Diversity, Abundance and Distribution of Terrestrial Birds in Tāmaki Makaurau / Auckland 2009-2024

State of the Environment Reporting

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August 2025 Technical Report 2025/17

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Executive summary

Birds serve as important environmental indicators; closely monitoring them helps us understand their population dynamics and gain insights into the quality of their habitats and the ecological functions essential for their survival. In New Zealand, bird surveys typically employ the standardised five-minute bird count method to collect the monitoring data presented in this report. This report outlines the findings from bird monitoring carried out within the Terrestrial Biodiversity Monitoring Programme (TBMP) covering forest and wetland habitats, which requires five years to complete a full monitoring cycle: forests (2009-2023) and wetlands (2011-2024).

Most birds counted in forest and wetland sites were indigenous species (67.8% and 55.63% respectively), with only a small percentage of these native species being regionally categorised as "Threatened" or "At Risk" (1.3% and 1.6% respectively). Four of the top five bird species monitored in forest plots were indigenous. Tauhou/silvereye (*Zosterops lateralis lateralis*) was the most common forest species, followed closely by tūī (*Prosthemadera novaeseelandiae novaeseelandiae*) and then riroriro/grey warbler *(Gerygone igata*), pīwakawaka/North Island fantail (*Rhipidura fuliginosa placabilis*) and the Eurasian chaffinch (*Fringilla coelebs*), all detected in >70% of bird counts. Silvereye was also the most counted species for wetland sites by far, followed by common myna (*Acridotheres tristis*), grey warbler, house sparrow *(Passer domesticus*) and tūī , all detected in >60% of counts.

Across both forest and wetland areas, species abundance and richness exhibited similar trends in different land classes. In regional and sub-regional forest and wetland sites, native species were more prevalent in indigenous land classes, while introduced species thrived in modified landscapes. Recent monitoring has shown a notable increase in the abundance and richness of native species over the years in forest and wetland sites, while the numbers of introduced species have remained stable. Further examination revealed that variations in populations of tūī, silvereye, grey warbler and pīwakawaka contributed to this increase in forests. Abundance of kererū (*Hemiphaga novaeseelandiae*) and kākā (*Nestor meridionalis*) in forests, and mātātā/fernbirds (*Poodytes punctatus*) in wetland were strongly linked to habitat quality, indicating their potential as indicators of habitat health. Although bird populations in wetlands displayed a strong preference for indigenous habitats, native species appear to be re-establishing themselves in altered areas. However, the still significant presence of introduced species in many wetland areas (Āwhitu, Inner Gulf Islands) is a sign of low-quality habitats that require management attention. As anticipated, regions surrounding expansive, healthy forests (Hunua and Waitākere Ranges, Aotea/Great Barrier Island) tend to support a greater diversity of native bird species.

This study identifies the importance of protecting the integrity of indigenous habitats to support our native bird populations. It has identified a positive trend in the numbers of native birds in forest and wetland habitats, which is encouraging. However, this trend is limited to habitat generalists, non-threatened species, highlighting the ongoing need for efforts to support native and endemic species

that rely on well-managed and preserved habitats for survival, as they remain largely marginalised in more urban and rural areas. It emphasises that well-managed forested areas, along with restored rural and urban environments, all serve as sanctuaries for the restoration and recovery of native biodiversity in forests and wetlands. It is vital to continually highlight the significance of refuge habitats in modified landscapes. The findings of this report illustrate the value of long-term biodiversity monitoring in identifying trends. They also uncover the need to reassess monitoring frameworks and planning to address information gaps, ultimately improving decision-making and management. Given that terrestrial birds serve as indicators of environmental health; their thriving populations reflect a healthier and more resilient Tāmaki Makaurau.

Contents

1 Introduction

Tāmaki Makaurau/the Auckland region is home to the largest human population in New Zealand, concentrated in the second smallest regional land area in the country. The region covers a mainland area of about 4,520 km^2 but also incorporates approximately 500 km^2 of islands in the Hauraki Gulf. Auckland has a diverse range of ecosystems within its boundaries, ranging from forests, freshwater wetlands, lakes, rivers, salt marshes, estuaries and duneland ecosystems in lowland and coastal areas (Auckland Council, 2015). The forest ecosystem alone presents wide diversity, composed of forest, scrub and shrubland vegetation (all hereafter collectively referred to as 'forest'), occurring from sea level to over 700 m altitude. Indigenous forests once dominated the Auckland region but has been progressively modified by socio-economic activities such as deforestation, agriculture and rapid urban growth (Meurk & Swaffield, 2000). The rapid development and use of Auckland's natural environment has resulted in less than half of the original forested land cover left with only 16 per cent of remaining forests classified as indigenous (LAWA, 2018). The result is a complex mosaic composition of largely fragmented and isolated small urban forest remnants and preserved forests in rural areas, limited unscathed forest areas in the mainland (Waitākere and Hunua Ranges), and significantly large and connected network of forests on offshore islands (Aotea/Great Barrier Island, and the predator-free Te Hauturu-o-Toi/Little Barrier Island) (Griffiths et al., 2021). Auckland's remaining freshwater wetland ecosystems comprise a tiny fragment of their previous extent, with only four per cent of the original wetland areas left (Lawrence & Bishop, 2017). Wetlands are highly significant habitats as they support specialist biodiversity as well as a myriad of ecosystem services (Ministry for the Environment & Stats NZ, 2024; Ministry for the Environment & Stats NZ, 2019; Zedler & Kercher, 2005).

Despite its fragmentation, and being New Zealand's largest urban area, Auckland continues to host a remarkable array of avian biodiversity (Griffiths et al., 2021; Landers et al., 2021; Lovegrove & Parker, 2023). Although Tāmaki Makaurau is home to 230 bird taxa (Woolly et al., 2024), a small part of Auckland's overall biodiversity, birds serve as crucial indicators of environmental shifts (Fraixedas et al., 2020; Gregory et al., 2003). They inhabit a variety of terrestrial environments and often play a top predator role in food webs, making them sensitive to ecological changes (MacLeod et al., 2012). Birds depend on healthy habitats for survival and successful reproduction, as well as robust trophic networks for sustenance. Environmental pressures that disrupt their habitat or the ecological web can threaten the stability of bird populations. Population trends may vary across environmental gradients, reflecting habitat quality. Consequently, birds are recognised as valuable indicators of environmental change (Díaz et al., 2006; Fea et al., 2020; Gregory et al., 2003). Bird monitoring can help evaluate the success of conservation and management efforts. Additionally, terrestrial birds play an essential ecological role by acting as pollinators and seed dispersers for indigenous plant species (Clout & Hay, 1989; Kelly et al., 2010). Certain species, like the kererū, occupy specific ecological niches, making them the sole dispersers of large-fruit-bearing plant species such as the karaka tree (Landers et al., 2021).

Further, New Zealand's terrestrial birds are well known for having interesting adaptations and high vulnerability to predation due to evolving in a land originally free of mammals. This has caused the human population of New Zealand to strongly identify with its flying feathered taonga, resulting in strong cultural value and interest in protection and restoration efforts (Galbraith et al., 2014; Tidemann & Gosler, 2010). Despite their ecological and cultural importance, 82% of indigenous bird species in New Zealand are Nationally Threatened (Ministry for the Environment & Stats NZ, 2024) and 23% percent of species in the Auckland region are Regionally Threatened or At Risk (Woolly et al., 2024). With the advancement of climate change and its impacts (Pearce et al., 2018), as well as biodiversity declines resulting from anthropogenic effects (e.g., habitat loss caused by urbanisation, introduction of invasive species) (Belder et al., 2018; Butchart et al., 2010; Waldron et al., 2017), the scenario is not in favour of terrestrial bird recovery. Thus, monitoring the state and trend of terrestrial bird populations in the most populated city of New Zealand is important in preserving their integrity, promoting their recovery and better understanding their habitats.

1.1 Regional Bird Monitoring Programme

Under Section 35 of the Resource Management Act 1991 regional councils are responsible for the ongoing monitoring and periodic reporting on the states and trends of the regional natural environment, named State and Trend of the Environment Reports (hereafter SoE). Auckland Council is committed to the management of regional biodiversity through the Auckland Council Indigenous Biodiversity Strategy 2012 and the Auckland Plan 2050 (Griffiths et al., 2021). Collecting and sharing knowledge from monitoring programmes is an important step for informing the evaluation of key regional and national policies and strategies. Auckland Council collects information on terrestrial bird populations across the Auckland region under the Terrestrial Biodiversity Monitoring Programme (TBMP) (Landers et al., 2021). The TBMP started in 2009 under the previous Auckland Regional Council (ARC) as a comprehensive and systematic effort to monitor the wide range of habitats present in the Auckland region (Hurst et al., 2022; McNutt, 2012). Initially, the TBMP monitored forest ecosystems across the region using standard 20 m by 20 m plots (Hurst et al., 2022; McNutt, 2012) along with secondary pest and bird monitoring metadata (Landers et al., 2021). In 2010 (under Auckland Council), the TBMP was expanded to include additional plot-based vegetation monitoring of regional wetland ecosystems, and in 2011, bird count monitoring was added to the wetlands programme (Landers et al., 2021). In 2017, a coastal dune monitoring programme was established on a 10-year rotation, which included both plant and bird surveys. This programme has not yet completed a full 10-year cycle of monitoring and therefore will be reported on a future document. Within the TBMP, the terrestrial bird monitoring focuses on monitoring the state and trends of terrestrial bird populations in forest, wetland and dune ecosystems across the Auckland region to better inform management strategies and decision making for terrestrial biodiversity.

1.2 Aims and scope

The Auckland region showcases significant variation in its geographical and topographical features, alongside differing development pressures and land use activities. Over the past 15 years, the Terrestrial Biodiversity Monitoring Programme (TBMP) has sought to capture this extensive spatial and temporal range of bird populations. This report intends to analyse the current state and trends of terrestrial bird communities within Auckland, based on data collected from 2009 to 2024, to highlight the region's rich and complex bird biodiversity. The TBMP has successfully completed three monitoring cycles, each spanning five years, with this being the third cycle. The cyclical approach, methodological rigour and expertise of bird specialists assigned as observers in the TBMP have yielded a substantial dataset that helps to inform trends in terrestrial bird communities and enhance the findings presented in the most recent State of the Environment Report (SoE) by Landers et al. (2021).

The Bird monitoring data were collected within the scope of the broader terrestrial monitoring (TBMP), resulting in bird monitoring data categorised into forest and wetland habitat types. The forest monitoring segment is further divided into tiers to focus on various aspects of terrestrial monitoring: Tier 1 provides comprehensive regional coverage for forest monitoring; Tier 2 offers site-specific coverage of significant 'Areas' of Auckland, selected based on ecological or public interest (e.g., areas of specific conservation importance or targeted management programmes); while Tier 3 provides site-specific coverage of important high conservation management 'Areas' of Auckland. Wetland data is divided into regular monitored data, which accounts for all birds identified during bird monitoring, as well as focused monitoring to account for specific wetland endemic species (e. g., fernbird), which might be overlooked during standard counts due to their elusive nature (see methods below).

The monitoring sites for forest and wetlands underwent an analysis to categorise their dominant landscapes (e. g., indigenous plant communities, agricultural landscapes) and were spatially classified into Ecological Districts that group plots according to various spatial, ecological, and socio-economic factors (see 2.3.2.2. Spatial scale/ecological regions: Ecological Districts). These variables reflect habitat quality, suggest increased fragmentation in highly modified regions (such as urban forests typically bordered by houses rather than forests), and enable us to explore the impact of forest and wetland distribution and management on our bird biodiversity. Our comprehensive monitoring dataset, combined with environmental, spatial, and temporal gradients, will be analysed to reveal the state and trends of terrestrial birds in the Auckland region over the past 15 years, informing decision-making and biodiversity management.

1.3 Supporting Information

This report is one of a series of technical publications prepared in support of *Te oranga o te taiao o Tāmaki Makaurau – The health of Tāmaki Makaurau Auckland's Natural Environment in 2025: a synthesis of Auckland Council State of the Environment reporting*.

All related reports (past and present) are published on the Knowledge Auckland website.

All data supporting this report can be requested through our Environment Auckland Data Portal. Here you can also view live rainfall data and use several data explorer tools.

2 Methods

2.1 Study area and frequency

Both the forest and wetland components of the TBMP include sites dispersed across the Auckland region (Figures 1 and 2), which were established using a grid-based approach.

For the forest programme, 313 sites were established and surveyed in forest, scrub, and shrubland vegetation across the region based on the national Tier 0 8 km × 8 km grid used by both the Department of Conservation and the Ministry for the Environment. Different spatial scales were used to allow adequate replication and statistical power to enable reporting on important areas of Auckland, with details of this 'tiered' approach shown in Table 1. Forest sites (Figure 1) have been surveyed between October and December every year, with only a few exceptions surveyed between February and March. A large number of sites in Rotation 2 were not re-surveyed as planned because of staff and funding shortages. Tier 3 sites are now monitored by the Environmental Services department at Auckland Council and the latest monitoring cycles for Tier 3 sites were not available for this report. Previous Tier 3 results are available in Landers et al. (2021).

For wetlands, 187 sites have been established using a 4 km ×4 km grid (based on the national 8 km × 8 km grid). Grids that met the criteria for sampling contained a freshwater or brackish wetland system within the grid square that was large enough to accommodate a 15 m ×15 m vegetation plot where bird surveys were conducted. All wetland sites (Figure 2) generally have been surveyed in March, however in some years this varied slightly, with some sites surveyed in early April.

Table 1. Forest programme tier structure. All Tier 1-3 sites are confined to forest, scrub or shrubland vegetation types. Most Tier 1 and 2 sites are on a ten-year rotation, except ~30 sites in the Waitākere Ranges which are maintained in a five-year rotation as part of the Waitākere Ranges Heritage Area reporting.

Tier	Site details	Reporting goals	Spatial grid size	Rotation period
I	Regional: (e.g., entire region, comparisons between public versus private lands, islands versus mainland)	State of the Environment Reporting and policy effectiveness, e.g., National Biodiversity Strategy (NBS), Regional Policy Statement (RPS), and Auckland Regional Pest Management Strategy (ARPMS)	4km ×4km	5-10 yearly
II	Site specific coverage of important 'Areas' of Auckland for ecological and/or public interest reasons: Aotea, Urban Auckland (MUL* based), Āwhitu, Hunua Ranges, South Kaipara, Tāpora , Waiheke Island, Waitākere Ranges	Policy effectiveness: Regional Policy Statement (RPS) and Waitākere Ranges Heritage Area Act (WRHAA)	2km ×2km	5-10 yearly
III	Site specific coverage of important 'Areas' of Auckland that have high management interventions: Ark in the Park, Glenfern, Kōkako Management Area, Hauturu, Motutapu Island, Rangitoto Island, Shakespear Regional Park (Rotation 2 only), Tamahunga, Tāwharanui Regional Park, Windy Hill	Management/Restoration plans (Performance / Result monitoring and biodiversity outcome monitoring)	Various (mostly 500-700m)	1-5 yearly

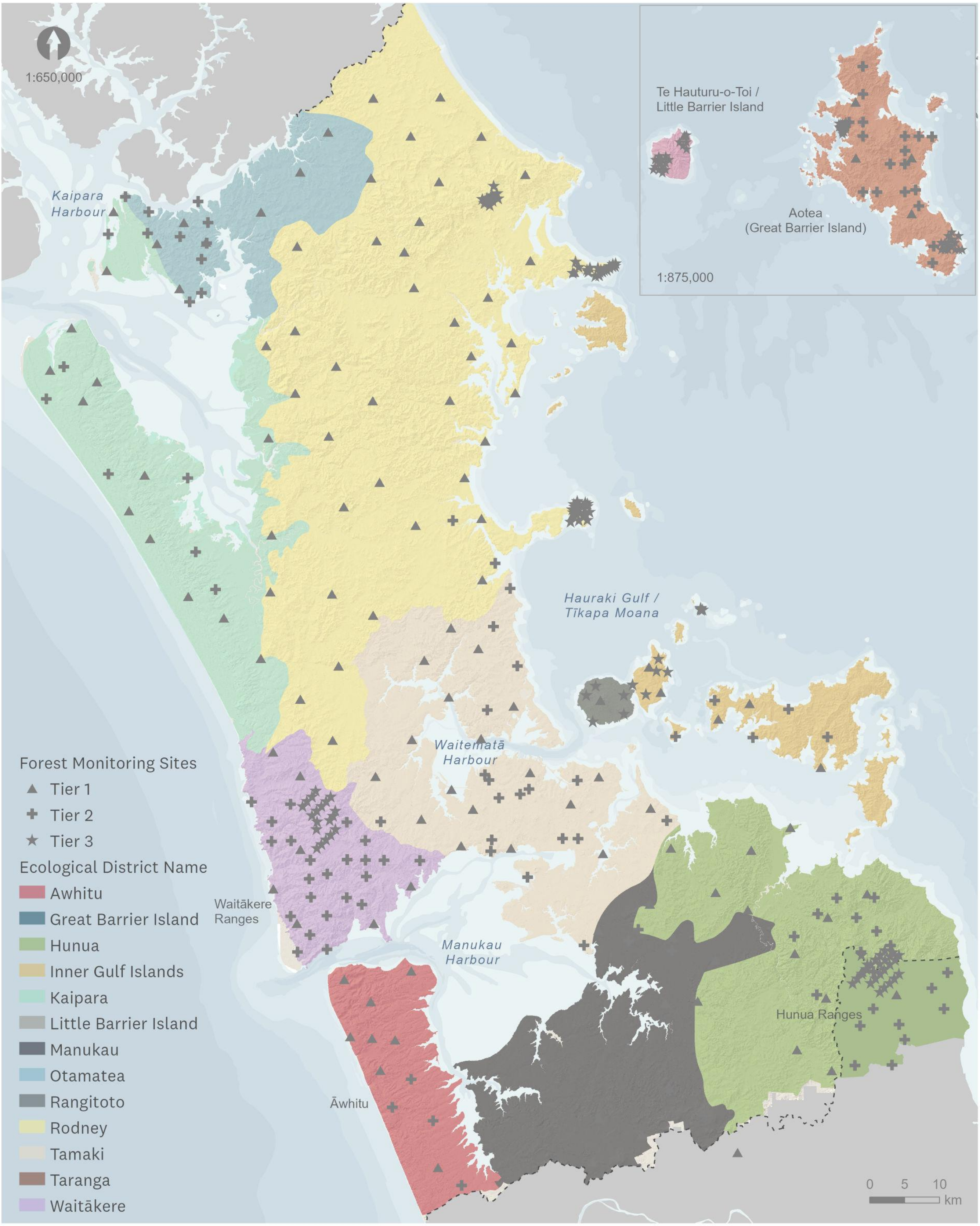

Figure 1. Regional Bird Monitoring Programme. Forest sites separated by Tiers (Forest only) and showing Ecological District distribution.

Figure 2. Regional Bird Monitoring Programme. Wetland sites showing Ecological District distribution.

2.2 Bird surveys

Bird monitoring was conducted at all TBMP sites using the ten-minute bird count method (hereafter 10MBC) divided into two distinct five-minute observation phases. At each site, observers performed three 10MBC monitoring counts on the same day for a given monitoring cycle (i.e., three 10MBC in one monitoring day per cycle per site). All three counts were conducted between the first hour after sunrise and before 13:00 hours, with each 10MBC count spaced by at least one hour from each other. Each count began with two minutes of silence, followed by five minutes of observation following the New Zealand standard “five-minute bird count protocol” commonly seen in New Zealand bird surveys (Dawson & Bull, 1975; Hartley, 2012; MacLeod et al., 2012; Miskelly, 2018). In this methodology, all birds heard and seen were counted and the species was identified and manually recorded for the Five-Minute Bird Count (hereafter 5MBC). During the second half of the 10BMC, after the first 5MBC was finalised, only new species not previously detected were recorded. Playback lures were used during the survey to detect the presence of wetland-specific species (fernbird- *Megalurus punctatus*, spotless crake - *Porzana tabuensis* and banded rail - *Gallirallus philippensis*), since these species are highly cryptic. This second five-minute observation period allows for a more thorough assessment of species richness at each site. Every bird observed was included regardless of the distance from the observer, with observation distance recorded in the metadata. In consideration of the possible impact of wind and rain on bird count results (Dawson & Bull, 1975; Hartley, 2012), counts were limited to ideal weather conditions, wherein observers considered their ability to properly hear and see birds would not be impaired.

2.3 Analyses

2.3.1 Variable calculations – Response variables.

This study examined three categories of bird biodiversity: indigenous species, introduced species, and the proportion of indigenous species among all species counted.

Three main variables were computed for analysis to represent these categories: The abundance of native and introduced birds (mean number of birds per count at each site), the richness of native and introduced birds, and indigenous dominance (percentage of indigenous species observed). Although our models did not indicate significant relationships between indigenous dominance and other metadata variables, we retained this variable to enhance our understanding of abundance and richness patterns. For all abundance calculations, we used the first five minutes of 10MBC (5MBC), while richness variables incorporated all species counted in the entire 10MBC. Refer to Table 2 for descriptions of the calculation process for all response variables.

The complete lists of species were compiled for forests and wetlands, as reported in sections 3.1.1 and 3.3.1, along with the mean abundance (mean number of individuals per 5MBC) and probability of detection (percentage of 5MBCs that included the species) for each species in each habitat type. We also calculated total species richness (the overall number of species from all counts) for both forests and wetlands. Lastly, the same calculation methodology was employed for the abundance of individual species at each site, which will be utilised in the indicator species analysis sections (section 3.2 for forest species and section 3.4 for wetland species).

Table 2. List of variables used in analyses. Further detail on how these variables were calculated in appendix.

Variable group	Variable names	Variable definition
Abundance	Mean Indigenous Species Abundance	Mean number of individuals per count that were indigenous species
	Mean Introduced Species Abundance	Mean number of individuals per count that were introduced species
	Mean Indigenous Dominance (Species Abundance)	Mean percentage of individuals that were indigenous species of the total individuals counted
Richness	Mean Indigenous Species Abundance	Mean number of indigenous species
	Mean Introduced Species Abundance	Mean number of introduced species
	Mean Indigenous Dominance (Species Richness)	Mean percentage of indigenous species of total species counted
Total species summary	Total Species Richness	Total number of species from all counts
	Mean Species Abundance	Mean number of individuals per 5MBC for each species detected
	Probability of Detection	Percent of 5MBCs that contained the species

2.3.2 Variable calculations – Independent variables

2.3.2.1 Time scale: rotation

Each monitoring rotation is associated with a five-year period when the TBMP was undertaken. To date there have been a total of three rotations between 2009-2023. In total, it takes five to ten years to sample the full set of sites (i.e., one fifth of each programme is sampled each year). There are three ‘classes’ of monitoring undertaken within each rotation – Forest Tier 1, Forest Tier 2 and Wetlands. For example, Rotation 1: Forests (Tier 1 and 2 sites) can be attributed to monitoring seasons between 2009-2013 and Rotation 1: Wetlands applies to monitoring undertaken between 2011-2014. Table 3 details these different rotations, the applicable time periods and the number of sites for each of the classes. It is important to note that each rotation for each monitoring class is not equal, as there have been changes between the number of sites monitored between each of the rotations for each class, but for many sites for each programme, at least two rotations had been completed. The major exceptions to this are for wetland sites, which had no bird counts conducted the first year in 2010 and experienced a reduction in the number of sites for Rotation 2: Wetlands.

