversity.

One of the greatest pressures affecting birdlife in the Heritage Area is pest animals (Innes et al 2010, Baker et al 2014, Byrom et al 2016). Possums are generally 'under control' (Auckland Council 2015, 2018, Auckland Council Research and Evaluation Unit RIMU 2021) following a multi-decade, successful programme, although this needs to continue to keep Residual Trap Catches (RTCs) below threshold levels.

The more serious pressure remains from the 'other' pest animals, namely mice, rats, and mustelids (stoats, weasels, ferrets, Innes et al 2010). In some cases, possum control has been shown to increase rat numbers, likely a consequence of more food available to other pests with the reduced possum competition (Innes et al 2010, Ruscoe et al 2011, Masuda et al 2014), however by controlling rats and possums at the same time bird populations can improve (Byrom et al 2016 and references within). There is a clear need to control a variety of pest animals to allow indigenous birds to reach resilient population sizes (Innes et al 2010, Byrom et al 2016). Resilient populations are especially important for Threatened and At Risk species which have added pressure from the potential negative consequences of climate change (Bishop and Landers 2019, Auckland Council 2020). Thus, future management needs to continue to be 'raising the bar' to reduce the full spectrum of pest animals to levels that result in significant biodiversity gains by allowing more indigenous birds species to reach resilient population sizes (Lovegrove and Parker *in review*). This could lead to the Heritage Area becoming an even more important biodiversity area by allowing more Threatened species, including seabirds, to thrive there (Davis et al 2018, Stolpmann et al 2019, Landers 2022).

The conservation of Heritage Area indigenous avifauna is also important for maintaining and enhancing forest health. Birds have important ecological roles, namely as pollinators, seed dispersers and predators (Clout and Hay 1989, Kelly et al 2010, Young et al 2012). The Heritage Area is also a vital foraging (food source) area for birds from local and neighbouring areas, and as a population source for birds to reproduce and then disperse to other areas in the region and further (Landers et al 2018, Landers et al 2019). All of these factors highlight the vital importance the Heritage Area has to the Auckland region.

5 Summary

The analysis of land cover, canopy cover, and landslides in the Heritage Area reveals important insights into vegetation change and its impacts. The findings highlight the dominance of indigenous vegetation, comprising 81 to 85 per cent (22,000 hectares) of the Heritage Area. Forest and scrub/shrubland are the primary land cover classes, occupying 62 per cent and 22 per cent of the land area, respectively. At this broad scale, land cover classes have shown relative stability over a six-year period (2012-2018).

Forest canopy cover and height distributions vary across different Auckland Unitary Plan zones within the Heritage Area. The Public Open Space zone exhibits the highest canopy cover (84%), followed by Rural (69%), Residential (59%), and General zones (56%). The distribution of canopy height follows a similar pattern across all planning zones, with most of the forest canopy surface area concentrated in the lower height classes.

The results obtained from the analysis of canopy loss events in the Heritage Area between 2013 and 2016-2017 provide valuable insights into the extent and distribution of canopy loss, and the contributing factors and associated land zones. Thousands of small canopy loss events were identified during this period, resulting in a total loss of 50 hectares of canopy cover without any vegetation remaining above three metres in height. This loss accounts for approximately 0.2 per cent of the total land area in the Heritage Area. These myriad small events contribute to the natural dynamics and ecological processes within the forest ecosystem. It is unclear what proportion of these losses are the result of deliberate clearance or natural processes, however, this appears to vary by zone. There was no clear evidence to suggest losses within the public open spaces were the result of deliberate removal.

Landslide analysis detected a significant number of landslides (more than 150) in the Waitākere Ranges Regional Park (within the Heritage Area), triggered by intense rainfall in August 2021. These landslides, mainly small shallow slides and flows, have caused vegetation loss, affecting approximately 18 hectares of forest. Most of the impacted forest comprises mature kauri, podocarp, and broadleaved forests. Further research and monitoring are necessary to fully understand the causes, ecological processes and biodiversity impacts of these landslides and those experienced in 2023.

There are no large-scale changes in the forest over the period of monitoring. Forest in the Heritage Area continues to recover from widespread disturbance from logging, burning, gum digging and clearance for farming which largely occurred prior to the 1940s. The most disturbed areas are now in regenerating forest types which make up 42 per cent of the forested area. Areas that were less disturbed or unlogged are classed as the dominant warm kauri-podocarp-broadleaved forest and make up 45 per cent of the forest area (other warm forest types make up a further seven per cent in total). Both warm (kauri-podocarp-broadleaved) and regenerating forest are highly species diverse, dominated by indigenous plants and following expected successional pathways.

