Ecological Integrity of Forests in Tāmaki Makaurau / Auckland 2009-2019. State of the Environment Reporting

Georgianne J. K. Griffiths, Jade Khin, Todd J. Landers, Grant Lawrence, Miriam R. Ludbrook, Craig D. Bishop

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Research and Evaluation Unit RIMU

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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Cover image credit: View from Te Hauturu-o-Toi. Photograph by Georgianne Griffiths.

Executive summary

Forest in the Auckland region covers a wide diversity of ecosystems each with its own unique complement of indigenous species. Auckland Council conducts long-term monitoring of the region’s forests as part of its State of the Environment programme to assess the state and trends in forest ecosystems, in fulfilment of Auckland Council’s obligations under the Resource Management Act 1991. Information gained is used to identify issues and inform policy development and environmental decision-making. Forests have ecological integrity when all the indigenous plants and animals typical of a region are present and key ecological functions are sustained. Ecological integrity is described using three elements: ecosystem representation, indigenous species occupancy, and indigenous species dominance. Change in ecosystem representation was examined using Auckland Council’s terrestrial ecosystem classification and mapping, together with geospatial data from the Landcover Database. Species occupancy and indigenous dominance were examined using 10 years of data from the network of unbiased, point-based, spatially stratified permanent forest plots in Auckland Council's Terrestrial Biodiversity Monitoring Programme (TBMP).

At a sub-regional scale there are numerous examples of forest and scrub supporting diverse indigenous plant communities with healthy forest structures. These are more common in the large, continuous forest patches with high habitat heterogeneity such as the Waitākere Ranges, Hunua Ranges and Aotea, and at sites with intensive conservation management including Tāwharanui, Shakespear and the offshore island of Te Hauturu-o-Toi. Absence of weed plants is typically a function of low exposure to propagules (e.g. large forest patch size, distant from rural or urban land, offshore island) and weed control. Few forests have high native bird species occupancy, which appears strongly determined by pest animal eradication in fenced or offshore locations. Native bird communities in unfenced sanctuaries appear to be limited, possibly due to continuous pest incursions. There are also numerous examples of forest and scrub with depauperate indigenous plant communities. These are more common in small forest patches where weeds are most abundant and may outcompete natives and disrupt normal ecosystem processes. Tāwharanui Regional Park however, illustrates how the ecological integrity of small forest patches in predominately rural areas can be improved, albeit with considerable effort.

At a regional scale, the ecological integrity of Auckland's forests is strongly impaired by the absence or reduced extent of many forest and scrub ecosystem types, the absence of many native bird species, the widespread abundance of pest animal species and the frequency of weed incursions. Indigenous forest ecosystems have been reduced to 23 per cent of their original extent, with some ecosystem types

disproportionately affected. For example, only 16 per cent of kauri, podocarp, broadleaf forest, two per cent of kahikatea, pukatea forest and 0.3 per cent of pūriri forest remain (Singers et al 2017). Much remaining forest and scrub has been disturbed and degraded to such an extent it has been reclassified as regenerating forest and scrub ecosystem types that did not previously occur in the Auckland region. This assessment of the ecological integrity of forests in Auckland has long been implicitly understood; what is new is the use of unbiased quantitative data to examine where and how ecological integrity is impaired, for those components of wildlife that the TBMP measures, namely plants and birds.

As New Zealand's most populated region, Auckland cannot replace all its lost forest and scrub habitat, but all remaining forest and scrub, however small the fragment, should be recognised as a precious and highly limited natural resource. Best practice for forest bird conservation is generally well understood; sustained pest animal eradication combined with fencing or isolation, native bird reintroductions and indigenous replanting where necessary, give the best conservation outcomes (Binny et al 2020). Successful examples of such conservation practices can be seen in Te Hauturu-o-Toi and Tāwharanui, but these native bird communities need secure forest to expand into if they are to be sustainable (Lovegrove and Parker in review). Many conservation groups across the Auckland region conduct intensive forest restoration and indigenous bird conservation projects, often in collaboration with Auckland Council and other conservation charities e.g. Forest and Bird. Better ecological monitoring and analytical support for these community groups could further enhance their conservation outcomes. This will be necessary if Auckland is to achieve the aim to be pest-free by 2050 (Pest-free Auckland 2050). Creation, expansion and restoration of forest habitats may be necessary to maintain the full range of forest and scrub ecosystem types that once occurred in the region, and provide a buffer against emerging risks such as myrtle rust and the effects of a changing climate. Ultimately, forest conservation needs to take a landscape approach; multi-partner initiatives such as the Northwest Wildlink provide a good example, by maximising the ecological value of and benefit to small and large forest patches.

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1.0 Introduction

Forest in the Auckland / Tāmaki Makaurau region covers a wide diversity of ecosystems each with its own unique complement of indigenous species. These ecosystems support a rich variety of over 20,000 species of native plants and animals (Cameron et al 2001); most are unique to New Zealand and a few are found only in the Auckland region. One of the most intact indigenous forest communities in the Auckland region is found on the offshore island of Te Hauturu-o-Toi (Little Barrier Island), where bird populations continue to fulfil the ecosystem functions of pollination and seed dispersal that many indigenous forest species depend on (Pattemore & Anderson 2012; Anderson et al 2011). For such a large urban centre, the Auckland region is also unusual in retaining several large continuous tracts of indigenous forest in the Waitākere Ranges, Hunua Ranges and on Aotea (Great Barrier Island). These forested areas have been logged for kauri[1] and other timber trees and parts burned or cleared for farming, but there has been significant regeneration and consolidation of forested land since. These large, continuous forested areas now represent a complex and diverse mosaic of mature and successional forest vegetation (Denyer et al 1993).

A large proportion of Auckland's forest habitat, however, is found in smaller and more isolated forest fragments, often surrounded by rural or urban land. Examples of unique forest remnants include patches of formerly widespread swamp forest at Omaha and Pakiri, enclaves of indigenous sand forest along the Awhitu and South Kaipara peninsulas, and fragments of lowland taraire forest, such as Kirk's Bush. Even the Auckland urban area contains many examples of rare forest types. These include remnants of indigenous lava forest at Otuataua and Maungawhau (Mt. Eden), a nationally uncommon vegetation type; pockets of hard beech-kauri forest in the Birkenhead-Chatswood area; and the best example of gumland in the Auckland region at Waikumete Cemetery.

The ecological integrity of Auckland's forests is vulnerable to a range of pressures, the ongoing impacts of habitat loss and fragmentation, exotic weeds, pest and pathogens, and the more poorly understood impacts of climate change.

1.1 Habitat loss, fragmentation and degradation

The current patchy distribution of forest and scrub cover reflects the processes of burning, logging, forest clearance, farming and urban development that have taken

[1] The Latin binomial, Māori and paheka names of all species referred to in text are listed in Appendix B. The naming convention for flora and fauna in this report uses Māori names for indigenous species where possible, or a combination of Māori, pakeha and/or Latin binomials where necessary.

place across the Auckland region since human colonisation, especially in lowland areas. The destruction of forest habitat is responsible in large part for declines in native biodiversity, with forest loss considered to have a greater impact on bird communities than invasive mammals in areas of high deforestation such as lowland Auckland (Innes et al 2009; Ruffell and Didham, 2017). As forest patches become smaller and more isolated they are less able to provide the conditions and resources necessary for indigenous forest species to persist, and are less likely to be recolonised by forest species when they go locally extinct (Fahrig 2003). Smaller forest patches have a greater edge to area ratio, and edge effects can be detrimental to forest communities (Norton 2002; Ewers and Didham 2008), although these transition zones can also be highly diverse. Adjacent land-uses vary in their ability to provide resources, support movement of native species between forest patches or expose forest patches to further pressures. It is increasingly recognised that forest conservation needs to take a landscape approach (Döbert et al 2014); understanding the impact of landscape structure and surrounding land-use on forest ecological integrity can help to inform future biodiversity conservation decision-making. For example, the Northwest Wildlink (www.northwestwildlink.org.nz) aims to connect pest-free or pest-suppressed Hauraki Gulf islands, peninsulas and open sanctuaries (e.g. Te Hauturu-o-Toi, Tiritiri Matangi, Tāwharanui, Shakespear) on Auckland's north-east coast, with the Waitākere ranges on Auckland's west coast using a series of wildlife 'corridors' and 'stepping stones' of smaller habitat patches.

1.2 Invasive weeds, pests and pathogens

Considerable degradation of Auckland's forests is driven by problematic non-native species. Forests that are disturbed, fragmented and exposed to human activity become both more exposed and more susceptible to weeds, pests and pathogens (Hobbs 2000; Jeschke & Starzer 2018). Adjacent land-use will also vary in the extent to which it supports reservoirs of weed, pest and pathogen species to colonise indigenous habitat patches. There are more than twice as many naturalised non-native plant species compared to native species in the Auckland region (Sullivan et al 2004), with 226 designated as problematic and listed in Auckland Council's *Regional Pest Management Plan 2020-2030*. These 226 weeds are considered capable of having serious adverse effects on the environment or people. The number of problematic weed species continues to grow as more invasive species arrive on our shores (Williams and Cameron 2006; Hulme 2020). Invasive plants pose a threat to more than half of New Zealand's critically endangered ecosystems and species (Wiser et al 2013). Weed plants can out-complete native species and displace them locally, affecting the abundance, species richness and local distribution of native flora

(McAlpine et al 2015). The naturalised flora contains more herbaceous and annual species, and naturalised trees have a higher leaf nitrogen concentration compared to the native flora, both of which could influence ecosystem processes such as decomposition and nutrient cycling (Brandt et al 2021).

The plant pathogens causing kauri dieback and myrtle rust threaten some of the most iconic tree species in the Auckland region, kauri trees and pōhutukawa respectively. Myrtle rust threatens a wide range of other important species (Beresford et al 2019) and many have been reclassified as nationally critical as a result, for example maire tawake (swamp maire*,* Lange et al 2012). Potential impacts to forest ecological integrity from myrtle rust are unknown and changing rapidly; as this report goes to press, tree mortality caused by myrtle rust has been reported in East Cape, three years after the pathogen was first detected there, and the first record of myrtle rust in the Waitākeres has been confirmed. Furthermore, the invasiveness of many non-native species will be exacerbated by climate change in the Auckland region (Sheppard et al 2016).

More than 80 non-native animals have become established in New Zealand (Craig et al 2000). In the Auckland region, the severe impacts of rats, mustelids, cats, dogs, the brush-tailed possum, deer, goats and pigs to native flora and fauna are well documented. Predatory mammals kill the eggs, nestlings and adults of native birds, and many predator-sensitive native species such as korimako (bellbird), hihi (stitchbird), toutouwai (North Island robin), North Island kōkako, kākā and popokatea (whitehead) can only exist in predator-free offshore or mainland islands (Ruffell and Didham 2017). Lizards and large invertebrates are also highly vulnerable to predators (St Clair 2011; Norbury et al 2014). Predatory mammals also impact forest ecosystem functioning by disrupting bird-mediated pollination and seed dispersal (Pattemore & Anderson 2012; Anderson et al 2011). Herbivorous mammals browse the young shoots of native plants and may affect forest composition and regeneration dynamics (Husheer 2007). As an omnivore, the brush-tailed possum does both (Brown et al 1993; Atkinson et al 1995; Bellingham et al 2016). Less well documented are the impacts of invasive invertebrates such as wasps and paper wasps. Where these species are abundant they are known to consume and seriously deplete invertebrate fauna, particularly butterflies and moths (Beggs et al 2011; Lefort et al 2020a; Lefort et al 2020b). For example, the disappearance of the forest ringlet butterfly from the Auckland mainland since the 1990s has in part been attributed to predation by invasive wasps (Wheatley 2017).

1.3 Climate change

There is a paucity of knowledge on how changes in climate will impact the ecological integrity of Auckland's forests directly, but it is widely agreed the climate emergency will exacerbate existing problems (Bishop et al 2018; Macinnis-Ng et al 2021). For example, changes in climate will expand the range and impact of existing invasive species and provide opportunities for new naturalisations, driving biodiversity losses (Sheppard et al 2017; Bishop et al 2018; Macinnis-Ng et al 2021). Forest flora and fauna that already have a reduced distribution and population size from habitat loss and fragmentation will have limited resilience to changes in climate (McGlone and Walker 2011). Predictions from NIWA for the Auckland region include increased temperatures, including the number of hot days (>25°C) per year (Pearce et al 2018). Changes in temperature can impact the phenology or timing of species and their interactions, such as the timing and intensity of synchronised mast-seeding events across multiple plant species (Schauber et al 2002). The length and intensity of both droughts and extreme rainfall events is expected to increase. Elevated stress from prolonged low soil moisture will impact native forest flora and fauna. There are few predictive traits for drought-induced mortality; but small trees are considered more susceptible than larger trees, and forest 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 tawa (*Beilschmiedia tawa)* and kanono (*Coprosma autumnalis*) are considered drought sensitive (Knowles and Beveridge 1982), but there is little comprehensive research. Droughts will increase wildfire hazard, impacting forest ecosystems that are already highly fragmented (McGlone and Walker 2011), and potentially changing successional trajectories to favour fire-adapted non-native taxa (Perry et al 2014). Finally, sea-levels will continue to rise, with increased frequency and severity of storm surges, resulting in increased coastal erosion and inundation. Erosion sensitivity is expected to be higher for Auckland's east coast, and greater sensitivity to inundation near estuaries where tidal ranges will be amplified. Some iconic forest ecosystems in the Auckland region, such as higher elevation kauri, tōwai, rātā, montane podocarp forest (MF25, Singers et al 2017) and coastal pōhutukawa, pūriri, broadleaf forest (WF4, Singers et al 2017), are exposed to multiple risk factors (Bishop et al 2018).

1.4 Policy and monitoring

Auckland Council has made commitments to protect biodiversity, ecosystems and their services through the *Indigenous Biodiversity Strategy 2012* and the *Auckland Plan 2050*, and these are strongly supported by the proposed National Policy Statement on Indigenous Biodiversity 2020 (Ministry for the Environment 2019). Key to protecting indigenous biodiversity is knowledge, and the *Indigenous Biodiversity Strategy* includes an objective to 'improve our knowledge and understanding of biodiversity in the region in order to protect and manage it more effectively'. Auckland Council started a Terrestrial Biodiversity Monitoring Programme (TBMP) in 2009 to monitor forests, wetlands and dunes in the Auckland region as part of State of the Environment monitoring requirements under Section 35 of the Resource Management Act 1991. In 2017 Auckland Council published a systematic classification of its terrestrial ecosystem types, for which historic and current distributions across the Auckland region have been mapped (Singers et al 2017). In this report, 10 years of data from the network of permanent forest plots in the TBMP, together with historic and current distributions of ecosystem types and geospatial data, are analysed to examine forest ecological integrity across the region and within targeted monitoring areas.

2.0 Methods

2.1 Measures of forest ecological integrity

Ecological integrity is the key concept underpinning conservation in New Zealand, defined as the full potential of indigenous biotic and abiotic features and natural processes, functioning in sustainable communities, habitats and landscapes (Lee et al 2005). The term can be measured at multiple spatial scales, from ecosystems, to regions, to a national level. Defining 'full potential' is somewhat subjective (Schallenberg et al 2011) and is often determined by comparison to a reference state, which may be historic or a pristine or near-pristine extant ecosystem (Wurtzebach & Schultz 2016). Neither are perfect; knowledge of an historic state is complicated by many factors including climate change, disturbance, ecological memory or shifting baselines, where returning to historic conditions is no longer feasible. Using pristine or near-pristine extant ecosystems allows these changes to be accounted for, but the omnipresence of pest animals and their ecological impacts means that even where primary forest undisturbed by clearance or logging exists, forest ecological integrity is likely to be impaired. For much of the Auckland region there is a good understanding of the historic distribution of the common and dominant flora and fauna. The Singers et al (2017) historic ecosystem type geospatial layer provides a more detailed and spatially explicit reference point for what ecosystems should exist in the absence of human activity.

In defining ecological integrity, Lee et al (2005) state, 'at its simplest, ecosystems have ecological integrity when all the indigenous plants and animals typical of a region are present, together with the key major ecosystem processes that sustain functional relationships between all these components. At larger scales, ecological integrity is achieved when ecosystems occupy their full environmental range'. McGlone et al (2020) state that 'all that is necessary for good ecological integrity at small scales is that the indigenous biota typical of a region dominates, at larger spatial scales, the more important absences become. Ecological integrity at a regional level must be regarded as impaired if species that should be present are sparse or totally absent'. The term ecological integrity is now widely used in policy and legislation and is a reporting requirement in the New Zealand Environmental Reporting Act 2015.

Three core elements define ecological integrity, which if satisfied, provide the best guarantee that ecological integrity is being achieved (Lee et al 2005):

1. Ecosystem representation – are the full range of ecosystems in the region being maintained and how are they structured within the landscape?

2. Species occupancy – are the species present that should be there?

3. Indigenous dominance – are the key natural ecological processes being maintained by native biota?

This report will address these three core elements of ecological integrity using a series of measures derived from current and historic ecosystem maps, geospatial data and 10 years of the TBMP forest plot network (Table 1). These measures are aligned with indicators developed for the Department of Conservation (Lee and Allen 2011; the Department of Conservation Outcome Monitoring Framework, www.doc.govt.nz/omf) and regional councils (Bellingham et al 2016).

Table 1: Description of the measures calculated using geospatial data and the TBMP forest plot network to describe ecosystem representation, native species occupancy, and indigenous species dominance of Auckland's forests. The acronyms LAWA and LCDB are defined in the following section 2.2.

Core element ecological integrity	Measure	Description
Ecosystem representation	Area (ha) of LAWA Medium Landcover classes	The total area of different landcover types on land is periodically mapped using remote sensing GIS techniques and made publicly available in the New Zealand Landcover Database (LCDB). Here, we examine and compare changes in landcover between 1996 and 2018 for the LAWA Medium Landcover classes (www.lawa.org.nz).
	Area (ha) of potential terrestrial ecosystems	The potential ecosystem geospatial layer is based on an understanding of pre-human vegetation and past and current environmental influences.
	Area (ha) of current terrestrial ecosystems	The current ecosystem geospatial layer is based on ecological surveys of 2000 sites and previous surveys by Auckland Council, Department of Conservation, Crown Institutes and academics. Auckland Council continues to refine maps of current extent as new data becomes available.
	Landscape structure: Habitat patch-size	For each TBMP forest plot, forest patch-size (ha) in which a plot is located was estimated as the polygon size from the current ecosystem type geospatial layer.
	Landscape structure: Connectivity	For each TBMP forest plot, the proportion of indigenous land within a 1000m radius of the plot centre was used as an area-based proxy for connectivity. This measure has been shown to perform better than several other measures including distance to nearest neighbour (Bender et al 2003).
	Landscape structure: Dominant land-use	For each TBMP forest plot, a categorical variable describing the dominant land-use (rural, urban, indigenous or mixed) was devised based on the proportion of each land-use >0.5 within a 1000m radius of the plot centre (Ruffel & Didham 2017).
Species occupancy	Native plant species richness	Number of native tree species
		Number of native non-woody understorey species
		Total number of native species: alpha, beta and gamma diversity
	Forest structure	Native tree size-class distribution
		Number of stems: native saplings
		Number of stems: native woody understorey
	Native birds	Number of native bird species
		Abundance of native birds
Indigenous dominance	Weeds	% sapling abundance composed of weeds
		% plot occupancy by non-woody understorey weeds (measured in seedling plots, n=24)
	Introduced birds	Number of introduced bird species
		Abundance of introduced birds
	Pests	% of chew cards per plot (n=40) with signs of rat and mouse damage
		% of chew cards per plot (n=40) with signs of possum damage

2.2 Ecosystem representation and landscape structure

Information on ecosystem representation is obtained from the Landcover Database (LCDB v5.0 2020) and the classification of New Zealand's terrestrial ecosystems (Singers & Rogers 2014; Singers et al 2017). The LCDB uses analysis of satellite imagery to differentiate Auckland's landscape into 29 different types of land cover (33 across New Zealand) and provides spatial distribution and changes over time. Version 5 of the Database, contains the latest land cover data from late 2018, and previous land cover data from summertime 1996/97, 2001/02, 2008/09 and 2012/13. Land, Air and Water Aotearoa (LAWA) have grouped detailed land cover types into 11 medium cover classes, as defined in the LAWA data portal classification hierarchy (www.lawa.org.nz). In this report we examine and compare changes in landcover between 1996 and 2018 for the LAWA Medium Landcover classes using data accessed on 30/01/2020.

The classification of New Zealand's terrestrial ecosystems identifies 36 terrestrial and wetland ecosystems in the Auckland region (Singers & Rogers 2014; Singers et al 2017). The historical (predicted pre-human) and current distribution of all 36 terrestrial and wetland ecosystems have been mapped and published as geospatial layers by Auckland Council (www.aucklandcouncil.govt.nz/geospatial/geomaps). The historic distribution is based on a wide range of data sources described in 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 Institutes and academics. Auckland Council continues to refine maps of current extent as new data becomes available. Historic and current ecosystem types do not include the built environment. We examined changes in extent for forest and scrub ecosystem types between the historic and current ecosystem geospatial layers.

Ecological integrity arising from ecosystem representation is defined not just by its extent, but also how it is structured in the landscape. Measures of landscape structure (patch-size, connectivity, dominant land-use) were calculated for each permanent forest plot within Auckland Council's TBMP forest plot network using LCDB data from 2018[2]. The patch size (ha) of the habitat in which a plot is located was based on the total area of continuous vegetation represented by classified polygons (regardless of indigenous or exotic origin). Of the 29 land cover classes found in Auckland, nine classes were used to define habitat patches (broadleaved indigenous hardwoods,

[2] The TBMP, established in 2009, was not designed to sample ecosystem types defined by Singers et al in 2017 and does not represent a balanced or complete coverage of Auckland's forest and scrub ecosystem types. The TBMP plot network covers 25 ecosystem types, including 16 that are forest and scrub.

fenland, flaxland, herbaceous freshwater vegetation, herbaceous saline vegetation, indigenous forest, mangrove, manuka and/or kanuka, matagouri or greyscrub). The habitat patch size was calculated by merging contiguous polygons of the specified classes and retrieving the sum area of the final polygon for each plot, in some cases multiple plots are located in the same habitat patch. The proportion of indigenous land within a 1000m radius of the plot centre was used as an area-based proxy for connectivity. This measure has been shown to perform better than several other measures including distance to nearest neighbour (Bender et al 2003). Finally, a categorical variable describing the dominant land-use (rural, urban, indigenous or mixed) was devised based on the dominant land-use within a 1000m radius of the plot centre (a land-use was dominant when it covered ≥0.5 of the landcover by proportion, Ruffell & Didham 2017).