Between Rotations 1 and 2 for Forest (Tier 1), there was a 60% reduction in the number of plots monitored – this was the result of a prioritised monitoring initiative that was applied to the whole TBMP programme. Seventy-eight plots from the first Forest Tier 1 rotation were either put on hold or moved to a 10-year rotation, while 56 plots continued to be visited on a five-year rotation and were monitored for Rotation 2 (Griffiths et al., 2021). Rotation 3: Forest Tier 1 was more complete due to the reintroduction of the sites that had been put on to the 10-year rotation period during Rotation 2. Tier 3 sites are now monitored by the Environmental Services department at Auckland Council. Results from the latest monitoring cycles for Tier 3 sites will be presented by Environmental Services, previous rotations are published in Landers et al. (2021).

Table 3. Number of sites monitored in each rotation (five-year cycle) for forest (tiers 1 and 2) and wetland sites included in this report.

Programme	Rotation	Rotation time-period	Number of sites
Forest – Tier 1	1	2009-2013	123
	2	2014-2018	50
	3	2019-2023	104
Forest – Tier 2	1	2009-2013	89
	2	2014-2018	46
	3	2019-2023	70
Wetland	1	2010-2014	146
	2	2015-2019	177
	3	2020-2024	158

2.3.2.2. Environmental gradient: Land Cover Classification

To analyse the relationship between habitat quality and terrestrial bird distribution, abundance, and richness, a variable indicating the proportions of broad land cover classes in forest and wetland sites was introduced. The New Zealand Land Cover Database (LCDB), a comprehensive classification of New Zealand's land cover over time at national and regional scales, served as the primary data source. While the national LCDB (version 5.0) identifies 33 mainland land cover classes (29 of which are relevant to Auckland) with time steps up to 2018/19, this study utilised a provisional 2023/24 LCDB update for the Auckland region (Auckland Council, 2025). This regional update was essential as the forthcoming national LCDBv6 was not yet available for inclusion in Auckland Council's State of the Environment 2025 reporting, thereby providing the most contemporary assessment of land cover for Auckland.

This provisional dataset allowed for a habitat quality variable to be calculated, representing a gradient from preserved to modified landscapes at each plot location. To quantify this, land cover data were calculated for each bird count site by summing all LCDB categories within a 1000m radius and subsequently grouping these into broad Land Classes (see Table 4). It's important to note that, as a provisional dataset, the information contained within is subject to change.

Table 4. Land Class categories calculated for bird count sites by summing all LCDB categories in a 1000m radius and then grouping the results if they had >50% coverage of the following classes:

Land Cover classification	LCDBv6 Categories
Indigenous	Broadleaved Indigenous Hardwoods
	Fernland
	Flaxland
	Herbaceous Freshwater Vegetation
	Herbaceous Saline Vegetation
	Mangrove
	Mānuka and/or Kānuka
	Indigenous Forest
	Grey Scrub
Rural	Gorse/Broom
	High Producing Exotic Grassland
	Low Producing Grassland
	Mixed Exotic Shrubland
Urban	Built-up Area (settlement)
	Transport Infrastructure
Mixed	All remaining categories

2.3.2.3. Spatial scale/ecological regions: Ecological Districts

Ecological District is a national framework that classifies different regions in New Zealand into a range of delimited landscapes with a unique combination of characteristics, according to a multifaceted combination of topography, geology, climate, soil, biological communities and anthropomorphic changes (Park et al., 1983). The resulting spatial data are presented as polygon objects representing each Ecological District, over a digital dataset including the boundaries on the 1:500,000 published maps of ecological regions and Ecological Districts of New Zealand (Department of Conservation, 1987). Figures 1 and 2 above show the distribution and boundaries of ecological districts in the Auckland region. This variable was included in our analysis to account for geo-spatial and socio-ecological similarities and differences between sites when interpreting the results.

2.3.3. Data analysis

2.3.3.1 Multivariate analysis

To maximise sample size, we pooled data from all sites across both Tier 1 and Tier 2 for forest samples. However, where variation observed in Rotation 3 suggested temporal changes and fluctuations in biodiversity trends, data from Rotation 3 were isolated for post hoc analysis.

Wetland data were analysed separately for the regular 5MBC and playback. For this analysis, we isolated richness and abundance in rotation 3 (2019-2024) to assess the current biodiversity state. To evaluate spatial and temporal scales in abundance and species richness, we tested normality (Shapiro-Wilk) and homogeneity of variance (Brown-Forsythe) for all response variables (abundance and richness) and log-transformed (log10) when necessary to meet normality and fulfil the assumptions of general and linear models. To evaluate the relationship between response and explanatory variables, we applied Linear Mixed Models (LMM) or Generalised Linear Models (GLM) in R version 4.5.1 for each response variable within each data category (Table 5), utilising the “lme4” and “glm2” packages. R2 values, the Akaike Information Criterion (AIC), and the “drop1” function in R were employed to assess the fit quality of statistical models to the data distribution (Berk et al., 2016) and to select the best predictors explaining variation in the response variables.

Both fixed and random effects were included as independent variables (Table 5), with only category combinations having at least five replicates included in the analyses. Initially, ecosystem types and wetland classes were treated as fixed effects in models to assess their predictive power concerning response variable variation (e.g., abundance for Tier 1 sites). However, preliminary results and close examination of data distributions showed these variables could act as covariates with other fixed effects in the models. Most variation within each ecosystem type stemmed from differences in land cover dominance or Ecological District. In essence, variations in abundance or richness within the same ecosystem type resulted from other environmental gradients rather than significant ecological type differences, leading to their exclusion as fixed effects to prevent model overfitting. Some ecosystem types exhibited no variation in land cover classification (our habitat quality indicator variable), rendering them unable to be accurately assessed for ecological differences between sites.

Similarly, variation in wetland class across our response variables was mostly influenced by the underlying data distribution, with many wetland sites categorised within the Swamp and Marsh classes. Due to data imbalances, these variables were included as random factors in models (Table 5) to manage and account for natural variations within environmental gradients, following Griffiths et al. (2021).

Finally, factors such as plot identity (site names) to account for resampling over the years, and observer ID to mitigate observer bias from the monitoring specialist conducting the counts, were also incorporated into the models as random effects. In some cases (e.g., indicator species – silvereye status) random effects were excluded entirely due to low variability in the data sample and linear mixed models (LM) were used instead of GLMs. All statistical analyses were performed using R packages and the R Studio console.

Table 5. List of variables used in analyses and structure of GLMs. All independent variables were initially included in the model formula to find the best prediction model. Upon model evaluation variables were excluded, if ecologically reasonable, to improve prediction.

Data group	Response variable	Independent variable – Fixed effects	Independent variable – Random effects	Test Type
Forest monitoring – tier 1	Richness, Abundance	Rotation, Land cover classification, Ecological District, plot history	Observer, site name, ecosystem type	GLM
Forest monitoring – tier 2	Richness, Abundance	Rotation, Land cover classification, Ecological District, plot history	Observer, site name, ecosystem type	GLM
Wetland monitoring – No playback data	Richness, Abundance	Rotation, Land cover classification, Ecological District	Observer, site name, wetland class	GLM
Wetland monitoring – Playback data	Abundance	Rotation, Land cover classification, Ecological District	Observer, site name, wetland class	GLM
Forest/Wetland Indicator Species	Species abundance	Rotation, Land cover classification, Ecological District, plot history	Observer, ecosystem type	GLM/LM

2.3.3.2. Indicator species – Threshold Indicator Taxa Analysis (TITAN)

To identify relevant species that varied significantly over gradients of monitoring in the TBMP, a Threshold Indicator Taxa Analysis (TITAN) was applied. TITAN uses abundance within a sample group to calculate Individual Value (IndVal) scores, and identify possible indicator species (Baker & King, 2010). IndVal scores are more useful in seeking to uncover indicator species than just simple models of abundance variance because they integrate occurrence, frequency and directionality of taxa response and result in a measure of association unbiased by group size (Dufrêne & Legendre, 1997).

3 Results

3.1 Forest birds – States and trends

3.1.1. Forest – Total species summary

In total, 477 bird counts were conducted across 241 forest sites (encompassing forest, scrub, and shrubland) during the monitoring study period from 2009 to 2023. During this timeframe, 32941 individual birds were observed. Most of the species recorded were indigenous, with 44.42% being endemic and 23.05% native, while 32.52% were introduced (see Table 6). This finding aligns with the results of a previous bird biodiversity survey in the Auckland region, published five years ago, which reported that introduced species comprised 31.2% of the monitored birds in forest plots (Landers et al., 2021). Furthermore, 1.3% of the species recorded have been designated as threatened or at risk (Table 7) based on the Regional Conservation Status (Woolly et al., 2024). The total species richness comprised 62 species, with four of the five most abundant species throughout the monitoring period being indigenous (Table 8), aligning with the findings from the 2021 report. Notably, in that report, the tūī was identified as the most abundant species, and the Eurasian blackbird ranked fifth (Landers et al., 2021); however, in the latest findings, the tauhou/silvereye has taken the top spot, and the chaffinch is now in fifth place (Table 8). Regarding bird counting methods, a significant majority of detections were made by sound, with 83.7% being aural compared to 4.7% visual detections, while 11.7% of birds were recorded under "Presence" only after the 5MBC. Since the 2021 report, the average number of birds detected per count has risen by 33.21%, with the total number of birds counted per rotation decreasing from 383.62 in rotation 1 to 288 in rotation 2 (considering only tier 1 and 2 sites) and increasing to 342.7 in rotation 3.

Table 6. Status of species counted at 241 forest sites in 477 counts in Auckland.

Status	Count	Percentage of total birds
Endemic	13477	44.42%
Indigenous	5920	23.05%
Introduced	9768	32.52%

Table 7. Regional conservation status of indigenous species (Woolly et al., 2024) counted at forest sites in the Auckland region. Species classified as “Regionally Critical”, Regionally Endangered”, “Regionally Vulnerable”, or “Threatened” were considered threatened or at risk for our proportion calculations. A small proportion of the species had no regional classification available and were not included in this table (Count = 298, 0.2% of total birds).

Conservation Status	Counts	Percentage of total birds
Regionally Not Threatened	77527	56.30%
Regionally Introduced and Naturalised	51650	37.50%
Regionally Recovering	4467	3.20%
Regionally Vulnerable	1612	1.20%
Regionally Relict	1696	1.20%
Regionally Increasing	119	0.10%
Regionally Endangered	199	0.10%
Regionally Critical	24	0.00%

Table 8. Mean Species Abundance and Probability of Detection of all bird species counted (32941 total individual birds in bird counts conducted from 2009-2023) at Tier 1 and Tier 2 forest sites (n = 241) in Auckland.

Species Counted		Total Species Abundance	Total Standard Error (SE)	Probability of Detection (%)
Silvereye	Tāhou	3.97	0.04	92.72
Tūī	Tūī	3.79	0.05	94.42
Grey warbler	Riroriro	2.98	0.03	96.84
North Island fantail	Pīwakawaka	1.74	0.03	88.35
Chaffinch	Pahirini	1.53	0.03	77.91
Eurasian blackbird	Manu pango	1.4	0.03	81.07
Common myna	Māina	1.27	0.04	68.93
Sacred kingfisher	Kōtare	1.12	0.02	80.34
Eastern rosella	Kākā uhi whero	1.07	0.04	68.45
Bellbird	Korimako	0.63	0.26	19.9
European goldfinch	Kōurarini	0.59	0.07	45.15
New Zealand pigeon	Kererū	0.5	0.03	53.64
House sparrow	Tiu	0.44	0.12	28.16
Kākā	Kākā	0.42	0.13	24.51
European greenfinch	Kākāriki matomato	0.38	0.05	39.32
Song thrush	Manu-kai-hua-rākau	0.37	0.04	40.78
Whitehead	Pōpokatea	0.35	0.14	12.14
Shining cuckoo	Pīpīwharauroa	0.34	0.03	44.9
Common pheasant	Peihana	0.28	0.02	34.95
Eurasian skylark	Kaireka	0.26	0.07	25.49
Pūkeko	Pūkeko	0.22	0.06	24.03
Australian magpie	Makipae	0.17	0.04	24.76
Yellowhammer	Hurukōwhai	0.16	0.06	20.39

Species Counted		Total Species Abundance	Total Standard Error (SE)	Probability of Detection (%)
North Island robin	Toutouwai	0.15	0.09	10.44
Common starling	Tāringi	0.13	0.08	17.72
Welcome swallow	Warou	0.1	0.15	14.56
Spur-winged plover		0.08	0.11	11.89
Paradise shelduck	Pūtangitangi	0.06	0.09	9.47
Peafowl	Pīkake or Pīkao	0.06	0.2	4.85
Dunnock		0.06	0.06	10.44
Red-billed gull	Tarāpunga	0.06	0.19	8.74
Red-crowned parakeet	Kākāriki	0.06	0.12	6.8
Swamp harrier	Kāhu	0.05	0.03	12.62
California quail		0.05	0.07	9.71
Long-tailed cuckoo	Koekoeā	0.05	0.15	3.16
Variable oystercatcher	Torea pango	0.04	0.33	5.34
Spotted dove		0.04	0.09	7.52
Chicken	Heihei	0.03	0.2	3.88
Sulphur-crested cockatoo		0.03	0.24	1.94
Rock pigeon		0.03	0.34	3.16
Black swan	Kakīānau	0.03	0	0.24
Stitchbird	Hihi	0.03	0.14	2.91
North Island kōkako	Kōkako	0.03	0.13	4.37
White-faced heron	Matuku moana	0.01	0.24	1.46
Gull species	Tarāpunga / Tarapuka	0.01	0.18	2.67
Mallard		0.01	0.06	3.4
Black shag	Kawau tūī / Kawau paka	0.01	0	0.24
Barbary dove		0.01	0	1.46
Canada goose		0.01	0.17	1.21
Yellow-crowned parakeet	Kākāriki	0.01	0.17	0.73
North Island rifleman	Titipounamu	0.01	0.42	0.97
Pied shag	Karuhiruhi	0	0	0.73
Wild turkey		0	0	0.97
Pied stilt	Poaka	0	0.5	0.49
Morepork	Ruru	0	0	1.21
White-fronted tern	Tara	0	0.5	0.97
Brown quail		0	0	0.24
Caspian tern	Taranui	0	0	0.24
Australasian gannet	Takapu	0	0	0.24
North Island fernbird	Mātātā	0	0	0.24
Spotless crake	Pūweto	0	0	0.73

3.1.2. Forest – Tier 1: Regional patterns

Abundance: State and Trends

For Tier 1 plots, we assessed the number of native and non-native birds per plot. Analysing these relative abundance values enables us to identify patterns and trends in the abundance of both native and introduced species as part of our comprehensive monitoring of regional forest sites. This monitoring tier includes a variety of forest types rather than focusing on specific areas of interest, and any observed patterns may reflect the overall state and trends of biodiversity in the Auckland region. Notably, overall species abundance was significantly higher in modified land classes (rural, mixed, urban), which exhibited substantially greater bird abundance (Table 9) compared to indigenous land classes (Figure 3). Specifically, rural areas demonstrated the highest species abundance among land classes (Figure 3). A portion of the variation in abundance arose from natural differences between sites (small variation) and observer bias (more significant variation) observed across different monitoring events (Table 9).

The initial modelling did not clearly indicate whether the abundance of native and introduced species varied across Land Classes. We specifically examined native abundance, which appeared significantly lower (Table 10) in rural locations compared to indigenous sites (Figure 4), contrasting with the overall abundance results (Figure 3). There was also a significant increase in native abundance from rotation 1 to rotation 2 of the bird monitoring programme (marginal significance) and a notable rise in rotation 3 compared to rotation 1 (Table 10 – Figure 5). Differences in natural forest sites and observer bias explain much of the variation in native abundance (Table 10).

Essentially, native species abundance follows a different trend from overall abundance across land classes. Bird numbers are the highest in rural landscapes, likely linked to increased food and habitat availability relative to urban and indigenous regions (Blackwell et al., 2008). These areas may also be home to introduced, more generalist species (Seto et al., 2012; Soanes et al., 2019). Native species seem more abundant in indigenous landscapes and there appears to be a positive trend in native species abundance over time.

Table 9: General Linear Mixed Model results for Tier 1 Forest sites comparing estimated abundance variation to land cover classification. Land cover as a fixed effect only explained 4.4% of abundance variation (Marginal R^2 = 0.044). Natural differences between sites and observer bias (random effects) were responsible for a small part of the abundance variation. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.73	-0.54	**<0.001**
Land Cover – Mixed	0.14	0.54	**<0.001**
Land Cover – Rural	0.12	0.46	**<0.001**
Land Cover – Urban	0.14	0.53	**<0.001**
Random Effects			
Site Identification	0.02		
Observer bias	0.05		
Observations	570		
Marginal R^2 / Conditional R^2	0.044 / 0.273		

Table 10. General Linear Mixed Model results for Tier 1 Forest sites isolating estimated native abundance variation and comparing to land cover classification and rotation. Land cover as a fixed effect explained 21.9% (Marginal R2 = 0.219) of native abundance. Natural differences between sites and observer bias, (random effects) had essentially zero variance. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.92	-0.20	**<0.001**
Land Cover – Mixed	0.03	0.14	0.436
Land Cover – Rural	-0.08	-0.41	**0.018**
Land Cover – Urban	0.02	0.12	0.595
Rotation 2	0.05	0.24	0.078
Rotation 3	0.09	0.48	**0.001**
Random Effects			
Site Identification	0.01		
Observer bias	0.01		
Observations	288		
Marginal R^2 / Conditional R^2	0.219 / NA		

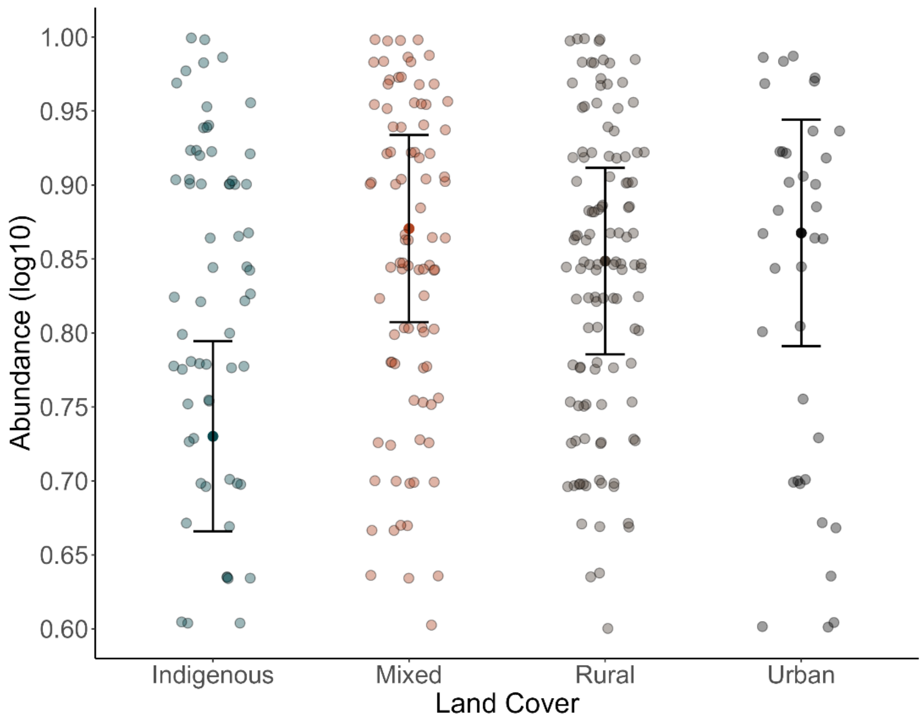

Figure 3. Overall predicted mean abundance for birds counted at Tier 1 (regional) forest sites by Land Class (Land Cover Classification). Error bars = Confidence Intervals from model estimates. Data points = abundance distribution.

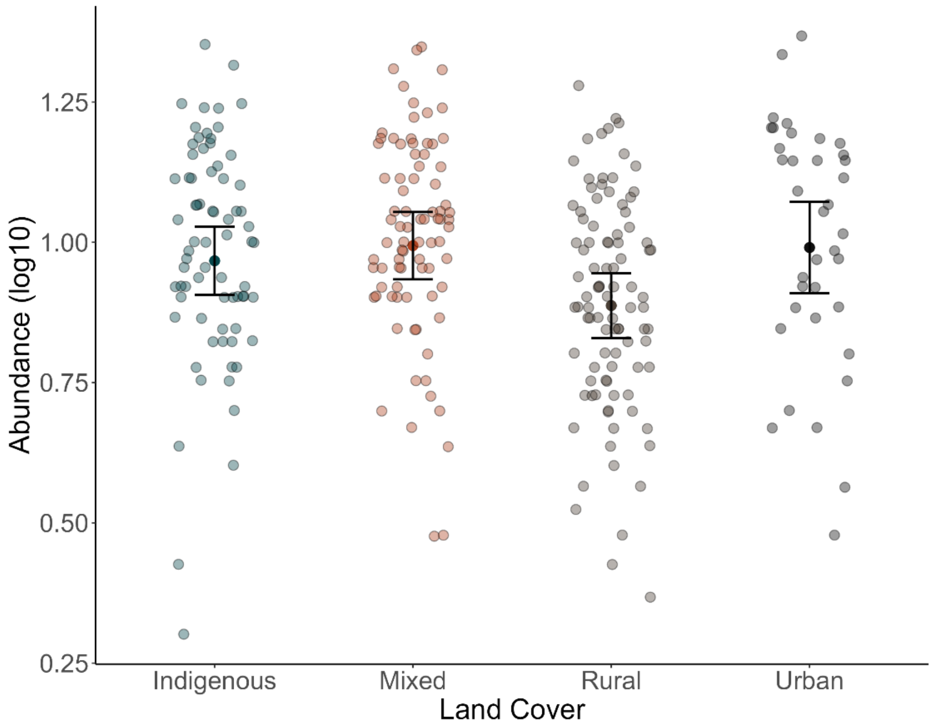

Figure 4. Predicted mean abundance for native species only for birds counted at Tier 1 (regional) forest sites by Land Class (Land Cover Classification). Error bars = Confidence Intervals from model estimates. Data points = abundance distribution.