The warm (kauri-podocarp-broadleaved) forest is structurally complex supporting a wide range of conifer and canopy broadleaved tree species including rewarewa, tawa, rimu, kohekohe, kauri, white maire, tōtara, kahikatea, northern rātā, pōhutukawa and miro. Warm forest has higher woody species basal area than regenerating forest dominated by conifer and canopy broadleaved species and a lower density of stems, typical of late successional maturing forest. Regenerating forest has low basal area of conifer and canopy broadleaved species, but good canopy closure and a high stem density, especially of sub-canopy broadleaved species typical of mid-successional regenerating forest.

The Heritage Area also supports a diverse range of bird species. Our surveys indicated that the most commonly counted birds were indigenous species, with half of all the birds counted being endemic species that are only found in New Zealand. There were significantly fewer introduced species within the Heritage Area in comparison to what was counted on average at other sites across the region, identifying how important the Waitākere habitat is for supporting indigenous biodiversity. Our 14-year study also showed that indigenous species are increasing over time, with some notable rises in the presence of tauhou, riririro, pīwakawaka, and korimako in the Heritage Area. To continue this trend and to potentially restore Heritage Area birdlife to a more natural functioning state (similar to what can be seen on predator-free Hauraki Gulf islands, Landers et al 2021), management of pest animal pressures will need to continue and be expanded.

There is a large amount of investment and effort spent in managing and protecting the Waitākere Ranges Heritage Area and the Waitākere Ranges Regional Park. A variety of management activities target pest plants as well as reducing weed density on private property in residential areas. Pest plant management is carried out for priority 'buffer' species including climbing asparagus, bushy asparagus, wild ginger, moth plant, woolly nightshade and rhamnus. (Auckland Council, 2020). Additional work is also underway to eradicate Low Incidence Pest Plants (LIPP) such as Cathedral Bells (*Cobaea scandens*). Pest animal management activities target the main pest animal species: possums, feral pigs, feral deer, feral goat, rats, mustelids, rabbits, and feral cats. The Waitākere Local Board funds a range of community initiatives such as pest and weed control, planting and education. The 2021 Waitākere Ranges Kauri Population Health Monitoring Survey (Froud et al, 2022) revealed that closing the Heritage Area was successful in limiting distribution of the kauri dieback pathogen to localised areas on the periphery of the regional park, and that it is not as widespread as previously thought.

The high ecological integrity of forest and high percentage of indigenous birds (with some notable increases) reported here arises in part from the large, unfragmented and continuous characteristics of the Heritage Area, and from ongoing management to limit weed and pest pressures. There remain areas of concern, however, from the current and potential future impacts of pest animals, plant pathogens, weeds and climate change. Froud et al (2022) noted that areas of elevated risk for kauri dieback still exist. The presence of myrtle rust continues to present a future threat to myrtaceous species including kānuka, mānuka and pōhutukawa and could severely impact species that are both rare and highly susceptible such as ramarama. The recent extremes in drought and rainfall events generating widespread land slips show how rapidly climate change may impact forest processes and reinforces the need to continue active management of pressures to protect and support the forest ecosystem to continue its own regeneration.

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7 Appendix: Plant species list