2.3 Terrestrial Biodiversity Monitoring Programme: Forest plot network

The TBMP forest plot network uses a grid-based systematic sampling approach centred around permanent 20 x 20m vegetation plots. The 20 x 20m vegetation plot has a long history in New Zealand. From the 1950s to 1980s they were used to monitor harvestable forest resources and other pressures (Wiser et al 2001). In the latter part of the 20th century the focus changed and permanent 20 x 20m plots formed the basis of biodiversity and carbon monitoring and reporting nationally (McGlone et al 2020). The national New Zealand Carbon Monitoring System was based on >1000 permanent plots on an 8-km-grid across New Zealand's indigenous forest and scrub (Payton et al 2004). An 8 x 8km grid was chosen to achieve a sample size sufficient to produce a national estimate of carbon storage in indigenous forest and shrubland with a statistical precision of 5% around the mean (Bellingham et al 2020).

In the Auckland region, the TBMP network of plots is designed around nested spatial scales ranging from regional plots (Tiers 0 and 1), targeted monitoring areas (Tiers 2 and 3) to localised, site-specific studies (Tier 4). Tier 0 and Tier 4 plots are omitted from this report; Tier 0 is a nationally implemented plot network designed to measure any vegetation type within a grid square, not just forest, while Tier 4 plots were established to address specific research questions. To generate a sufficient regional (Tier 1) sample size the national 8 x 8km grid was split into four quarters, and plots allocated to alternate 4 x 4km grid squares. Plots were located in the nearest suitable patch of forest closest to the centroid of each selected square. For each plot, a randomly selected plot corner had to be at least 20m from any edge, this limited the minimum patch size suitable for sampling to around one hectare. Where forest patches occurred on public land, permission to establish a permanent plot was typically granted. Permission to establish a permanent vegetation plot on private land could not always be obtained. If this was the case, the next nearest suitable forest patch for which permission could be obtained was used. On occasion, no other suitable patches of forest occurred in that square or no permission was granted, in which case no plots could be established in that square. In total 134 permanent forest plots have been established forming the Auckland region Tier 1 monitoring network, designed to monitor and report on the state and trends in the region's forest and scrub (Map 1).

Map 1: The network of Tier 0 - 4 permanent forest plots in the Terrestrial Biodiversity Monitoring Programme.

The alternate 4 x 4km grid scale generates sufficient plots to report regionally, but insufficient plots to calculate estimates of forest ecological integrity within more localised areas. In addition to the state and trend Tier 1 plots, further permanent forest plots have been established at greater spatial resolution within targeted monitoring areas to better describe the ecological integrity of these forests. These Tier 2 and Tier 3 plots differ only in the spatial scale at which they were established. Tier 2 plots were established using a 2km grid to measure ecological integrity in large tracts of indigenous forest on Aotea (Great Barrier Island), in the Hunua and Waitākere Ranges; at high conservation value sites at Tapora, Kaipara, Awhitu and Tamahunga; and in urban areas (inside the Metropolitan Urban Limit) where indigenous biodiversity is considered to be under high pressure from external threats (e.g. high habitat loss, fragmentation and degradation resulting from urban development, Map 1). Tier 3 plots were established on a variable grid scale always <2 x 2km in locations with active conservation management including suppression or eradication of pest animals. These Tier 3 plots are located at Shakespear and Tāwharanui open sanctuaries, Ark in the Park (Waitākere Ranges), Kōkako Management Area (Hunua Ranges), Te Hauturu-o-Toi (Little Barrier Island), the Inner Gulf islands of Rangitoto, Motutapu, Motuihe and Waiheke, and the privately run Glenfern and Windy Hill sanctuaries on Aotea (Map 1). Detailed descriptions of the history, management and forest ecosystem for all monitoring units (regional Tier 1 and targeted monitoring areas in Tier 2 and 3) can be found in Appendix A. The number of plots established in each tier are shown in Table 2.

Table 2: The number of plots from each rotation and in total for Tier 1 regional forests, and Tiers 2 and 3 targeted monitoring areas.

Tier	Scale	Extent	Number of plots established
0	8 km grid	Regional	12
1	alternate 4 km grid squares	Regional	134
2	2 km grid	Targeted monitoring areas	110
3	<2 km grid	Targeted monitoring areas	159
4	no grid	Targeted monitoring areas	8

The network of forest plots was started in 2009, with the intention to visit all plots on a five-year rotation. Rotation 1 represents plots established and sampled between 2009 and 2013, Rotation 2 represents plots sampled between 2014 and 2018, and Rotation 3 started in 2019 and will complete in 2023. Plot visits take place between October to December annually. Unfortunately a series of budget cuts during Rotation 2 lead to a 60% reduction in the number of Tier 1 plots monitored on a five yearly basis. Seventy-eight plots were either put on hold or moved to a 10-year rotation, while 56 plots continue to be visited on a five-year rotation. Consequently, there are baseline data for 134 Tier 1 plots, but only 56 Tier 1 plots continue to be remeasured every five years.

2.4 Forest plot protocol

At each permanent plot, a standardised protocol is followed based on the 'standard' 20m x 20m permanent plot protocol (Hurst & Allen 2007), but with some adaptation. Using this standard method ensures our forest monitoring is best practice and makes Auckland data comparable with information from across New Zealand. The aim of the protocol is to capture as complete a snapshot of the forest structure, composition and life stages as is feasible, given limited resources. At each location, the 20 x 20m permanent plot is marked out, and sub-divided into 16 5 x 5m subplots (labelled A - P) using measuring tapes and 24 1m^2 understorey plots (labelled 1 - 24, Figure 1).

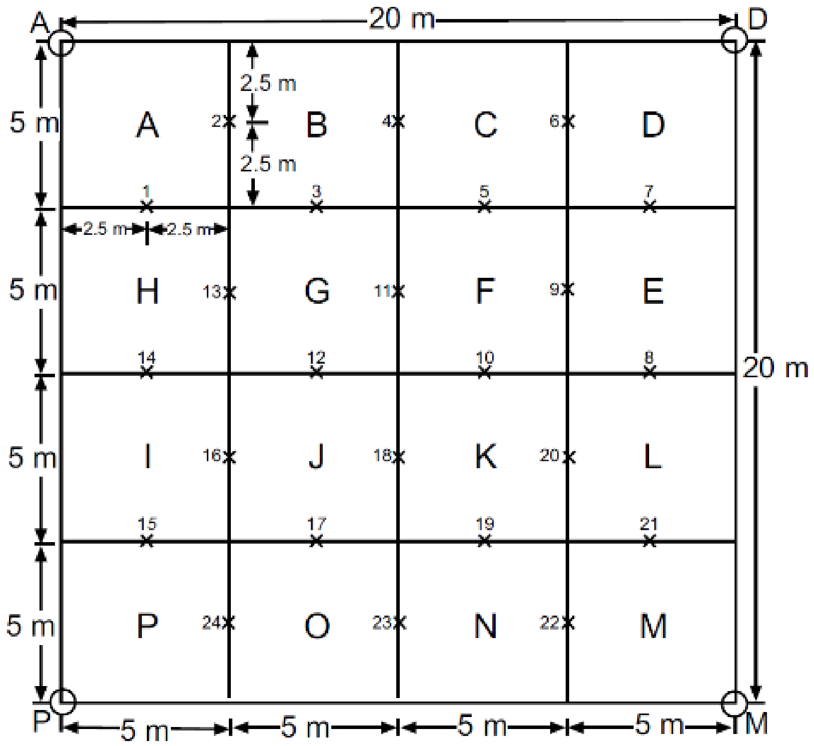


Figure 1: Permanent forest plot layout, showing subplots (A - P) and understorey plots (1 - 24).

Once the 20 x 20m permanent plots are laid out, plants are measured in standardised ways as described in Table 3. Birds are monitored at each plot using three 10 minute bird counts with a detection probability and a distance sampling component (Landers et al 2021). At a subset of TBMP forest plots, possum, rat and mice populations are monitored using chew cards. Deployment of chew cards ceased in 2016 due to funding cuts; a review of pest monitoring as part of the TBMP is planned in 2021. Full details of the forest plot protocol for Tiers 1 to 4, and Tier 0 are available (Forest Monitoring Protocol SOE Version 5.08).

Over the years, small changes in the protocol have been made to address gaps in data collection. For example, unlike the NVS plot protocol, in 2009 when the TBMP was first established trees within plots were not tagged. This decision was revisited in 2016 once sufficient data had been collected, and tree tagging on all existing and new plots was introduced.

Table 3: Plant, bird and pest measurements taken in fulfilment of forest plot protocol.

Measures	Description
Meta-data	Meta-data such as is colleceted for RECCE plots in the NVS (Hurst & Allen 2007), e.g. aspect, altitude, ground cover, canopy height, canopy cover, ground cover, history, evidence of clearing/logging, etc.
Forest condition	A number of condition scores are collected based on the plot interior and immediate surrounding forest. Conditions measured include canopy dieback, understorey vegetation, weeds, fencing or stock access, mammal pests and whether the plot is representative of the surrounding forest.
Tree diameter	The species and diameter (at 1.35m height) of individual trees is measured per subplot, for tree ≥1.35m tall and ≥2.5 cm diameter. All trees meeting these criteria are now tagged. This measure gives both the diameter and number of trees per subplot. Tree diameter is used to calculate tree basal area per plot.
Sapling count	For saplings ≥1.35m tall and <2.5cm diameter, count the number of each species per subplot.
Understorey count	Count the number, species and height tier of woody seedlings <1.35m tall within 24 seedling plots. Height is recorded in fixed height tiers <15cm, 15-30cm, 31-45cm, 46-75cm, 76-105cm and 106-135cm.
Understorey presence	Record the presence, species and height tier of non-woody plants (e.g. ferns, herbaceous, liana, grass) <1.35m tall within 24 seedling plots. Height is recorded in fixed height tiers <15cm, 15-30cm, 31-45cm, 46-75cm, 76-105cm and 106-135cm.
Birds	Three 10 minute bird counts are conducted at the plot P-corner. During the first 5 minutes, each bird seen or heard is counted with associated distance bands, in the second five minutes only the presence of birds not recorded in the first five minutes are recorded. Bird counts are conducted between the first hour after sunrise and before 1300 hours, at least one hour apart. Bird counds are conducted differently for the national Tier 0 plots.
Pests	Chew cards are laid out on a single 200m transect that intersects at its mid-point with the plot P corner, and runs diagonal to the P-A and P-M plot sides. A chew card tarnsect line consists of 10 chew cards at 20m intervals. Chew cards are retreived after three nights and the % cards chewed by possum, rats and mice recorded. Pests are recorded differently for the national Tier 0 plots. Chew cards were only deployed on a subset of TBMP plots and ceased entirely in 2016. Animal signs are also recorded including species (e.g. cattle, deer, goat, sheep, pig, possum, rat, etc), sign (e.g. canopy browse, footprint, rooting, pellects/stools, etc), and the plant species and severity of any plant damage.

2.5 Analyses

Summary statistics are used to describe patterns and changes in LCDB data using LAWA Medium landcover classes, historic and current ecosystem extent.

Measures of ecological integrity (e.g. native plant species richness) were modelled against measures of landscape structure (e.g. patch-size, connectivity and dominant land-use) using linear mixed-effects models (Gelman & Hill 2006). All samples of all plots from all tiers were used in the analysis to maximise the sample size. Since the data were not designed to test these variables in a balanced way, a number of factors need to be controlled or accounted for as random effects that will introduce natural variation in ecological integrity measures. Random effects included a factor describing plot identity to account for temporal autocorrelation between resamples, year sampled to account for natural variation between years and ecosystem type due to natural variation between forest and scrub ecosystem types. Mixed-effects models were used to partition the variance between random effects (plot, year and ecosystem type) and our fixed effects of patch-size, connectivity and dominant land-use. Significance of fixed effects and their interactions was tested using likelihood ratio tests using the chi-squared distribution. Analyses were performed using R 4.0.2 and the mixed effects package lme4 (Bates et al 2015).

'Mixed' land-use plots (those plots with a 1000m radius without >0.5 indigenous, rural or urban land-use) were dropped from the analyses as they performed in direct relation to their proportion of different land-uses and did not add further to our understanding of land-use impacts on ecological integrity. Patch size and the proportion of indigenous habitat within a 1000m radius were found to be strongly, positively correlated (Pearson's = 0.88, t=42.9, df=561, P<0.001, Figure 2). Correlated variables cannot be included in regression modelling as they fail the assumption of independence. Consequently, a multiplicative combination of both variables (on a log scale) was created to describe a pattern of increasing patch size and connectivity across the landscape (patch-size/connectivity, Figure 2).

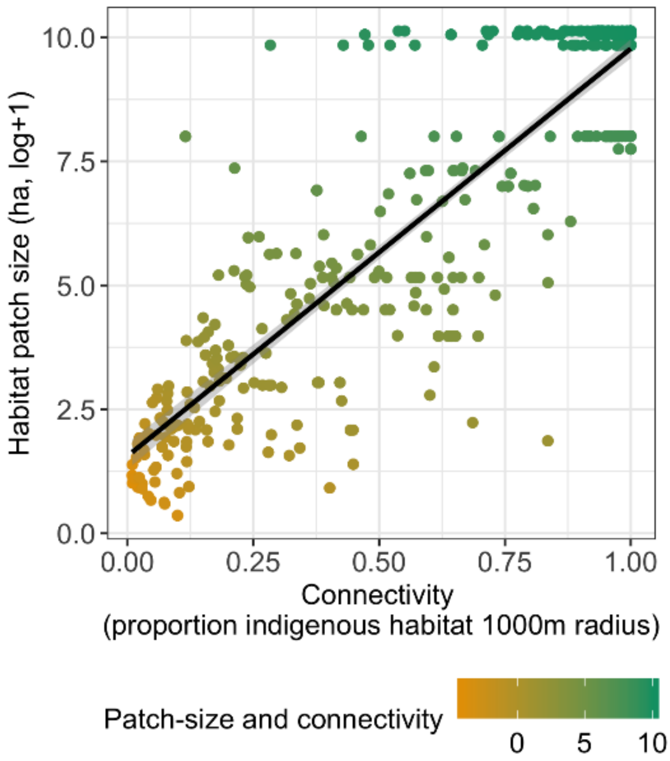


Figure 2: The relationship between forest patch size and connectivity (the proportion of indigenous habitat within a 1000m radius of the plot centre) for all TBMP forest plots.

As expected, patch-size also varied with land-use, with smallest patch-sizes in rural and urban landscapes, and larger forest patches in more indigenous landscapes (Figure 3). Mean forest patch size was 14,619 (± 565) ha in indigenous landscapes, 120 (± 42) ha in rural landscapes and 57 (± 14) ha in urban landscapes.

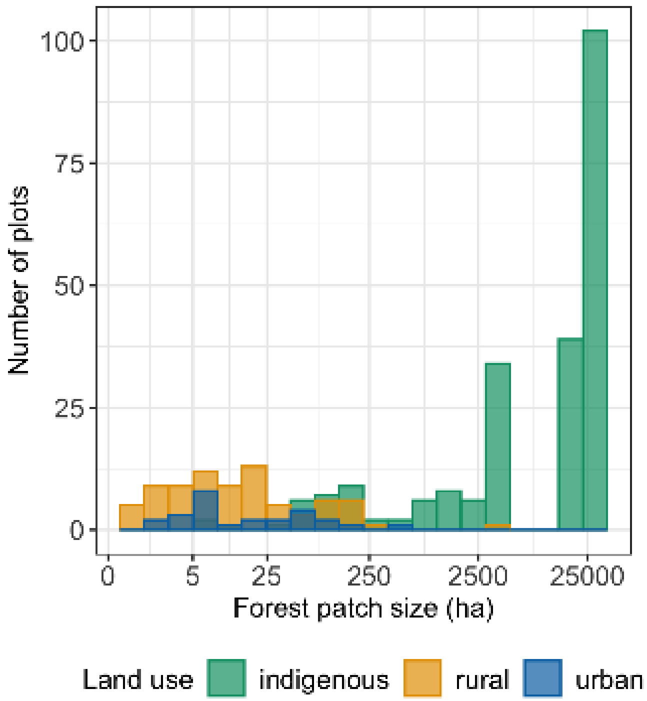


Figure 3: Distribution of forest patch sizes for each dominant land-use for forest plots within the TBMP.

Summary statistics (mean ± 1 standard error) were used to compare patterns in measures of ecological integrity across regional Tier 1 and targeted monitoring areas in Tiers 2 and 3. Comparisons used the most recent sample of each plot in Tiers 1 - 3 from 10 years of TBMP forest plot network data (Table 4). The regional Tier 1 data provides an overview of regional forest ecological integrity across a wide range of environmental contexts (e.g. ecosystem types, history, management, patch size, etc). Areas in Tiers 2 include large continuous forest, areas of high conservation value, and urban forest. Areas in Tier 3 have considerable conservation management intervention, including pest suppression or eradication, weed control, replanting and/or bird translocations.

Formal hypothesis testing to compare sites was not used because the magnitude of differences that occur between regional and targeted monitoring areas precludes any single hypothesis. For example, areas are sampled from different parts of the region and with different geographical extents, from forests that vary in their history of logging or disturbance, past and present management, soil and ecosystem type, local climate, age, proximity to indigenous forest, exposure to invasive species, surrounding land-use, etc. All these variables will contribute to current ecological integrity in ways that may be confounding or hard to unpick (Lee et al 2005). When examining patterns amongst regional and targeted monitoring areas, there were insufficient degrees of freedom to formally account for variation in sampling, climate, soils or ecosystem types.

Table 4: The number of plots from each rotation and in total for Tier 1 regional forests, and Tiers 2 and 3 targeted monitoring areas.

Tier	Monitoring unit	Interest	Most recent plot measures			Total number of plots
			rotation 1 2009-13	rotation 2 20014-18	rotation 3 2019-23	
Tier 1	Regional	Regional state and trends	78	33	23	134
Tier 2	Aotea (Great Barrier Island)	large, contiguous forest	6	12	0	18
Tier 2	Hunua Ranges	large, contiguous forest	11	3	4	18
Tier 2	Waitākere Ranges	large, contiguous forest	0	16	7	23
Tier 2	Awhitu	high conservation value	4	0	0	4
Tier 2	Kaipara	high conservation value	8	0	0	8
Tier 2	Tapora	high conservation value	7	2	0	9
Tier 2	Tamahunga	high conservation value	0	14	0	14
Tier 2	Urban	high pressure	16	2	3	21
Tier 3	Te Hauturu-o-Toi (Little Barrier Island)	high pest management	9	9	0	18
Tier 3	Kōkako Management Area (Hunuas)	high pest management	23	1	3	27
Tier 3	Ark in the Park (Waitākeres)	high pest management	15	0	4	19
Tier 3	Shakespear Regional Park	high pest management	1	20	0	21
Tier 3	Tāwharanui Regional Park	high pest management	0	20	0	20
Tier 3	Inner Gulf Islands	high conservation value	15	0	0	15
Tier 3	Glen Fern (Aotea)	high conservation value private sanctuary	10	6	0	16
Tier 3	Windy Hill (Aotea)	high conservation value private sanctuary	6	10	0	16

Three components of species diversity or richness can be measured using the TBMP plot network, alpha (α), beta (β) and gamma (γ) diversity. These three components can be additively partitioned (gamma = mean(alpha) + beta, Lande 1996) at different spatial extents (Crist et al 2003). Alpha(α), beta (β) and gamma (γ) diversity are additively partitioned at two spatial extents, within monitoring units and across the Auckland region, using the TBMP indigenous plant and native bird composition data. Measurements within monitoring units are mean native species richness per plot (α_1), turnover in species between plots (β_1) and total native species richness for each monitoring unit (γ_1). Measurements across the region are mean native species richness per monitoring unit (α_2), species turnover between monitoring units (β_2) and how they contribute to the Auckland region species pool (γ_2).

Measurements of species richness, especially γ diversity are in part a function of the sampling effort, in this case the number of plots. To assess whether the sampling effort was adequate to report on γ diversity, native plant species accumulation plots were constructed to assess how much of the native plant species pool is recorded given the sampling effort (number of permanent plots sampled). When a species pool is fully sampled, the number of new species recorded with each new plot diminishes and the species accumulation curve flattens out. Species accumulation curves indicate that for all monitoring units, the full species pool has not been recorded and new species continue to be recorded with each new plot (Figure 4). For most monitoring units however, the species accumulation curves are starting to level out. This gives some certainty that monitoring captures a reasonable and similar proportion of the full plant species composition for most Tier 1-3 monitoring units. The exception to this is Awhitu (the shortest curve on the plot), with only 4 plots the species accumulation curve shows no sign of levelling out, and estimates of α, β and γ diversity do not adequately represent this targeted monitoring area. The regional Tier 1 species accumulation curve is based on the full complement of 134 plots; fewer native plants would be sampled by the 56 Tier 1 plots currently included in regular remeasures.