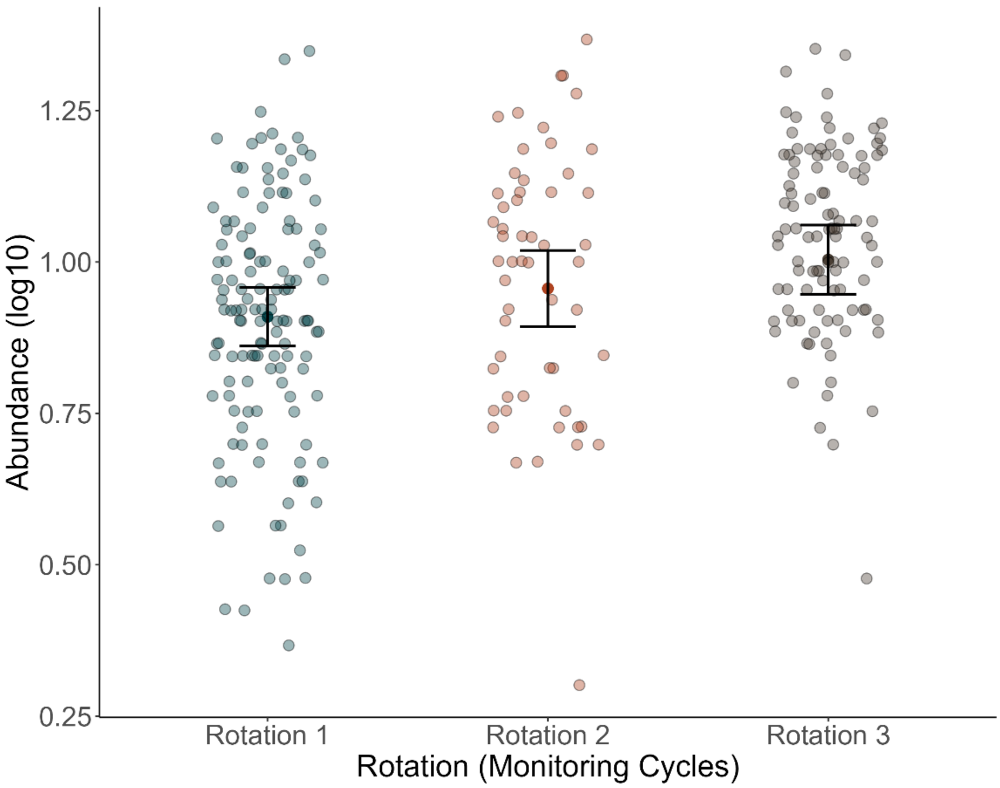

Figure 5. Variation in predicted mean native bird abundance among monitoring rotations for Tier 1 sites (regional). Native bird abundance increases significantly between rotations 1 and 3. Error bars = Confidence Intervals from model estimates. Data points = abundance distribution.

Richness: States and Trends

We calculated the number of native and introduced species per site for Tier 1 plots, using this variable to evaluate any significant patterns and relationships in how the number of species varied over time and? space. Richness variation was analysed to identify the current state of native/introduced species in forest plots and uncover any trends in richness variation for our regional sites. Modelling showed that richness varied significantly across land classes, and richness trends across land cover differed for native and introduced species (Table 11). Plots dominated by rural and urban land classes showed significantly lower difference between introduced and native species richness compared to indigenous land classes, where native species dominated (Figure 6). Native species showed significantly higher richness than introduced species in indigenous dominated land classes (Figure 6).

In other words, native species tend to be more dominant in indigenous landscapes compared to introduced species, which can thrive similarly to native species in more modified environments (Figure 6).

Table 11. General Linear Mixed Model estimates for Tier 1 Forest sites comparing estimated richness variation for introduced and native species separately to Land Class (land cover classification). Land cover as a fixed effect only explained 36.8% of richness variation (Marginal R^2 = 0.368). Random effects included in the models all had negligible variances (Conditional R^2 = NA). Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.40	-1.52	<0.001
Land Cover – Mixed	0.24	1.37	<0.001
Land Cover – Rural	0.33	1.85	<0.001
Land Cover – Urban	0.23	1.30	<0.001
Native (vs Introduced)	0.27	1.51	<0.001
Land Cover – Mixed * Native	-0.22	-1.26	<0.001
Land Cover – Rural *Native	-0.32	-1.82	<0.001
Land Cover – Urban *Native	-0.25	-1.40	<0.001
Random Effects			
Site Identification	0.00		
Observer bias	0.00		
Ecosystem type	0.00		
Observations	570		
Marginal R^2 / Conditional R^2	0.368 / NA		

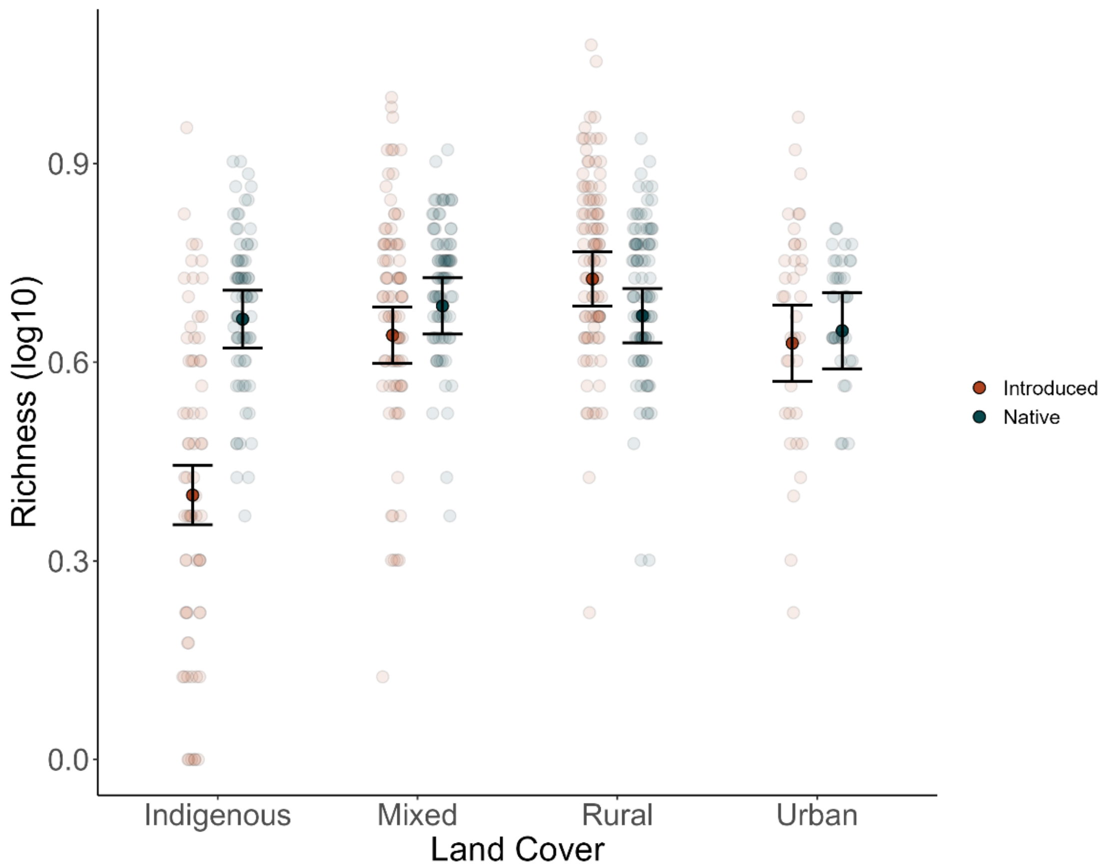

Figure 6. Predicted mean species richness variation among Land Classes (land cover classification) for Tier 1 sites (regional) considering variation between native and introduced bird species numbers. Error bars = Mean +/- Confidence Intervals from model estimates. Data points = richness distribution.

3.1.2.1. Summary: Forest Tier 1

Our general regional trend indicates that native birds were more abundant in sites dominated by indigenous plant communities than in modified landscapes. In contrast, non-native species showed lower richness in indigenous landscapes compared to native species but were more abundant and diverse in modified environments. Essentially, these findings support the idea that areas dominated by indigenous Land Classes offer suitable habitats and resources for native species to thrive (Singers et al., 2017). Meanwhile, more modified landscapes benefit introduced species, which typically possess broader habitat tolerances and more general resource needs (Seto et al., 2012; Soanes et al., 2019). Over time, native bird abundance also seems to have risen at regional sites, indicating a moderate but positive shift in native biodiversity, favouring our indigenous forests.

3.1.3. Forest – Tier 2: Large sub-regional 'Areas' of interest State and Trends

Abundance: State and Trends

For each Tier 2 site, we calculated the abundances of both native and non-native birds, focusing on areas crucial for conservation and management. We analysed the variation in relative abundance to uncover significant patterns or relationships that might reveal the status and trends of bird biodiversity in these plots. Our modelling uncovered distinct abundance patterns among land classes for both native and introduced species, highlighting shifts in biodiversity trends over the years (Table 12). Generally, we found that native species were more abundant than introduced species; however, this trend significantly changed in mixed, rural, and urban landscapes (Figure 7). An intriguing finding was the surprisingly high abundance of native species in urban land cover, even surpassing that of introduced species, although this difference was not statistically significant (Figure 7). Moreover, we observed a significant overall increase in abundance over time (Table 12), especially in later rotations (2014-2023), which showed a noticeable rise in total abundance (Figure 8). Notably, most of the variation in abundance could be linked to land cover and rotation (Table 12).

We then aimed to uncover whether the overall abundance increase over the years was driven by native abundance. Native abundance for Tier 2 showed a positive relationship with rotation, increasing progressively (Figure 9). However, much of the data's natural variation remains unexplained (High residual random effects – Table 13).

In other words, while native species thrived in indigenous landscapes, their numbers were nearly on par with non-native species in modified areas like rural and urban settings. Landers et al (2021) noted that Tier 2 sites had greater native abundance than introduced abundance in urban areas. Although the additional data from Rotation 3 supports this pattern, it is still not statistically significant. Average native abundance in Rotation 1 was 2.4 birds per count, while in Rotation 3 it increased to 2.82 birds, a 17% boost.

Table 12. General Linear Mixed Model results for Tier 2 Forest sites comparing estimated abundance variation for introduced and native species separately to Land Class (land cover classification) and rotation. Ecological districts were included in the model for better fit, but none resulted in significant abundance variation. Fixed effects explained a good portion of abundance variance 51.6%), with random effects adding about 5.6% of explanatory power only (Marginal R^2 = 0.516, Conditional R^2 = 0.571). This means that variation between sites and observer bias for different monitoring events had a very small impact on abundance for Tier 2, and most of the variation was explained by land cover and rotation. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.45	-1.11	**<0.001**
[Great Barrier Island]	-0.17	-0.57	0.067
[Hunua]	-0.10	-0.31	0.276
[Inner Gulf Islands]	0.10	0.33	0.266
[Kaipara]	0.03	0.09	0.700
[Manukau]	0.14	0.44	0.162
[Rodney]	-0.08	-0.27	0.360
[Tamaki]	0.02	0.08	0.783
[Waitākere]	-0.04	-0.13	0.668
Land Cover – Mixed	0.27	0.87	**<0.001**
Land Cover – Rural	0.42	1.35	**<0.001**
Land Cover – Urban	0.33	1.06	**<0.001**
Native (vs Introduced)	0.52	1.67	**<0.001**
Rotation 2	0.05	0.18	0.097
Rotation 3	0.11	0.34	**0.004**
Land Cover – Mixed * Native	-0.36	-1.17	**<0.001**
Land Cover – Rural * Native	-0.49	-1.59	**<0.001**
Land Cover – Urban * Native	-0.41	-1.32	**<0.001**
Random Effects			
Site identification	0.00		
Observer bias	0.01		
Observations	435		
Marginal R^2 / Conditional R^2	0.516 / 0.571		

Table 13. General Linear Mixed Model results for estimated native species abundance at Tier 2 Forest sites comparing abundance variation over time (monitoring rotation cycles) Only about 13% of the variance in native abundance can be explained by rotation, with random effects adding another 25% of prediction power (Marginal R^2 = 0.13, Conditional R^2 = 0.38). Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p*
(Intercept)	0.88	-0.35	**<0.001**
Rotation 2	0.02	0.11	0.528
Rotation 3	0.16	0.83	**<0.001**
Random Effects			
Site identification	0.00		
Observer bias	0.01		
Ecosystem type	0.00		
Observations	221		
Marginal R^2 / Conditional R^2	0.130 / 0.379		

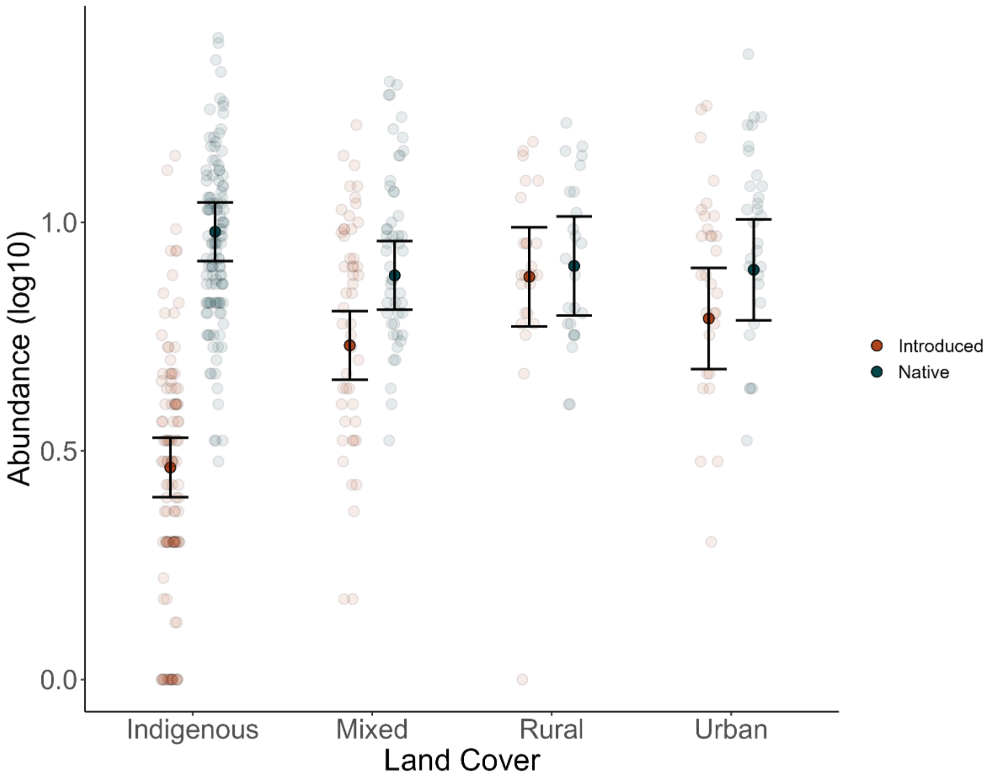

Figure 7. Variation in overall predicted mean bird abundance among Land Classes (land cover classification) at Tier 2 sites (sub-regional) considering native and introduced species numbers. Error bars = Confidence Intervals from model estimates. Data points = native and introduced species abundance distribution.

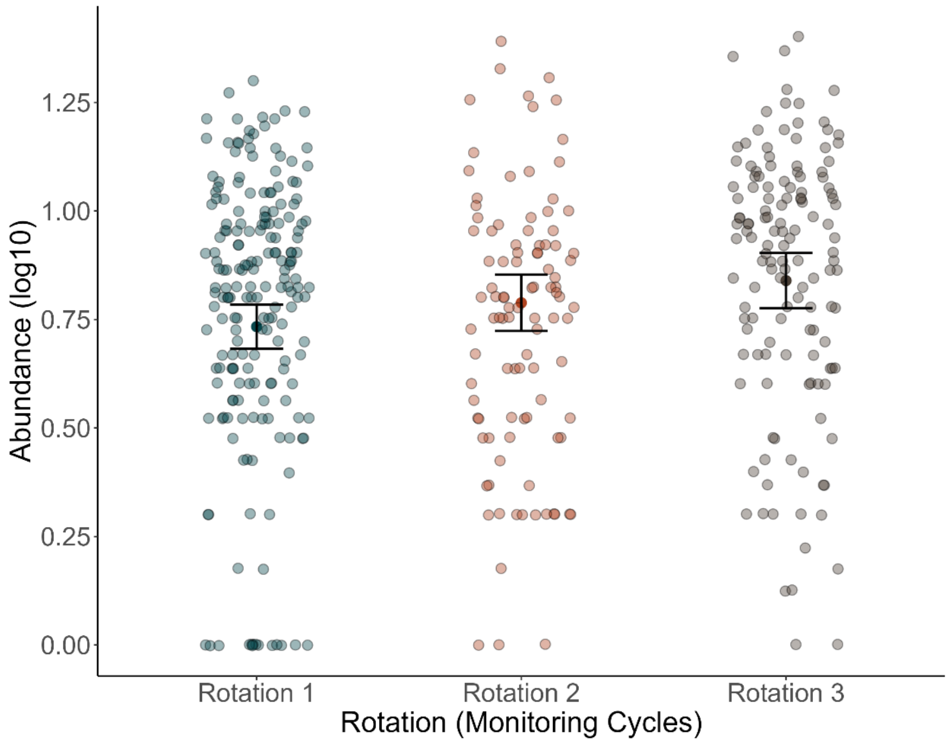

Figure 8. Overall predicted mean abundance variation among monitoring rotations for Tier 2 sites (sub-regional). Bird abundance increases significantly between rotations 1 and 3. Error bars = Confidence Intervals from model estimates. Data points = native and introduced species abundance distribution.

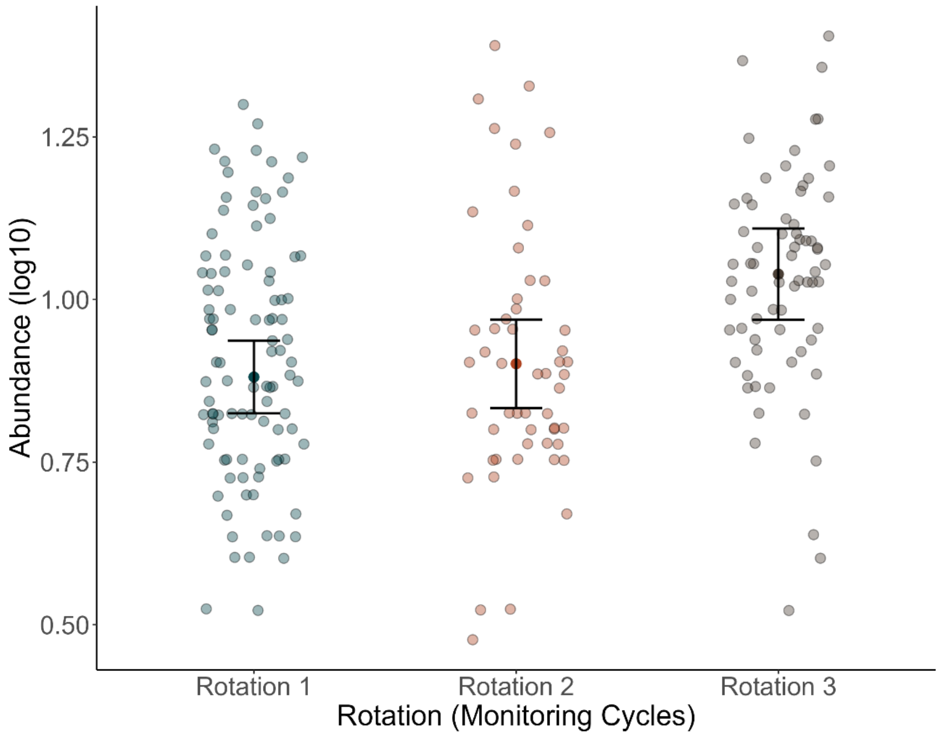

Figure 9. Predicted mean native species abundance variation among monitoring rotations for Tier 2 sites (sub-regional). Native bird abundance increases significantly between rotations 1 and 3. Error bars = Confidence Intervals from model estimates. Data points = isolated native species abundance distribution.

Richness: State and Trends

We calculated native and introduced species richness per site for Tier 2 plots, analysing richness trends and the current state of species distribution. Richness followed different trends between land classes and Ecological Districts (Table 13). Modified land covers exhibited higher overall species richness (Figure 10). Among them, Rural was the land class most positively associated with richness, supporting significantly more native species than other classes, as well as significantly more introduced species. In contrast, indigenous landscapes were the only land class where native species outnumbered introduced species. In terms of Ecological Districts, Great Barrier Island showed a significant rise – Hunua and Waitākere a borderline significant rise (Table 13) – in native richness compared to others, with Great Barrier Island exhibiting notably lower introduced species richness (Figure 11).

In other words, native species (richness) dominated indigenous land classes over introduced species, a pattern also observed in Tier 1 sites. However, the highest number of native species was found in rural landscapes. Areas around large, healthy forests (Aotea/Great Barrier Island, Waitākere Ranges, Hunua Ranges) with high habitat heterogeneity (Griffiths et al., 2021) support more native bird species. These findings mirror those of the Tier 1 richness analysis, except for greater native species richness in rural sites.

Table 13. General Linear Mixed Model results for Tier 2 Forest sites comparing estimated richness variation for introduced and native species separately to Land Class and ecological districts. Fixed effects explained a good portion (59%) of abundance variance (Marginal R^2 = 0.590). This means that variation between sites, observer bias and ecosystem type for different monitoring events (the random effects) had a very small impact on richness for Tier 2, and most of the variation was explained by land cover and ecological district differences for native and introduced species numbers.

Predictors	*Estimates*	*std. Beta*	*p*
(Intercept)	0.47	-0.60	**<0.001**
[Great Barrier Island]	-0.23	-1.07	**0.010**
[Hunua]	-0.14	-0.63	0.104
[Inner Gulf Islands]	0.10	0.46	0.266
[Kaipara]	0.00	0.00	0.995
[Manukau]	0.01	0.02	0.955
[Rodney]	-0.08	-0.38	0.355
[Tamaki]	0.02	0.08	0.838
[Waitākere]	-0.12	-0.53	0.179
Land Cover – Mixed	0.22	0.99	**<0.001**
Land Cover – Rural	0.34	1.57	**<0.001**
Land Cover – Urban	0.18	0.83	**0.003**
Native (vs Introduced)	0.12	0.56	0.267
Great Barrier Island * Native	0.27	1.24	**0.021**
Hunua * Native	0.24	1.12	**0.025**
Inner Gulf Islands * Native	0.01	0.06	0.904
Kaipara * Native	0.02	0.12	0.795
Manukau * Native	0.12	0.53	0.347
Rodney * Native	0.17	0.78	0.142
Tamaki * Native	0.07	0.31	0.535
Waitākere * Native	0.20	0.93	0.068
Land Cover – Mixed * Native	-0.22	-1.01	**<0.001**
Land Cover – Rural * Native	-0.24	-1.11	**0.001**
Land Cover – Urban * Native	-0.22	-1.04	**0.004**
Random Effects			
Site identification	0.00		
Observer bias	0.00		
Ecosystem type	0.00		
Observations	435		
Marginal R^2 / Conditional R^2	0.590 / NA		

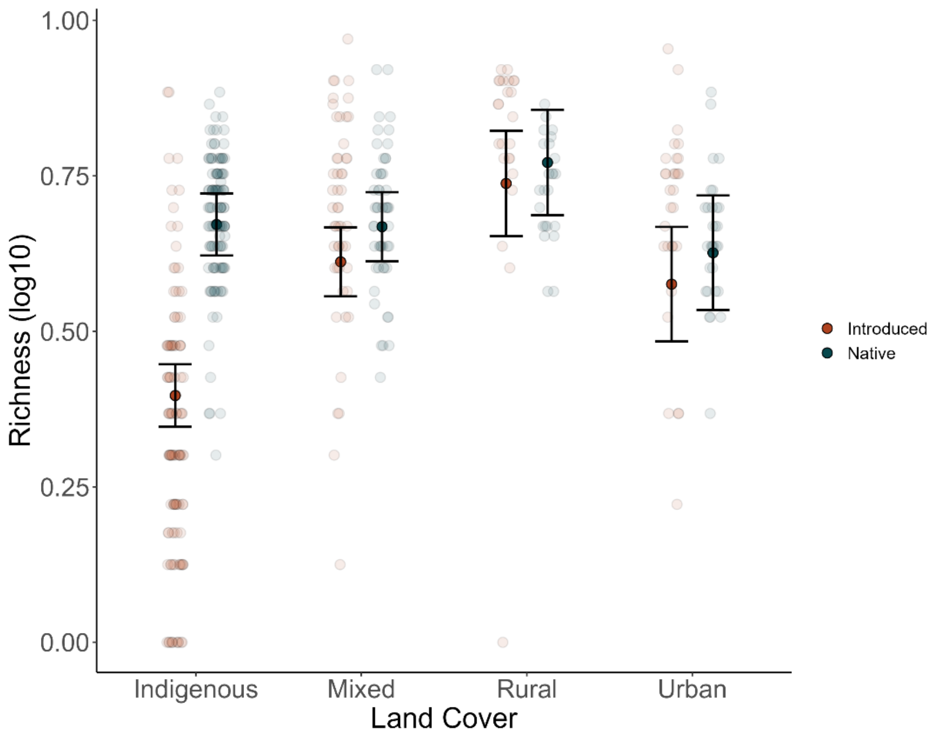

Figure 10. Predicted mean richness variation among Land Classes at Tier 2 sites (sub-regional) considering variation between native and introduced species numbers. Error bars = Confidence Intervals from model estimates. Data points = richness distribution.