Plant species	NVS code	Tree type	Biostatus
Beilschmiedia tarairi	BEITAR	Canopy broadleaf	native
Beilschmiedia tawa	BEITAW	Canopy broadleaf	native
Corynocarpus laevigatus	CORLAE	Canopy broadleaf	native
Didymocheton spectabilis	DIDSPE	Canopy broadleaf	native
Elaeocarpus dentatus var. dentatus	ELADEN	Canopy broadleaf	native
Knightia excelsa	KNIEXC	Canopy broadleaf	native
Laurelia novae-zelandiae	LAUNOV	Canopy broadleaf	native
Litsea calicaris	LITCAL	Canopy broadleaf	native
Metrosideros excelsa	METEXC	Canopy broadleaf	native
Metrosideros robusta	METROB	Canopy broadleaf	native
Nestegis cunninghamii	NESCUN	Canopy broadleaf	native
Nestegis lanceolata	NESLAN	Canopy broadleaf	native
Vitex lucens	VITLUC	Canopy broadleaf	native
Agathis australis	AGAAUS	Conifer	native
Dacrycarpus dacrydioides	DACDAC	Conifer	native
Dacrydium cupressinum	DACCUP	Conifer	native
Libocedrus plumosa	LIBPLU	Conifer	native
Pectinopitys ferruginea	PRUFER	Conifer	native
Phyllocladus trichomanoides	PHYTRI	Conifer	native
Podocarpus laetus	PODLAE	Conifer	native
Podocarpus totara var. totara	PODTOT	Conifer	native
Prumnopitys taxifolia	PRUTAX	Conifer	native
Acacia mearnsii	ACAMEA	Sub-canopy broadleaf	exotic
Alectryon excelsus	ALEEXC	Sub-canopy broadleaf	native
Aristotelia serrata	ARISER	Sub-canopy broadleaf	native
Ascarina lucida	ASCLUC	Sub-canopy broadleaf	native
Carmichaelia australis	CARAUS	Sub-canopy broadleaf	native
Carpodetus serratus	CARSER	Sub-canopy broadleaf	native
Coprosma arborea	COPARB	Sub-canopy broadleaf	native
Dodonaea viscosa	DODVIS	Sub-canopy broadleaf	native
Dracophyllum traversii	DRATRA	Sub-canopy broadleaf	native
Geniostoma ligustrifolium var. ligustrifolium	GENLVL	Sub-canopy broadleaf	native
Griselinia littoralis	GRILIT	Sub-canopy broadleaf	native
Hedycarya arborea	HEDARB	Sub-canopy broadleaf	native
Hoheria populnea	HOHPOP	Sub-canopy broadleaf	native
Ixerba brexioides	IXEBRE	Sub-canopy broadleaf	native
Kunzea robusta	KUNROB	Sub-canopy broadleaf	native
Leptospermum scoparium	LEPSCO	Sub-canopy broadleaf	native
Lophomyrtus bullata	LOPBUL	Sub-canopy broadleaf	native
Melicytus macrophyllus	MELMAC	Sub-canopy broadleaf	native
Melicytus macrophyllus x ramiflorus	MELMXR	Sub-canopy broadleaf	native
Melicytus ramiflorus	MELRAM	Sub-canopy broadleaf	native
Mida salicifolia	MIDSAL	Sub-canopy broadleaf	native
Myrsine salicina	MYRSAL	Sub-canopy broadleaf	native

Plant species	NVS code	Tree type	Biostatus
Nestegis montana	NESMON	Sub-canopy broadleaf	native
Olearia furfuracea	OLEFUR	Sub-canopy broadleaf	native
Olearia rani	OLERAN	Sub-canopy broadleaf	native
Pittosporum crassifolium	PITCRF	Sub-canopy broadleaf	native
Pittosporum ellipticum	PITELL	Sub-canopy broadleaf	native
Pittosporum eugenioides	PITEUG	Sub-canopy broadleaf	native
Pittosporum tenuifolium	PITTEN	Sub-canopy broadleaf	native
Pseudopanax arboreus	PSEARB	Sub-canopy broadleaf	native
Pseudopanax crassifolius	PSECRA	Sub-canopy broadleaf	native
Pseudopanax crassifolius x lessonii	PSECXL	Sub-canopy broadleaf	native
Pseudopanax discolor	PSEDIS	Sub-canopy broadleaf	native
Pseudopanax lessonii	PSELES	Sub-canopy broadleaf	native
Quintinia serrata	QUISER	Sub-canopy broadleaf	native
Raukaua edgerleyi	RAUEDG	Sub-canopy broadleaf	native
Rhaphiolepis bibas	RHABIB	Sub-canopy broadleaf	exotic
Schefflera digitata	SCHDIG	Sub-canopy broadleaf	native
Sophora chathamica	SOPCHA	Sub-canopy broadleaf	native
Sophora fulvida	SOPFUL	Sub-canopy broadleaf	native
Sophora microphylla	SOPMIC	Sub-canopy broadleaf	native
Streblus banksii	STRBAN	Sub-canopy broadleaf	native
Streblus heterophyllus	STRHET	Sub-canopy broadleaf	native
Syzygium smithii	SYZSMI	Sub-canopy broadleaf	exotic
Toronia toru	TORTOR	Sub-canopy broadleaf	native
Alseuosmia macrophylla	ALSMAC	Shrub	native
Brachyglottis kirkii	BRAKIR	Shrub	native
Brachyglottis kirkii var. angustior	BRAKVA	Shrub	native
Brachyglottis kirkii var. kirkii	BRAKVK	Shrub	native
Brachyglottis repanda	BRAREP	Shrub	native
Coprosma areolata	COPARE	Shrub	native
Coprosma autumnalis	COPAUT	Shrub	native
Coprosma crassifolia	COPCRA	Shrub	native
Coprosma lucida	COPLUC	Shrub	native
Coprosma macrocarpa	COPMAC	Shrub	native
Coprosma repens	COPREP	Shrub	native
Coprosma rhamnoides	COPRHA	Shrub	native
Coprosma robusta	COPROB	Shrub	native
Coprosma rotundifolia	COPROT	Shrub	native
Coprosma spathulata	COPSPA	Shrub	native
Coriaria arborea	CORARB	Shrub	native
Corokia buddleioides	CORBUD	Shrub	native
Corokia cotoneaster	CORCOT	Shrub	native
Dracophyllum latifolium	DRALAT	Shrub	native
Dracophyllum sinclairii	DRASIN	Shrub	native
Hakea sericea	HAKSER	Shrub	exotic