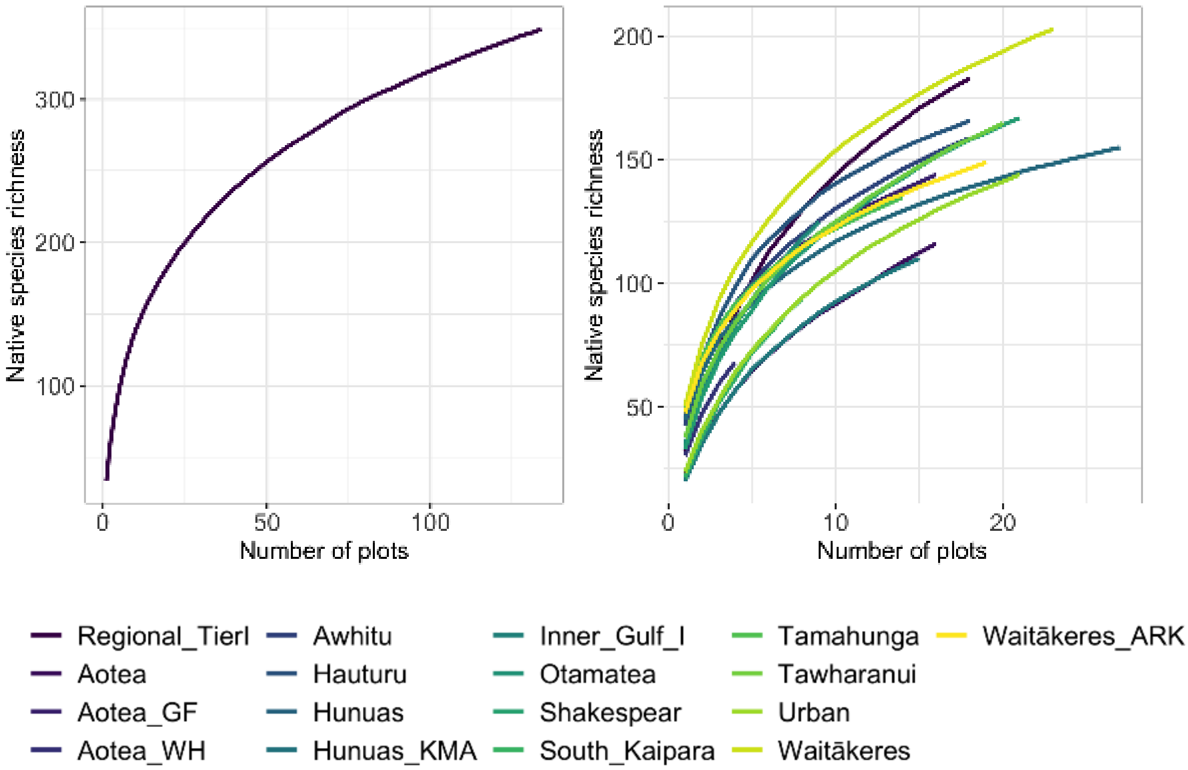


Figure 4: Species accumulation curves against sampling effort (number of plots) for Regional Tier 1 and targeted monitoring areas in Tiers 2 and 3.

Native tree size-class distributions based on stem diameter (DBH, or diameter at breast height (1.35m)), were calculated for each monitoring unit. All DBH measurements were standardised between the minimum stem diameter of 2.5cm and the 99.9th percentile and divided into 20 equal-sized bins. The frequency of stems per bin were expressed as a percentage relative to the total for each monitoring unit. All analyses were performed using R software version 4.0.2.

3.0 Results and Discussion

3.1 Ecosystem representation

The most recent measure of landcover data (LCDB 2018) shows indigenous forest and scrub habitat covers 26% of the Auckland region. The largest landcover category was exotic grassland at 45%, while urban areas cover 11% and exotic forest 10% (Table 5).

Table 5: Area (ha and %) of LAWA Medium Landcover classes in the Auckland region.

LAWA Medium Landcover classes	ha	% of total
Exotic grassland	233,244	45.4
Indigenous forest	88,595	17.3
Urban area	57,312	11.2
Exotic Forest	51,759	10.1
Indigenous scrub/shrubland	44,188	8.6
Water bodies	14,675	2.9
Cropping/horticulture	12,147	2.4
Natural bare/lightly-vegetated surfaces	4,063	0.8
Other herbaceous vegetation	3,394	0.7
Exotic scrub/shrubland	2,208	0.4
Artificial bare surfaces	1,750	0.3

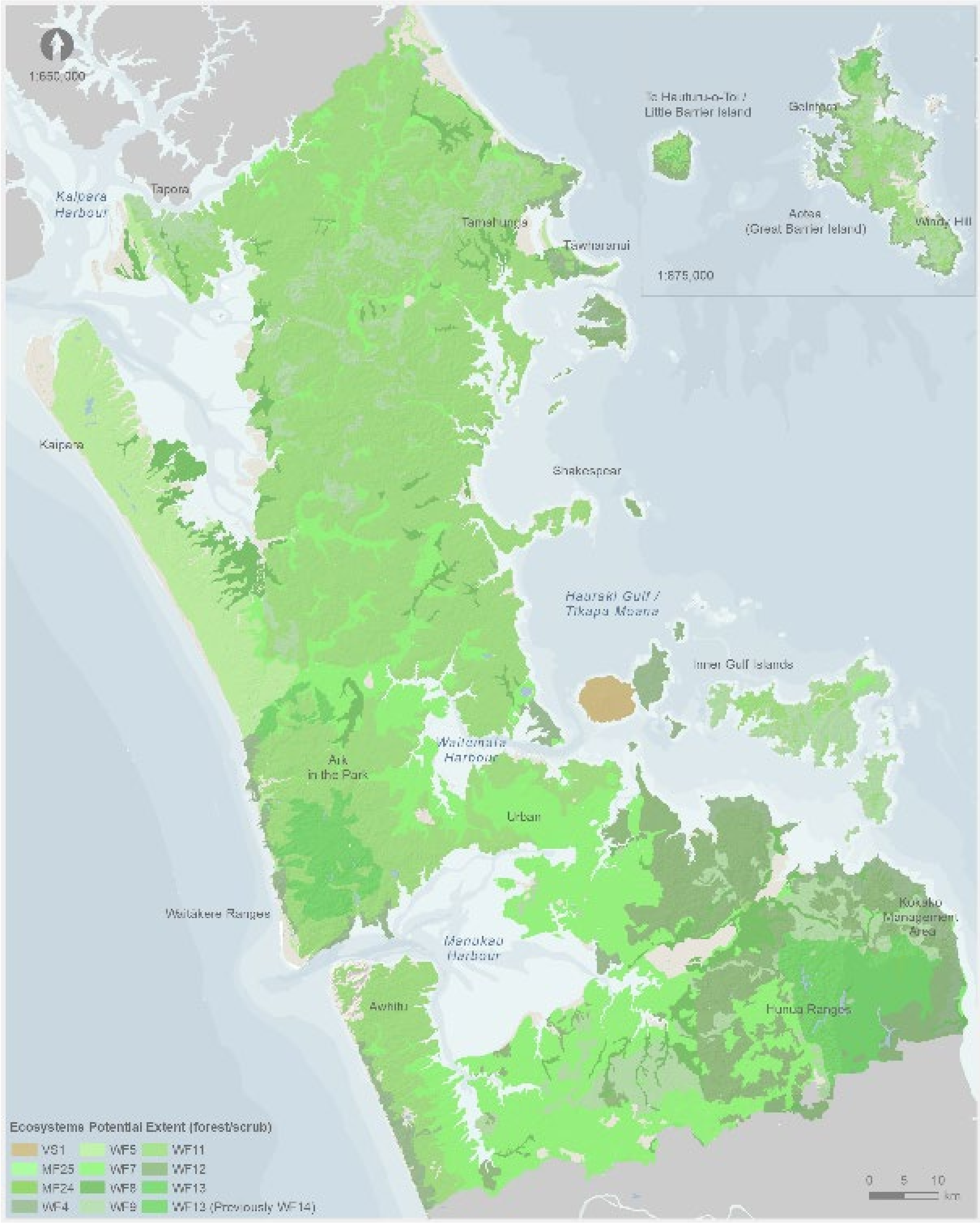
Although there has been minimal net change in indigenous forest cover since 1996, this masks an equivalent gain and loss of approximately 700ha. Table 6 shows the breakdown in the area (ha) lost and gained to indigenous forest and scrub landcover classes. Existing indigenous forest and scrub was removed to make way for exotic forest, exotic grassland and urban development. Newly created indigenous forest and scrub came from land that had previously been exotic forest or grassland. Loss of indigenous forest and scrub is relevant since mature ecosystems will typically support greater biodiversity, including more specialised species unable to survive elsewhere.

Table 6: Area (ha) of indigenous forest and scrub lost and gained between LAWA Medium Landcover classes between 1996 and 2018.

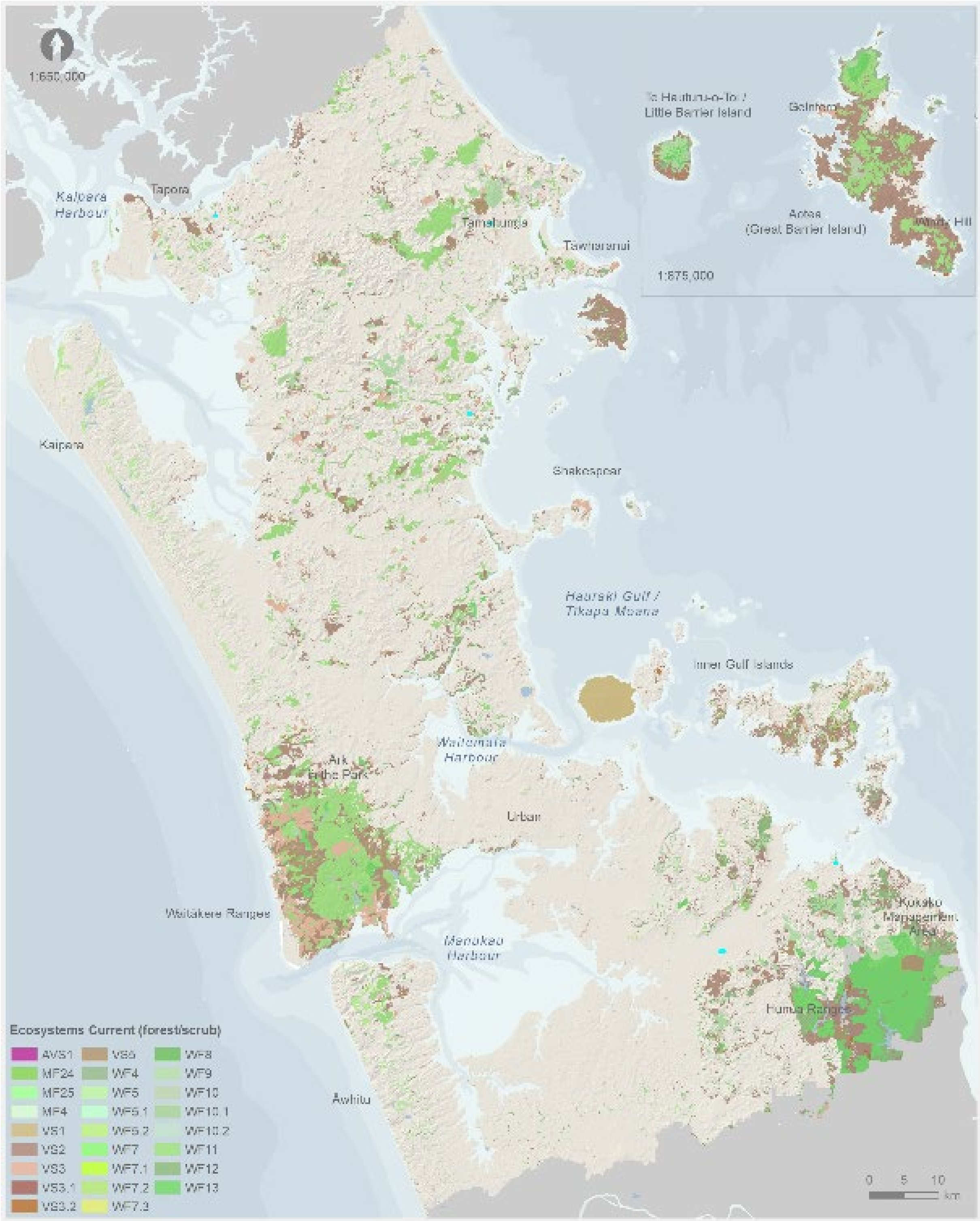
LAWA Medium Landcover classes	Losses and gains (ha) between 1996 and 2018			
	Losses from indigenous forest	Gains to indigenous forest	Losses from indigenous scrub	Gains to indigenous scrub
Artificial bare surfaces	71		29	4
Cropping/horticulture			1	6
Exotic Forest	233	324	130	187
Exotic grassland	116	388	121	632
Exotic scrub/shrubland		14		6
Indigenous forest			3	15
Indigenous scrub/shrubland	15	3	24	
Natural bare/lightly-vegetated surfaces	3		17	1
Other herbaceous vegetation	57			
Urban area	122	10		
Water bodies	2	13		
Total	619	752	325	851
Net gain		133		526

Map 2 shows the historic dominance of forest ecosystem types across the Auckland region. Map 3 shows the current distribution of forest and scrub ecosystem types for the Auckland region. Indigenous forest and scrub continue to be the most widespread indigenous ecosystem types but have been reduced to 23% of their original extent. This represents a massive loss of habitat for forest dwelling flora and fauna.

For remaining forest and scrub, there have been distinct changes in ecosystem composition. There has been a massive reduction in the extent of previously dominant forest ecosystem, especially those typical of lowland areas. Indigenous forest types that lost more than 80% of their original cover include pūriri (WF7), kahikatea, pukatea (WF8), tōtara, kānuka, broadleaf (WF5), kauri, podocarp, broadleaf, beech (WF12), kauri, podocarp, broadleaf (WF11), taraire, tawa, podocarp (WF9) and pōhutukawa, pūriri, broadleaf (WF4, Table 7). Pūriri (WF7) forest has been reduced to 0.3% of its original extent, kahikatea, pukatea (WF8) to 2% of its original extent. In addition, for the remaining forest and scrub, 37% of it has been disturbed and degraded to such an extent it has been reclassified as regenerating forest and scrub ecosystem types that did not previously occur in the Auckland region. The one exception to this is the representation of pōhutukawa scrub/forest (VS1) which is essentially unchanged and found predominately on Rangitoto island. There has been a massive increase in kānuka (VS2), mānuka/kānuka (VS3) and broadleaved species (VS5). Finally, a further 14% of it has been converted to anthropogenic or novel forest and scrub ecosystems such as exotic forest and scrub, planted forest/scrub, treeland and anthropogenic tōtara. Maps 2 and 3 clearly illustrate the reduction and fragmentation of remaining forest cover and the extensive transition to regenerating forest ecosystem types.



Map 2: Distribution and extent of historic forest and scrub ecosystem types in the Auckland region (Singers et al 2017).



Map 3: Distribution and extent of current forest and scrub ecosystem types in the Auckland region (Singers et al 2017).

Table 7: Extent (ha) of historic and current forest and scrub ecosystem types and per cent of each historic ecosystem remaining (Singers et al 2017).

Broad description	Code	Ecosystem type	Potential (ha)	Current (ha)	% remaining
Regenerating forest/scrub	VS1	Pōhutukawa scrub/forest	2,327	2,335	100.35
Regenerating forest/scrub	VS2	Kānuka scrub/forest	0	33,712	na
Regenerating forest/scrub	VS3	Mānuka, kānuka scrub	0	8,348	na
Regenerating forest/scrub	VS5	Broadleaved species scrub/forest	0	5,167	na
Warm forest	WF4	Pōhutukawa, pūriri, broadleaved forest	22,685	4,505	19.86
Warm forest	WF5	Tōtara, kānuka, broadleaved forest	30,042	3,102	10.32
Warm forest	WF7	Pūriri forest	91,201	242	0.27
Warm forest	WF8	Kahikatea, pukatea forest	19,874	415	2.09
Warm forest	WF9	Taraire, tawa, podocarp forest	49,253	8,249	16.75
Warm forest	WF10	Kauri forest	657	1,083	164.79
Warm forest	WF11	Kauri, podocarp, broadleaved forest	195,616	31,588	16.15
Warm forest	WF12	Kauri, podocarp, broadleaved, beech forest	33,270	3,219	9.68
Warm forest	WF13	Tawa, kohekohe, rewarewa, hīnau, podocarp forest	19,123	4,893	25.59
Mild forest	MF4	Kahikatea forest	0	630	na
Mild forest	MF24	Rimu, tōwai forest	13	13	100.00
Mild forest	MF25	Kauri, tōwai, rātā, montane podocarp forest	260	157	60.16
Anthropogenic forest/scrub	AVS1	Anthropogenic tōtara forest	0	2	na
Anthropogenic forest/scrub	EF	Exotic forest (>50% cover exotic species)	0	14,143	na
Anthropogenic forest/scrub	ES	Exotic scrub (>50% cover/biomass exotic species)	0	969	na
Anthropogenic forest/scrub	PL	Planted native scrub/forest	0	1,211	na
Anthropogenic forest/scrub	TL	Treeland (20 - 80% canopy cover)	0	1,071	na

3.2 Landscape structure

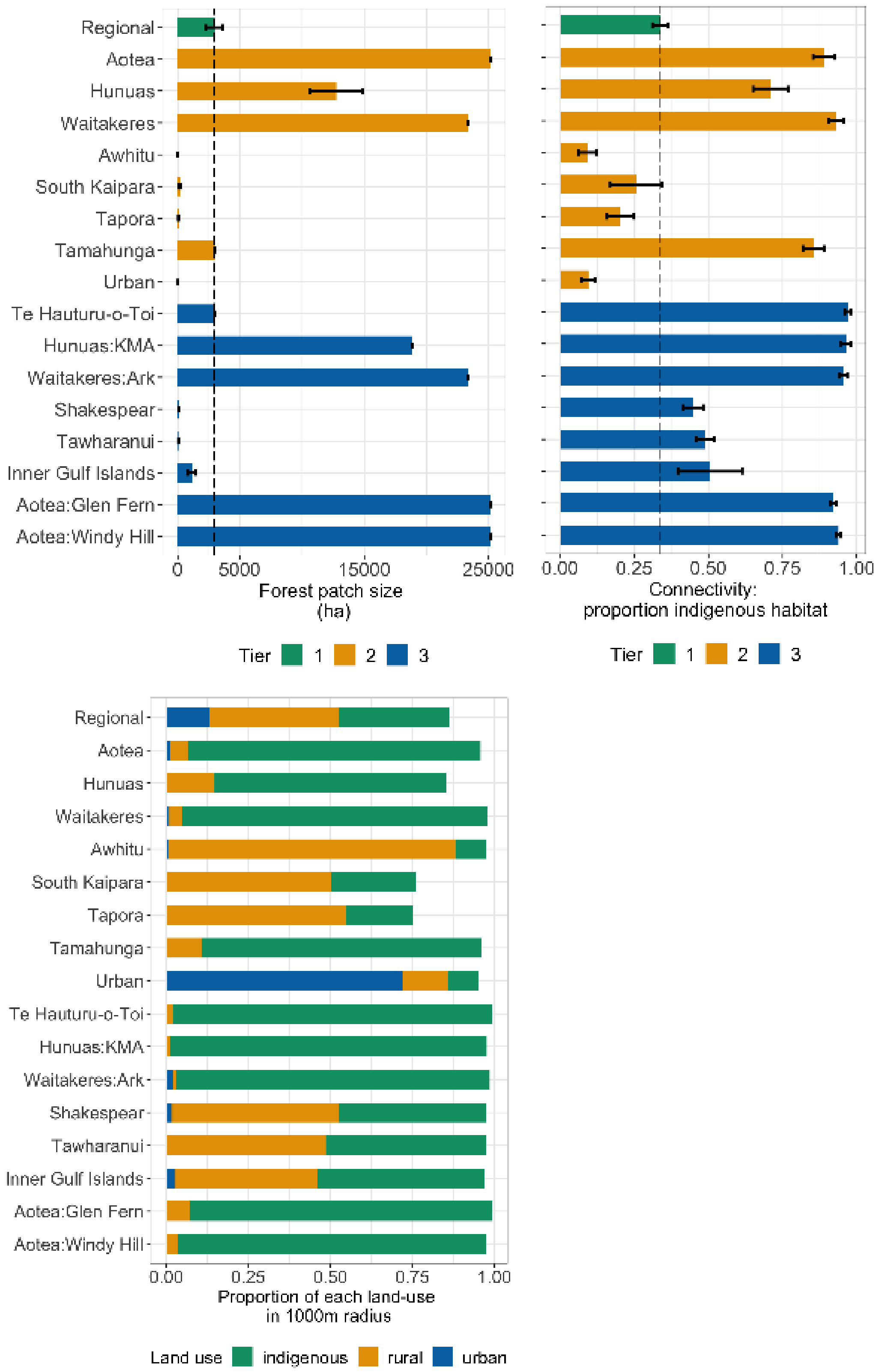


Figure 5: Forest patch-size (ha), connectivity (proportion of indigenous forest in 1000m radius) and proportion of each land-use (indigenous, rural, urban) per plot for regional Tier 1 and targeted Tier 2 and 3 monitoring areas. For land-use, proportions do not add to 1 because 'mixed' land-use areas were omitted.

The three large tracts of continuous forest in the Auckland region, the Waitākere Ranges, Hunua Ranges and Aotea, including the sanctuaries that lie within them, form the largest forest patches, are most connected to indigenous forest and are embedded within an indigenous forest landscape (Figure 5). Six of the targeted monitoring areas (Awhitu, South Kaipara, Tapora, Shakespear, Tāwharanui, Inner Gulf Islands) occur within more rural landscapes, have very small patch size and low to medium connectivity to other indigenous forest. Urban forests, predominately surrounded by urban land-uses, have among the lowest patch-size and connectivity.

3.2.1 Landscape structure and native plant species richness

Native plant species richness showed a strong, positive relationship with patch size/connectivity (Figure 6). Higher native plant species richness could arise from increased immigration into, or higher survival of species in larger, more connected forest areas. In addition, larger forests have a lower edge to area ratio, meaning more forest is buffered from edge effects such as greater fluctuations in microclimate or weed incursions (Norton 2002). Forests in urban landscapes had the lowest native plant species richness. The difference in native plant species richness between rural and indigenous landscapes was mostly driven by their characteristic forest patch size and connectivity; rural forests are smaller and less connected. Where plots in rural and indigenous landscapes had similar patch size/connectivity, rural forests supported marginally more native plant species. This reinforces the value of smaller indigenous forests in rural areas. Patch-size/connectivity and dominant land-use explained 16.4% of the variation in native plant species richness; despite this relatively high explanatory power, Figure 6 shows how much variation in native species richness there is between individual plots of similar patch size and connectivity.

It is important to note that small, less connected urban habitat patches with low species richness can still be highly valuable. The plot at Kirk's bush for example, records only 20 native species, but is a precious example of a taraire dominated forest in an urban context.