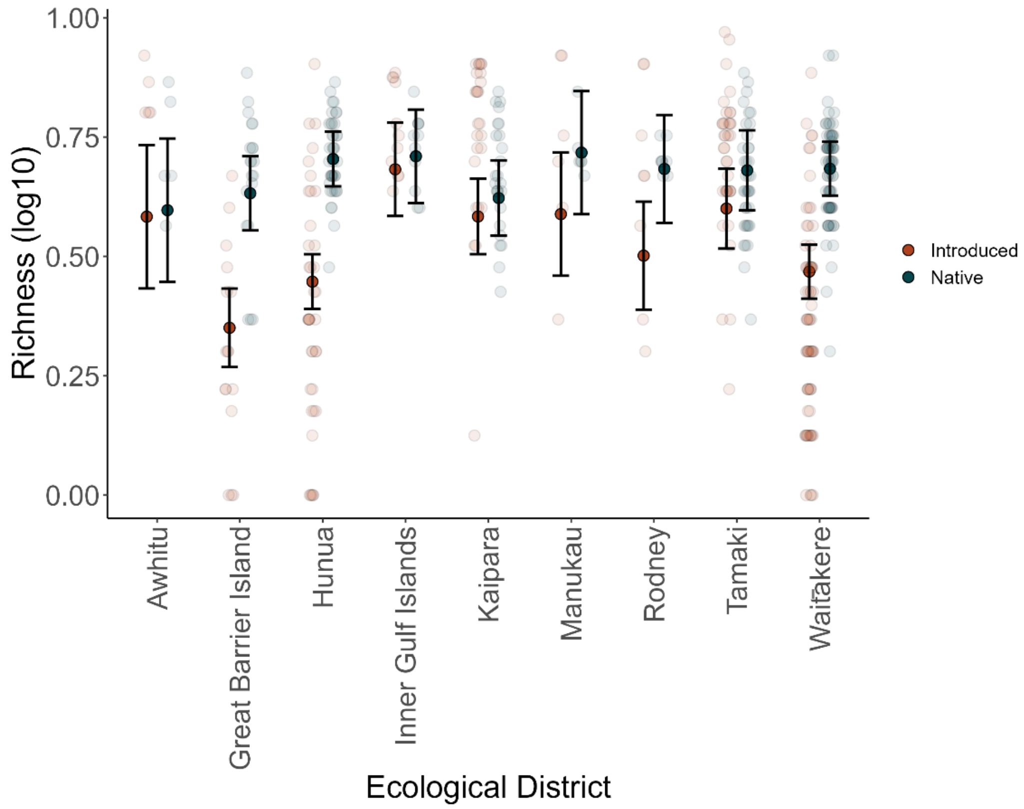

Figure 11. Predicted mean richness variation among Ecological Districts at Tier 2 sites (sub-regional) considering variation between both native and introduced species numbers. Error bars = Confidence Intervals from model estimates. Data points = richness distribution.

3.1.3.1. Summary: Forest Tier 2

Patterns of abundance in Tier 2 sites resembled those in Tier 1 (Section 3.1.2.1: Abundance: State and Trends). Rural landscapes appeared favourable for native bird species richness. Native species outnumbered introduced species in indigenous land classes. The abundance and richness patterns were expected in Tier 2, which includes large conservation areas focused on biodiversity and restoration (Griffiths et al., 2021). This likely supports the dominance of native birds in indigenous sites, while rural sites are well restored to support more native species than in Tier 1, especially near preferred Ecological Districts such as the Waitākere Ranges, Hunua Ranges, and Aotea/Great Barrier Island, which help sustain native birds. Abundance variation shows a 17% increase in native bird abundance over time.

3.2. Forest birds – Indicator species

The results of bird abundance and richness for forest sites revealed notable trends in native biodiversity over time and across land classes. These findings indicate that certain native species are exhibiting significant variations in their status and trends, influencing these differences. This analysis explores if the trends of any specific species are closely related to annual variations or the prevalence of indigenous land cover. Positive results may suggest potential indicator species that could signal improvements in the landscape and the recovery of native bird populations when assessing management and conservation efforts.

3.2.1 Indicator species for biodiversity trend: Timescale (year)

TITAN (refer to methods) examined if any species exhibited notable changes over time. Only four species (tūī, tauhou, pīwakawaka, riroriro) among all monitored species met the criteria for significant variation thresholds (Table 14). The results indicated positive trends (response direction), showing population growth over the years (Figure 12). Each species was analysed against monitoring variables to further assess their potential as indicator species.

Table 14. Forest species selected for showing significant changes in abundance over a particular monitoring year threshold. Only four species showed sufficient Purity (>950), and Reliability (>950) to be deemed trustworthy environmental indicators (filter = 2 – indicated in bold). Ienv.cp = Individual Change Point: Estimated environmental threshold (year) for a single taxon. Zenv.cp = Z-Score-Weighted Change Point: Indicates the environmental change point weighted by the taxon's indicator strength.

Species	ienv.cp	zenv.cp	Frequency	IndVal	z-score	Purity	Reliability	Filter
Bellbird	2023	2019	99	11.25	3.4	0.786	0.984	0
Pīwakawaka	2023	2017	584	49.54	8.88	0.996	1	2
Riroriro	2023	2019	678	53.29	8.02	1	1	2
Kākā	2023	2023	118	15.75	1.96	0.84	0.958	0
Kererū	2023	2023	282	29.89	2.17	0.726	0.876	0
Kōtare	2009	2023	481	47.6	3.4	0.922	0.928	0
Shining cuckoo	2023	2011	239	24.39	3.88	0.65	0.978	0
Tauhou	2009	2018	652	52.23	6.72	1	1	2
Tūī	2009	2016	641	50.68	5.71	0.97	0.988	2
Gradient (Year)	2020.5	2019	713	50.11	0.1	1	1	2

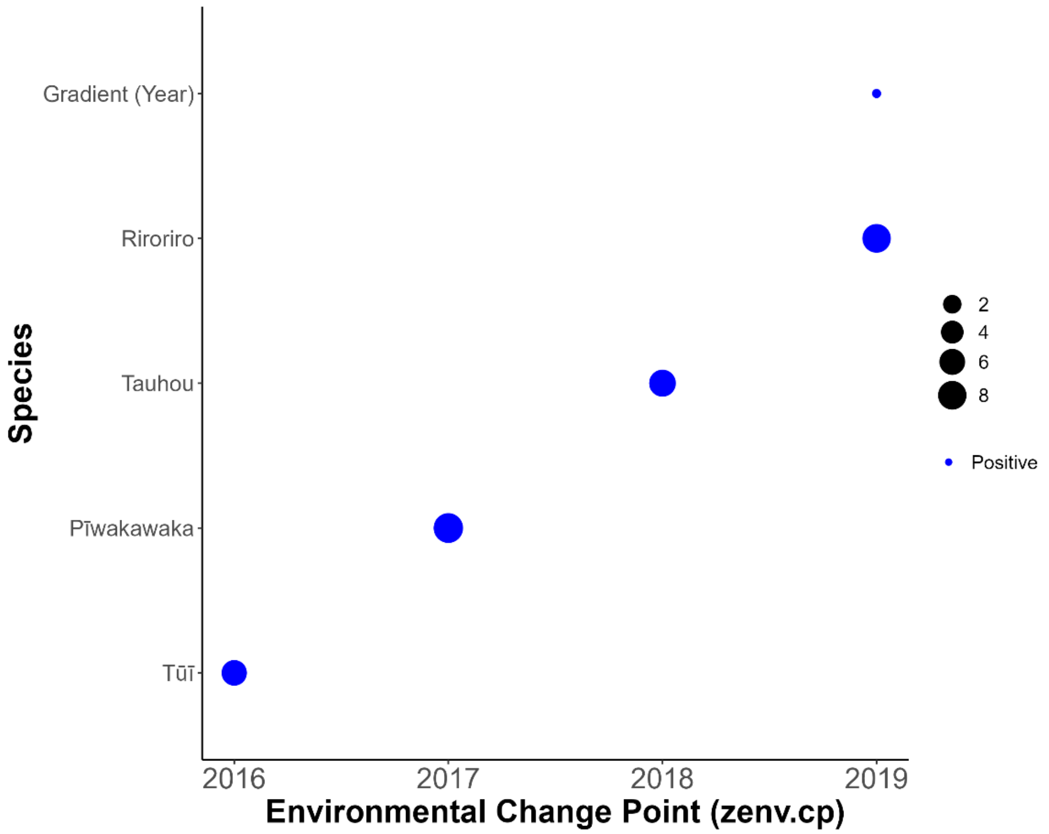

Figure 12. TITAN z-scores for year variation showing tūī, pīwakawaka, tauhou and riroriro as species identified to have significant variation thresholds, sufficient purity, and sufficient reliability to be deemed trustworthy environmental indicators for forests. The response direction is positive, indicating a significant increase in bird numbers at the selected year threshold. Higher z-scores indicate that change over the environmental gradient is significant, and not just random fluctuation. Zenv.cp = Z-Score-Weighted Change Point: Indicates the environmental change point weighted by the taxon's indicator strength. The environmental gradient tested (year) showed small variability strength (Z-score = 0.1) and only after 2020, which was expected since the environmental gradient in question was year, and the monitoring cycle for the TBMP is every 5 years.

3.2.1.1. Species analysis

Tūī

To explore the tūī's potential as an indicator species, analysing their distribution showed varying bird populations across land classes. Urban and indigenous sites had similar tūī abundance (Figure 13). Rural sites showed a 14% decrease in tūī numbers compared to indigenous sites (Figure 13). Natural variation in tūī abundance between monitoring sites accounted for most observed variation from random effects (Table 15). In summary, tūī prefer habitats with indigenous plant communities and urban forests. Urban locations can serve as essential habitats for native species such as tūī, providing ample resources in urban forest patches and gardens (MacLeod et al., 2022). The positive relationship between tūī abundance and urban sites would need further investigation to confirm any strong environmental links to tūī variation that could function as environmental indicators.

Table 15. General Linear Mixed Model results for tūī abundance in forest sites comparing estimated abundance variation to land cover classification. Land cover as a fixed effect only explained 6.2% of tūī abundance variation (Marginal $R^2 = 0.062$). Natural differences between sites and observer bias (random effects) were responsible for a small part of the abundance variation. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p*
(Intercept)	0.02	0.17	0.397
Land Cover – Mixed	-0.06	-0.25	0.100
Land Cover – Rural	-0.15	-0.60	**<0.001**
Land Cover – Urban	0.04	0.15	0.425
Random Effects			
Site Identification	0.02		
Observer Bias	0.00		
Ecosystem Type	0.00		
Observations	379		
Marginal R^2 / Conditional R^2	0.062 / 0.363		

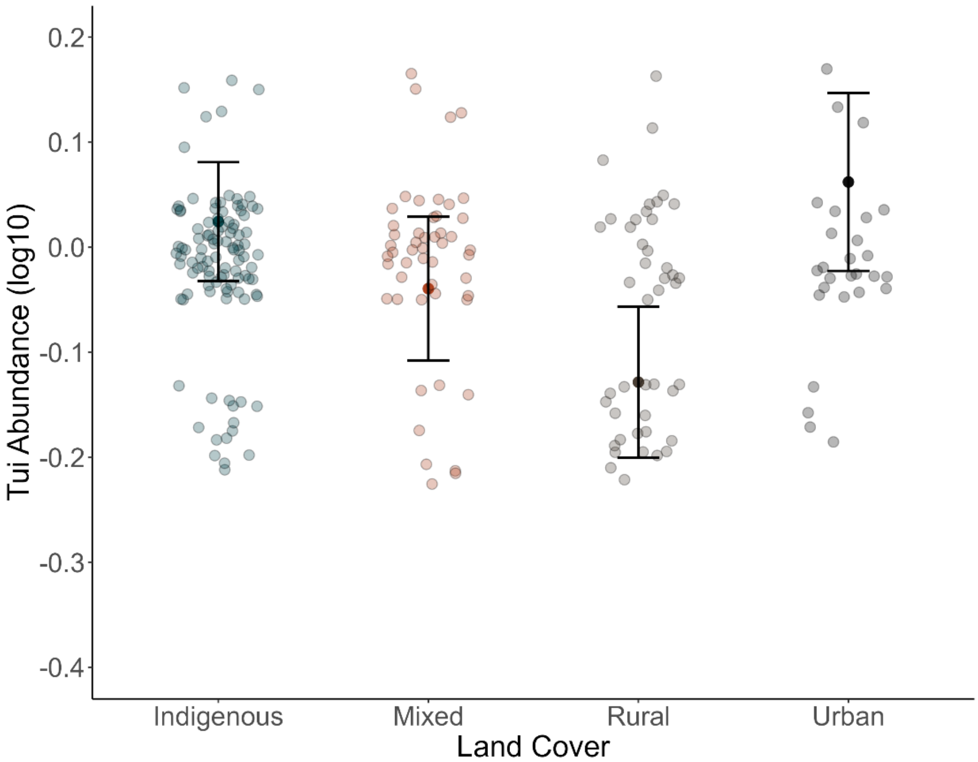

Figure 13. Tūī predicted mean abundance variation at forest sites by Land Class (Land cover Classification). Error bars = Confidence Intervals from model estimates. Data points = tūī abundance distributions.

Tauhou

Analysis of tauhou distribution to assess their potential as indicator species demonstrated that this species varied mainly between rotations (Table 16). Variation in the urban land class was borderline significant, suggesting higher tauhou abundance in urban than in indigenous areas (Table 16). Further investigation may confirm this trend. Tauhou populations exhibit marked interannual variation, with significant fluctuations between years (Figure 14). Lovegrove et al (2023) have described a similar pattern of tauhou abundance fluctuation. These fluctuations in tauhou populations and their ambiguous connections to environmental gradients disqualify this species currently as a reliable indicator species within the TBMP.

Table 16. General Linear Mixed Model results for tauhou abundance in forest sites comparing estimated abundance variation to land cover classification. Land cover as a fixed effect only explained 12.7% of tauhou abundance variation. Natural differences between sites (random effects) were responsible for a small part of the abundance variation. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.08	-0.48	0.189
Land Cover – Mixed	-0.03	-0.10	0.448
Land Cover – Rural	-0.06	-0.21	0.139
Land Cover – Urban	0.10	0.33	0.077
Year [2010]	0.21	0.69	**0.015**
Year [2011]	0.15	0.49	0.053
Year [2012]	0.29	0.97	**<0.001**
Year [2013]	0.03	0.10	0.688
Year [2014]	0.03	0.11	0.634
Year [2015]	0.16	0.53	**0.038**
Year [2016]	0.04	0.14	0.663
Year [2019]	0.19	0.65	**0.005**
Year [2020]	0.11	0.36	0.204
Year [2021]	0.28	0.94	**0.005**
Year [2022]	0.12	0.39	0.095
Year [2023]	0.07	0.23	0.408
Random Effects			
Site Identification	0.02		
Observer bias	0.00		
Ecosystem Type	0.00		
Observations	432		
Marginal R^2 / Conditional R^2	0.127 / 0.384		

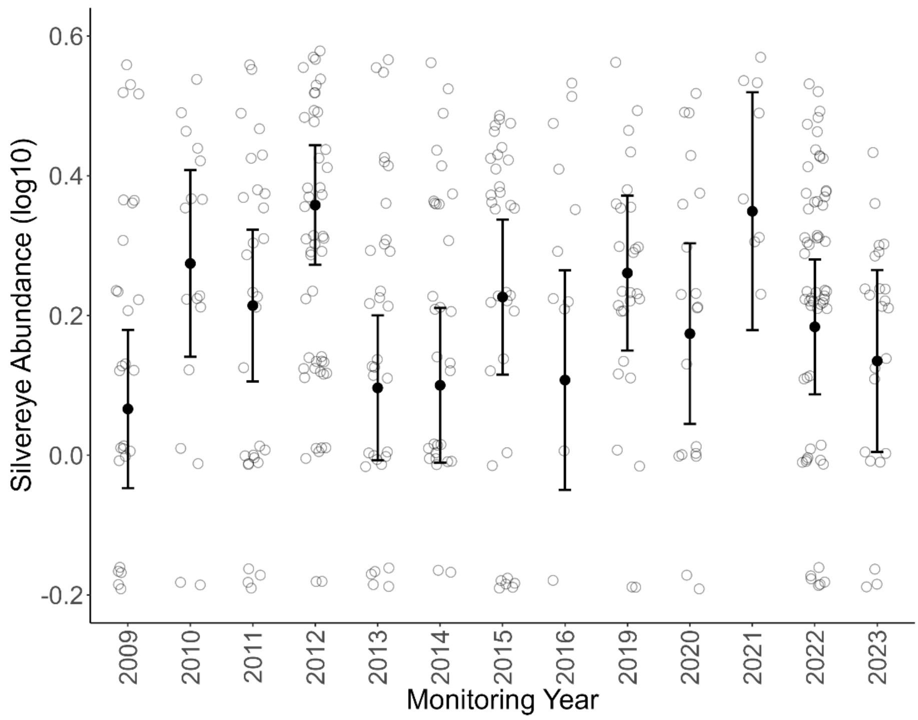

Figure 14. Interannual predicted mean tauhou abundance variation at forest sites. Error bars = Confidence Intervals from model estimates. Data points = tauhou abundance distribution.

Pīwakawaka

Following the indicator species analysis, the numbers of fantails varied significantly between Tier 1 and Tier 2 sites and showed modest interannual variation (Table 17). Pīwakawaka abundance showed a significant drop in 2011 and a boost in 2020 compared to the first year of monitoring (2009) (Figure 15). Tier 2 plots showed lower pīwakawaka abundance than Tier 1 (Figure 16). The distribution of land classes for Tiers 1 and 2 (Figure 16) reveals more sites with indigenous plant communities in Tier 2. This lower pīwakawaka abundance in more indigenous sites suggests interspecific competition and dominance of other native species in preserved forests is a pattern observed for fantails in Auckland. This result suggests that monitoring fantails could indicate an increase in other native species in managed areas, warranting further investigation into their role as an indicator species.

Table 17. General Linear Mixed Model results for pīwakawaka abundance in forest sites considering estimated abundance variation between different Tier sites and monitoring years. Land cover as a fixed effect only explained 9% of pīwakawaka abundance variation. Results in bold show significant results (p-value <0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	-0.15	-0.09	**0.002**
Tier 2 (vs Tier 1)	-0.04	-0.17	0.097
Year [2010]	0.08	0.33	0.296
Year [2011]	-0.16	-0.69	**0.025**
Year [2012]	0.04	0.19	0.445
Year [2013]	0.04	0.19	0.487
Year [2014]	0.08	0.32	0.246
Year [2015]	0.04	0.18	0.513
Year [2016]	-0.03	-0.11	0.754
Year [2019]	0.04	0.18	0.515
Year [2020]	0.17	0.71	**0.022**
Year [2021]	0.19	0.81	0.068
Year [2022]	-0.02	-0.08	0.764
Year [2023]	0.08	0.35	0.245
Random Effects			
Site Identification	0.00		
Observer Bias	0.00		
Ecosystem Type	0.00		
Observations	353		
Marginal R^2 / Conditional R^2	0.090 / 0.217		

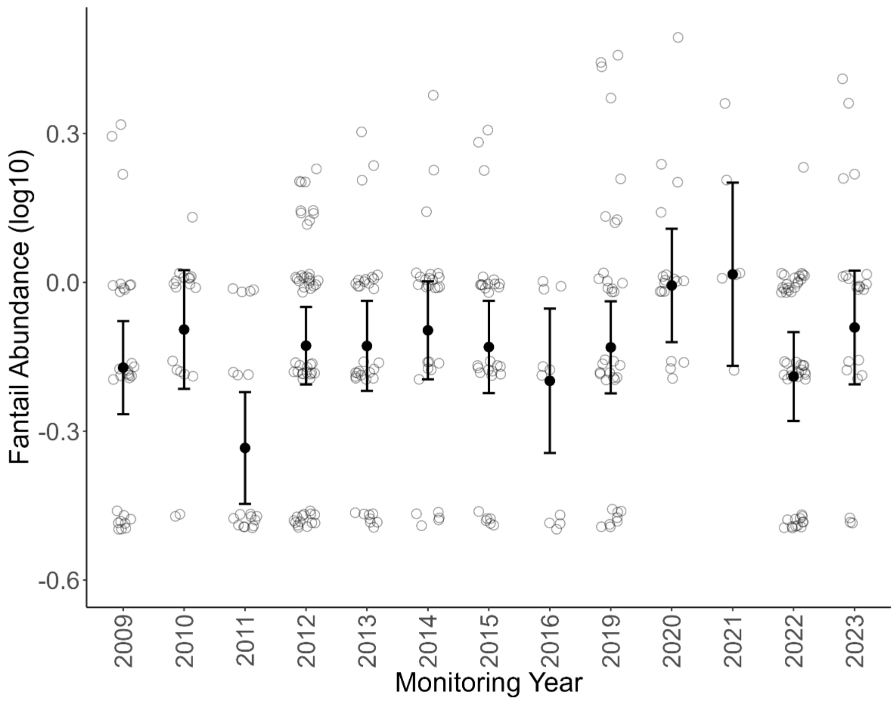

Figure 15. Interannual pīwakawaka predicted mean abundance variation at forest sites. Error bars = Confidence Intervals from model estimates. Data points = pīwakawaka abundance.