Plant species	NVS code	Tree type	Biostatus
Ileostylus micranthus	ILEMIC	Shrub	native
Leionema nudum	LEINUD	Shrub	native
Leptecophylla juniperina	LEPJUN	Shrub	native
Leucopogon fasciculatus	LEUFAS	Shrub	native
Melicope simplex	MELSIM	Shrub	native
Myrsine australis	MYRAUS	Shrub	native
Piper excelsum	PIPEXC	Shrub	native
Pittosporum cornifolium	PITCOR	Shrub	native
Pomaderris amoena	POMAMO	Shrub	native
Raukaua anomalus	RAUANO	Shrub	native
Rhabdothamnus solandri	RHASOL	Shrub	native
Ulex europaeus	ULEEUR	Shrub	exotic
Veronica macrocarpa	VERMAC	Shrub	native
Veronica stricta	VERSTR	Shrub	native
Cyathea cunninghamii	CYACUN	Tree fern	native
Cyathea dealbata	CYADEA	Tree fern	native
Cyathea medullaris	CYAMED	Tree fern	native
Cyathea smithii	CYASMI	Tree fern	native
Dicksonia squarrosa	DICSQU	Tree fern	native
Cordyline australis	CORAUS	Monocot tree	native
Cordyline banksii	CORBAN	Monocot tree	native
Rhopalostylis sapida	RHOSAP	Monocot tree	native
Acaena agnipila	ACAAGN		exotic
Acianthus sinclairii	ACISIN		native
Adiantum cunninghamii	ADICUN		native
Adiantum fulvum	ADIFUL		native
Adiantum hispidulum	ADIHIS		native
Anaphalioides bellidioides	ANABEL		native
Arthropteris tenella	ARTTEN		native
Asparagus scandens	ASPSCA		exotic
Asplenium bulbiferum	ASPBUL		native
Asplenium flaccidum	ASPFLA		native
Asplenium lamprophyllum	ASPLAM		native
Asplenium oblongifolium	ASPOBL		native
Asplenium polyodon	ASPPOL		native
Astelia banksii	ASTBAN		native
Astelia fragrans	ASTFRA		native
Astelia hastata	ASTHAS		native
Astelia solandri	ASTSOL		native
Astelia trinervia	ASTTRI		native
Austroblechnum membranaceum	BLEMEM		native
Austroderia fulvida	AUSFUL		native
Austroderia splendens	AUSSPL		native
Blechnum chambersii	BLECHA		native
Blechnum parrisiae	BLEPAR		native
Bulbophyllum pygmaeum	BULPYG		native
Carex banksiana	CARBAN		native
Carex dissita	CARDIS		native
Carex flagellifera	CARFGL		native
Carex lambertiana	CARLAM		native
Carex ochrosaccus	CAROCH		native
Carex raoulii	CARRAO		native
Carex solandri	CARSOL		native
Carex testacea	CARTES		native
Carex uncinata	CARUCN		native
Centaurium erythraea	CENERY		exotic
Clematis foetida	CLEFOE		native
Clematis paniculata	CLEPAN		native
Cortaderia jubata	CORJUB		exotic
Cortaderia selloana	CORSEL		exotic
Corybas rivularis	CORRIV		native
Corybas trilobus	CORTRI		native
Cotula coronopifolia	COTCOR		native
Cranfillia fluviatalis	BLEFLU		native
Cranfillia nigrum	BLENIG		native
Cyperus ustulatus	CYPUST		native
Dactylis glomerata	DACGLO		exotic
Dendrobium cunninghamii	DENCUN		native
Dianella nigra	DIANIG		native
Diploblechnum fraseri	BLEFRA		native
Earina aestivalis	EARAES		native
Earina autumnalis	EARAUT		native
Earina mucronata	EARMUC		native
Ehrharta erecta	EHRERE		exotic
Ehrharta villosa	EHRVIL		exotic
Elatostema rugosum	ELARUG		native
Ficinia nodosa	FICNOD		native
Freycinetia banksii	FREBAN		native
Gahnia lacera	GAHLAC		native
Gahnia pauciflora	GAHPAU		native
Gahnia setifolia	GAHSET		native
Gahnia xanthocarpa	GAHXAN		native
Gleichenia dicarpa	GLEDIC		native
Gleichenia microphylla	GLEMIC		native
Gonocarpus incanus	GONINC		native
Gonocarpus micranthus	GONMIC		native
Griselinia lucida	GRILUC		native
Hedychium gardnerianum	HEDGAR		exotic
Helichrysum lanceolatum	HELLAN		native
Histiopteris incisa	HISINC		native