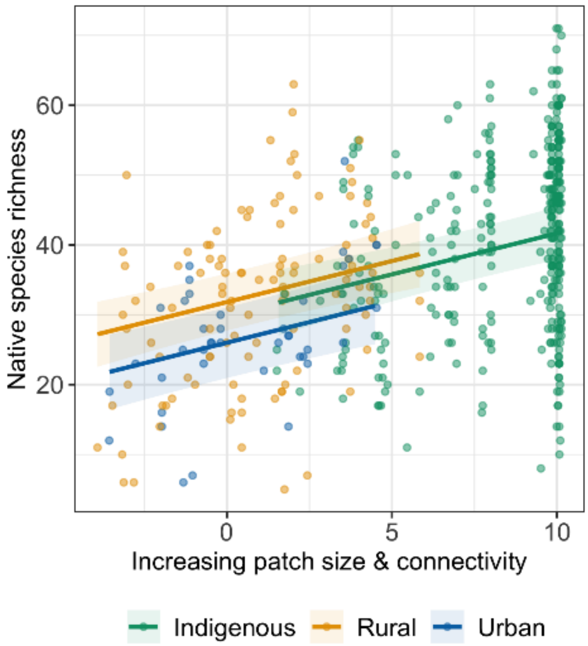


Figure 6: Relationship between the native species richness of forest plots with forest patch-size, connectivity and dominant land-use type. LMER native species richness; patch size and connectivity χ^2 = 21.0, df=6,9, P<0.001; dominant land-use χ^2 = 9.9, df=6,9, P<0.01; interaction n.s.

3.2.2 Landscape structure and weeds

Problematic weeds showed a strong association with forests in urban landscapes. The proportion of species that are weeds, and the basal area composed of weeds was much higher in plots in urban landscapes, compared to those in rural and especially indigenous landscapes (Figure 7). The most dominant weeds by tree basal area in urban plots were pine (*Pinus radiata*) and tree privet (*Ligustrum lucidum*). Weediness of forest plots was highest in small forest patches with low connectivity, especially in forests in urban and rural landscapes. Common weeds in small urban forest patches were woolly nightshade (*Solanum mauritianum*), climbing asparagus (*Asparagus scandens*), gorse (*Ulex europaeus*), tree privet, grey sedge (*Carex divulsa*), wandering willie (*Tradescantia fluminensis*) and Japanese spindleberry (*Euonymus japonicus*). Patch-size/connectivity and dominant land-use explained 28.8% of the variation in the per cent of species that are weeds, and 7.4% of the variation in basal area composed of weeds.

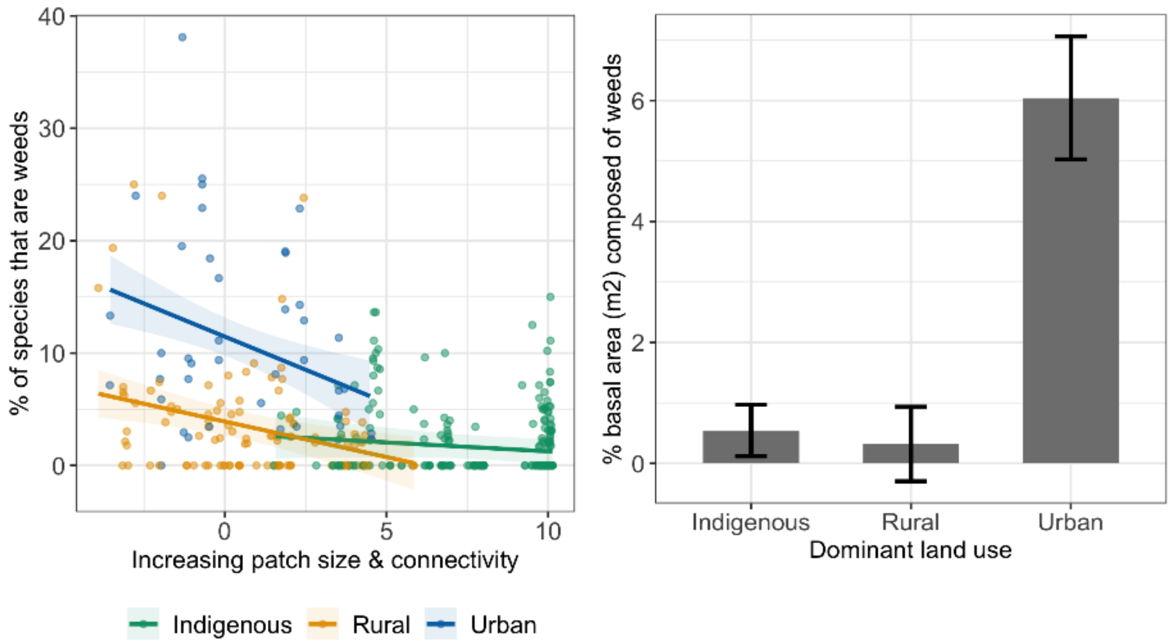


Figure 7: Relationships between the per cent of species that are weeds, and the per cent basal area (m^2) composed of weeds, with forest patch-size, connectivity and dominant land-use (LMER % species that are weeds; patch-size and connectivity χ^2 = 18.6, df=7,8, P<0.001; dominant land-use χ^2 = 62.0, df=5,8, P<0.001; interaction χ^2 = 10.7, df=8,11, P<0.05. LMER % basal area composed of weeds; dominant land-use χ^2=23.4, df = 5,8, P<0.001).

3.2.3 Landscape structure and native birds

Native bird communities were most species rich in forests surrounded by indigenous land-use, and least species rich in urban forests (Figure 8). Forest in urban and rural landscapes, which tend to be smaller patches/less connected, showed a weak increase in native bird species richness with patch-size/connectivity. In contrast, for forest surrounded by indigenous land-use, native bird species richness decreased with patch-size/connectivity. This may result from the higher edge to area ratio associated with smaller forest patches. Certain bird species can benefit from the types of additional resources available at forest edges (e.g. more diverse shrub layer, dead wood, high-fruiting species, etc), especially in mosaic landscapes (Berry 2001; Terraube et al 2016), and there is no evidence to suggest that nest predation is higher at forest edges (Whyte et al 2005).

Native bird species abundance showed no variation in response to landscape structure (Figure 8). The three plots in rural dominated landscapes with especially high native bird abundance were all located inside Tāwharanui regional park. It is likely that intensive pest management, such as that conducted on Te Hauturu-o-Toi or

Tāwharanui, are the main drivers of native bird species abundance. More detailed analysis of bird data from the TBMP can be found in Landers et al (2021).

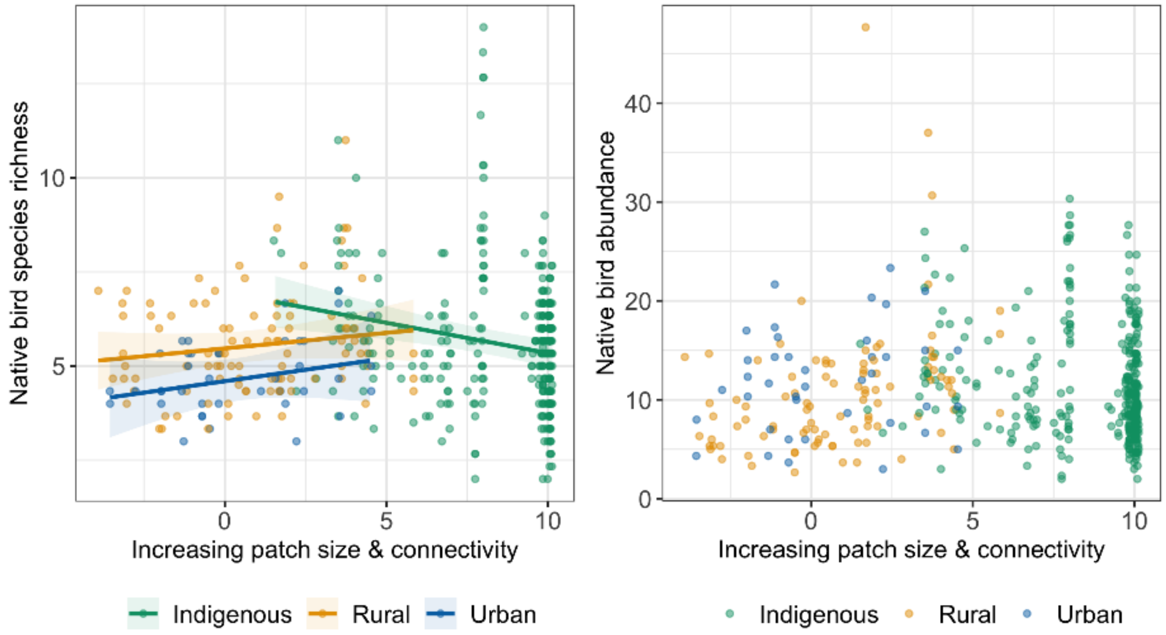


Figure 8: Relationships between native bird species richness with forest patch-size, connectivity and dominant land-use (LMER native bird species richness; patch-size and connectivity χ^2 = 4.0, df=7,8, P<0.05; dominant land-use χ^2 = 16.6, df=5,8, P<0.001; interaction χ^2 = 3.0, df=8,11, P<0.05. LMER native bird abundance; patch-size and connectivity n.s.; dominant land-use n.s.).

3.2.4 Landscape structure and introduced birds

Introduced or non-native birds were most species rich and abundant in rural forests, and least speciose or abundant in forest surrounded by indigenous land-use (Figure 9). Species richness and abundance of introduced birds showed a negative relationship with patch-size/connectivity, and this negative slope was strongest in forest surrounded by indigenous land-use. More detailed analysis of bird data from the TBMP can be found in Landers et al (2021).

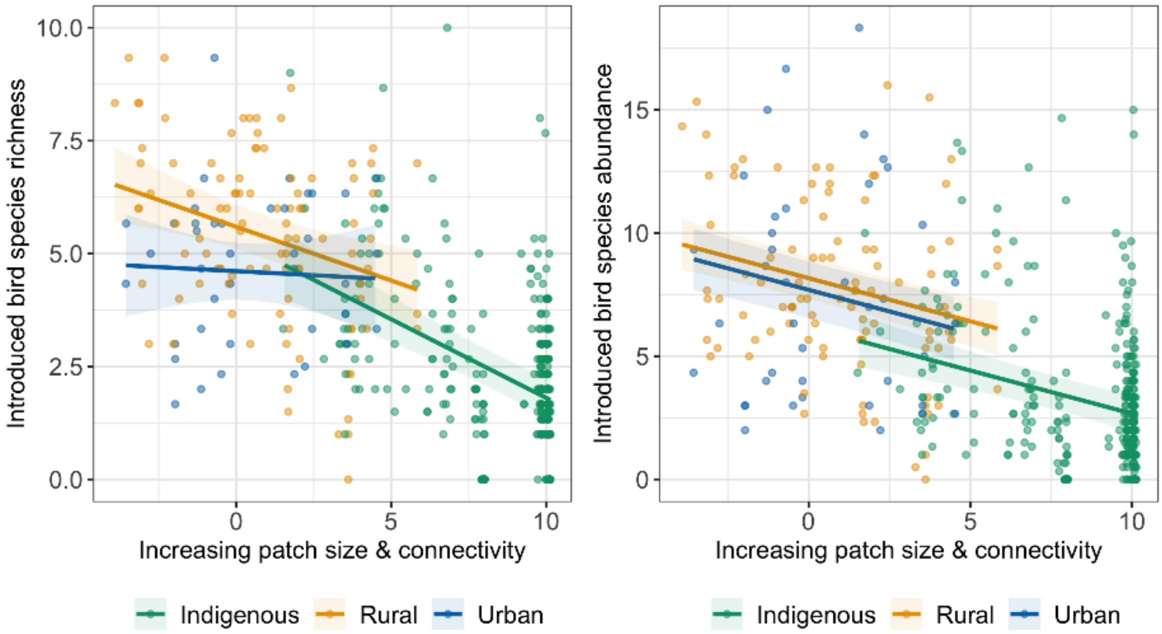


Figure 9: Relationships between introduced bird species richness and abundance with forest patch-size, connectivity and dominant land-use (LMER: introduced bird species richness; patch-size and connectivity χ^2 = 53.9, df=7,8, P<0.001; dominant land-use χ^2 = 18.6, df=5,8, P<0.001; interaction χ^2 = 8.6, df=8,11, P<0.05. LMER introduced bird abundance; patch-size and connectivity χ^2 = 27.2, df=7,8, P<0.001; dominant land-use χ^2 = 13.5, df=5,8, P<0.01; interaction n.s.).

Measures of native plant species abundance, weed occupancy, rat, mouse and possum abundance showed little or no variation with dominant land-use or increasing patch size/connectivity. It is likely that abundances of rat, mouse and possum are more influenced by levels of predator control.

3.3 Native plant species richness

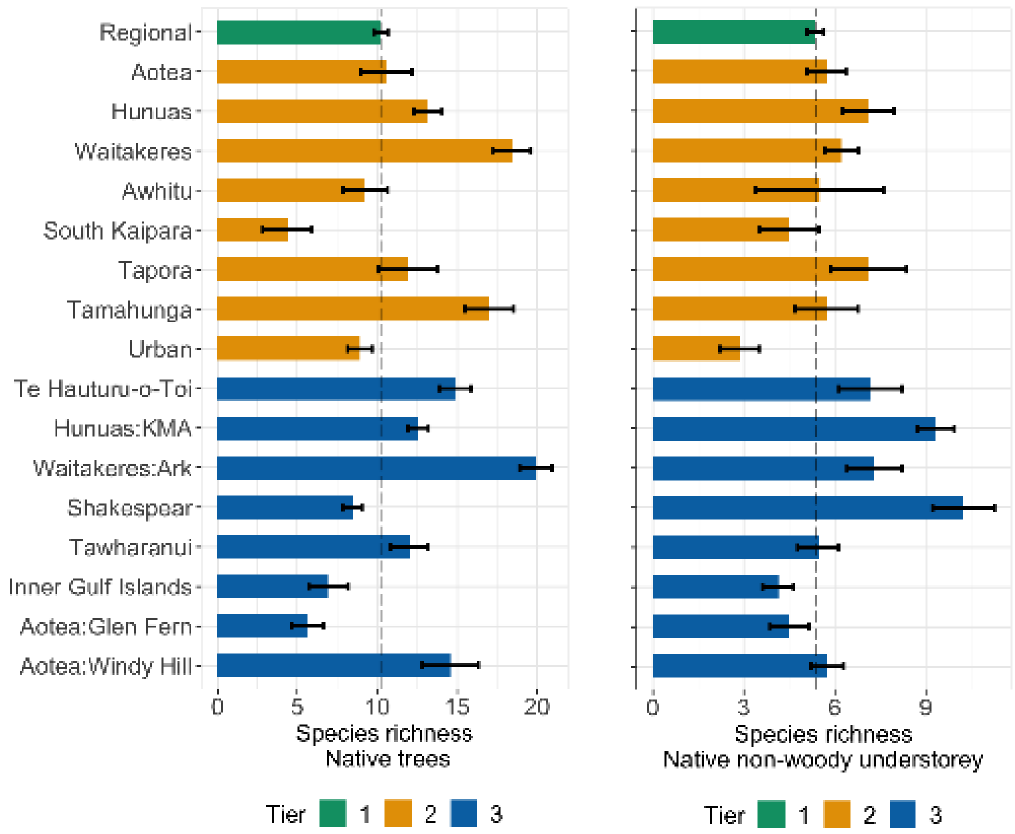


Figure 10: Species richness of native trees (>2.5cm at 1.35m height) per plot (mean ± 1 s.e.), and species richness of the non-woody understorey per plot (mean ± 1 s.e.), for regional Tier 1 and targeted Tier 2 and 3 monitoring areas.

In total 457 native plant species were recorded in Tiers 1-3 of the forest plot network. Regionally, most plots supported 10 native tree species (Figure 10). Ark in the Park (Waitākeres:Ark) plots had the highest tree species richness, with 20 tree species on average per plot. Targeted monitoring areas with high tree species richness included the Waitākere Ranges, Tamahunga, Te Hauturu-o-Toi and Windy Hill (Aotea). Tree species richness in the Hunuas and Kōkako Management Area (Hunuas:KMA) were also above the regional average. Areas with low tree species richness were Awhitu, South Kaipara, urban forests, Inner Gulf Islands, Shakespear and Glen Fern sanctuary (Aotea).

For the native non-woody understorey, the four targeted monitoring areas with highest species richness, Shakespear, Kōkako Management Area (Hunuas:KMA), Ark in the Park (Waitākeres:Ark) and Te Hauturu-o-Toi, are all Tier 3 sites with considerable management intervention, including control of mammalian herbivores and pest animals, weeding or plant reintroductions. The Hunua Ranges, Waitākere Ranges and

Tapora all had non-woody understorey species richness above the regional average of 5.4 (±0.3) species per plot.

Urban forests had the lowest native non-woody understorey species richness at 2.9 (±0.6) species per plot. Indeed, several urban forest plots had no native non-woody understorey species at all. Some forests will have few understorey plants as part of their natural dynamics, but in the case of urban forests many native non-woody understorey species may have been displaced by weed species (see section 3.5 below) or result from ecosystem degradation.

The low native species richness on the Inner Gulf islands was strongly influenced by a few plots on Motutapu and Waiheke. Two plots on Motutapu were classified as exotic grassland (EG) according to Singers et al 2017, and there was also one example of Pōhutukawa treeland/flaxland/rockland (CL1) on the island. All three plots supported less than seven species across all plant structural categories (tree, sapling, woody and non-woody understorey). One plot on Waiheke was classified as Native/amenity planting (PL3) and supported less than 11 native species in total. Species richness on islands can be lower than equivalent mainland habitats due to the effects of isolation and limited dispersal, but the low species richness observed in these sites most probably results from ecosystem degradation.

All species combined (tree, sapling, woody and non-woody understorey) were used to examine additive partitioning of alpha (α), beta (β) and gamma (γ) diversity within monitoring units (Table 8a) and across the region (Table 8b).

Table 8: Alpha (α), beta (β) and gamma (γ) diversity for native plant species richness at a (a) monitoring unit scale, and (b) regional scale. Alpha diversity refers to mean species richness per plot (α_1) or mean species richness per monitoring unit (α_2). Beta diversity refers to turnover in species richness between plots (β_1) or between monitoring units (β_2). Gamma diversity refers to the species pool or total species richness per monitoring unit (γ_1) or for Tiers 1 - 3 across the whole Auckland region (γ_2).

(a) Monitoring units		Number of plots	Species richness (SR)			% contribution to SR		Unique species
			α_1	β_1	γ_1	α_1	β_1	
Tier 1	Regional Tier I	134	33.7	315.3	349	9.7	90.3	39
Tier 2	Aotea	18	33.9	149.1	183	18.5	81.5	7
Tier 2	Hunua Ranges	18	45.1	120.9	166	27.2	72.8	1
Tier 2	Waitākere Ranges	23	48.3	154.7	203	23.8	76.2	5
Tier 2	Awhitu	4	30.8	37.3	68	45.3	54.9	0
Tier 2	Kaipara	8	21.6	72.4	94	23.0	77.0	1
Tier 2	Tapora	9	35.8	89.2	125	28.6	71.4	4
Tier 2	Tamahunga	14	50.0	85.0	135	37.0	63.0	2
Tier 2	Urban	21	23.9	120.1	144	16.6	83.4	8
Tier 3	Te Hauturu-o-Toi	18	40.6	118.4	159	25.5	74.5	3
Tier 3	Hunuas: KMA	27	45.9	109.1	155	29.6	70.4	2
Tier 3	Waitākeres:Ark	19	48.5	100.5	149	32.6	67.4	0
Tier 3	Shakespear	21	34.7	132.3	167	20.8	79.2	10
Tier 3	Tāwharanui	20	36.0	129.1	165	21.8	78.2	10
Tier 3	Inner Gulf Islands	15	19.3	90.7	110	17.5	82.5	7
Tier 3	Aotea: Glen Fern	16	23.6	92.4	116	20.3	79.7	5
Tier 3	Aotea: Windy Hill	16	42.7	101.3	144	29.7	70.3	2
(b) Region			Species richness (SR)			% contribution to SR		
			α_2	β_2	γ_2	α_2	β_2	
	Auckland region	401	154.8	302.2	457	33.9	66.1	

Across all monitoring units, 457 native plant species were recorded (Table 8). Targeted monitoring areas with the largest native species pool (γ_1) were the Waitākere Ranges, Aotea, Hunua Ranges, and the two sanctuaries at Shakespear and Tāwharanui. In addition, Shakespear and Tāwharanui each supported 10 unique species not found elsewhere. These large species pools (γ_1) demonstrate the ecological value of large tracts of continuous forest, and the effectiveness of conservation intervention. Most monitoring units show a similar pattern of considerably higher β diversity to α diversity. For example, on Aotea α diversity was a mean of 33.9 indigenous plant species per plot, but β diversity or turnover of species between plots was 149.1 species. This means that α diversity contributed 18.5% of total species richness on Aotea, while β

diversity contributed 81.5%, indicating considerable heterogeneity between plots. Targeted monitoring areas with high β diversity include the Waitākere Ranges, Aotea, Shakespear and Tāwharanui, the Hunua Ranges, urban forests and Te Hauturu-o-Toi. Relatively high β diversity of urban forests also demonstrates the collective (and landscape scale) value of these sites for species conservation as well as local amenity, despite low α species richness. Tamahunga supports the highest α or plot-level diversity of 50 native plant species. Other areas with high α diversity include the Hunua Ranges and the Kōkako Management Area (Hunuas:KMA), the Waitākere Ranges and Ark in the Park (Waitākeres:Ark).

The high species pool or γ diversity recorded for Tier 1 plots (they contained 76.3% or 349 of 457 species found in Tiers 1-3) is in large part a function of the amount of effort put into sampling. Regional Tier 1 data was based on more plots (n=134) than used for the targeted monitoring areas (n=4 to n=27). Within the Tier 1 plots, α diversity is relatively low, but β diversity is high, indicating the wide range of habitats and environments captured by the Tier 1 network. In addition, Tier 1 plots capture 39 species not recorded in any other plot. These results demonstrate the value of the complete Tier 1 network, rather than the currently reduced set of 56 plots, for assessing regional state and trends in forest and scrub.