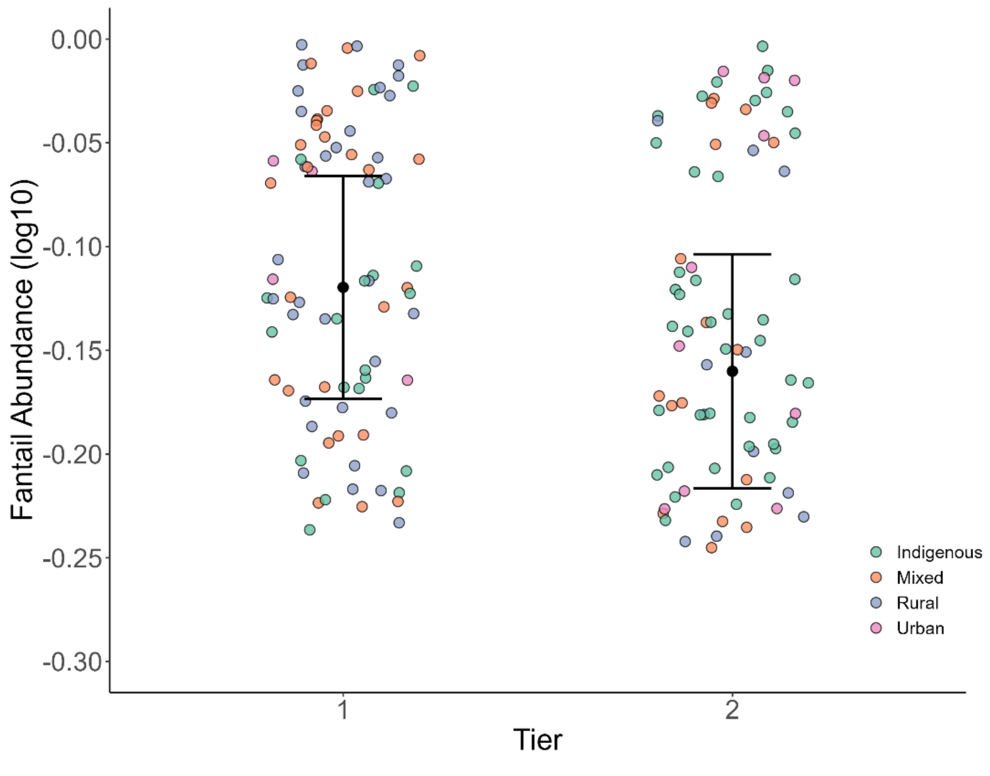

Figure 16. Pīwakawaka predicted mean abundance variation between Tier 1 and Tier 2 forest sites. Error bars = Confidence Intervals from model estimates. Data points = Pīwakawaka abundance distribution. Land Classes were included to help understand if a significant difference in pīwakawaka abundance between regional and subregional sites may be connected to environmental differences.

Riroriro

The last species assessed for environmental indicator potential shows significant interannual differences in abundance, with marked increase in riroriro numbers over the last five years (2019-2023) (Figure 17). Riroriro numbers were also significantly lower in urban than in indigenous sites (Figure 18). A substantial portion of riroriro variation (48%) is attributed to natural plot differences and observer bias (Table 18). Thus, the lack of specificity in riroriro variation concerning any environmental gradient analysed disqualifies this species as an environmental indicator within the TBMP.

Table 18. General Linear Mixed Model results for riroriro abundance in forest sites considering estimated abundance variation between different Land Classes and monitoring years. Land Class and year only explained 18% of riroriro abundance variation. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	-0.05	-0.12	0.177
Year [2010]	0.09	0.47	0.104
Year [2011]	-0.03	-0.14	0.597
Year [2012]	0.01	0.07	0.763
Year [2013]	0.02	0.11	0.675
Year [2014]	0.09	0.50	0.058
Year [2015]	0.02	0.12	0.647
Year [2016]	0.09	0.50	0.138
Year [2019]	0.17	0.91	**<0.001**
Year [2020]	0.16	0.85	**0.004**
Year [2021]	0.23	1.23	**0.001**
Year [2022]	0.05	0.29	0.259
Year [2023]	0.15	0.80	**0.007**
Land Cover – Mixed	0.00	0.00	0.986
Land Cover – Rural	-0.03	-0.14	0.320
Land Cover – Urban	-0.11	-0.58	**0.002**
Tier 2 (vs Tier 1)	-0.02	-0.12	0.233
Random Effects			
Site Identification	0.00		
Observer bias	0.00		
Ecosystem Type	0.00		
Observations	436		
Marginal R^2 / Conditional R^2	0.181 / NA		

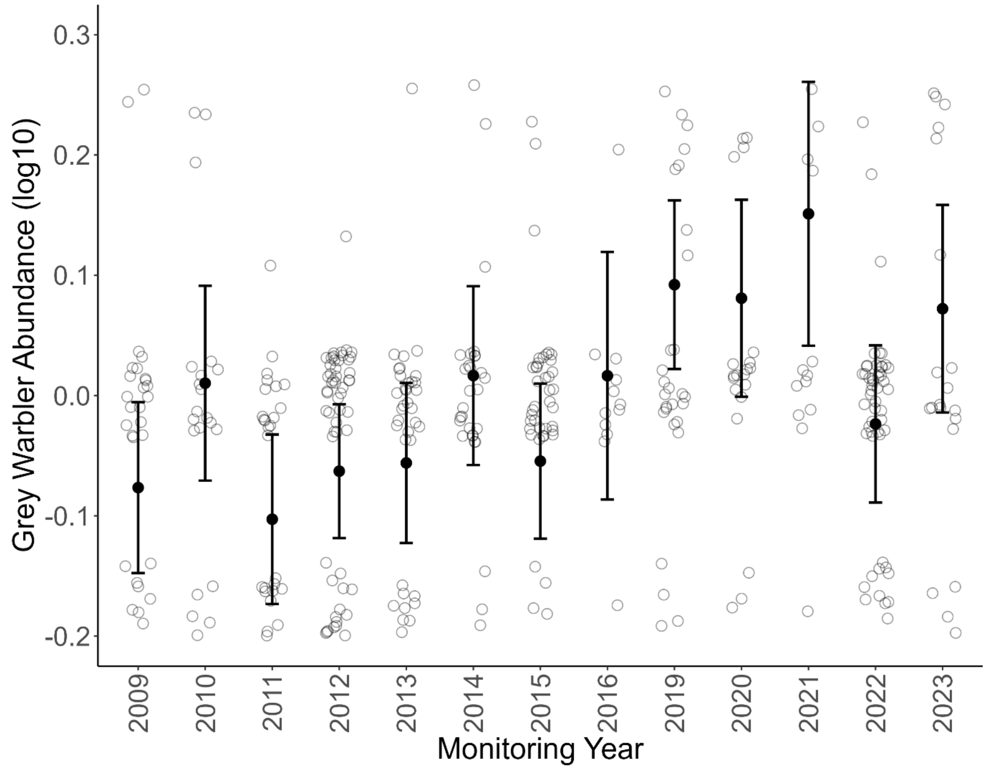

Figure 17. Interannual riroriro predicted mean abundance variation at forest sites. Error bars = Confidence Intervals from model estimates. Data points = riroriro abundance.

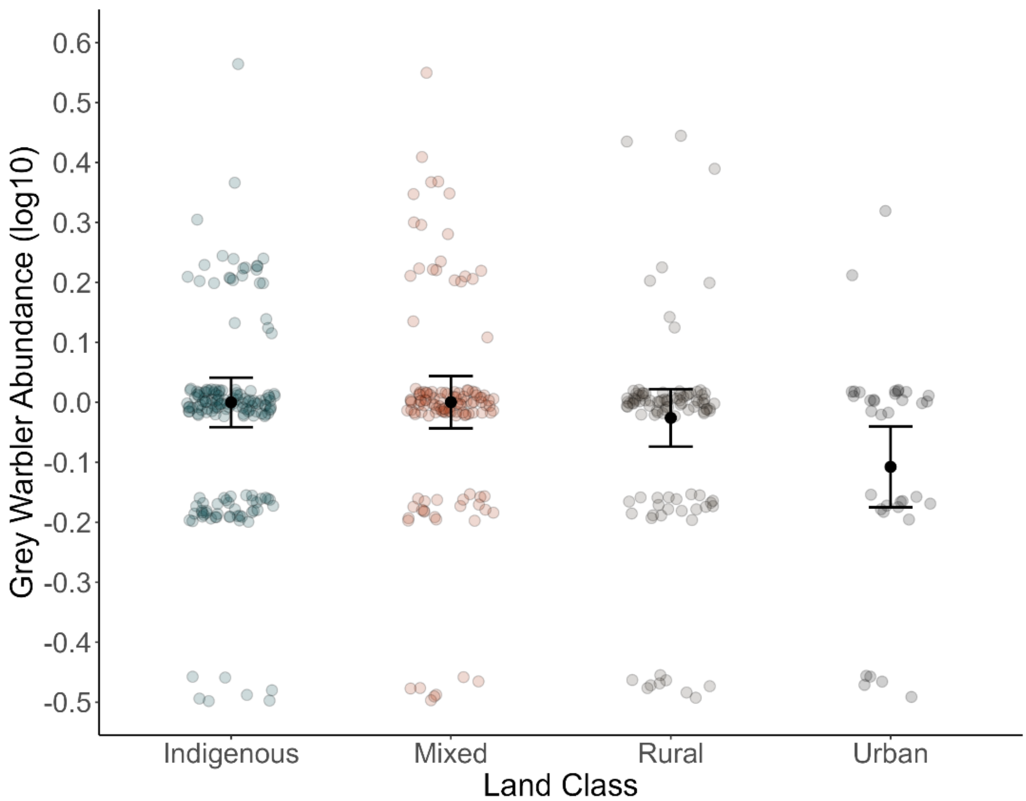

Figure 18. Riroriro predicted mean abundance variation at forest sites by Land Class (Land cover Classification). Error bars = Confidence Intervals from model estimates. Data points = riroriro abundance distribution.

3.2.1.2. Summary: Interannual variation (Year) indicator species

Essentially, only the abundance of tūī and fantails demonstrated significant connections to variations in land classes. This suggests that trends in these species could reflect the condition of those land classes. In other words, assessing the relationship between tūī populations and the restoration or connectivity of urban forests could position tūī as an indicator of conservation efforts and fragmentation in urban settings. Likewise, if we quantify pīwakawaka numbers that signal habitat recovery and the recolonisation by other native species, they could serve as indicators for restoration initiatives in forest areas. However, their noticeable interannual variations may partly stem from their prevalence in the Auckland region, where they are some of? the most abundant species overall, thus exhibiting a stronger presence across various environmental gradients. This contributes to more reliable data compared to other species.

3.2.2. Indicator species for Environmental Gradient: Indigenous land cover

TITAN (refer to methods) was used to uncover any species that exhibited notable changes over the ecological gradient of indigenous vegetation cover (percentage). We hoped to identify any species whose numbers would be more substantial over a certain threshold of habitat quality. Only three species (kererū, kākā and bellbird) from all monitored species (Table 19) were considered reliable environmental indicators (filter = 2) (Table 19). Bellbird results were disregarded due to limited counts, heavily skewed towards Little Barrier Island, with occurrences per environmental category <5, thus failing to indicate environmental gradients effectively (Monks et al., 2013). Results also showed positive response directions, which means that all species increased in abundance with increasing proportion of indigenous land cover (Figure 19). Each species was analysed against monitoring variables to properly assess their potential as indicator species.

Table 19. Species selected by the model for showing significant changes in abundance over particular indigenous cover percentage thresholds. Only three species with sufficient Purity (>950), and Reliability (>950) to be deemed trustworthy environmental indicators (filter = 2 – indicated in bold) are displayed. Ienv.cp = Individual Change Point: Estimated environmental threshold (year) for a single taxon. Zenv.cp = Z-Score-Weighted Change Point: Indicates the environmental change point weighted by the taxon's indicator strength.

Species	ienv.cp	zenv.cp	Frequency	IndVal	z-score	Purity	Reliability	Filter
Korimako	100	100	67	36.69	7.13	0.998	1	2
Pīwakawaka	100	51.85	358	52.82	6.98	0.992	1	1
Riroriro	100	100	398	53.51	2.34	0.876	0.872	0
Kākā	77.15	58.3	100	34.76	15.45	1	1	2
Kererū	1.85	89.1	207	43.08	9.12	1	1	2
Kōtare	100	28.1	318	52.23	8.9	1	1	1
Shining cuckoo	1.85	1.85	184	46.23	2.76	0.706	0.994	0
Tauhou	100	26.1	374	56.38	8.04	1	1	1
Tūī	4.1	4.1	376	53.81	1.8	0.828	0.93	0
Environmental Gradient (Indigenous Cover)	0.6	26.85	408	85.55	35.55	1	1	2

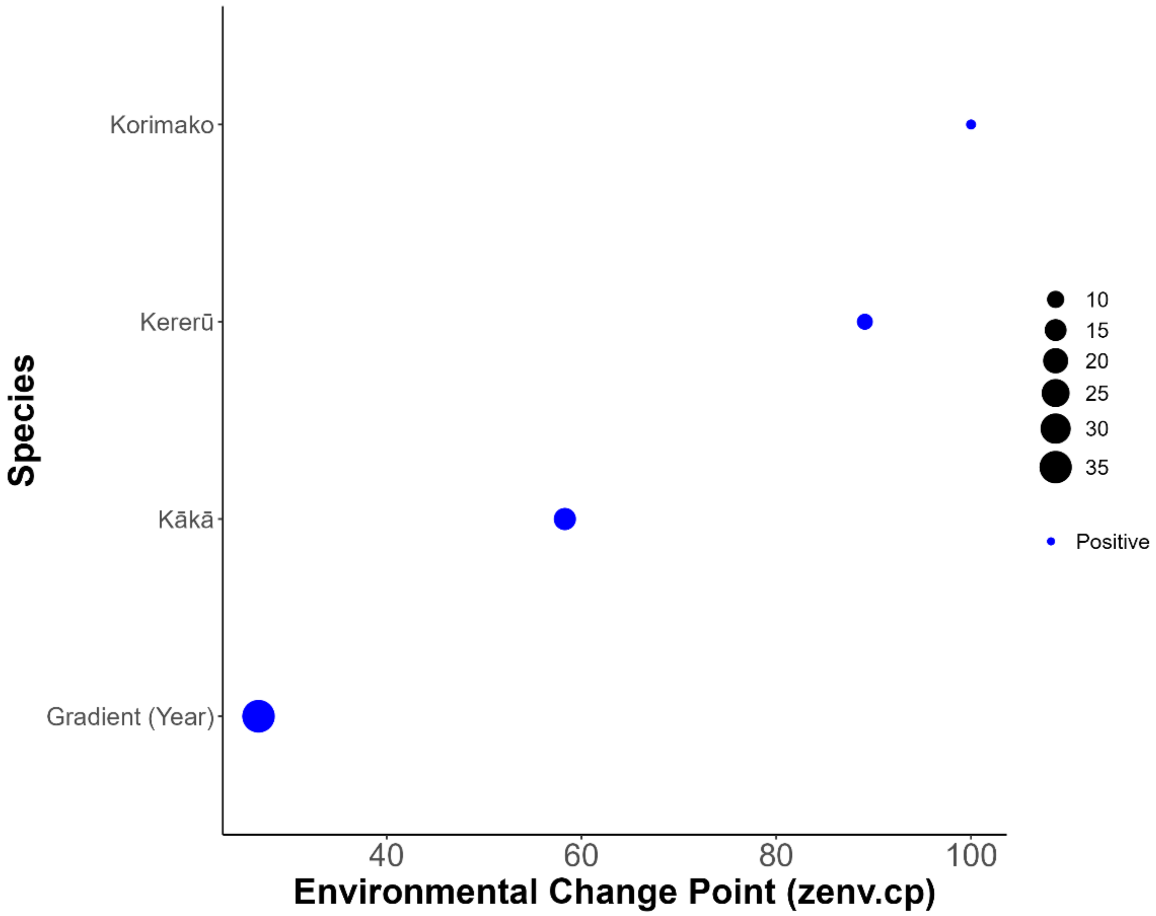

Figure 19. TITAN z-scores for year variation showing korimako, kererū, and kākā as species identified to have significant variation thresholds, sufficient purity, and reliability to be deemed trustworthy environmental indicators for forests. The response direction is positive, indicating a significant increase in bird numbers at the selected year threshold. Higher z-scores indicate that change over the environmental gradient is significant, and not just random fluctuation. Zenv.cp = Z-Score-Weighted Change Point: Indicates the environmental change point weighted by the taxon's indicator strength.

Kererū

This analysis evaluated the potential of kererū as an indicator of habitat quality, as their abundance is closely related to a high proportion of indigenous plant communities. It was found that kererū abundance varies significantly across geographic areas. All Ecological Districts reported substantially lower kererū abundance compared to the Āwhitu Ecological District (Table 20), particularly in Kaipara, Waitākere and Great Barrier Island (Figure 20). Additionally, Tier 1 sites exhibited significantly lower kererū abundance than Tier 2 sites (Figure 21). This indicates that kererū favours preserved, contiguous forest habitats present in Tier 2 plots. However, Ecological Districts renowned for their more pristine forest habitats, such as Great Barrier Island and Hunua, display lower kererū abundance than the relatively rural Āwhitu. The findings from the Ecological Districts suggest that other management factors are at play and warrant further investigation.

Table 20. General Linear Mixed Model results for kererū abundance in forest sites considering estimated abundance variation between different Ecological Districts and Tier 1 and 2 sites. Fixed effects seemed to explain about 14% of kererū abundance variance, with a total of 33% being explained by the model (mostly observer bias) when including random effects (Marginal R^2 = 0,14 Conditional R^2 = 0.33). Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	-0.16	0.81	**0.011**
Great Barrier Island	-0.27	-1.41	**0.003**
Hunua	-0.23	-1.20	**0.001**
Kaipara	-0.28	-1.47	**<0.001**
Rodney	-0.15	-0.81	**0.023**
Waitākere	-0.24	-1.23	**<0.001**
Tier 2 (vs Tier 1)	0.10	0.53	**0.016**
Random Effects			
Observer bias	0.01		
Observations	123		
Marginal R^2 / Conditional R^2	0.138 / 0.329		

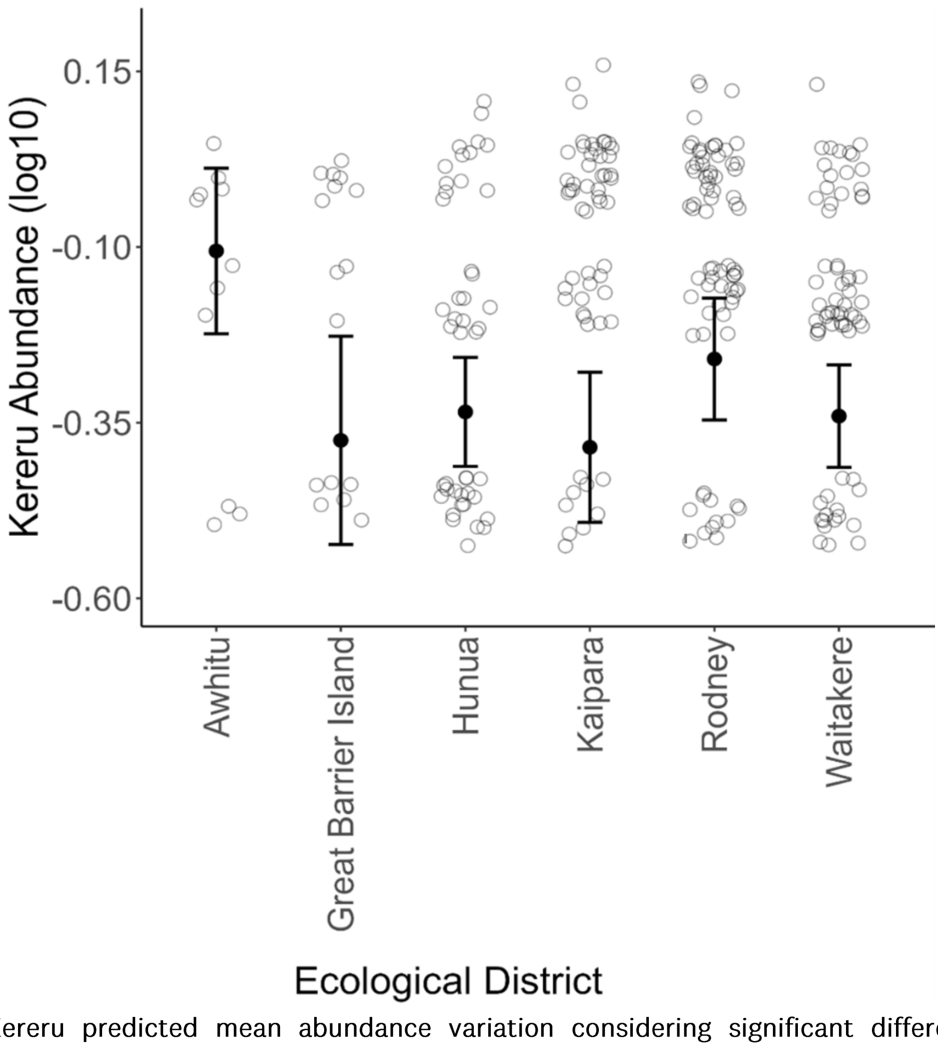

Figure 20. Kereru predicted mean abundance variation considering significant differences between Ecological Districts. Error bars = Confidence Interval from model estimates. Data points = Kereru abundance distribution.

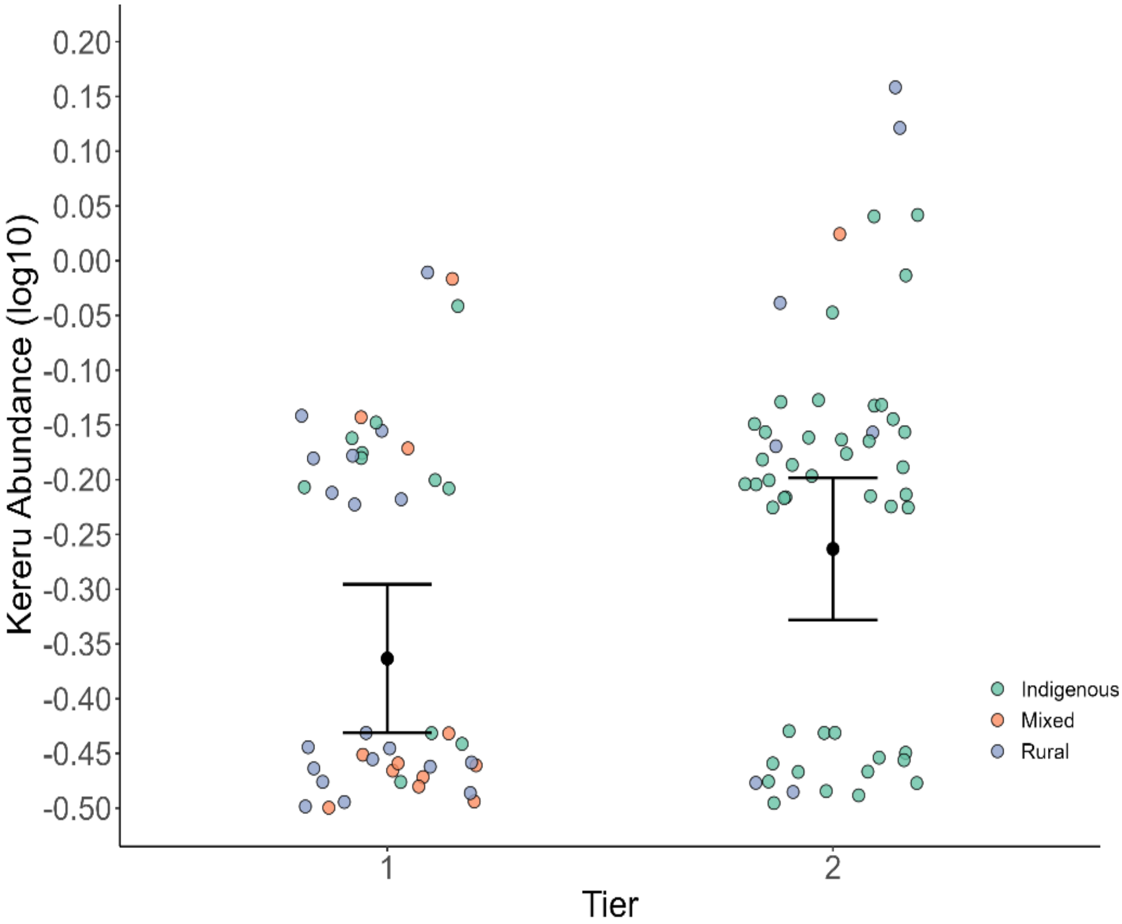

Figure 21. Kererū predicted mean abundance variation between Tier 1 and Tier 2 forest sites. Error bars = Confidence Intervals from model estimates. Data points = kererū abundance distributions. Land Classes were included to help understand if a significant difference in kererū abundance between regional and subregional sites may be connected to environmental differences.