Plant species	NVS code	Tree type	Biostatus
Hiya distans	HIYDIS		native
Hydrocotyle elongata	HYDELO		native
Hydrocotyle moschata	HYDMOS		native
Hymenophyllum demissum	HYMDEM		native
Hymenophyllum dilatatum	HYMDIL		native
Hymenophyllum flabellatum	HYMFLA		native
Hymenophyllum lyallii	HYMLYA		native
Hymenophyllum nephrophyllum	HYMNEP		native
Hymenophyllum rarum	HYMRAR		native
Hymenophyllum revolutum	HYMREV		native
Hymenophyllum sanguinolentum	HYMSAN		native
Hymenophyllum scabrum	HYMSCA		native
Hypochaeris radicata	HYPRAD		exotic
Icarus filiformis	BLEFIL		native
Juncus pallidus	JUNPAL		native
Lagurus ovatus	LAGOVA		exotic
Lastreopsis hispida	LASHIS		native
Lecanopteris pustulata subsp. pustulata	LECPUS		native
Lecanopteris scandens	LECSCA		native
Lepidosperma australe	LEPAUS		native
Lepidosperma laterale	LEPLAT		native
Leptopteris hymenophylloides	LEPHYM		native
Lindsaea linearis	LINLIN		native
Lindsaea trichomanoides	LINTRI		native
Lobelia anceps	LOBANC		native
Lomaria discolor	BLEDIS		native
Loxogramme dictyopteris	LOXDIC		native
Lycopodium deuterodensum	LYCDEU		native
Lycopodium volubile	LYCVOL		native
Lygodium articulatum	LYGART		native
Machaerina sinclairii	MACSIN		native
Metrosideros carminea	METCAR		native
Metrosideros diffusa	METDIF		native
Metrosideros fulgens	METFUL		native
Metrosideros perforata	METPER		native
Microlaena avenacea	MICAVE		native
Microlaena stipoides	MICSTI		native
Muehlenbeckia complexa	MUECOM		native
Nertera depressa	NERDEP		native
Nertera dichondrifolia	NERDIC		native
Notogrammitis heterophylla	NOTHET		native
Oplismenus hirtellus subsp. imbecillis	OPLHSI		native
Paesia scaberula	PAESCA		native
Parablechnum novae-zelandiae	BLENOV		native
Parapolystichum glabellum	PARGLA		native

Plant species	NVS code	Tree type	Biostatus
Parsonsia heterophylla	PARHET		native
Passiflora tetrandra	PASTET		native
Peperomia urvilleana	PEPURV		native
Phlegmariurus varius	PHLVAR		native
Phormium cookianum	PHOCOO		native
Phormium tenax	PHOTEN		native
Pneumatopteris pennigera	PNEPEN		native
Polystichum neozelandicum	POLNEO		native
Pteridium esculentum	PTEESC		native
Pteris macilenta	PTEMAC		native
Pteris saxatilis	PTESAX		native
Pteris tremula	PTETRE		native
Pterostylis agathicola	PTEAGA		native
Pterostylis alobula	PTEALO		native
Pterostylis banksii	PTEBAN		native
Pterostylis trullifolia	PTETRU		native
Pyrrosia elaeagnifolia	PYRELE		native
Ripogonum scandens	RIPSCA		native
Rubus australis	RUBAUS		native
Rubus cissoides	RUBCIS		native
Rumohra adiantiformis	RUMADI		native
Schizaea dichotoma	SCHDIC		native
Schoenus tendo	SCHTEN		native
Selaginella kraussiana	SELKRA		exotic
Sticherus cunninghamii	STICUN		native
Tetragonia implexicoma	TETIMP		native
Thelymitra longifolia	THELON		native
Tmesipteris elongata	TMEELO		native
Tmesipteris lanceolata	TMELAN		native
Tmesipteris sigmatifolia	TMESIG		native
Tmesipteris tannensis	TMETAN		native
Trichomanes elongatum	TRIELO		native
Trichomanes venosum	TRIVEN		native
Vitis vinifera	VITVIN		exotic

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