3.4 Forest structure

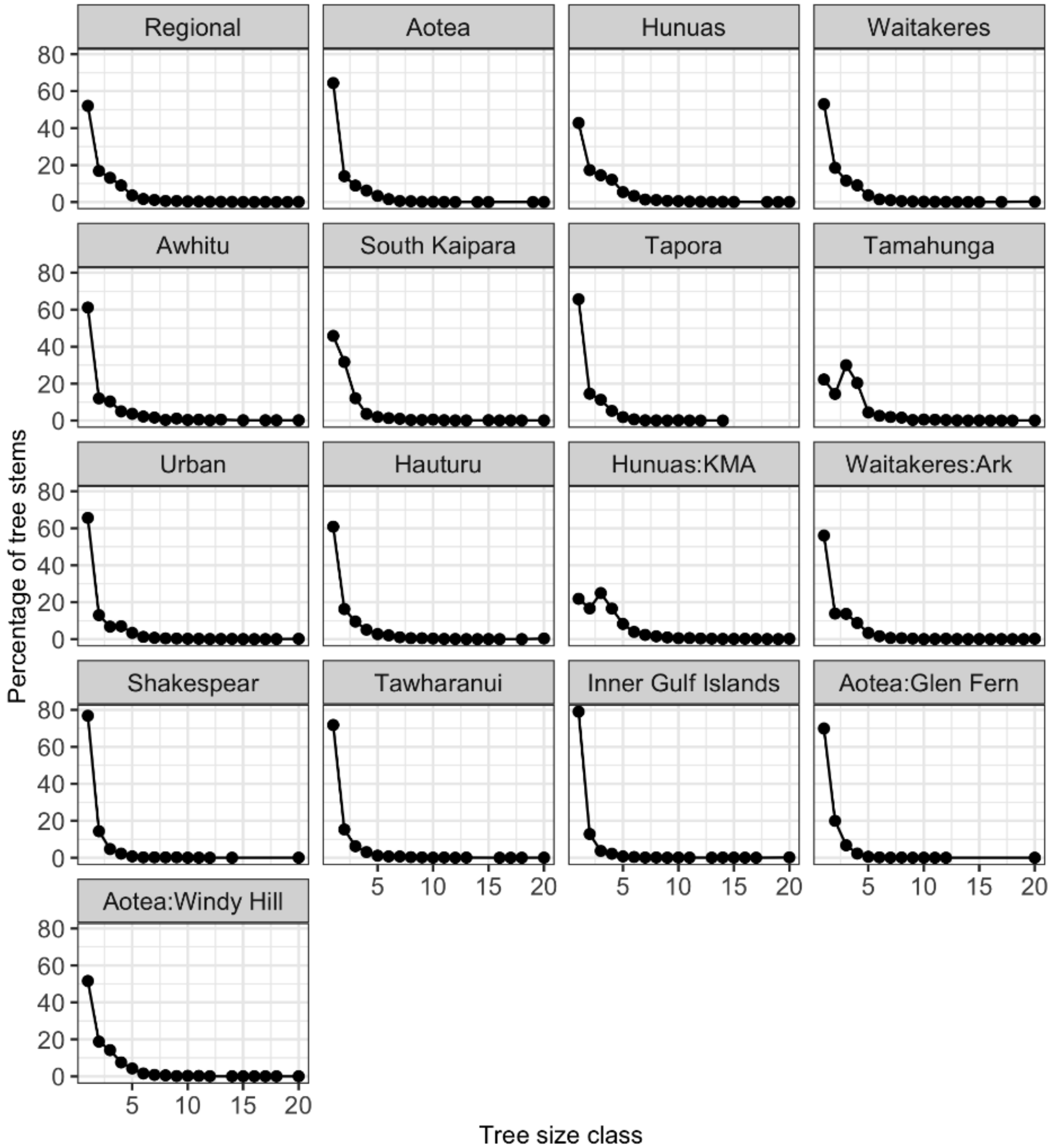


Figure 11: Tree size-class (DBH) frequency distributions for regional Tier 1 and targeted monitoring areas Tier 2 and 3. Tree size classes are 20 equal-sized bins fitted to DBH data normalised between the minimum measure of 2.5cm and the 99.9th percentile.

The size-class distribution of tree stands is influenced by successional dynamics, natural and anthropogenic disturbance and pest damage. Tree size distributions for a healthy, mature forest stand typically follow an 'inverse-J' shape (MacLeod et al 2012) once sufficient spatial extent has been sampled. This pattern indicates higher abundance of small stemmed relative to larger stemmed trees, and is observed for Te Hauturu-o-Toi (Hauturu), with a long tail illustrating the presence of some very large mature trees (Figure 11). Strong deviations from this pattern can signal disruption to normal forest dynamics, though not always (Westphal et al 2007).

Across the Auckland region, tree size-class distributions show a low frequency of small stems in Tamahunga and the Kōkako Management Area (Hunuas: KMA), and to a lesser degree in the Hunua Ranges, South Kaipara and Windy Hill (Aotea). A low frequency of small stems can result from browsing herbivores (for preferred species only) or reproductive failure (Peltzer et al 2014). Browsing herbivores are controlled at Tamahunga and the Kōkako Management Area (Hunuas:KMA, see Appendix A), and although these control measures are relatively recent, success may be judged by the presence of palatable sapling species such as kanono (*Coprosma autumnalis*), māhoe (*Melicytus ramiflorus*), and heketara (*Olearia rani*).

Evidence of reproductive failure needs to consider the forest ecosystem at each location. Tamahunga forest plots are predominately in taraire, tawa, broadleaf forest (WF9), while plots in the Kōkako Management Area (Hunuas:KMA) are in tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13) and taraire, tawa, broadleaf forest (WF9); both are lowland and coastal forests.

Typically, tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13) forest shows an 'inverse-J' size distribution, with uneven aged stands undergoing continuous replacement (Smale et al 1986). Occasionally however, tawa forests can form pure stands with dense canopies, a sparse understorey and little seedling regeneration (Barton 1972; Knowles & Beveridge 1982). Tawa may follow a reciprocal replacement mechanism, where tawa replace non-tawa canopy species (e.g. kohekohe or emergent podocarps), and vice versa (Esler 1967; Smale and Kimberley 1983). This suggest that tawa may not naturally replace itself, leading to a dynamic and potentially successional forest ecosystem type (Smale et al 2008). Tawa seedlings and saplings are highly shade tolerant and can survive for decades until a tree gap or thining tree crown increase light intensity and allow seedling and sapling growth (Smale et al 1986). Tawa pollination is predominately by insects and wind (Smale et al 2008) and Kelly et al 2009 found little evidence of dispersal limitation from native birds. Tawa seeds are consumed by possum and pigs and are highly sensitive to dessication; reduced humidity from a depleted ground vegetation (due to browsing, disturbance or fragmentation) may be sufficient to prevent germination (Knowles & Beveridge, 1982;

Smales et al 1986). As light intensity at forest edges increases this can also favour more light-demanding species which outcompete tawa saplings. Morales et al 2016 found that in fragmented forest and where forest is exposed to herbivory, tawa are less able to replace themselves, and will become less abundant in the canopy. These effects of fragmentation were attributed to increased temperature fluctuations in smaller forest patches (Morales et al 2016).

Taraire is insect pollinated and has some of the largest fruit of all native trees; it is reliant on kereru, or kōkako where present, for seed dispersal. However, seeds can still germinate under the parent tree so absence of kereru would not induce local regeneration failure (Kelly et al 2009). Taraire seeds are considered highly sensitive to dessication and are consumed by moth larvae, rats and possum (Wright 1984; Wilcox, 2001; Atkinson 2004). Where taraire is regenerating, seedling densities of 110-500 (and up to 15,000) seedlings per hectare have been observed (Wilcox 2001), but low taraire seedling and sapling abundance has been observed for taraire forest on Te Hauturu-o-Toi (Campbell et al 2011), Tiritiri Matangi (Myers and Court 2013) and Kirk's bush, Papakura (Wilcox 2001). Low light levels and a thick taraire litter layer may inhibit regeneration in taraire-dominated forest, with regeneration more likely at forest edges or in canopy gaps (Myers and Court 2013). As a bird-dispersed species, taraire can enter successions as later immigrants and this has been observed for kānuka forests (Atkinson 2004; Campbell et al 2011). Taraire forests are considered highly drought sensitive (Wright 1984), and lack of taraire regeneration on Tiritiri Matangi was attributed to soil compaction from past farming and the impacts of drought on seedling survival (Myers and Court 2013).

In the Kōkako Management Area, tawa had a relatively flat size-class distribution (Figure 12) and the number of tawa understorey and sapling stems were low (Table 9). Although woody understorey and sapling abundance was low for all species in the Kōkako Management Area (Figure 13), which may be a natural consequence of its dense canopy cover (at 68% the Kōkako Management Area had the second highest canopy density, the highest was Tamahunga at 77%), the sparseness of tawa seedlings and saplings is surprising for a species that is so shade tolerant. Smale et al 2008 concluded tawa seedling populations of thousands per hectare were sufficient for tawa forest regeneration, but populations of hundreds of seedlings per hectare were not. In the Kōkako Management Area, tawa seedling densities averaged 40 stems per hectare (Table 9). Herbivore and predator control in the Kōkako Management Area do not appear to be sufficient to enable tawa forest regeneration of this potentially successional forest type, supporting previous findings by Morales et al (2016).

In Tamahunga and especially the Kōkako Management Area, taraire had a relatively flat size-class distribution (Figure 12) and the number of taraire understorey and sapling stems were low (Table 9), despite high abundance of other species in the woody understorey at Tamahunga (Figure 13). This suggests that taraire is not regenerating underneath itself at these sites, possibly a result of desiccation due to depleted ground vegetation. Although the woody understorey contained many species that could become canopy dominants (e.g. tariare, tawa, rewarewa, kahikatea, white maire, miro, pūriri and hīnau), rewarewa was the only potential canopy dominant growing as a sapling at both sites. Considerable dieback and death of taraire trees has been observed on Auckland's east coast following droughts in 2010, 2013 and 2020, including forest at Wenderholm, Tāwharanui, Waiheke and the Hunua Ranges. More research is required to understand the natural regeneration dynamics of tawa and taraire forest. The question is whether new tawa and taraire successional forests can develop from regenerating forest types, on cooler/buffered south facing slopes for example, or whether the combined effects of fragmentation, pest damage and climate change will impact forest extent. The TBMP tree-tag data will ultimately provide knowledge of individual and population-level recruitment, growth and mortality and insight into forest dynamics.

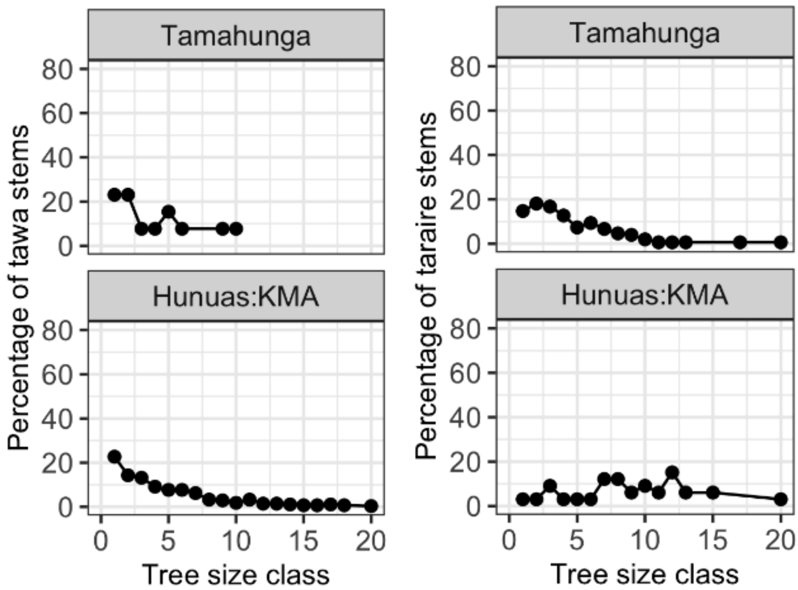


Figure 12: Tawa (*Beilschmiedia tawa*) and taraire (*B. tarairi*) size-class (DBH) frequency distributions for Tamahunga, the Kōkako Management Area (Hunuas:KMA) and Te Hauturu-o-Toi (Hauturu). Tree size classes are 20 equal-sized bins fitted to DBH data normalised between the minimum measure of 2.5cm and the 99.9th percentile.

Table 9: Density of understorey and sapling stems for tawa (*Beilschmiedia tawa*) and taraire (*B. tarairi*) in Tamahunga, the Kōkako Management Area (Hunuas:KMA) and Te Hauturu-o-Toi (Hauturu).

(a) Tawa		tawa understorey					tawa saplings				
Tier	Monitoring unit	number of plots	mean stems /plot	s.e.	mean stems /ha	s.e.	number of plots	mean stems /plot	s.e.	mean stems /ha	s.e.
Tier 2	Tamahunga	0	0.0	0.0	0.0	0.0	1	1.0		25.0	
Tier 3	Hunuas:KMA	10	1.6	0.3	40.0	7.6	10	4.0	1.0	100.0	25.0
(b) Taraire		taraire understorey					taraire saplings				
Tier	Monitoring unit	number of plots	mean stems /plot	s.e.	mean stems /ha	s.e.	number of plots	mean stems /plot	s.e.	mean stems /ha	s.e.
Tier 2	Tamahunga	9	3.9	1.8	97.2	45.2	2	1.5	0.5	37.5	12.5
Tier 3	Hunuas:KMA	11	4.5	1.5	111.4	38.5	0	0.0	0.0	0.0	0.0

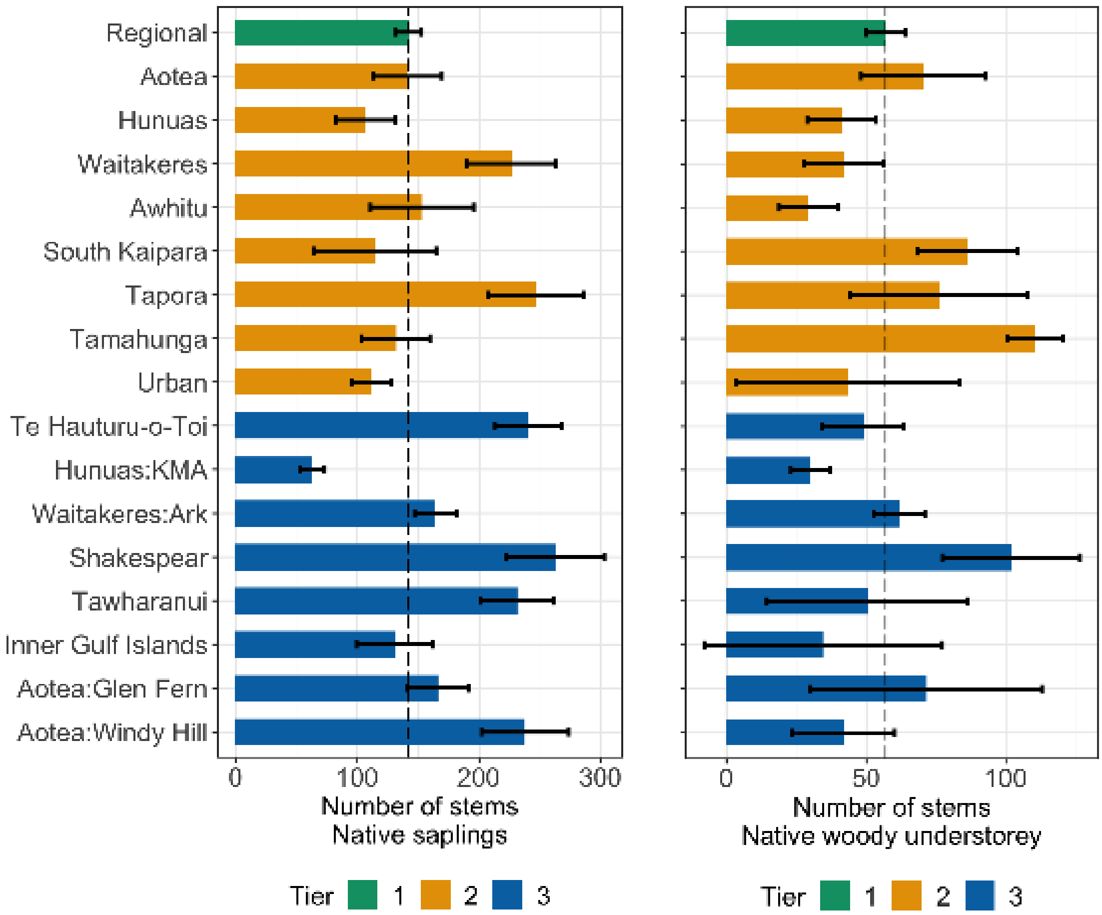


Figure 13: The mean (± 1 s.e.) number of native saplings per plot and mean (± 1 s.e.) number of stems in the native woody understorey, for regional Tier 1 and targeted Tier 2 and 3 monitoring areas.

The high frequency of small-stemmed trees at Shakespear, Tāwharanui, Inner Gulf Islands and Glen Fern (Aotea), provide evidence of early forest regeneration through natural growth and restoration plantings (Figure 11). A study predicting successional trajectories at Glen Fern indicate a stable final composition including more tawa (*B. tawa*), taraire (*B. taraire*), kohekohe (*Dysoxylum spectabile*), conifer and tree ferns (Perry et al 2010).

At the other end of the tree size-class distribution, a low frequency of large stems can indicate folivory by possums (for preferred species only), or disturbance from natural or anthropogenic causes (Peltzer et al 2014). Low frequency of large, mature trees was observed in Glen Fern, Tapora and Shakespear regional park (Figure 11). Possums have never been on Aotea and are unlikely to account for this pattern in Glen Fern, and have been removed more recently from Shakespear. These sites have all been logged and/or cleared in the past, and the impacts of this disturbance are still evident in the loss of large mature trees from the forest structure. Large mature trees perform many critical ecological roles in forest and support much biodiversity; their absence will impact forest ecological integrity (Lindenmayer et al 2013).

3.5 Weeds

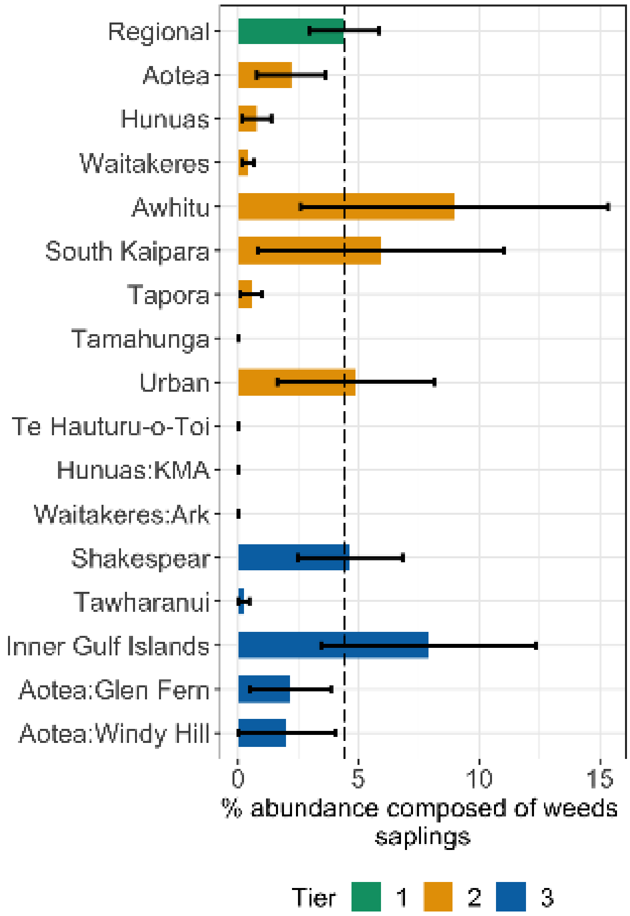


Figure 14: The per cent of saplings stems that are weeds per plot for regional Tier 1 and targeted monitoring areas, Tiers 2 and 3.

Regionally, only about 5% of all species are weeds, across all plant structural categories, indicating that our forests are composed predominately of indigenous species. Similarly, just under 5% of sapling abundance was composed of weeds in the regional Tier 1 plots (Figure 14). Saplings are the new recruits to the forest canopy and the proportion of sapling weeds can indicate the potential for forest canopy composition to shift (McAlpine et al 2020). As saplings grow, these weed species can become increasing problematic as they start to produce seeds and spread. Awhitu, South Kaipara, the Inner Gulf Islands, Urban and Shakespear had a higher percentage of weed saplings, but there was high variability between plots suggesting that weed problems are localised within targeted monitoring areas. For example, the high per cent for the Inner Gulf islands was caused by high weediness of three plots located on Motuihe, Motutapu and Waiheke. These plots were surrounded by predominately rural land-uses, two were classed as exotic grassland (EG), two as regenerating forest/scrub ecosystem types (kānuka forest/scrub (VS2) and broadleaved forest/scrub (VS5)), and one was native/amenity planting (PL3).

There were very few sapling weeds within the large contiguous blocks of forest (Aotea, Hunua Ranges and Waitākere Ranges), in the high conservation value areas of Tapora and Tamahunga, or in the high management areas of Te Hauturu-o-Toi, Kōkako Management Area (Hunuas:KMA), Ark in the Park (Waitākeres:Ark) or Tāwharanui. Low weed abundance at these locations demonstrates the value of large forest patches, isolation or distance from seed sources, and the enormous efforts put into weed removal and eradication by Auckland Council and community groups. Further research is required to understand the relative importance of these however. For example, to what extent does the absence of weeds in plots within the Kōkako Management Area (Hunuas:KMA) and Ark in the Park (Waitākeres:Ark), relative to low incidence in the Hunua Ranges and Waitākere Ranges respectively, reflect isolation from weed sources or weed control (see Appendix A)?

The 15 most common sapling weed species recorded in the Regional Tier 1 plots are shown in Table 10. This list is similar to the most common sapling weeds recorded across all targeted monitoring areas. Sapling weed species formed a greater portion of the composition in Awhitu (woolly nightshade), South Kaipara (gorse, woolly nightshade and monkey apple (*Syzygium smithii*)), the Inner Gulf islands (woolly nightshade, brush wattle (*Paraserianthes lophantha*), gorse and evergreen buckthorn (*Rhamnus alaternus*), and Shakepear Regional Park (gorse, prickly hakea (*Hakea sericea*), pampas grass (*Cortaderia selloana*) and Spanish heath (*Erica lusitanica*)). For the Inner Gulf islands, plots with highest proportion of sapling weed species were on Waiheke and Motutapu; plots on Rangitoto were almost entirely free of weeds. In Shakespear Regional Park sapling weed species were most prevalent in ecosystem type kānuka/mānuka scrub (VS3). This regenerating ecosystem type is particularly sensitive to weed invasion as many weeds are early colonisers, growing well on disturbed ground or on forest and scrub margins.

Table 10: Fifteen most abundant sapling weed species recorded in Regional Tier 1 plots.