Kākā

The analysis assessing kākā as an indicator of habitat quality revealed significant counts of this species in the TBMP were confined to a few Ecological Districts, showing substantial variation between them (Table 21). Kākā abundance in Waitākere, Hunua and Rodney was significantly lower than on Great Barrier Island (Figure 22). Other Ecological Districts also showed lower kākā abundance than Great Barrier Island, but those results were borderline significant (Table 21). Given the habitat specificity and that 29.3% of kākā abundance variation arises from Ecological Districts (R^2 = 0.293 – Table 21), quantifying how their numbers relate to environmental quality differences between Great Barrier Island and all other lower abundance habitats may reveal their indicator potential. Results should be interpreted cautiously due to the limited species distribution in this dataset.

Table 21. General Linear Mixed Model results for kākā abundance in forest sites considering estimated abundance variation between different Ecological Districts. Fixed effects seemed to explain about 29.3% of kākā abundance variance. Results in bold were statistically significant (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.07	0.64	0.119
Hunua	-0.37	-1.14	**<0.001**
Inner Gulf Islands	-0.54	-1.69	0.055
Little Barrier Island	-0.15	-0.46	0.053
Manukau	-0.54	-1.69	0.055
Rodney	-0.34	-1.05	**<0.001**
Waitākere	-0.54	-1.69	**0.008**
Observations	123		
R^2 / R^2 adjusted	0.293 / 0.256		

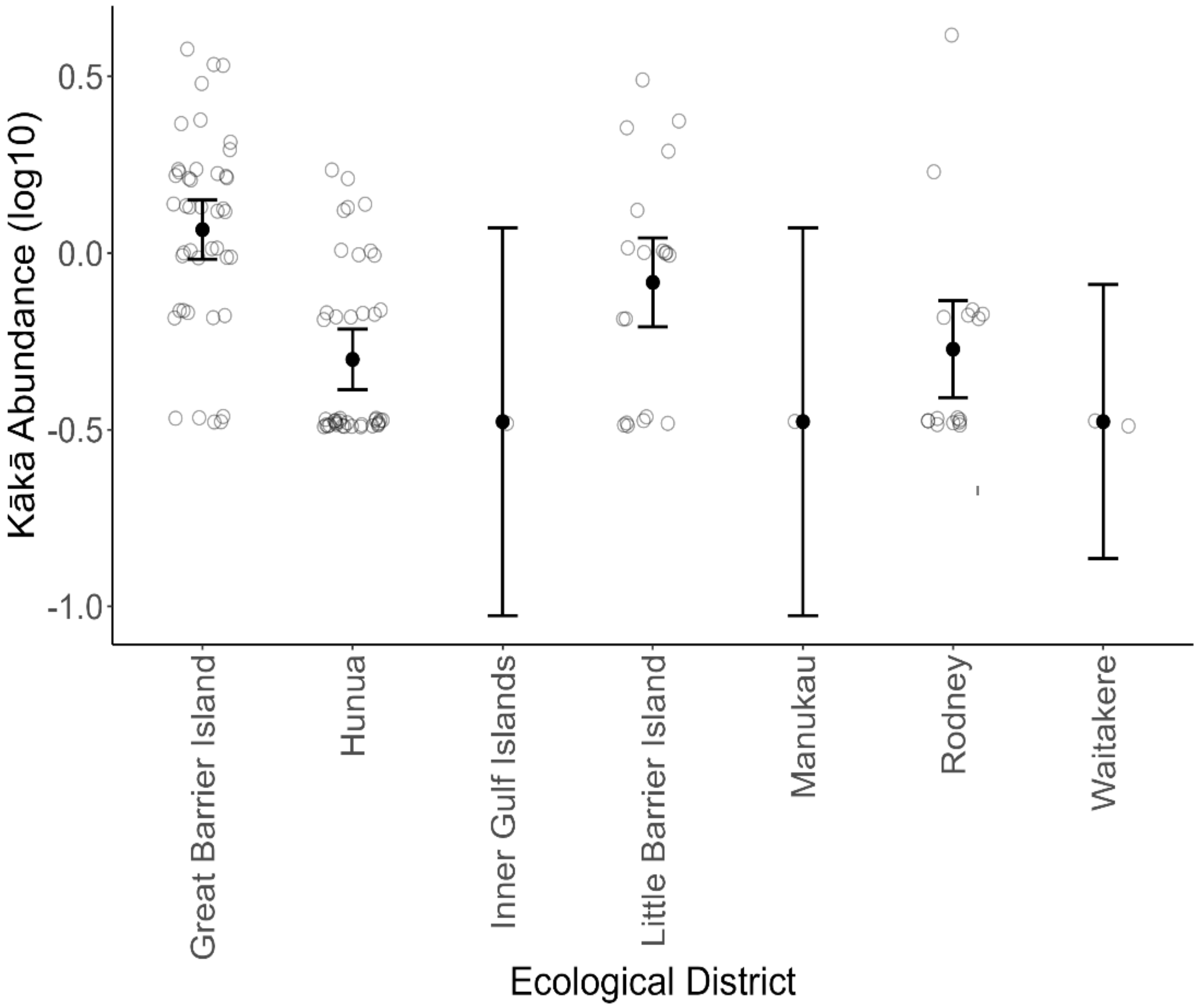

Figure 22. Kākā predicted mean abundance variation considering significant differences between Ecological Districts. Error bars = Confidence Intervals from model estimates. Data points = Kākā abundance distribution.

3.2.1.1. Summary: Habitat quality (Indigenous Cover) indicator species

Both kererū and kākā abundance were linked to environmental gradients. Kererū thrived in high-quality habitats, as well as in the predominantly rural Āwhitu. Kākā were limited to a few high-quality Ecological Districts (e.g. Waitākere, Hunua), with substantially higher numbers in Great Barrier Island than elsewhere. Further investigation into the relationships between these species' abundances and environmental conditions may reveal opportunities to quantify population sizes, thereby supporting conservation status assessments and the evaluation of management outcomes.

3.3. Wetland birds – States and trends

3.3.1. Wetlands – Total species summary

Throughout this study (2010-2024), bird counts were conducted across 189 wetland sites, where 20370 individual birds were recorded. Most of the species identified were native (21.22% endemic and 34.41% indigenous), with 44.37% of species classified as introduced (Table 22). This mirrors findings from the last bird biodiversity survey published in the Auckland region five years ago (Landers et al., 2021). Among the species counted, only 1.6% have been designated as threatened or at risk (Table 23) based on their Regional Conservation Status (Woolly et al., 2024). The monitoring revealed a total of 60 species, with three of the five most abundant species being native (Table 24), which is one more than reported in 2021 (Landers et al., 2021). In 2021, the top five species by abundance were tauhou, common Myna, riroriro, European goldfinch, and house sparrow (Landers et al., 2021). In this current study, house sparrow and tūī have risen to 4th and 5th place, respectively, while the abundance of European goldfinch has decreased to the 7th highest. Regarding bird counting methods, a significant majority of detections were made by sound, with 68.2% being aural compared to 17.6% visual detections, while 14.2% of birds were recorded under "Presence" only after the 5MBC. Wetlands had substantially more birds seen than in forest monitoring (Forest = 4.7%, Wetlands = 17.6%). Since the last terrestrial bird report was published in 2021, the average number of birds detected per count in wetlands has decreased by 45%, with the total number of birds counted per rotation decreasing from 450 in rotation 1 to 598 in rotation 2 and dropping to 329 in rotation 3.

Table 22. Status of species counted at 189 wetland sites in 515 counts in Auckland.

Status	Count	Percentage of total birds
Endemic	4263	21.22%
Indigenous	6920	34.41%
Introduced	6760	44.37%

Table 23. Regional conservation of indigenous species (Woolly et al., 2024) counted at wetland sites in the Auckland region. Species classified as “Regionally Critical”, Regionally Endangered”, “Regionally Vulnerable”, or “Threatened” were considered threatened or at risk for our proportion calculations. A small proportion of the species had no regional classification available and were not included in this table (Count = 579, 0.7% of total birds).

Conservation Status	Counts	Percentage of total birds
Regionally Not Threatened	43131	50.2%
Introduced and Naturalised	39766	46.3%
Regionally Vulnerable	1231	1.4%
Regionally Recovering	781	0.9%
Regionally Relict	215	0.3%
Regionally Critical	112	0.1%
Regionally Endangered	40	0%
Naturally Uncommon	28	0%

Table 24. Mean Species Abundance and Probability of Detection of all bird species counted (20370 total individual birds counted from 2009-2024) at wetland sites (n = 189) in Auckland.

Species Counted		Total abundance	Total Standard Error (SE)	Probability of Detection (%)
Silvereye	Tauhou	3.85	0.07	90.37
Common Myna		2.29	0.05	83.85
House sparrow		1.43	0.11	64.29
Grey warbler	Riroriro	1.37	0.03	82.92
Tūī	Tūī	1.21	0.06	62.73
European goldfinch		1.17	0.12	66.15
Common Starling		1.06	0.8	37.27
Australian Magpie		0.83	0.05	61.18
Pukeko	Pūkeko	0.8	0.05	62.42
Paradise shelduck	Pūtangitangi	0.78	0.6	25.78
Welcome swallow		0.78	0.11	53.73
Eurasian blackbird		0.67	0.05	63.98
Eastern rosella		0.62	0.06	56.83
South Island pied oystercatcher	Tōrea	0.52	7.89	2.48
Variable oystercatcher	Tōrea pango	0.38	0.31	34.78
Chaffinch		0.33	0.05	42.55
Sacred kingfisher	Kōtare	0.33	0.03	45.34
New Zealand fernbird	Mātātā	0.25	0.03	85.09
Mallard		0.23	0.32	17.08
Black swan	Kawau pū	0.21	5.59	4.04
Swamp harrier	Kāhu	0.2	0.04	38.51
European greenfinch		0.2	0.08	26.4
Southern black backed gull	Karoro	0.2	0.43	17.39

Species Counted		Total abundance	Total Standard Error (SE)	Probability of Detection (%)
Yellowhammer		0.15	0.11	20.5
Spotted dove		0.14	0.1	21.74
Spotless crake		0.13	0.01	84.16
Pied stilt	Poaka	0.12	1.71	4.97
Rock pigeon		0.12	1.24	8.07
Bellbird	Korimako	0.11	0.38	4.66
Eurasian skylark		0.09	0.09	13.04
White-faced heron	Matuku moana	0.08	0.3	10.25
Canada goose		0.08	1.45	4.97
Variable oystercatcher	Tōrea pango	0.07	0.58	5.59
Pied Shag	Kāruhiruhi	0.06	0.7	5.59
Grey teal	Tētē moroiti	0.06	0	0.31
Red-billed gull	Tarāpunga	0.05	0.54	5.28
Song thrush		0.05	0.05	10.25
Chicken		0.04	0.27	6.21
Gull species		0.03	0.11	4.97
Dunnock		0.03	1.47	2.8
Red-crowned parakeet	Kākāriki	0.03	0.18	2.17
Banded rail	Moho pererū	0.02	0.01	66.15
Common pheasant		0.02	0	5.9
Wild turkey	Korukoru	0.02	1.97	2.17
Little black shag	Kawau tūī	0.02	0.5	0.62
Whitehead	Pōpokotea	0.02	2	0.62
Peafowl	Pīkao	0.01	0	1.86
Bar-tailed godwit	Kūaka	0.01	0	0.31
Black shag	Kawau	0.01	0	2.8
Australasian shoveler		0.01	0.67	0.62
New Zealand dabchick	Weweia	0.01	0.15	1.24
New Zealand pipit	Pihoihoi	0.01	0.26	1.86
Common redpoll		0.01	0.49	1.55
Barbary dove		0.01	0.21	2.8
North Island saddleback	Tīeke	0.01	0.13	1.86
Kākā	Kākā	0	0	0.93
Caspian tern	Taranui	0	0	0.62
Shining cuckoo	Pīpīwharauroa	0	0	0.93
Black-billed gull	Tarāpuka	0	0	0.93
Brown teal	Pāteke	0	0	0.31

3.3.2. Wetlands – Regular 5MBC data

Abundance: State and Trends

Our analysis of wetland species abundance across monitoring categories aimed to uncover the status and trends of wetland bird biodiversity in the Auckland region. Results indicated that native birds displayed a significantly higher average abundance than introduced species (Table 25) in wetland plots, particularly thriving in indigenous areas (Figure 23). In contrast, introduced birds were more common in urban and rural areas (Table 25 – Figure 23). Furthermore, spatial variations in wetland biodiversity were apparent, with most Ecological Districts showing greater native abundance compared to the analysis reference Ecological District Āwhitu (Table 25 – Figure 24). The results also uncovered a positive trend in overall bird abundance during rotation 3, reflecting a 6.3% increase in numbers compared to rotation 1 (Figure 25).

We analysed native bird abundance independently to determine if native species are contributing to the overall increase in abundance over time (Table 26). The findings reinforced that native species favour indigenous habitats over rural and urban ones (Figure 26). Notably, time variation (assessed by rotation) indicated a slight declining trend in native bird abundance over time, although this was only marginally significant (Table 25). However, when examining native abundance trends for each Land Class, the presence of native birds varied over time among different habitat types (Figure 26). Rural and urban locations experienced increases of 13.6% and 13.4% in native bird biodiversity, respectively, between rotations 1 (2010-2014) and rotation 3 (2020-2024) (Figure 26).

Essentially, native birds in New Zealand's highly threatened wetland environments (Dymond et al., 2021), appear to occupy areas with more indigenous plants, while introduced birds expand into modified habitats. Āwhitu had the lowest number of native birds of all the Ecological Districts. Lastly, isolating native abundance data reinforced their preference for indigenous Land Classes, but indicated an increase in native bird numbers in rural and urban wetlands.

Table 25. General Linear Mixed Model results for estimated abundance in wetland sites considering native and introduced species abundance variation between different Ecological Districts, time variation (monitoring cycle rotation) and land cover classification. Despite the many factors included in the model, fixed effects are only responsible for explaining 15.6% of the wetland abundance variation, with random effects adding an extra 28.4% of explanatory value (Marginal R^2 = 0.156, Conditional R^2 = 0.440). Plot identification was the biggest source of variation explained by random effects, but they were still modest. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.59	-0.93	**<0.001**
Rotation 2	0.04	0.16	0.064
Rotation 3	0.06	0.22	**0.038**
Hunua	-0.08	-0.29	0.301
Inner Gulf Islands	0.12	0.43	0.139
Kaipara	-0.12	-0.41	0.091
Manukau	0.10	0.34	0.175
Rodney	-0.04	-0.14	0.565
Tāmaki	-0.02	-0.06	0.833
Waitākere	0.06	0.22	0.431
Native birds (vs Introduced)	0.19	0.68	**0.006**
Hunua * [Native]	0.24	0.86	**0.001**
Inner Gulf Islands * [Native]	0.16	0.57	**0.036**
Kaipara *[Native]	0.31	1.10	**<0.001**
Manukau * [Native]	0.06	0.21	0.390
Rodney * [Native]	0.17	0.60	**0.008**
Tāmaki * [Native]	0.16	0.58	**0.023**
Waitākere * [Native]	0.06	0.21	0.429
[Introduced] * Land Cover – Mixed	0.10	0.36	**0.020**
[Native] * Land Cover – Mixed	-0.03	-0.11	0.457
[Introduced * Land Cover – Rural	0.29	1.05	**<0.001**
[Native] * Land Cover – Rural	-0.11	-0.40	**0.006**
[Introduced] * Land Cover – Urban	0.31	1.10	**<0.001**
[Native] * Land Cover – Urban	-0.09	-0.31	0.132
Random Effects			
Site Identification	0.01		
Observer bias	0.01		
Ecosystem Type	0.00		
Observations	1745		
Marginal R^2 / Conditional R^2	0.156 / 0.440		

Table 26. General Linear Mixed Model results for estimated native species abundance variation in wetland sites between different rotations and considering land cover classification. Random effects were responsible for explaining most of the variation in native abundance (40.6%), with natural site variation contributing to 34.8% (Marginal R^2 = 0.058, Conditional R^2 = 0.406), a high percentage for ecological models. Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.88	0.05	**<0.001**
Land cover – Mixed	-0.03	-0.10	0.584
Land cover – Rural	-0.12	-0.44	**0.010**
Land cover – Urban	-0.09	-0.34	0.122
Rotation_2	0.08	0.30	**0.022**
Rotation_3	0.11	0.41	**0.006**
Random Effects			
Site identification	0.02		
Observer bias	0.00		
Observations	511		
Marginal R^2 / Conditional R^2	0.058 / 0.406		

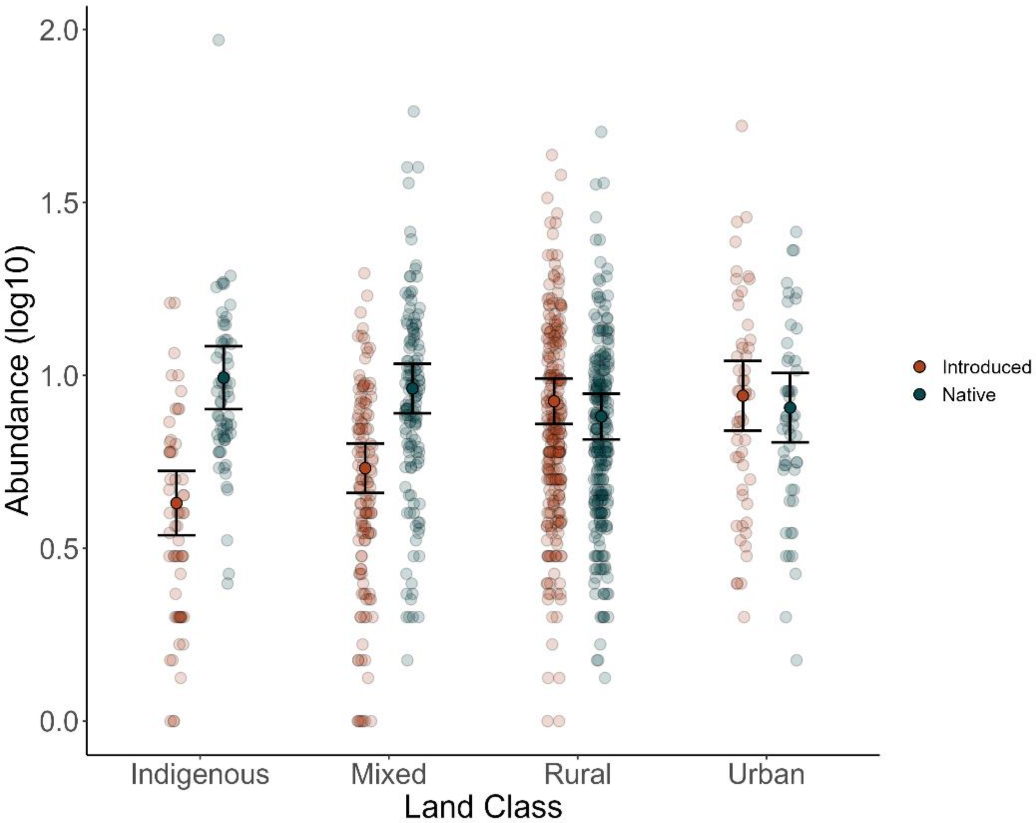

Figure 23. Predicted mean abundance variation among Land Classes for regular wetland 5MBC data considering variation between native and introduced bird numbers. Error bars = Confidence Intervals from model estimates. Data points = abundance distribution.

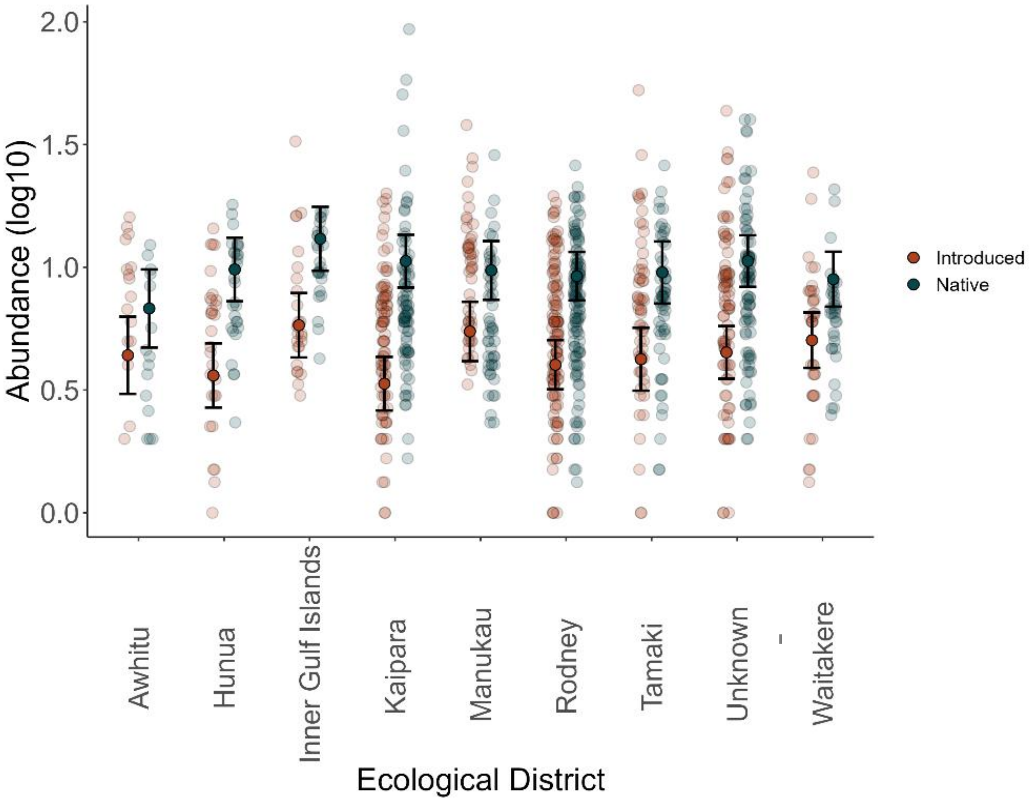

Figure 24. Predicted mean abundance variation among Ecological Districts considering native and introduced species numbers for regular wetland 5MBC data. Error bars = Confidence Intervals from model estimates. Data points = abundance distribution.