	Sapling weed species	Common name	Total sapling count for regional Tier 1 plots (n=134)
1	*Ligustrum lucidum*	Tree privet	1658
2	*Acacia longifolia*	Long-leaved/golden wattle	423
3	*Acacia* spp.	Acacia	392
4	*Hakea sericea*	Prickly hakea	227
5	*Ulex europaeus*	Gorse	183
6	*Cortaderia selloana*	Pampas grass	97
7	*Ligustrum sinense*	Chinese privet	87
8	*Pomaderris aspera*	Hazel pomaderris	60
9	*Solanum mauritianum*	Woolly nightshade	41
10	*Acacia mearnsii*	Black wattle	13
11	*Pinus pinaster*	Maritime/ cluster pine	11
12	*Solanum pseudocapsicum*	Jerusalem cherry	11
13	*Euonymus japonicus*	Japanese spindle tree	9
14	*Crataegus monogyna*	Common hawthorn	5
15	*Syzygium smithii*	Lilly pilly/ monkey apple	5

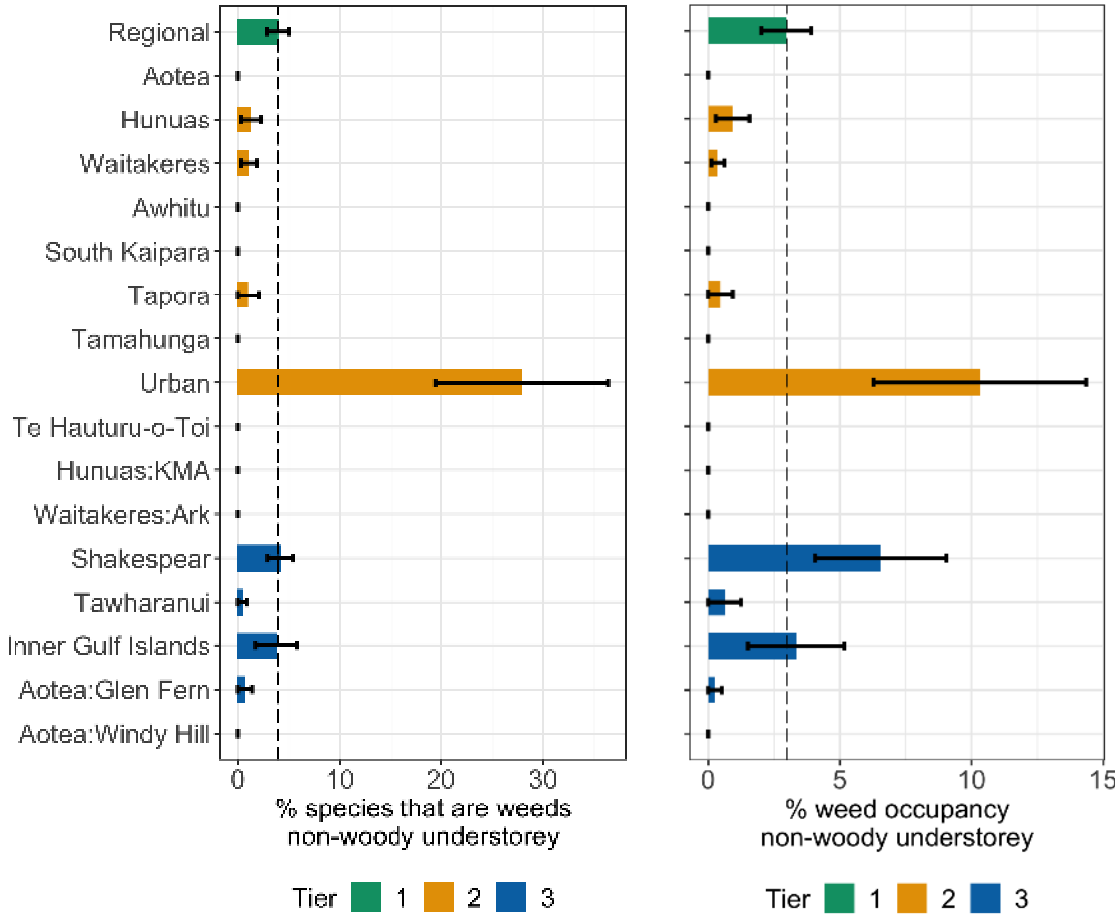


Figure 15: For the non-woody understorey, the per cent of species that are weeds, and per cent weed occupancy of a plot, in regional Tier 1 plots and in targeted Tier 2 and 3 monitoring areas.

Within the non-woody understorey, again only about 5% or fewer species are weeds in Regional Tier 1 plots and across most targeted monitoring areas (Figure 15). The exception is urban forest plots where 28% of non-woody understorey species (or 35 species) were weeds. Abundance of non-woody understorey weeds is demonstrated by the per cent occupancy of the 24 understorey plots within each plot. Plot occupancy by non-woody understorey weeds was especially problematic in urban forests and Shakespear. Non-woody weeds occupied 10.3% of urban forest plots and 6.6% of Shakespear plots, while the regional average was 3%. Several urban plots had a non-woody understorey composed entirely of weed species (100%). This is not to say that the entire forest was weedy but suggests that parts of these forests are overwhelmed by non-woody weeds. It is important to note that most of the Shakespear plots were sampled in rotation 2 (2014-2018) and much effort has gone into weed removal since then. The most abundant non-woody weeds are shown in Table 11.

Table 11: Fifteen most abundant non-woody understorey weed species recorded in Regional Tier 1 plots.

	Herbaceous weed species	Common name	Total non-woody understorey count for regional Tier 1 plots (n=134)
1	*Anthoxanthum odoratum*	Sweet vernal grass	80
2	*Tradescantia fluminensis*	Wandering willie	60
3	*Phytolacca octandra*	Ink weed	49
4	*Lotus pedunculatus*	Greater birds-foot trefoil	45
5	*Holcus lanatus*	Yorkshire fog	42
6	*Aristea ecklonii*	Aristea	37
7	*Dactylis glomerata*	Cocksfoot	29
8	*Jasminum polyanthum*	Jasmine	27
9	*Galium aparine*	Cleavers	26
10	*Raphanus raphanistrum*	Wild radish	24
11	*Asparagus scandens*	Climbing asparagus	23
12	*Lonicera japonica*	Japanese honeysuckle	23
13	*Bromus hordeaceus*	Soft brome	22
14	*Ranunculus repens*	Creeping buttercup	22
15	*Araujia sericifera*	Moth plant	17

Most targeted monitoring areas had a level of weediness below that found regionally. Lack of weediness in these areas probably results from the large patch size of some areas, the isolation of some habitats, and the intensive weeding work carried out by Auckland Council and community groups. Again, further research is required to understand their relative importance.

3.6 Birds

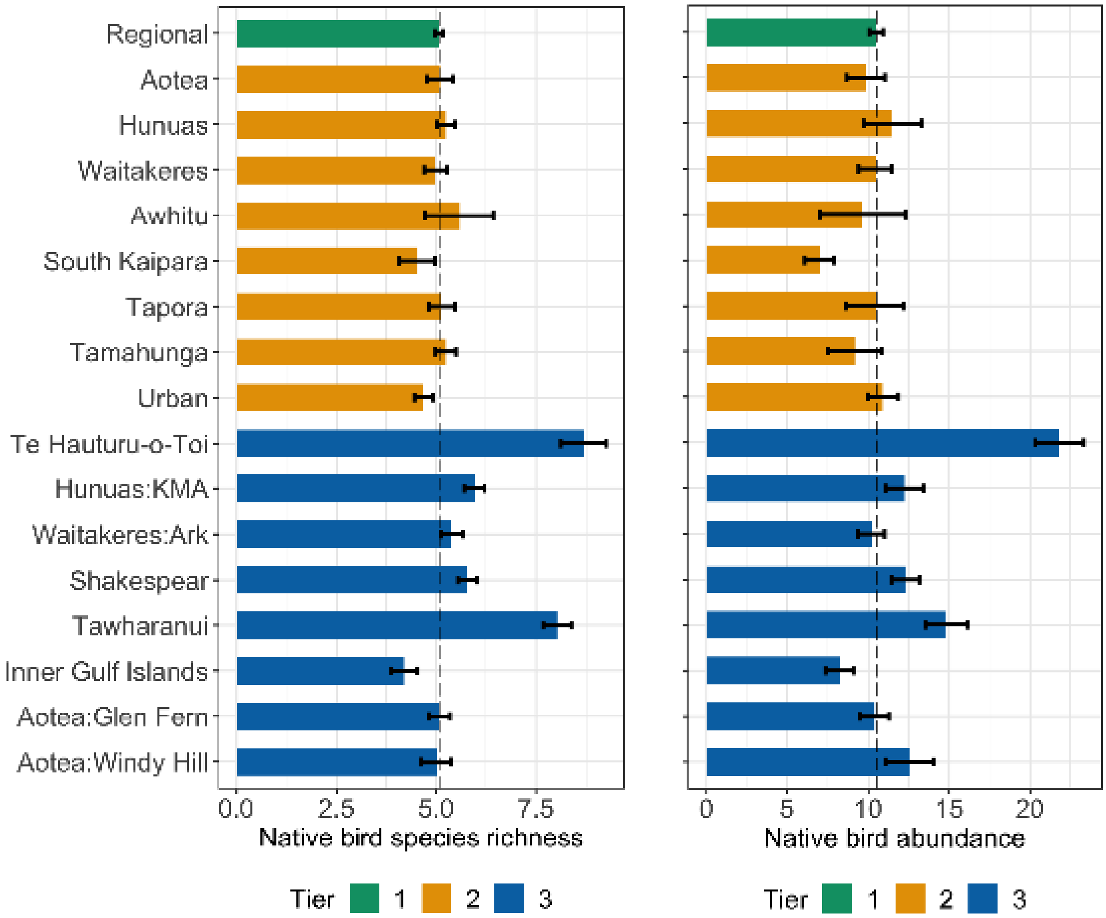


Figure 16: Native bird species richness and abundance (mean ± 1 s.e.) per bird count, for plots in regional Tier 1 and targeted Tier 2 and 3 monitoring areas.

Data on native and introduced (non-native) birds from the TBMP forest plot network are examined in more detail in the Auckland Council report 'Diversity, abundance and distribution of birds in Tāmaki Makaurau / Auckland 2009-2019 (Landers et al 2021). A summary of the TBMP bird data is provided here due to the role of birds in forest ecological integrity. Regionally, five native bird species and 10 individuals were recorded on average per plot (averaged over three 10 minute bird counts, Figure 16). Species richness and abundance of native birds per plot was broadly similar across most of the monitoring units. The exception to this were four sites: Te Hauturu-o-Toi and Tāwharanui supported the most species rich and abundant native bird communities, the Kōkako Management Area (Hunuas:KMA) and Shakespear supported native bird communities marginally more speciose and abundant than the regional average. Te Hauturu-o-Toi and Tāwharanui have the longest running pest animal eradication and bird reintroduction programmes with both locations mostly pest-free since 2004. Shakespear is also fenced with a pest animal eradication strategy and bird reintroductions, but was only established in 2011. Native bird communities in Shakepear are increasing (Tim Lovegrove, *pers comm*) but bird populations take time to build up. The Kōkako Management Area (Hunuas:KMA) is an open sanctuary with a pest suppression strategy. Although it has a dense network of bait and trapping stations, two aerial 1080 drops (administered in 2015 and 2018 to suppress pest animal populations in response to cyclical mast fruiting) have had a considerable impact on pest animal populations (Morrison 2020). Kōkako breeding pairs have been steadily increasing in the area (Morrison 2020).

These data demonstrate the enormous efforts required to increase native bird communities beyond what can currently persist without human intervention in our forested ecosystems. These patterns support findings by Binny et al (2020) who found that pest animal eradication is more effective than pest animal suppression for achieving biodiversity benefits for indigenous bird communities. Similar benefits to native and endemic bird species were observed with eradication of pest animals in the fenced sanctuary at Zealandia (Miskelly 2018).

Three further targeted monitoring areas, Ark in the Park (Waitākeres:Ark), Glen Fern and Windy Hill (both on Aotea) are either fenced with pest eradication strategies or open sanctuaries with dense bait and trap stations. Despite these efforts, native bird species richness and abundance was similar to forest areas largely without these bird conservation strategies (although native bird communities in the Ark in the Park (Waitākeres:Ark) may be improving, Table 12). Further research is required to understand the differences between pest animal eradication or suppression strategies, pest species targeted, the scale and effectiveness with which control measures are conducted, and how they impact on habitat quality for native bird communities (e.g. availability of resources, Spurr and Anderson 2004).

One of the difficulties with unfenced sanctuaries is dealing with the continuous incursions of pest animals from the sanctuary edges. As one of the larger (c. 2100 ha) community-run unfenced sanctuaries in the Auckland region, Ark in the Park might be expected to minimise these edge effects sufficiently to allow native bird populations to increase more. Results of TBMP pest animal monitoring indicate low numbers of rats, mice and possum at Ark in the Park (see section 3.7). Although rats, mice and possums may be well controlled for most of the time their populations can occasionally exceed target thresholds which can be especially damaging during the bird breeding season (Morrison 2020). In addition, mustelids and feral cats can pass undetected and evade traps within an unfenced sanctuary and cause considerable damage, and at longer established sanctuaries predators have been observed to become increasingly trap shy (Tim Lovegrove, *pers comm*). Ark in the Park (Waitākeres:Ark), Glenn Fern and Windy Hill could benefit from further research, particularly pest monitoring, to optimise the intensity of pest animal control and the types of pests being effectively targeted. Novel pest animal control methods may also be required to address trap shy populations.

It should be noted that budget cuts during Rotation 2 of the TBMP lead to a halt or five year delay in the remeasurement of a large number of plots in Tiers 1 - 3. Consequently, much of the data for monitoring areas such as Ark in the Park (Waitākeres:Ark) and the Kōkako Management Area (Hunuas:KMA) is based on forest plots measured during Rotation 1 (2009-13, Table 4). For areas where there has been intense pest control, the data may not capture more recent changes in native bird communities. Native bird species richness and abundance showed small increases between Rotation 1 and Rotation 3 for Ark in the Park (Waitākeres:Ark) and the Kōkako Management Area (Hunuas:KMA), these were not significant (Table 12) but may show that native bird species richness and abundance in Ark in the Park (Waitākeres:Ark) is starting to increase above the regional average.

Table 12: Comparison of native bird species richness and abundance between plots sampled during Rotation 1 (2009-13) and Rotation 3 (2019-23) for the Kōkako Management Area (Hunuas:KMA) and Ark in the Park (Waitākeres:Ark). Comparison used Welch's t-test with unequal sample size.

Targeted monitoring area	Rotation	n	Mean native bird species richness	s.e.	t	P	Mean native bird abundance	s.e.	t	P
Hunuas:KMA	1	23	5.91	0.28			12.12	1.21		
Hunuas:KMA	3	3	6.17	1.13	0.2	n.s.	15.06	4.91	0.58	n.s.
Waitakeres:Ark	1	15	5.29	0.31			9.02	0.70		
Waitakeres:Ark	3	4	5.75	0.48	0.8	n.s.	13.42	2.01	2.01	n.s.

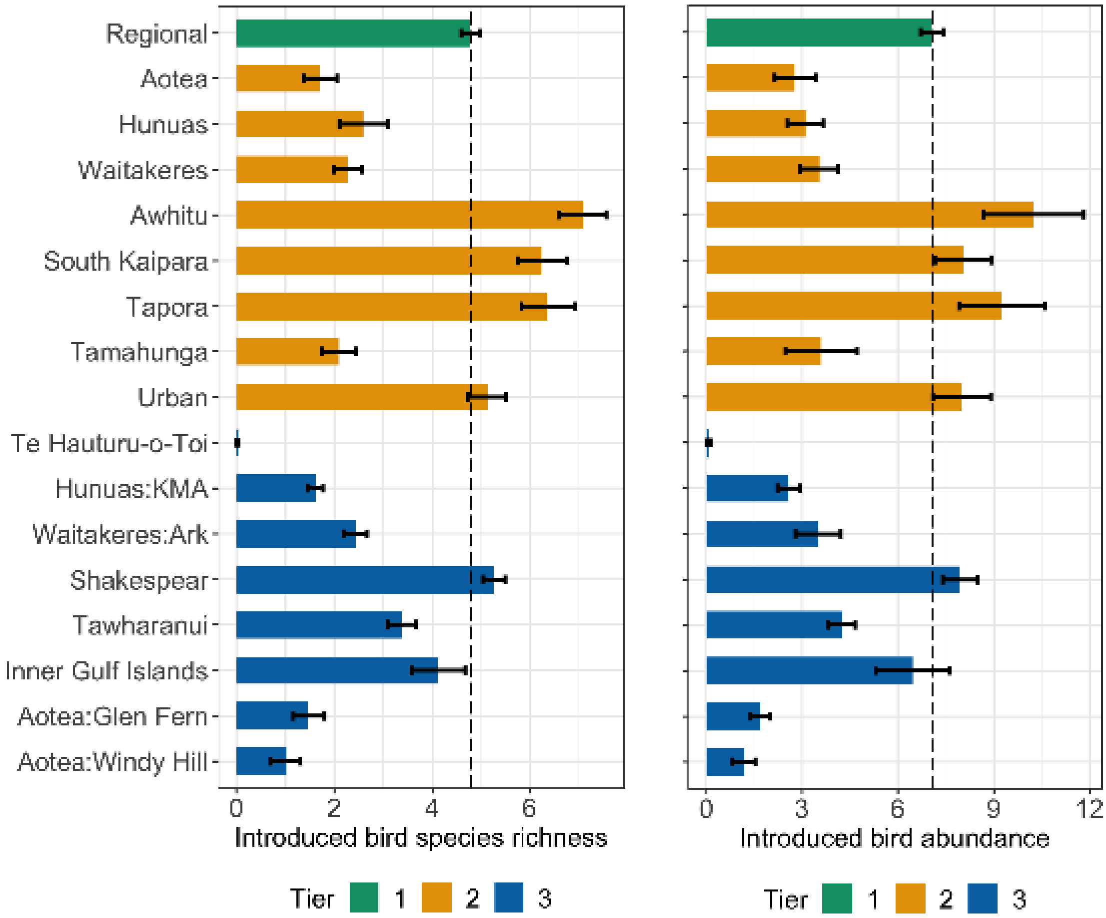


Figure 17: Introduced (non-native) bird species richness and abundance (mean ± 1 s.e.) per bird count, for plots in regional Tier 1 and targeted Tier 2 and 3 monitoring areas.

Introduced (non-native) bird species show a different pattern (Figure 17). Introduced bird species richness and abundance is highest in the regional forest network (Tier 1 plots), Awhitu, South Kaipara, Tapora and Shakespear Regional Park. Many of these forested areas are characterised by their small patch-size. Areas of large contiguous forest or isolation from human activity have some of the lowest introduced bird populations, including Aotea, the Hunua Ranges, Waitākere Ranges and especially Te Hauturu-o-Toi. For more details on the introduced bird data from the TBMP see Landers et al 2021.

Table 13: Alpha (α), beta (β) and gamma (γ) diversity for native and introduced bird species richness at a (a) monitoring unit scale, and (b) regional scale. Alpha diversity refers to mean species richness per plot (averaged across 3 bird counts, α1) or mean species richness per monitoring unit (α2). Beta diversity refers to turnover in species richness between plots (β1) or between monitoring units (β2). Gamma diversity refers to the species pool or total species richness per monitoring unit (γ1) or for Tiers 1 - 3 across the whole Auckland region (γ2).

(a) Monitoring units		Number of plots	Bird species richness					
			Native			Introduced		
			α_1	β_1	γ_1	α_1	β_1	γ_1
Tier 1	Regional	134	5.1	21.9	27	4.8	17.2	22
Tier 2	Aotea	18	5.1	13.9	19	1.9	11.1	13
Tier 2	Hunua Ranges	18	5.2	8.8	14	2.7	15.3	18
Tier 2	Waitākere Ranges	23	5.0	11.0	16	2.3	11.7	14
Tier 2	Awhitu	4	5.6	4.4	10	7.1	5.9	13
Tier 2	South Kaipara	8	4.5	7.5	12	6.3	8.8	15
Tier 2	Tapora	9	5.1	8.9	14	6.4	9.6	16
Tier 2	Tamahunga	14	5.3	4.7	10	2.1	8.9	11
Tier 2	Urban	21	4.7	10.3	15	5.1	14.9	20
Tier 3	Te Hauturu-o-Toi	18	8.7	8.3	17	0.1	4.9	5
Tier 3	Hunuas: KMA	27	6.0	9.0	15	1.8	8.2	10
Tier 3	Waitākeres:Ark	19	5.4	10.6	16	2.5	10.5	13
Tier 3	Shakespear	21	5.8	13.2	19	5.3	11.7	17
Tier 3	Tāwharanui	20	8.0	15.0	23	3.4	9.6	13
Tier 3	Inner Gulf Islands	15	4.2	17.8	22	4.1	11.9	16
Tier 3	Aotea:Glen Fern	16	5.1	12.9	18	1.6	10.4	12
Tier 3	Aotea:Windy Hill	16	5.0	8.0	13	1.2	7.8	9
(b) Regional			α_2	β_2	γ_2	α_2	β_2	γ_2
	Auckland region	401	16.5	20.5	37	13.9	11.1	25

Of the 37 native bird species recorded as part of TBMP forest plot monitoring across the region (γ_2), the five most common were tūī, grey warbler, silvereye, fantail and sacred kingfisher (Table 13). For many targeted monitoring areas however, there was considerable turnover (β_1) in species composition between plots. The highest heterogeneity in native bird composition (β_1) and the largest species pools (γ_1) were recorded in Tāwharanui, Inner Gulf Islands, Shakespear, Aotea and Glen Fern (Aotea). Large native bird species pools (γ_1) demonstrate the effectiveness of conservation management practices conducted at Tāwharanui and Shakespear.

In total, 25 introduced bird species were recorded in the TBMP forest plot monitoring (γ_2), of which the five most common were the Eurasian blackbird, chaffinch, common myna, Eastern rosella and European goldfinch. Introduced species were lowest on Te Hauturu-o-Toi, probably a result of the islands isolation and abundance of native birds (Miskelly 2018). Introduced bird communities were more homogenous across the region.

3.7 Pest animals

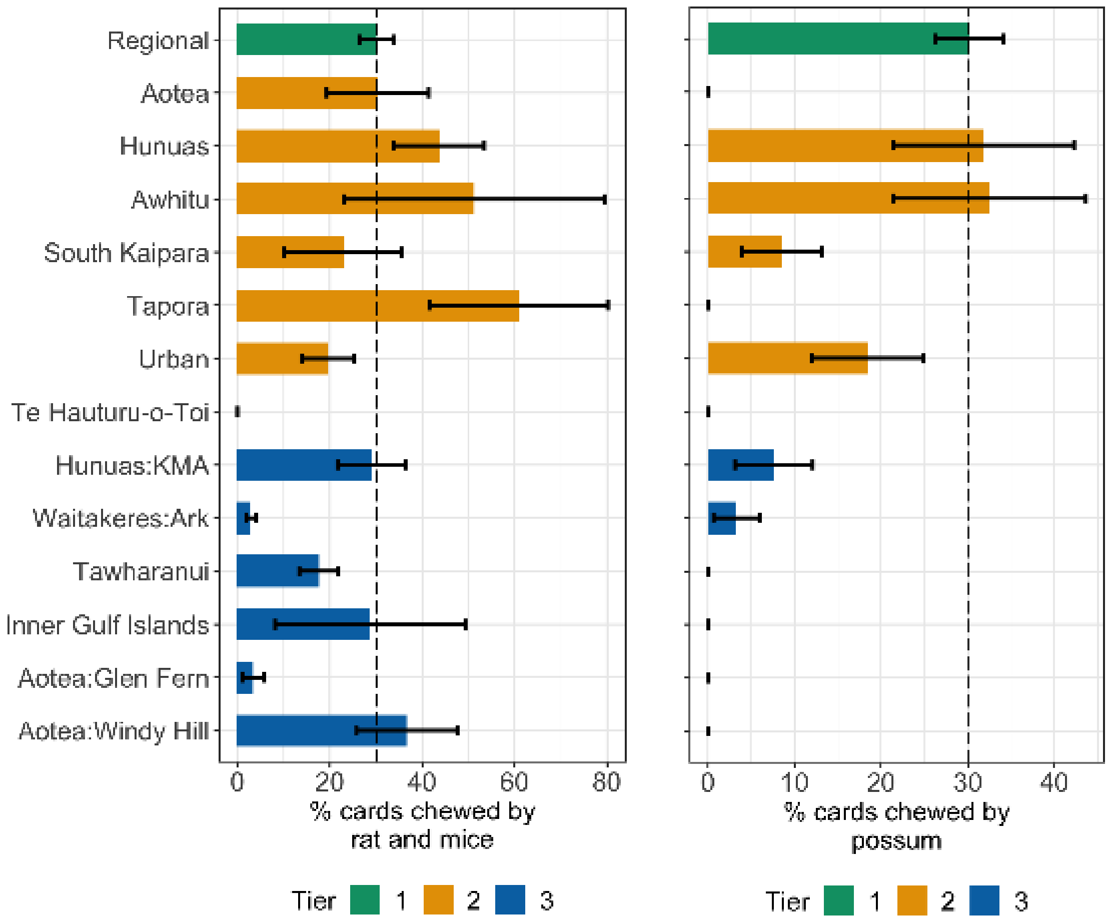


Figure 18: The per cent cards chewed by rats and mice and possums in the regional Tier 1 plots and in a subset of the targeted Tiers 2 and 3 monitoring areas.

Te Hauturu-o-Toi was the only entirely pest-free location in the Auckland region, and the only site without rats and mice (Figure 18). Rats and mice were detected at all monitored sites, including the fenced peninsula at Tāwharanui (note that the plots on Tāwharanui were sampled prior to 2016 and rat incursions may have been reduced since then). Apart from Te Hauturu-o-Toi, lowest rat and mice populations were observed in Ark in the Park (Waitākeres) which is not fenced but has an intensive network of trapping stations run as a partnership between Forest and Bird and

Auckland Council, and Glen Fern (Aotea) with its predator proof fence and ongoing trapping to deal with pest incursions. This illustrates the amount of effort and collaboration required to even maintain rats and mice at low numbers. In the Hunuas, rat and mice populations are higher outside the intensive predator control zone in the Kōkako Management Area (KMA), illustrating the extent to which the pest control activities in the Kōkako Management Area (KMA) reduce rat and mice numbers. Rat and mice populations were highest in the Hunua Ranges, Awhitu and Tapora, but were reasonably high across many areas including the regional Tier 1 plots. No pest monitoring was conducted as part of the TBMP in the Hunua Ranges or Kōkako Management Area after the aerial 1080 drop that was highly successful at reducing pest animal populations during mast seeding (Auckland Council 2019). This reinforces the need for long-term monitoring to understand the impact of multiple pest management strategies within these dynamic forest ecosystems.

Possums were not detected on Aotea (possums never colonised Aotea but monitoring is undertaken to ensure the island remains possum free), Tapora, Tāwharanui (possum were eradicated in 2004), and the Inner Gulf Islands (Waiheke, Rangitoto and Motutapu were eradicated of possums in the 1990s). Unfortunately, possums were present at two intensively managed bird conservation areas Kōkako Management Area and Ark in the Park (Waitākeres:Ark). The effectiveness of possum control in the Kōkako Management Area (Hunuas:KMA) is illustrated by the considerably higher possum numbers in adjacent plots within the Hunua ranges. Possum populations are high across the regional Tier 1 forest plots, the Hunua Ranges, Awhitu and relatively high in urban forests. Possum populations have since been reduced in the Hunua Ranges including the Kōkako Management Area following the aerial 1080 drop in 2018 (Auckland Council 2019).

Only 14 of the 17 monitoring units were monitored for pest animals as part of the TBMP. Furthermore, all pest animal monitoring as part of the TBMP ceased in 2016 following budget cuts. While pests are monitored as part of operational pest control programmes, Auckland Council lacks any systematic regional pest monitoring system, however, discussions are underway across council to address this gap.

4.0 Summary

This report analyses data from the Landcover Database (LCDB v5 2018), Auckland Council's historic and current ecosystem mapping (Singers et al 2017) and 10 years of data from the network of permanent forest plots in the Terrestrial Biodiversity Monitoring Programme to report on the ecological integrity of forests in Tāmaki Makaurau / Auckland. Three core elements are used to define ecological integrity and each of these are addressed below:

4.1 Ecosystem representation – are the full range of ecosystems in the region being maintained?

Auckland's forest landcover has been severely reduced since human colonisation, replaced mostly by exotic grassland and some urban development. There continues to be some turnover in indigenous forest and scrub habitat which represents a loss of biodiversity until newly replanted or restored indigenous forest and scrub has had time to mature. Indigenous forest and scrub ecosystems have been reduced to 23% of their original extent. Many formerly common ecosystem types have been reduced, for example, kauri, podocarp, broadleaf forest which once dominated the Auckland region has been reduced to 16% of its original extent, kahikatea, pukatea forest has been reduced to 2% and pūriri forest has been reduced to 0.3% of its original extent. Of the remaining forest and scrub, 37% has been disturbed and degraded to such an extent it has been reclassified as regenerating forest and scrub ecosystem types new to the Auckland region, and 14% has been degraded to anthropogenic forest and scrub ecosystems.

Fragmentation of remaining forest further impacts forest ecological integrity. Forest patch-size, connectivity and surrounding land-use affect the ability of forests to support indigenous species, and changes the exposure and susceptibility to weed incursions. Small, fragmented forest patches support lower indigenous plant species richness, fewer indigenous birds, more introduced birds and more weed species and abundance. Urban forests in particular were notable for their weediness and lower species richness of native plants and birds. Many small, rural and urban forest patches however, remain important habitats for indigenous forest species, and may fulfil vital roles as stepping stones or corridors for indigenous biodiversity, but require active management to prevent further degradation. In contrast, the three large, contiguous tracts of indigenous forest in the Waitākere Ranges, Hunua Ranges and Aotea, support some of the highest levels of indigenous plant species richness at multiple spatial scales, low incursion of weeds and only small communities of introduced birds. These benefits emerge in large part from their size and lack of fragmentation, although further research is required to understand the role of isolation or distance from seed sources in reducing weediness in large forest patches.

4.2 Species occupancy – are the species present that should be there?

This report looks broadly at indigenous species occupancy across the region using indigenous plant species richness, indigenous tree size-class distribution and indigenous bird populations. Complex and species-rich communities of indigenous plant species occur within the large, continuous tracts of forest in the Waitākere Ranges (including Ark in the Park), Hunua Ranges (including the Kōkako Management Area) and Aotea, within a distinctive forest patch at Tamahunga and within the highly restored sanctuaries of Tāwharanui and Shakespear. Smaller, more fragmented and isolated forest patches support fewer indigenous plant species on average but when considered collectively, support a wide range of native species and ecosystems. Monitoring units mostly show a healthy indigenous forest structure. Indigenous tree size-class distributions in some monitoring units show evidence of past logging, with some forests lacking mature canopy dominants. Patterns of low seedling and sapling abundance in tawa and taraire dominated forest at Tamahunga and the Kōkako Management Area raise questions about regeneration of this forest type, and how this may impact its future extent, especially given its sensitivity to fragmentation, pests and changes in climate. The TBMP tree-tag data will ultimately provide knowledge of individual and population-level recruitment, growth and mortality and insight into forest dynamics.

The most species-rich and abundant native bird communities were found on Te Hauturu-o-Toi and Tāwharanui; both locations are well established (since 2004), fenced or isolated, with pest animal eradication and indigenous bird species translocations. These sites indicate the effectiveness of pest animal eradication strategies for indigenous bird conservation (Binny et al 2020). Shakespear supported native bird communities marginally more speciose and abundant than the regional average; established in 2011, this fenced sanctuary with a pest eradication strategy is expected to support more native birds over time. The Kōkako Management Area was the only open sanctuary with a marginally more speciose and abundant native bird community than the regional average. Kōkako breeding pairs have increased in the area and native bird communities have benefited from two drops of aerial 1080 (Morrison 2020). Further research is required to understand the differences between pest animal eradication or suppression strategies, the pest species targeted, the scale and effectiveness with which control measures are conducted, and how they impact on habitat quality for native bird communities. Some community-run projects targeting native bird conservation would benefit from further research, particularly pest monitoring, to optimise the intensity of pest animal control and the types of pests being effectively targeted (Lovegrove and Parker in review). Novel pest animal control methods may also be required to address trap shy populations. See Landers et al 2021 for more detailed analysis of forest bird communities in the TBMP.

Evidence from the TBMP on species occupancy is limited to those species monitored, namely plants and birds. In the Auckland region, loss of species occupancy has been documented for some iconic species such as the tuatara (*Sphenodon punctatus*) which has long been absent from the mainland as a result of rat predation, or more recently the forest ringlet (*Dodonidia helmsii*). This forest species was once abundant in the Auckland region including the Waitākere and Hunua Ranges but is now thought to be locally extinct on the mainland (the last confirmed sighting was in 1996) due to habitat loss and wasp predation (Wheatley 2017). Based on what we know of indigenous communities and the pressures they face in the Auckland region, there are likely to be innumerable undocumented losses to species occupancy.

4.3 Indigenous dominance – are the key natural ecological processes being maintained by native biota?

The TBMP records weeds, introduced (non-native) birds and three pest animals (mice, rats and possums) which contribute to an assessment of indigenous dominance. Indigenous plant species make up the vast majority of plant species in Auckland's forests, composing 95% of all plant species, and 95% of sapling abundance regionally. Forests with few or no weeds, however, only occur where there is intensive weed control and/or the site is isolated from seed sources, including Te Hauturu-o-Toi, Tāwharanui, the Kōkako Management Area and Ark in the Park. Even the large continuous forest tracts such as the Waitākere Ranges, Hunua Ranges and Aotea are not insulated from weed incursions, although weed abundance is higher in smaller forest patches. Urban forests had the most weeds across all plant categories, reflecting the high propagule pressure and susceptibility of these habitats.

Indigenous birds composed 69% of all birds counted in the TBMP forest plot network, with the three most common species tūī, tauhou (silvereye) and riroriro (grey warbler) also the most widespread, occurring in >70% of all bird counts (Landers et al 2021). Introduced bird communities were more homogenous and widespread across Auckland's forests, but tend to be less speciose or abundant in large, continuous forest. These sites include Te Hauturu-o-Toi, the Waitākere Ranges, Hunua Ranges, Aotea and their associated sanctuaries.

Pest monitoring showed rats, mice and possum are widespread, often abundant, and are only absent from those sites where they have been controlled, or never colonised in the first place. Weeds and pests are known to impact indigenous species occupancy, thereby damaging many essential ecosystem processes such as bird-mediated pollination and seed dispersal. Unfortunately, the TBMP currently lacks a pest animal monitoring component, and with cyclical forest dynamics such as mast seeding and aerial 1080 drops, pest animal populations can change quickly. Discussions are underway in Auckland Council to address this gap.

Plant pathogens are a major threat to many iconic tree species, and therefore indigenous dominance in the Auckland region. Although no myrtle rust was detected in forest plots in 2020 as part of the TBMP pilot myrtle rust assessment, despite the presence of several highly susceptible tree species (Beresford et al 2019), myrtle rust has now been detected in the Waitākere Ranges. Monitoring of kauri dieback is performed by another department of Auckland Council and is not included in the TBMP. Finally, a technique to monitor *Vespula* and *Polistes* species pest wasp populations was successfully piloted in the TBMP forest plots in 2020.

5.0 Conclusions

The ecological integrity of forests in Tāmaki Makaurau / Auckland can be examined at multiple spatial scales (Lee et al 2005; McGlone et al 2020). At a sub-regional scale there are numerous examples of forest and scrub supporting diverse indigenous plant communities with healthy forest structures. These are more common in the large, continuous forest patches with high habitat heterogeneity such as the Waitākere Ranges, Hunua Ranges and Aotea, and at sites with intensive conservation management including Tāwharanui, Shakespear and the offshore island of Te Hauturu-o-Toi. Absence of weed plants is typically a function of low exposure to propagules (e.g. large forest patch size, distant from rural or urban land, offshore island) and weed control. Few forests have high native bird species occupancy, which appears strongly determined by pest animal eradication in fenced or offshore locations. Native bird communities in unfenced sanctuaries appear to be limited, possibly due to continuous pest incursions. There are also numerous examples of forest and scrub with depauperate indigenous plant communities. These are more common in small forest patches where weeds are most abundant and may outcompete natives and disrupt normal ecosystem processes. Tāwharanui Regional Park however, illustrates how the ecological integrity of small forest patches in predominately rural areas can be improved, albeit with considerable effort.

At a regional scale, the ecological integrity of Auckland's forests is strongly impaired by the absence or reduced extent of many forest and scrub ecosystem types, the absence of many native bird species, the widespread abundance of pest animal species and the frequency of weed incursions. This assessment of the ecological integrity of forests in Auckland has long been implicitly understood; what is new is the use of unbiased quantitative data to examine where and how ecological integrity is impaired, for those components of Auckland's indigenous wildlife that the TBMP measures, namely plants and birds.

As New Zealand’s most populated region, Auckland cannot replace all its lost forest and scrub habitat, but all remaining forest and scrub, however small the fragment, should be recognised as a precious and highly limited natural resource. Simple, practical steps can be taken to protect forest fragments from further degradation resulting from fragmentation; though fencing may not be sufficient to allow regeneration of tawa and taraire forests (Morales et al 2016; Norton et al 2020). Best practice for forest bird conservation is well understood. Sustained pest animal eradication combined with fencing or isolation, native bird reintroductions and indigenous replanting where necessary, give the best conservation outcomes (Binny et al 2020). Successful examples of such conservation practices can be seen in Te

Hauturu-o-Toi and Tāwharanui, but these native bird communities need secure forest to expand into if they are to be sustainable (Lovegrove and Parker in review). Many conservation groups across the Auckland region conduct intensive forest restoration and indigenous bird conservation projects, often in collaboration with Auckland Council and other conservation charities e.g. Forest and Bird. Better ecological monitoring and analytical support for these community groups could further enhance their conservation outcomes. This is essential if Auckland is to achieve its target to be pest-free by 2050 (Pest Free Auckland 2050). Creation, expansion and restoration of forest habitats may be necessary to maintain the full range of forest and scrub ecosystem types that once occurred in the region, and provide a buffer against emerging risks such as myrtle rust and the effects of a changing climate. Ultimately, forest conservation needs to take a landscape approach; multi-partner initiatives such as the Northwest Wildlink provide a good example, by maximising the ecological value of and benefit to small and large forest patches.

This report highlights the knowledge that can be gained from long-term ecological monitoring to understand ecological processes and aid environmental decision-making (Lindenmayer et al 2012). It also highlights how data gaps, such as pest animal monitoring, and reductions in sample size or plot remeasurements, can undermine our interpretation of patterns and processes. Discussions across council are planned for 2021 to design pest animal monitoring as part of the TBMP. A number of issues raised in this report would benefit from more detailed analysis. For example, more formal hypothesis testing could be used to examine differences in pest animal management strategies relative to forest characteristics, scale of management activities and resource availability; statistical tools such as propensity scoring could be used to reduce systematic differences in confounding variables (Ramsey et al 2019). In addition, there are further informative ways in which the data collected by the TBMP can be used. For example, functional traits can be used to good effect to examine ecosystem processes. Finally, future monitoring and analyses need to assess the risks to forest ecosystems from climate change and how they may interact with existing pressures.

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Appendix A Regional Tier 1 and Targeted Monitoring Areas in Tiers 2 and 3

A.1 Tier 1: regional forest

Regional Tier I plots are distributed in forest and scrub across the Auckland region, representing the full range of elevations, forest patch sizes, history, management, surrounding land uses and ecosystem types. Plots are located in kānuka scrub/forest (VS2, 26 plots), kauri, podocarp, broadleaf forest (WF11, 26 plots), tōtara, kānuka, broadleaf forest (WF5, 12 plots), taraire, tawa, broadleaf forest (WF9, 10 plots), exotic forest (EF, 9 plots), pōhutukawa, pūriri broadleaf (WF4, 7 plots) and other less common ecosystem types, including 20 unclassified plots (the Singers et al 2017 geospatial layer of current ecosystem type is a living document that is continually updated as new habitats are surveyed and more information comes available, ultimately all habitat patches across the Auckland region will be classified).

A.2 Tier 2: Aotea (Great Barrier Island)

Aotea (Great Barrier Island) is New Zealand's sixth largest island (28,500ha) and is located in the outer Hauraki Gulf, 100km north-east of central Auckland. Aotea is of international, national and regional significance for its biodiversity, has high cultural value to mana whenua, and the Auckland public. Much of Aotea was logged for kauri from c.1850-1940 and farming was later attempted on the more gently sloping and warmer landforms. However, the relative isolation, ruggedness of the terrain and nutrient deficiencies in the soil meant that most of these farmed areas have long since reverted to indigenous scrub and forest. Land Cover Database 2012 figures (LINZ 2014) show that only around 8% of the island is dominated by exotic pasture and residential 'urban' areas. The remainder of the island comprises indigenous scrub and secondary forest (66% cover), indigenous forest (23% cover) and indigenous freshwater and saline wetlands (3% cover). Nearly two thirds of the island is in public ownership, with expectation to be managed for conservation.

Exotic pest species which have a significant impact as browsers and predators on the mainland have either never made it to Aotea (deer, stoats, ferrets, weasels, possums, hedgehogs and Norway rats) or have been eliminated from the island through active control (goats). Aotea is the second largest area of possum free habitat in New Zealand after Campbell Island. The isolation and island nature of Aotea also has obvious advantages in terms of controlling the invasion of new pest and weed species, and future possible eradications (e.g. pigs, rabbits, cats or the other rat species).

Aotea plots are predominately located in kānuka scrub/forest (VS2, 12 plots) and kauri, podocarp, broadleaf forest (WF11, 4 plots), with one plot each of taraire, tawa, broadleaf forest (WF9, 1 plots) and tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13, 1 plot).

A.3 Tier 2: Hunua Ranges

The Hunua Ranges comprise 17,000ha of native forest in south-east Auckland with the highest point at Mt Kohukohunui (688m). Areas of the Hunua Ranges were settled by Māori and early Europeans and from the 1890s the foothills (up to about 250m) and alluvial flats were logged for kauri and other timber and cleared for farming (Silvester 1964). Severe damage to the forest has been caused by high populations of goats and pigs. There has been substantial regeneration since the 1930s. At higher altitudes, tawa, broadleaf and podocarps dominate, on northern slopes taraire and pūriri are common, in lowland areas kauri and hard beech are found (Silvester 1964). From the 1950s to 1970s five reservoirs were built in the Hunua Ranges, four of which currently supply water to Auckland, the last is due to be connected to the Auckland supply network in 2021. Auckland Council regularly control feral pigs, goats, deer, possums and mustelids within parkland and buffer land surrounding the park. Deer are considered absent from the Hunua Ranges. Weed control activities are highly restricted within or near reservoir water catchments, but at least 36 weed species are controlled regularly in specified blocks across the Hunua Ranges.

Plots in the Hunua Ranges are spread across tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13, 7 plots), taraire, tawa, broadleaf forest (WF9, 5 plots), kānuka scrub/forest (VS2, 4 plots), kauri, podocarp, broadleaf forest (WF11, 1 plot) and one unclassified plot.

A.4 Tier 2: Waitākere Ranges

The Waitākere Ranges Regional Park covers 17,000ha of public land, but a wider area of public and private land is recognised under the Waitākere Ranges Heritage Area Act 2008 which seeks to protect the ecological and cultural significance of the area, as well recognising its role in water catchment and supply to the Auckland region. Twenty-eight of the 36 terrestrial ecosystems found within the Auckland region occur within the heritage area (Singers et al 2017; Landers et al 2018) and many have been identified as Biodiversity Focus Areas under the Unitary Plan to ensure their long-term conservation. The most common forest type, accounting for 45% of all native ecosystems, is kauri, podocarp, broadleaf forest (WF11), followed by mānuka, kānuka scrub (VS3, 17%), broadleaf scrub/forest (VS5, 13%) and kānuka scrub/forest (VS2, 12%). These ecosystems are reflected in the distribution of plots in the Waitākere Ranges which are predominately located in kauri, podocarp, broadleaf forest (WF11, 10 plots), mānuka, kānuka scrub (VS3, 5 plots), broadleaved species scrub/forest (VS5, 4 plots), kānuka scrub/forest (VS2, 2 plots) and one plot each of pōhutukawa, pūriri broadleaf (WF4) and tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13).

Coastal areas of the Waitākere Ranges were intensively modified and burnt by Māori but the forest interior left largely untouched. This changed following European colonisation when kauri and other timber trees were milled and large areas burned and cleared for farming (Esler 1983; Denyer et al 1993; Lovegrove & Parker in prep). Today, only small remnants of undisturbed forest remain, but there has been extensive natural regeneration and the forests have been described as a complex and diverse mosaic of mature forest remnants and successional forest vegetation (Denyer et al 1993).