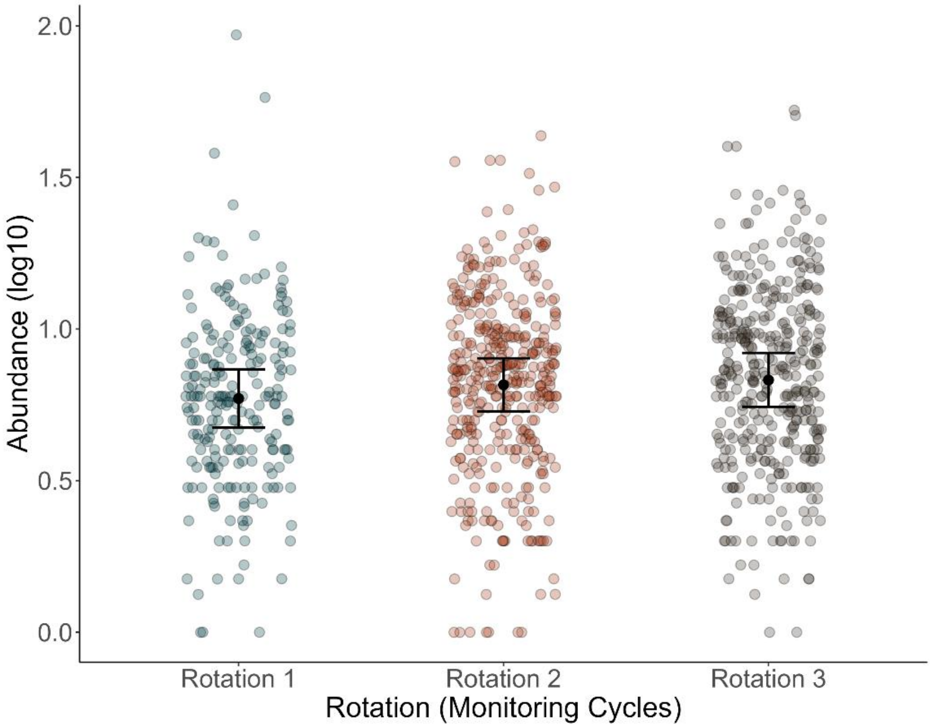

Figure 25. Predicted mean abundance variation over time (monitoring rotation cycles) for regular wetland 5MBC data. Results revealed a positive trend in bird abundance between rotations 1 and 2 (4.6% increase), and a small but significant increase in abundance between rotations 1 and 3 (6.3%). Error bars = Confidence Intervals from model estimates. Data points = abundance distribution.

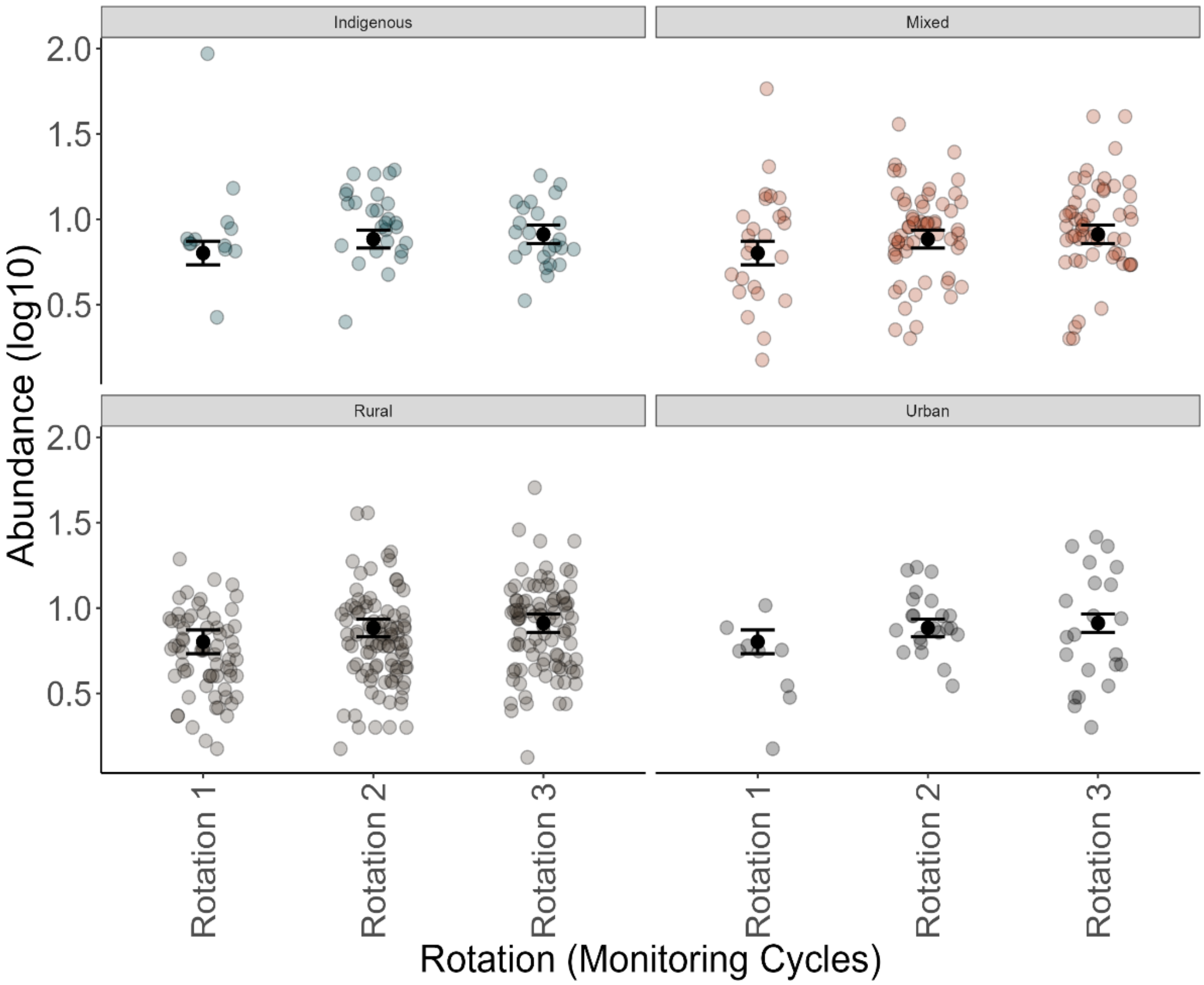

Figure 26. Native bird predicted mean abundance variation over time (monitoring rotation cycles) considering differences between Land Classes for wetland sites. Rural sites showed a 4.9% and 13.6% increase in native bird biodiversity, respectively, in rotations 2 and 3 compared to rotation 1. Similarly, urban sites showed 16.8% increase in rotation 2 and 13.4% increase in rotation 2 compared to rotation 1. Error bars = Confidence Intervals from model estimates. Data points = Abundance distribution.

Richness: State and Trends

A similar analysis assessed differences in species richness across wetland sites through our monitoring variables (Table 27). The Ecological District analysis indicated that the wetland plots in the Inner Gulf Islands contained between 14.3% and 5.7% more introduced species compared to plots in Kaipara, Hunua, Rodney, Tāmaki, and Āwhitu (Figure 27). Additionally, the findings revealed that rural and urban areas have 11.4% and 16.1% more introduced species, respectively, than indigenous areas (Figure 28). In contrast, native species richness is 6.4% greater in predominantly indigenous areas than in urban ones (Figure 28). Native species richness significantly increased over time, with 11.5% more native species counted in rotation 3 compared to rotation 1 (Figure 29). The richness of introduced species did not vary over time (Table 27).

In summary, Ecological District analysis revealed that the Inner Gulf Islands feature more introduced species than other Ecological Districts. Findings also indicate that native species significantly prefer wetlands dominated by indigenous plant communities, and numbers of native species inhabiting wetland plots has been significantly increasing over time. In contrast, richness of introduced species remains stable.

Table 27. General Linear Mixed Model results for native and introduced species estimated richness variation in wetland sites between different rotations, Ecological Districts and considering land cover classification. Fixed effects were responsible for explaining 15.5% (Marginal R^2 = 0.155) of the variation in species richness, and the study's random effects did not contribute to richness variance (estimates 0.00). Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*P-value*
(Intercept)	0.58	-0.08	**<0.001**
Āwhitu * [Introduced]	-0.09	-0.52	0.125
Hunua * [Introduced]	-0.16	-0.95	**0.001**
Inner Gulf Islands – [Introduced]	0.00	0.02	0.956
Kaipara * [Introduced]	-0.18	-1.08	**<0.001**
Manukau * [Introduced]	-0.05	-0.29	0.302
Rodney * [Introduced]	-0.11	-0.62	**0.011**
Tāmaki * [Introduced]	-0.10	-0.58	**0.044**
Waitākere * [Introduced]	-0.06	-0.34	0.143
Āwhitu * [Native]	-0.11	-0.63	**0.042**
Hunua * [Native]	-0.05	-0.30	0.235
Inner Gulf Islands * [Native]	0.08	0.48	0.066
Kaipara * [Native]	-0.04	-0.24	0.268
Manukau * [Native]	-0.02	-0.09	0.681
Rodney * [Native]	-0.03	-0.20	0.307
Tāmaki * [Native]	-0.03	-0.17	0.474
[Introduced] * Land Cover – Mixed	0.05	0.30	0.065
[Native] * Land Cover – Mixed	0.02	0.14	0.366
[Introduced]* Land Cover – Rural	0.17	1.02	**<0.001**
[Native] * Land Cover – Rural	0.01	0.06	0.678
[Introduced]* Land Cover – Urban	0.13	0.76	**0.001**
[Native] * Land Cover – Urban	-0.07	-0.40	0.074
[Introduced] * Rotation 2	0.02	0.11	0.358
[Native] * Rotation 2	0.07	0.42	**0.001**
[Introduced]* Rotation 3	0.03	0.15	0.286
[Native] * Rotation 3	0.11	0.63	**<0.001**
Random Effects			
Site Identification	0.00		
Observer bias	0.00		
Wetland class	0.00		
Observations	1022		
Marginal R^2 / Conditional R^2	0.155 / 0.388		

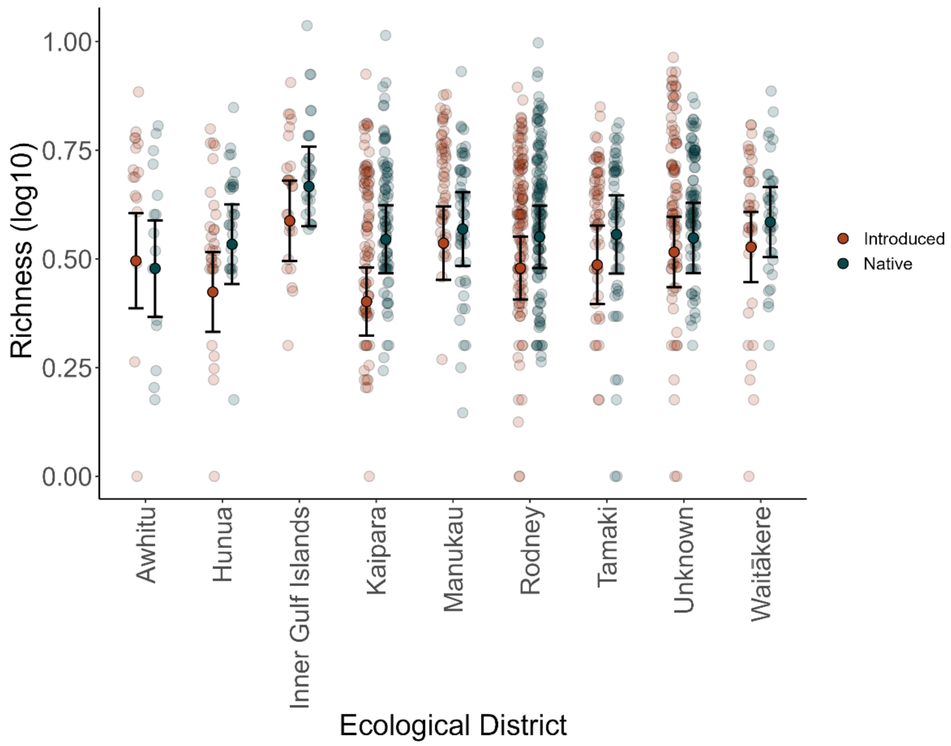

Figure 27. Predicted mean richness variation among wetland Ecological Districts considering variation between native and introduced species richness for regular 5MBC data. Wetland plots in the Inner Gulf Islands contained between 14.3% and 5.7% more introduced species compared to plots in Kaipara, Hunua, Rodney, Tāmaki, and Āwhitu. Error bars = Confidence Intervals from model estimates. Data points = wetland species richness distribution

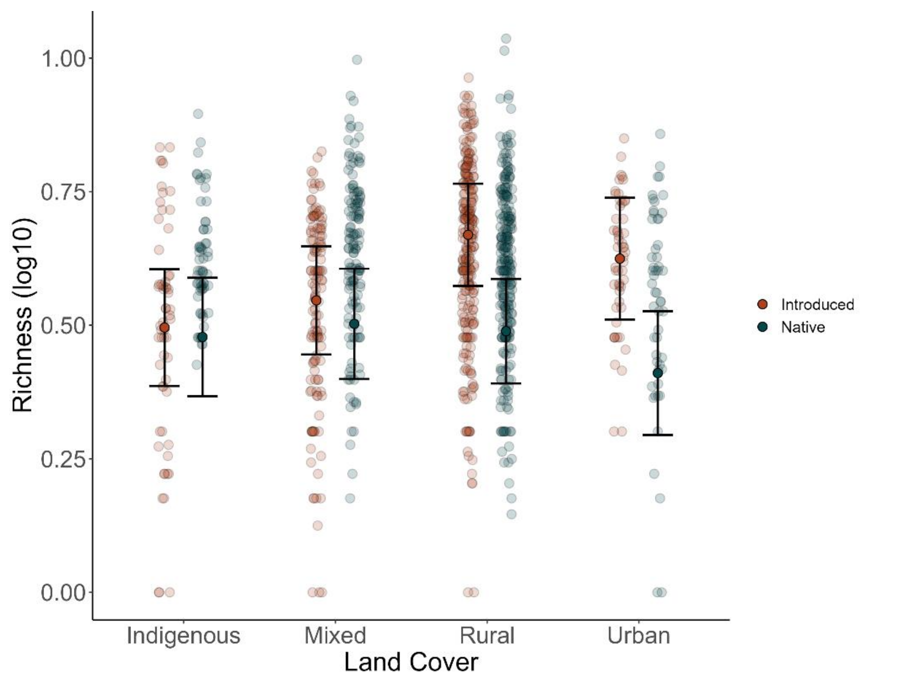

Figure 28. Predicted mean richness variation among Land Classes for regular wetland 5MBC data considering variation between native and introduced bird species richness. Rural and urban areas have 11.4% and 16.1% more introduced species, respectively, than indigenous areas. In contrast, native species richness is 6.4% greater in predominantly indigenous areas than in urban ones. Error bars = Confidence Intervals from model estimates. Data points = Richness distribution.

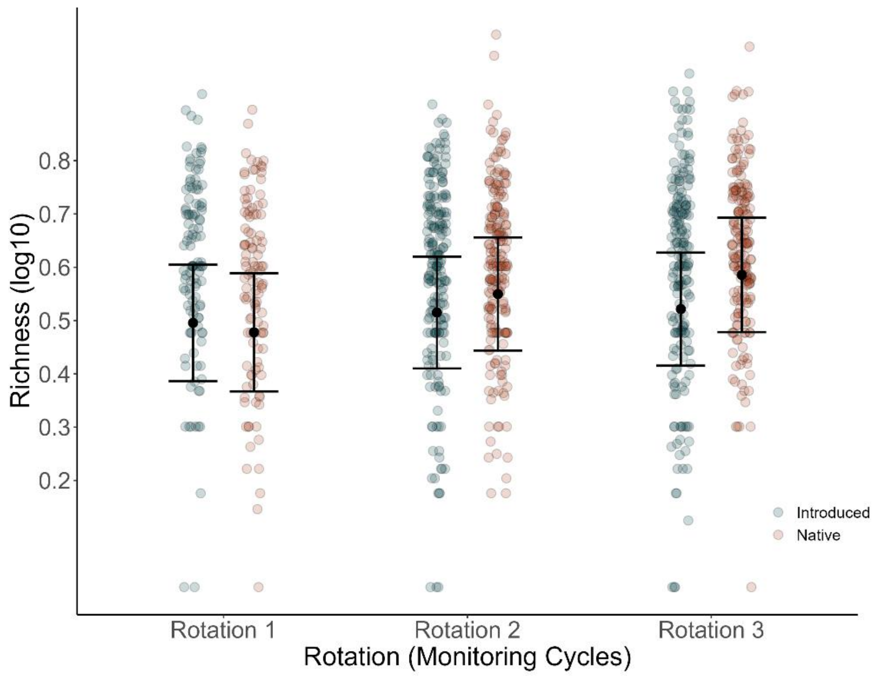

Figure 29. Predicted mean richness variation over time (monitoring rotation cycles) for regular wetland 5MBC data, considering variation between native and introduced species richness. Results revealed a positive trend for native species richness in rotation 2 (6.2%), and rotation 3 (11.5%) compared to species richness in rotation 1. Error bars = Confidence Intervals from model estimates. Data points = richness distribution.

3.3.2.1. Summary: Wetland 5MBC data

Bird numbers (abundance) in wetlands show lower native numbers in rural and urban sites versus indigenous habitats, but native species appear to be returning to altered landscapes. Introduced species are currently more common than natives in Auckland's wetlands, especially in urban areas, yet the number of native species (richness) seems to be increasing while introduced species remain stable. This indicates a shift in wetland biodiversity and supports findings of improved native bird populations in more modified landscapes. The prevalence of native species in indigenous habitats suggests that the high numbers of introduced species in the Inner Gulf Islands and high numbers of introduced birds in Āwhitu stem from modified habitats needing management attention.

3.3.3. Wetlands – Playback data abundance

To enhance the analysis of wetland endemic species' distribution, which tend to be cryptic and often significantly underestimated in the standard 5MBC, we examined playback data separately to identify states and trends for mātātā, spotless crakes, and banded rails. Although the playback dataset was limited ($n = 135$), the data indicated a significantly lower presence of endemic wetland species in rural areas compared to indigenous areas (Table 28 – Figure 30), similar to the abundance of native species found in the regular 5MBC data (Table 27). To determine if our indicator of environmental quality (land cover classification) correlated with variation in each separate endemic species' abundance, we applied the Kruskal-Wallis test for each playback species. The findings indicated a significant effect of Land Class on mātātā abundance only ($\chi^2 = 33.33$, df = 8, $p < 0.001$). Post-hoc pairwise comparisons

(Wilcoxon rank-sum test, BH-adjusted) demonstrated that indigenous sites positively influenced mātātā abundance compared to mixed (p = 0.017) and rural (p = 0.017) sites (Figure 31).

In other words, mātātās were observed more often in wetlands identified as having predominantly indigenous plant communities. This aligns with expectations based on the species' strong ecological specialisation and sensitivity to loss of habitat quality (Hill et al., 2015).

Table 28. Results from the General Linear Mixed Model for the estimated abundance variation of playback data (wetland endemic species), taking land cover classification into account. Random effects were responsible for explaining most of the total variance in abundance (30.2%), with natural site variation explaining 22.7% (Marginal $R^2 = 0.075$, Conditional $R^2 = 0.302$). Results in bold show significant results (p-value<0.05).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	-0.12	0.52	0.071
Land Cover – Mixed	-0.12	-0.45	0.060
Land Cover – Rural	-0.18	-0.67	**0.003**
Land Cover – Urban	-0.04	-0.16	0.813
Random Effects			
Site identification	0.01		
Observer bias	0.00		
Wetland Class	0.00		
Observations	135		
Marginal R^2 / Conditional R^2	0.075 / 0.302		

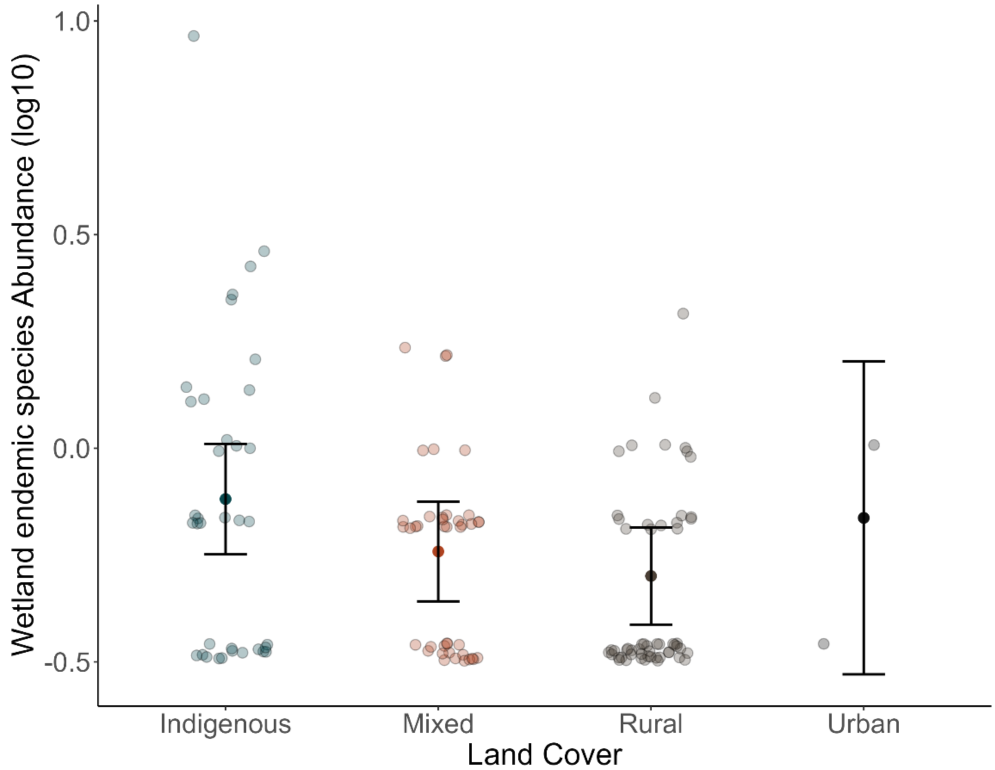

Figure 30. Predicted mean abundance variation among Land Classes for playback data of wetland endemic bird species. Rural areas have 33.9% lower endemic wetland bird abundance than indigenous areas. Error bars = Confidence Intervals from model estimates. Data points = abundance distribution.

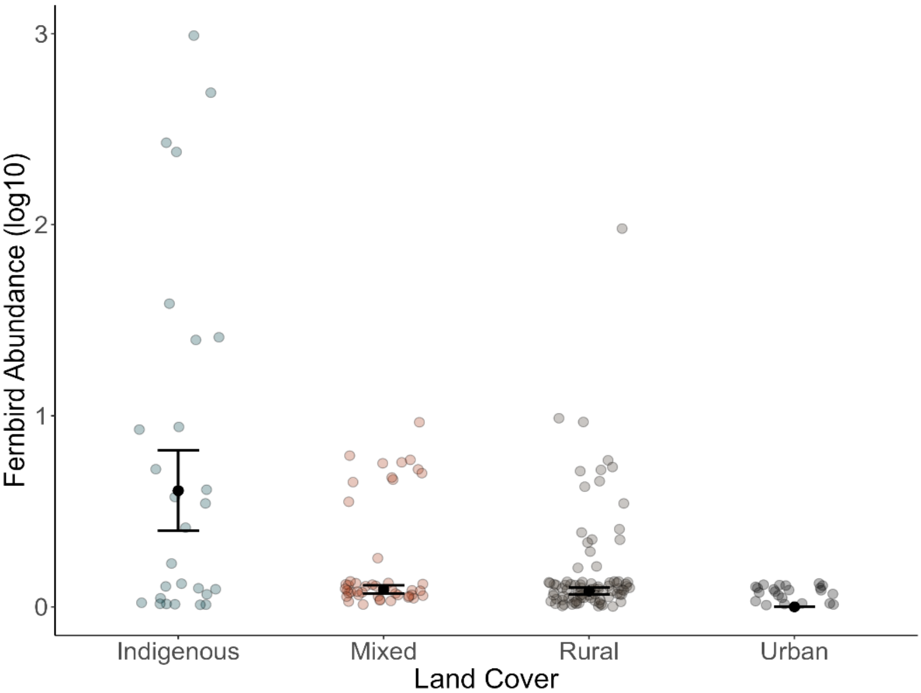

Figure 31. Variation among Land Classes for mātātā predicted mean abundance. Indigenous areas showed significantly higher fernbird abundance compared to mixed and rural sites. Error bars = Confidence Intervals from model estimates. Data points = fernbird abundance distribution.