Even remnant primary forest, however, will have been impacted by the brushtail possum (*Trichosurus vulpecula*), rats and other introduced mammals which have had a massive impact on the forest. Forest browse and seed consumption have seriously affected Northern rātā, Hall's tōtara, tōtara, maire tawake, pōhutukawa, mamaku, broadleaf, pūriri, kohekohe, large-leaved māhoe and whauwhaupaku, with reports of tree mortality (Barton & McClure 1990; Ogden & Carlaw 1997). Forest health surveys conducted in the 1990s demonstrated considerable impacts on the forest canopy and seedling populations, with consequences for forest regeneration. Operation Forestsave started in 1997. This Waitākere-wide possum control programme has effectively maintained possum numbers below 7% of the residual trap catch (a measure of their abundance) to date (Lovegrove and Parker, in prep).

In addition, Auckland Council regularly controls pigs, which are vectors of the pathogen causing kauri dieback. There has been ongoing work by Auckland Council to understand and control the spread of kauri dieback. Local iwi Te Kawerau a Maki placed a rāhui on the Waitākeres in December 2017 to further prevent spread of the pathogen and this was followed by a Controlled Area Notice imposed by Auckland Council to close the majority of the regional park to public access.

A.5 Tier 2: Awhitu (Landcare Trust)

The Awhitu peninsula covers ~22,000 ha of predominately rural land. The Awhitu Landcare group supports pest and weed control on public and private land across the peninsula, and Auckland Council provide possum control. The community group has an active replanting programme on public land.

All Awhitu plots are in tōtara, kānuka, broadleaf forest (WF5, 4 plots).

A.6 Tier 2: Kaipara (Landcare Trust)

Six South Kaipara plots are in tōtara, kānuka, broadleaf forest (WF5, 6 plots), and one each in kānuka scrub/forest (VS2, 1 plots) and spinifex/pingao grassland/sedgeland (DN2, 1 plot).

A.7 Tier 2: Tapora (Landcare Trust)

Tapora/Otamatea plots are spread across kānuka scrub/forest (VS2, 4 plots), kauri, podocarp, broadleaf forest (WF11, 2 plots), and one plot each of pōhutukawa, pūriri broadleaf (WF4, 1 plot), exotic scrub (ES, 1 plot) and unclassified.

A.8 Tier 2: Tamahunga (Department of Conservation)

This 230ha Department of Conservation reserve near Matakana includes Mt Tamahunga at 445m. An active community group monitor 150 DOC predator traps across the site and a neighbouring section of 270ha of privately owned bush, with stoats being the main focus. Insufficient rats are currently trapped to reduce the population. Auckland Council and DOC have eradicated goats and continue to target pigs, possums and weeds on an annual basis. Monitoring is undertaken to detect goat and deer. The majority of Tamahunga plots are in taraire, tawa, broadleaf forest (WF9, 12 plots), with two plots in broadleaved species scrub/forest (VS5, 2 plots).

A.9 Tier 2: Urban forests

The 21 plots in urban forest represent a wide range of ecosystem types, with varied histories and management. The sampling area lies within Auckland’s Metropolitan Urban Limits (MUL) and includes most of Tamaki (c. 76%), Manukau (c.12%), Inner Gulf Islands (c.8%), Waitākere (c.5%), Rodney (c.2.5%) and Hunua (c.1%) ecological districts. Represented in decreasing order are pōhutukawa, pūriri broadleaf (WF4, 3 plots), kānuka scrub/forest (VS2, 2 plots), pūriri, taraire forest (WF7.2, 2 plots), kauri, podocarp, broadleaf forest (WF11, 2 plots), and one plot each of mānuka, kānuka scrub (VS3), broadleaved species scrub/forest (VS5), pūriri forest (WF7), taraire, tawa, broadleaf forest (WF9), tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13), planted native scrub/forest <20 years old (PL1), exotic forest (EF), treeland (TL). Four plots are unclassified.

A.10 Tier 3: Te Hauturu-o-Toi

Te Hauturu-o-Toi has experienced only limited logging and farming since human colonisation and has been eradicated of cats since 1980 and kiore since 2004 (Wade & Veitch 2019). Ongoing pest monitoring focusses on detecting any new incursions through pest stations across the island and strict biosecurity checks for Department of Conservation approved visitors. Systematic control of climbing asparagus began in 1996 and continues with an annual search of 175ha per year. Systematic control of pampas began in 2004, mostly by spraying cliffs from a helicopter with the aim to search and treat about 50% of cliff and slip faces each year. Other weeds are controlled as they are encountered, including an infestation of panic veldt grass that requires ongoing surveillance. The aim for weed control is eradication or control to zero-density.

Plots on Te Hauturu-o-toi are located in kānuka scrub/forest (VS2, 6 plots), taraire, tawa, broadleaf forest (WF9, 3 plots), the rare for Auckland kauri, podocarp, broadleaf, beech forest (WF12, 3 plots), tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13, 2 plots), and one plot each of mānuka, kānuka scrub (VS3), kauri, podocarp, broadleaf forest (WF11) and the rare for Auckland kauri, towai, rata, montane podocarp forest (MF25). One forest plot is classified as exotic grassland (EG).

A.11 Tier 3: Kōkako Management Area, Hunuas

The combined effects of habitat loss, habitat degradation and invasive pests are reported to have had a profound impact on the bird fauna of the Hunua Ranges (McKenzie 1979). In the 1990s the kōkako population was estimated to have been reduced to 22 males and 1 female bird (Nature Space 2020). In response, the Kōkako Management Area was established on 1500ha of native forest dominated by mature tawa (*Beilschmiedia tawa*), and including northern rātā (*Metrosideros robusta*), rewarewa (*Knightia excelsa*), rimu (*Dacrydium cupressinum*) and tāwheowheo (*Quintinia serrata*). Intensive pest control within the Kōkako

Management Area targets rats and possums using 2777 bait stations and a range of trap types to target mustelids and rats. Rat monitoring is used to assess control effectiveness and determine whether targets are met. A series of 1080 drops in 2015 and 2018 in the Hunuas were highly effective at controlling pest animals. Yearly average control levels were achieved for the 2019-20 reporting year, but rat numbers exceeded targets for the kōkako breeding season (Morrison 2020). Despite that, six pairs of kōkako successfully bred. The Kōkako Management Area is considered to have goats at zero density (boundary and hotspot checks are conducted annually), deer are not in the Hunua Ranges and there is a buffer control programme to protect the parkland.

The majority of plots in the Kōkako Management Area are in tawa, kohekohe, rewarewa, hīnau, podocarp forest (WF13, 21 plots). The remainder are in taraire, tawa, broadleaf forest (WF9, 5 plots) and kānuka scrub/forest (VS2, 1 plot).

A.12 Tier 3: Ark in the Park, Waitākeres

Ark in the Park is a volunteer based collaborative project with Forest and Bird and Auckland Council. It is an unfenced sanctuary covering approximately 2100ha. The main activities are predator control which started in 2002, and there is a dense network of traps and bait stations run by volunteers to control rats and stoats. In total there are 4780 bait stations and 550 traps, with over 400 volunteers who dedicate more than 10,000 hours to conservation every year. Pigs and possum are also targeted by Auckland Council employed contractors. There have been reintroductions of toutouwai (North Island robin), pōpokatea (whitehead), hihi (stitchbird) and kōkako (North Island kōkako). Volunteers regularly control pest plants in the forest. Weed incidence within intact forest is typically low but incursions are common around borders, tracks and waterways. The main weed targets have been ginger species, bamboo species, woolly nightshade, blackberry and gorse. The Ark in the Park buffer zone includes some 200 neighbouring properties where land-owners are encouraged to control pest animals.

Plots in the Waitākere Ranges are dominated by kauri, podocarp, broadleaf forest (WF11, 14 plots) and kānuka scrub/forest (VS2, 4 plots). There is one plot of mature kauri forest (WF10.1).

A.13 Tier 3: Shakespear Regional Park

A predator proof fence was built around the peninsula in 2011 and pest eradication successfully removed nine of ten target species (Norway rat, ship rat, possum, cat, hedgehog, weasel, stoat, ferret, rabbit) with only mice persisting. New incursions of these pest species are eradicated. Weed control undertaken by Auckland Council and community groups has mostly limited spread. There have been many reintroductions of missing fauna including the kiwi pukupuku (little spotted kiwi), toutouwai (North Island robin), pōpokatea (whitehead), pāteke (brown teal), kākāriki (red-crowned kakariki), tieke (North Island saddleback), takahē (South Island takahe) and Duvaucel's gecko. There have also been natural or assisted natural colonisation by korimako (bellbird), ōi (grey faced petrel), kuaka (diving petrel) and pakahā (fluttering shearwater) and a few individual records of hihi (stitchbird), mātātā (fernbird) and tītīpounamou (rifleman). In addition, a number of extant reptiles have been discovered, the moko skink, shore skink, pacific gecko and forest gecko. Plant reintroductions include pirita (green mistletoe), *Pomaderris hamiltonii*, hinarepe (sand tussock) and *Hibiscus richardsonii*. Revegetation at Shakespear includes 2000-5000 plants per year up until 2010 and then approximately 15,000 plants (1.5ha) per year from 2010 to the present. Plantings have been in retired pasture areas unsuitable for grazing with a focus on increasing the size of key forest remnants.

Shakespear Regional Park plots are dominated by mānuka, kānuka scrub (VS3, 10 plots), pōhutukawa, pūriri broadleaf (WF4, 5 plots) and planted native scrub/forest <20 years old (PL1, 3 plots). One plot is unclassified.

A.14 Tier 3: Tāwharanui Regional Park

A predator proof fence was built around the peninsula in 2004 and pest eradication successfully removed eight of ten target species (Norway rat, ship rat, possum, cat, hedgehog, weasel, stoat and ferret) with only rabbit and mice persisting. New incursions of these pest species are eradicated. Weed control undertaken by Auckland Council and community groups has mostly limited spread, with one weed species eradicated. There have been many reintroductions of missing fauna including the North Island Brown kiwi, toutouwai (North Island robin), pōpokatea (whitehead), pāteke (brown teal), kākāriki (red-crowned kakariki), tieke (North Island saddleback), takahē (South Island takahe), forest, green and Duvaucel's gecko. There have also been natural or assisted natural colonisation by korimako (bellbird), ōi (grey faced petrel), kuaka (diving petrel) and pakahā (fluttering shearwater) and a few individual records of miromiro (tomtit), hihi (stitchbird), titi (cooks petrel) and weka (woodhen). Plant reintroductions include pirita (green mistletoe), *Pomaderris hamiltonii*, hinarepe (sand tussock) and *Hibiscus richardsonii*. Revegetation at Tāwharanui included 2000-5000 plants per year between 2005-2008, and approximately 20,000 plants (2ha) per year from 2008 to the present.

The plots in Tāwharanui are predominately located in pōhutukawa, pūriri broadleaf forest (WF4, 12 plots) and mānuka, kānuka scrub (VS3, 5 plots). There is one plot each of kānuka scrub/forest (VS2) and kauri, podocarp, broadleaf forest (WF11). One plot is unclassified.

A.15 Tier 3: Inner Gulf Islands

Plots in the Inner Gulf Islands represent a diverse range of ecosystem types across four very different islands of Rangitoto, Motutapu, Motuihe and Waiheke. Rangitoto only formed 600 years ago during a series of volcanic eruptions, as such it is the youngest land mass in the Auckland region. It now forms 2311ha of mostly pōhutukawa scrub forest, reaching 260m in elevation. Uniquely, it has never been permanently inhabited. There have been occasional forest fires, but no official records of logging exist. The island has been goat free since the 1880s and deer free since the 1980s. Brushtail possums and the brush-tailed rock wallabies were eradicated in the 1990s and DOC eradicated all other mammalian pests (rats, cats, stoats, mice, rabbits, and hedgehogs) by 2009. Rangitoto and neighbouring Motutapu, between which there is a land bridge, were declared pest-free in 2011. Management interventions have since focussed on removing or controlling weeds (especially maurandya vine, mile a minute, panic veldt grass, boneseed) on the island. The island has a large number of exotic plants, though not all of them are problematic. Control of evergreen buckthorn proved impossible and has been abandoned.

Motutapu, linked to Rangitoto by a land-bridge, has had a very different history. Most of the original forest on the island was removed during Māori occupation and by the eruption of Rangitoto. It was settled by Māori from the 1300s, and the fertile land from ash fall used for horticulture. The removal of pests from Motutapu follows the same timeline as Rangitoto. Restoration, undertaken by the Motutapu Restoration Trust, aims to replant 500ha of forest, or about one third of the island. The remainder is farmed for sheep and beef under a concession recently taken over by Ngāi Tai ki Tāmaki following Treaty settlement in 2018. Weed control is undertaken by the Motutapu Restoration Trust and Motutapu Outdoor Education Centre. Since 2011, a number of native bird species have been translocated to Motutapu, the takahē, tieke and North Island brown kiwi.

Motoihe Island (179ha) has had a long history of Māori and then European settlement. Most of the forest has been removed apart from c.18ha of remnant coastal forest. The island is controlled by DOC and administered by the Motuihe Trust which formed in 2000. The Motuihe Trust has undertaken replanting, weed control and species reintroductions including the red-crowned parakeet, tieke, little spotted kiwi and tuatara. The main weed species on the island are evergreen buckthorn, moth plant and pampas.

Waiheke Island is the second largest island in the Hauraki Gulf after Aotea and is the most densely populated. A large proportion of the land is owned privately. Reserve land is managed by Auckland Council, DOC and Forest and Bird with regular control undertaken against a wide range of weed plants. The island has a plan to become pest free by 2050.

The only examples of pōhutukawa scrub/forest (VS1, 5 plots) in the plot network occur on Rangitoto. Other ecosystem types represented are kānuka scrub/forest (VS2, 3 plots), exotic grassland (EG, 2 plots), and one plot each of mānuka, kānuka scrub (VS3), broadleaved species scrub/forest (VS5), pōhutukawa, pūriri broadleaf (WF4), pōhutukawa treeland/flaxland/rockland and native/amenity planting (PL3).

A.16 Tier 3: Glenfern Sanctuary, Aotea

Glenfern started as a private sanctuary in 1994 and was purchased by Auckland Council in 2017. It forms part of the Kotuku Peninsula Sanctuary on the western side of Aotea, together with privately owned and Department of Conservation land. A predator proof fence was built around the peninsula in 2008. Aerial eradication of pests occurred in 2009 with intensive monitoring for incursions. Glenfern sanctuary covers c. 80ha, most of which is under QEII covenant, and is actively managed with replanting and restoration, bird reintroductions, monitoring of endangered and threatened species (e.g. tāiko (black petrel), tītī (cooks petrel), pāteke (brown teal), kākā, chevron skink), and environmental education.

Historically, much of the area was cleared for agriculture during European settlement, and parts were cleared by fire multiple times during the first few decades of the 20th century and until as recently as 1965 (Perry et al 2010). Since the 1950s it has been gradually reverting to forest. The main forest type is relatively young kānuka scrubland with exotic woody species such as prickly hakea on drier north-facing slopes. Small patches of remnant forest are found in some gullies, kauri pole stands (rickers) are common on ridges and pōhutukawa in coastal areas. Plots on Glenfern are mostly in kānuka scrub/forest (VS2, 15 plots), with one plot in pōhutukawa, pūriri broadleaf (WF4). More information is available for the Glenfern archives on the website, https://www.glenfern.org.nz/archives.

A.17 Tier 3: Windy Hill private sanctuary, Aotea

Windy Hill private sanctuary covers 750ha on the southern part of Aotea, with intensive predator control across 300ha (Ogden & Gilbert 2009) including 5500 tap and bait stations. Weeds are regularly monitored and removed, especially key species (pampas, jasmine, plectranthus, Mexican devilweed, hakea, aristea, pine trees). There is regular monitoring of endangered and threatened species. This community-based restoration project was started in 2000. More information is available on their website (https://www.windyhillsanctuary.nz)

Historically, this land has been partially cleared including multiple times by fire during the first few decades of the 20th century, and as recently as c.1940 (Perry et al 2010). It has since reverted back to relatively young mānuka and kānuka scrubland, with remnant kauri, podocarp, broadleaf forest in gullies, and pōhutukawa forest on cliffs. Permanent forest plots on Glenfern are in kānuka scrub/forest (VS2, 11 plots) and kauri, podocarp, broadleaf forest (WF11, 5 plots).

Appendix B List of species in the text

B1. Native plant species

Latin binomial	Māori name	Pakeha name
Agathis australis	kauri	
Beilschmiedia tarairi	taraire	
Beilschmiedia tawa	tawa	
Coprosma autumnalis	kanono	
Cyathea medullaris	mamaku	black tree fern
Dacrycarpus dacrydioides	kahikatea	white pine
Dacrydium cupressinum	rimu	red pine
Dysoxylum spectabile	kohekohe	New Zealand mahogany
Elaeocarpus dentatus	hīnau	
Griselinia littoralis	kapuka	broadleaf
Hibiscus richardsonii	puarangi	native hibiscus
Ileostylus micranthus	pirita	green mistletoe
Knightea excelsa	rewarewa	New Zealand honeysuckle
Kunzea ericoides complex	kānuka	
Laurelia novae-zealandiae	pukatea	
Leptospermum scoparium	mānuka	
Melicytus macrophyllus	large-leaved māhoe	large-leaved māhoe
Melicytus ramiflorus	māhoe	whitey wood
Metrosideros excelsa	pōhutukawa	
Metrosideros robusta	Northern rātā	Northern rata
Nestigis lanceolata	white maire	
Olearia rani	heketara	
Poa billardierei	hinarepe	sand tussock
Podocarpus laetus	tōtara-kiri-kotukutuku	Hall's tōtara
Podocarpus totara	tōtara	
Pomaderris hamiltonii	kūmarahou	pale flowered kumarahou
Prumnopitys ferruginea	miro	brown pine
Psuedopanax arboreus	whauwhaupaku	five-finger
Quintinia serrata	tāwheowheo	
Syzygium maire	maire tawake	swamp maire
Vitex lucens	pūriri	
Weinmannia silvicola	tōwai	

B2. Weed species

Latin binomial	Māori name	Pakeha name
Asparagus scandens		climbing asparagus
Carex divulsa		grey sedge
Chrysanthemoides monilifera subsp. monilifera		boneseed
Cortaderia selloana		pampas grass
Dipogon lignnosis		mile a minute
Ehrharta erecta		panic veldt grass
Erica lusitanica		Spanish heath
Euonymus japonicus		Japanese spindleberry
Hakea sericea		prickly hakea
Hedychium gardnerianum		ginger
Ligustrum lucidum		tree privet
Lophospernum erubescens		maurandya vine
Paraserianthes lophantha		brush wattle
Phyllostachys species		bamboo species
Pinus radiata		pine
Rhamnus alaternus		evergreen buckthorn
Rubus fructicosus		blackberry
Solanum mauritianum		woolly nightshade
Syzygium smithii		monkey apple
Tradescantia fluminensis		wandering willie
Ulex europaeus		gorse

B3. Plant pathogen species

Latin binomial	Māori name	Pakeha name
Austropuccinia psidii		myrtle rust
Phytophthora agathidicida		kauri dieback

B4. Pest animal species

Latin binomial	Māori name	Pakeha name
Canis lupus familiaris		dog
Capra hircus		feral goat
Cervus elaphus scoticus		red deer
Cervus nippon		sika deer
Dama dama		fallow deer
Erinaceus europaeus occidentalis		hedgehog
Felis catus		cat
Mus musculus		mouse
Mustela erminea		stoat
Mustela furo		ferret
Mustela nivalis vulgari		weasel
Petrogale penicillata		brush-tailed rock wallabies
Polistes chinensis		Asian paper wasp
Polistes humilis		Australian paper wasp
Rattus exulans		kiore
Rattus norvegicus		Norway rat
Rattus rattus		Ship rat
Sus scrofa		feral pig
Trichosurus vulpecula		brush-tailed possum
Vespula germanica		German wasp
Vespula vulgaris		common wasp

B5. Insect species

Latin binomial	Māori name	Pakeha name
Dodonidia helmsii	pepe pouri	forest ringlet

B6. Reptile species

Latin binomial	Māori name	Pakeha name
Dactylconemis pacificus	mokopāpā	pacific gecko
Hoplodactylus duvaucelii		Duvaucel's gecko
Hoplodactylus granulatus	mokopirirakau	forest gecko
Oligosoma moco	mokomoko	moko skink
Oligosoma smithi	mokomoko	shore skink
Sphenodon punctatus	tuatara	

B7. Native bird species

Latin binomial	Māori name	Pakeha name
Acanthisitta chloris	tītipounamu	rifleman
Anas chlorotis	pāteke	brown teal
Anthornis melanura melanura	korimako	bellbird
Apteryx mantelli		north island brown kiwi
Apteryx owenii	kiwi pukupuku	little spotted kiwi
Bowdleria punctata	mātātā; koroātito	fernbird
Callaeas wilsoni	kōkako	North Island kōkako
Cyanoramphus novaezelandiae	kākāriki	red crowned parakeet
Gallirallus australis	weka	woodhen
Gerygone igata	riroriro	grey warbler
Mohoua albicilla	popokatea	whitehead
Nestor meridionalis	kākā	
Notiomystis cincta	hihi	stitchbird
Pelecanoides urinatrix	kuaka	commonn diving petrel
Petroica longipes	toutouwai	North Island robin
Petroica macrocephala	miromiro	tomtit
Philesturnus rufusater	tīeke	North Island saddleback
Porphyrio hochstetteri	takahē	South Island takahe
Prosthemadera novaeseelandiae novaeseelandiae	tūī	tui
Pterodroma macroptera	ōi; tītī	grey faced petrel
Puffinus gavia	pakahā	fluttering shearwater
Rhipidura fuliginosa placabilis	pīwakawaka; pīwaiwaka	North Island fantail
Todiramphus sanctus vagans	kōtare	sacred kingfisher
Zosterops lateralis lateralis	tauhou	silvereye

B8. Introduced bird species

Latin binomial	Māori name	Pakeha name
Acridotheres tristis		common myna
Carduelis carduelis		European goldfinch
Fringilla coelebs	pahirini	chaffinch
Platycercus eximius		Eastern rosella
Turdus merula	manu pango	Eurasisn blackbird

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aucklandcouncil.govt.nz and knowledgeauckland.org.nz

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