3.4. Wetland birds – Indicator species

3.4.1. Indicator species for biodiversity trend: Timescale (year)

TITAN (see methods) investigated whether any species displayed significant changes over time. Among all the monitored species, only two (tauhou and welcome swallow) met the criteria for significant variation thresholds, sufficient purity (>950), and reliability (>950) to be considered reliable environmental indicators (filter = 2) (Table 29). The findings revealed positive trends (response direction), indicating population growth over the years (Figure 32). Each species was evaluated against monitoring variables to explore their potential as indicator species further. Tauhou distribution in wetlands had a substantially higher sample size for the rural land cover classification. The data remained unbalanced despite removing overfitting groups (land cover vs year sampling size <5). Tauhou abundance correlated only with interannual variation, possibly due to their high mobility and detection bias across sites and observers. Therefore, tauhou variation lacks the specificity to reliably indicate wetland recovery (Monks et al., 2013). Finally, the analysis of indigenous land cover dominance for wetland indicator species yielded no reliable results (filter = 2), likely because specific wetland species are better monitored using playback-only data, making them incomparable to the 5MBC dataset, and thus could not be included in the results.

Table 29: Wetland species selected by the model for showing significant changes in abundance over a particular monitoring year threshold. Only two species showed sufficient Purity (>950), Reliability (>950), and variation thresholds to be deemed trustworthy environmental indicators (filter = 2 – indicated in bold). Ienv.cp = Individual Change Point: Estimated environmental threshold (year) for a single taxon. Zenv.cp = Z-Score-Weighted Change Point: Indicates the environmental change point weighted by the taxon's indicator strength.

Species	ienv.cp	zenv.cp	Frequency	IndVal	z-score	Purity	Reliability	Filter
Pūkeko	2024	2024	245	66.21	3.07	0.24	0.738	0
Silvereye	2011	2011	448	58.54	4.45	0.988	0.998	2
Welcome swallow	2024	2023	206	46.77	7.4	0.978	0.992	2
Gradient (Year)	2023.5	2019	477	50.09	0.08	1	1	2

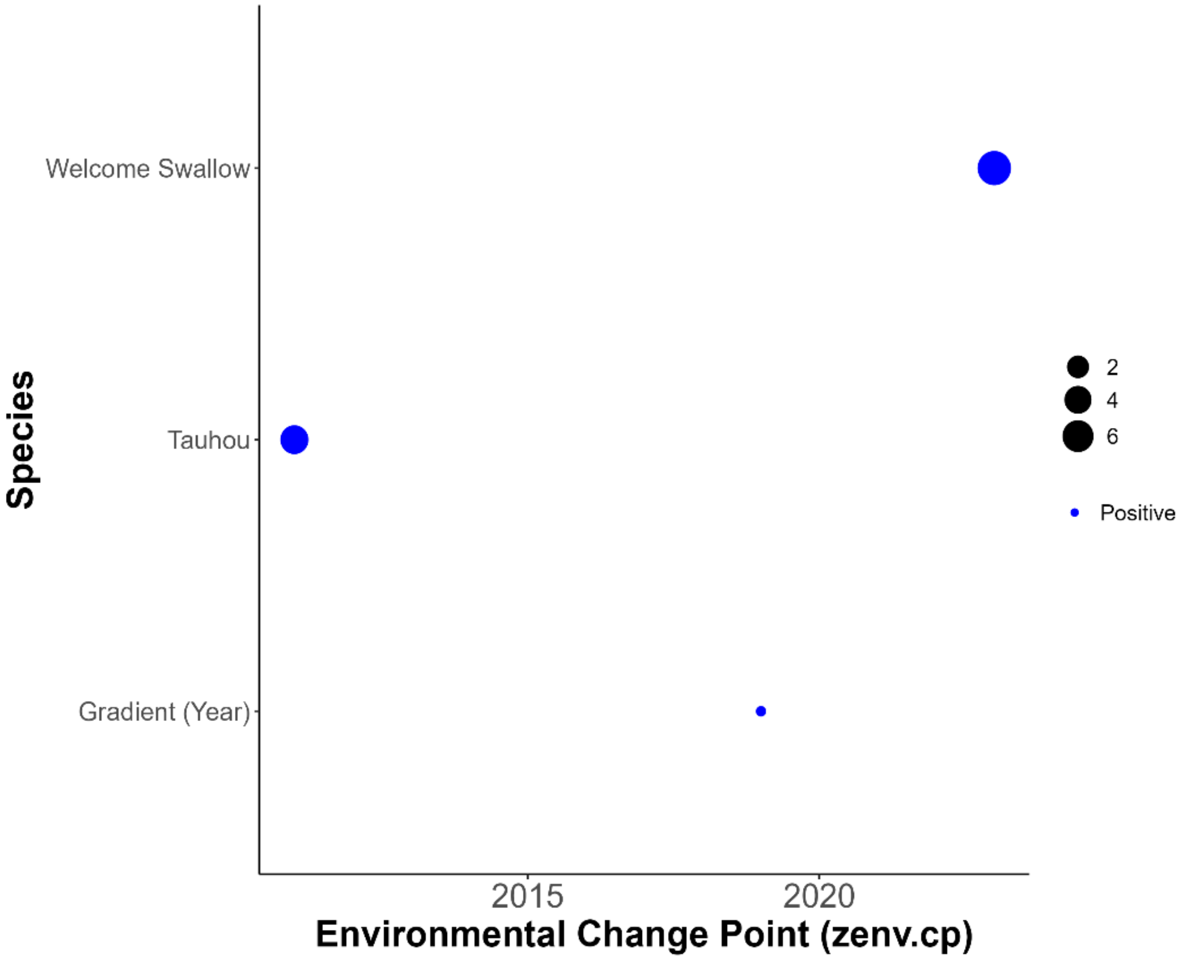

Figure 32. TITAN z-scores for year variation showing welcome swallow and tauhou as species identified to have significant variation thresholds, sufficient purity, and reliability to be deemed trustworthy environmental indicators for wetlands. The response direction is positive, indicating a significant increase in bird numbers at the selected year threshold. Higher z-scores indicate that change over the environmental gradient is significant, and not just random fluctuation. Zenv.cp = Z-Score-Weighted Change Point: Indicates the environmental change point weighted by the taxon's indicator strength. The environmental gradient tested (year) showed small variability strength (Z-score = 0.1) and only after 2020, which was expected since the environmental gradient in question was year, and the monitoring cycle for the TBMP is every 5 years.

3.4.1.1. Wetland Indicator Species: Welcome Swallow

In our investigation into the distribution of welcome swallows in wetland plots, we discovered that modified land classes (rural and urban) exhibited lower welcome swallow abundance (Table 30). While the abundance of this species varied over time, seeing a notable rise in 2018; trends were more apparent when examining interannual variation for different land classes. Specifically, rural plots showed higher welcome swallow abundance in the past few years (2017-2021) than in 2015, whereas other areas seemed to oscillate (Figure 33). It is important to interpret results from rural sites cautiously, as this species was observed to be significantly more prevalent in rural areas than in any other land cover classification (Figure 33). Mixed sites pose interpretive challenges from an ecological standpoint due to their inherent lack of specificity. Urban sites were not incorporated into models due to having fewer than five samples for each urban versus year interaction category. Interestingly, 95% of the variation in welcome swallow abundance was accounted for by land cover and year differences, along with observer bias and natural plot differences (Table 30), making these findings particularly interesting.

In summary, indigenous plots displayed higher overall numbers of these birds, suggesting their preference for well-preserved habitats. Rural areas showed the lowest abundance but had a steady increase in numbers after 2018. This suggested increase in welcome swallow abundance in 2018, compared to 2015, requires further exploration before drawing conclusions.

Table 30. Results from the General Linear Mixed Model for welcome swallow estimated abundance variation at wetland sites, taking interannual differences and land cover classification into account. The model fixed effects seemed to explain about 27% of the welcome swallow abundance variance, with 95% of the variation in this dataset being explained by the whole model when added random effects (Marginal R^2 = 0.27, Conditional R^2 = 0.95).

Predictors	*Estimates*	*std. Beta*	*p-value*
(Intercept)	0.22	0.92	0.359
Land Cover – Mixed	-0.49	-1.30	0.128
Land Cover – Rural	-1.05	-2.78	**<0.001**
Year 2017	-0.69	-1.83	**0.034**
Year 2018	0.93	2.45	**<0.001**
Year 2021	-0.46	-1.21	**<0.001**
Land Cover – Mixed * [2017]	1.34	3.53	**0.016**
Land Cover – Rural * [2017]	1.38	3.63	**<0.001**
Land Cover – Mixed *[2018]	-0.98	-2.58	**0.015**
Land Cover – Mixed *[2021]	0.61	1.60	0.071
Land Cover – Rural * [2021]	1.15	3.03	**<0.001**
Random Effects			
Site Identification	0.13		
Observations	61		
Marginal R^2 / Conditional R^2	0.273 / 0.949		

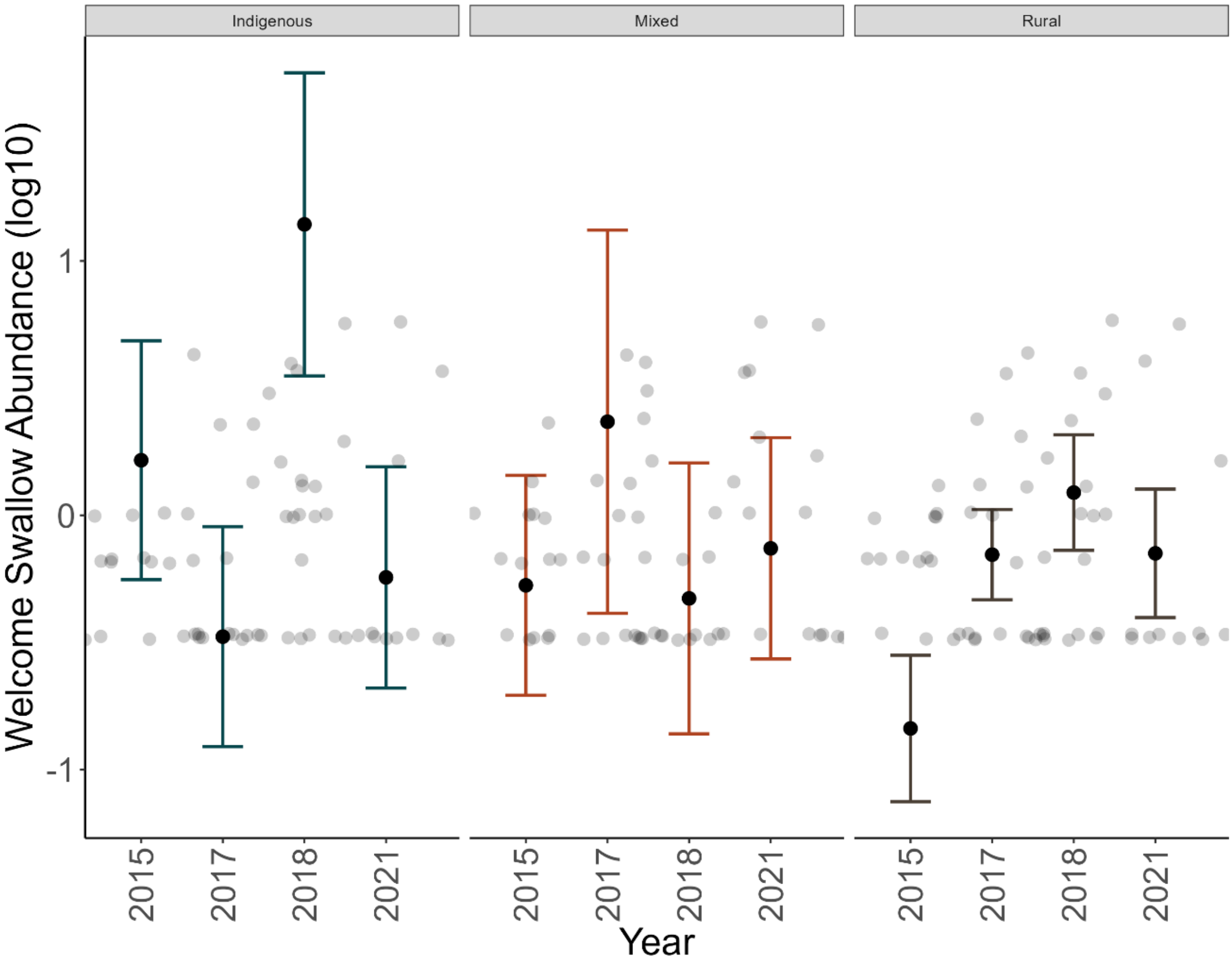

Figure 33. Welcome swallow predicted mean abundance variation over time (monitoring rotation cycles) considering differences between Land Classes for wetland sites. 1. Error bars = Confidence Intervals from model estimates. Data points = welcome swallow abundance distribution.

4 Discussion

Similar to considerations in Landers et al. (2021), this 15-year monitoring project covering diverse forest and wetland bird habitats reinforced the importance of using the established Five Minute Bird Count (5MBC) methodology (Dawson & Bull, 1975; Fitzgerald et al., 2019; MacLeod et al., 2015; Miskelly, 2018; Mortimer & Clark, 2012). Overall, the biodiversity data showed some variation in both abundance and richness variables, with significant variations being discrete. This report cannot yet confirm if these discrete results can be reliably extrapolated as terrestrial bird population trends. However, since this monitoring study is conducted consistently across similar environments within each programme (forests and wetlands separately) where detectability generally remains consistent, the analysed data exhibits sufficient power for comparisons across spatial, temporal, and environmental gradients. Nevertheless, the inferences drawn should be approached with caution when considered outside the scope of the TBMP, particularly for rare species where smaller sample sizes and limited categorical variations may reveal data limitations collection.

4.1. Forest birds

A total of 61 species were recorded in the counts conducted at the forest sites, compared to 64 species in the previous State of Environment report (Landers et al., 2021). Unlike in the period covered by the previous report (2009-2018), the new results (2009-2023) found that tauhou, rather than tūī, were the most abundant bird species, and the chaffinch, not the Eurasian blackbird, ranked as the 5th most abundant species (Landers et al., 2021).

Tauhou being the dominant bird species was also noted in a 22-year monitoring report for the Waitākere ranges (Lovegrove & Parker, 2023). It remains uncertain whether these patterns are driven by an ecological signal reflecting changes in bird distribution or are a result of monitoring biases and natural annual fluctuations. For instance, tauhou often travel in mobile flocks, which hinders accurate counting by observers (Lovegrove & Parker, 2023).

This report analysed native and introduced abundance and richness in terrestrial birds across Tier 1 and 2 forest sites. Results indicated that both metrics were consistently higher in indigenous land classes for these sites, while urban and rural areas exhibited the highest abundance and richness of introduced species. Interestingly, both Landers et al (2021) and this analysis found a slightly higher abundance of native than introduced species in urban tier 2 landscapes, albeit not significantly. Although the 2021 pattern could not be confirmed, we believe native species such as tūī and tauhou may be influencing this trend. These species thrive in urban gardens and parks, benefiting from frequent community and government-led pest management, and national surveys have reported a significantly high presence of these birds (MacLeod et al., 2022).

The preference of native birds for indigenous Land Classes is further supported by a significant increase in native richness in the Ecological Districts containing the largest patches of indigenous plant communities, that is the Great Barrier Island, Hunua, and Waitākere Ecological Districts (Landers et al., 2021). This pattern is accompanied by particularly low richness of introduced species within the forested areas of Great Barrier Island. Although this island is not pest-free, its isolation from the mainland, high forest connectivity and high frequency of conservation and pest control activities favour indigenous species (Ogden & Gilbert, 2011). Native abundance and richness also increased between rotations 1 and 3 for regional sites and areas of interest, with a more pronounced increase in Tier 2.

In summary, results for forest biodiversity in regional sites align with Landers et al (2021). Urban and rural areas often present high-pressure environments for native biodiversity, characterised by habitat loss and invasive species dominance (McKinney, 2006; Seto et al., 2012; Soanes et al., 2019). Agricultural activities lead to homogenised rural landscapes through farming expansion, deforestation, and soil modification (Blackwell et al., 2008). The resulting loss of ecosystem function facilitates the invasion and establishment of introduced species. Similarly, urban areas pose a significant threat to biodiversity due to severe habitat loss and depletion of resources (Aronson et al., 2006; McKinney, 2006; Seto et al., 2012; Soanes et al., 2019). Pockets of remnant and restored urban forests are often fragmented and isolated (Marzluff & Ewing, 2001), allowing invasive species to thrive due to their lower competitive resource demands compared to native species(McKinney, 2002).

Results emphasise the need for restored, connected fragments of healthy plant communities to shelter native species amid ongoing pressures. Increased native bird biodiversity in later monitoring years for Tier 2 sites aligns with enhanced management and restoration initiatives at these sites and supports findings from Landers et al (2021) on the high value of managed Tier 2 areas on islands and the mainland (e.g., Hunua Ranges).

4.1.1. Indicator species: interannual variation

A detailed look at native species revealed which bird populations are influencing biodiversity changes, pointing towards possible indicator species among forest birds. The analysis indicated that tūī, riroriro, pīwakawaka, and tauhou are the primary species contributing to the increase in native abundance during the last monitoring period (rotation 3). Notably, these wide-ranging, generalist species (Lovegrove & Parker, 2023) are also the most prevalent throughout the entire TBMP. Tūī showed the highest abundance in both indigenous and urban areas. Similarly, the tauhou data indicated a stronger presence in urban settings compared to indigenous plots. This tendency towards urban habitats may be associated with the ecological restoration efforts often undertaken in urban forests, which may positively impact native bird biodiversity (Noe et al., 2022). Additionally, the abundance of food sources in gardens and the limited presence of competing native species in these areas (MacLeod et al., 2022) may further contribute to this trend. The importance of refuge habitats such as urban forests in highly modified landscapes should be acknowledged for their conservation value to indigenous species (Blackwell et al., 2008) and should be integrated into urban planning and management.

Pīwakawaka numbers were higher in Tier 1 than Tier 2. Tier 2 sites have more contiguous indigenous land and conservation areas, which should benefit indigenous species. However, results align with

Lovegrove et al (2023), showing declines in fantails at sites where pests were reduced (e.g., Tier 2 sites) and missing endemic species recolonised, likely due to increased competition (Graham et al. 2013, Miskelly 2018, Binny et al. 2021). Miskelly (2018) noted that fantails and tauhou thrive in unmanaged New Zealand habitats and are largely unaffected by mammalian pests. Variation in both species may reflect the absence of other indigenous species, rather than invasive mammal density, which would regulate pīwakawaka and riroriro populations (Lovegrove & Parker, 2023; Ruffell & Didham, 2017). Absent or only single-species pest control hinders the recolonisation of missing endemic species and favours pest-resistant natives like pīwakawaka and tauhou (Lovegrove et al, 2023).

4.1.2. Indicator species: Indigenous land cover

Analysis of variation in native species related to indigenous land cover areas identified kererū and kākā as potential indicators. Their abundance increased in sites with high indigenous forest dominance, based on the percentage of indigenous land cover. Thus, their populations may serve as a proxy for the successful restoration of native plants and the recolonisation by fauna, contingent on evaluating established criteria and developing a framework for indicator species (Monks et al. 2013).

Kererū abundance increased significantly at nearly 90% indigenous cover, especially in Tier 2 forest sites of conservation interest. Higher abundance was noted in the Āwhitu Ecological District compared to the Waitākere District. While Āwhitu falls under the rural land cover classification, monitored plots included tōtara, kānuka, and broadleaf forest, a threatened ecosystem type of coastal forest (Griffiths et al., 2021). Numerous areas in Āwhitu are managed for pest and weed control on public and private land, with Auckland Council aiding in replanting and possum control (Griffiths et al., 2021). Ruffell & Didham (2017) noted that pest control directly affects kererū abundance, unlike other native species. Lovegrove et al. (2023) expressed that the Waitākere ranges lack sufficient pest control for the recovery of indigenous species due to ship rats and other invasive mammals benefiting from reduced possum numbers. Our findings, indicating high kererū presence in Āwhitu, may suggest early success of conservation efforts in the region, although further monitoring is needed to clarify. The kererū can be an indicator of effective possum control and habitat restoration, showing increased numbers post-possum removal (Innes et al., 2004; Lovegrove & Parker, 2023; Lovegrove, 1988) and indigenous forest cover (Carpenter et al., 2021). Kererū have previously been selected as a national indicator species (Monks et al., 2013), and this indicates that kererū populations are potentially directly associated with habitat restoration in the Auckland region due to management efforts, highlighting the need to explore this relationship further to assess their indicator potential in the TBMP.

During the TBMP period, kākā were found in a limited number of locations, exhibiting significantly higher populations on Great Barrier Island compared to other Ecological Districts of high conservation interest (Hunua and Waitākere), which experience intensive management. Monitoring of this species across various regions in New Zealand has shown that in conservation and translocation efforts, kākā favour native forest fragments, even in urban settings, provided there is a reserve nearby with minimal mustelid presence and native plant communities that supply resources for feeding and reproduction, such as beech forests and rimu trees. These conditions offer protection and additional dietary support, while the forest patches enhance their dispersal (Greene et al., 2004; Recio et al., 2016). Conversely, the Hunua and Waitākere Ranges are a vast, protected indigenous forest that has undergone possum management, including aerial applications of 1080 poison in 1994, 2015, and 2018 in the Hunuas (Lovegrove & Parker, 2023). However, a detailed overview of kākā conservation strategies indicated that while 1080 operations did not harm their populations, the long-term impact on productivity (via possum control) was insignificant (Greene et al., 2004). Although Great Barrier Island is not pest-free, it is free of mustelids and possums. In line with these criteria, Great Barrier Island offers the necessary space and resources to sustain this species. In contrast, other Ecological Districts may not have achieved optimal pest control, suggested from the significantly larger population of this species on the island.

In summary, kākā distribution is linked to well-preserved areas and has been recognised as an indicator of habitat quality, with their presence indicating conditions suitable for the restoration of other species (Greene et al., 2004). This suggests the benefits of expanding kākā monitoring in Auckland to track the success of forest restoration and management. In conclusion, Greene et al. (2004) recommend using distance sampling to establish baseline monitoring of kākā and kererū populations in areas with adequate numbers of these species. This method effectively evaluates long-term population trends and tracks advancements in ongoing pest control initiatives, and the establishment of a programme such as this aligns with our findings about the potential usefulness of these species as indicators.

4.2. Wetland birds

A total of 60 species were documented during counts at wetland sites. Similar to findings from the previous State of the Environment (SoE) period (2009-2018) and other studies conducted in Auckland wetlands, tauhou emerged as the most frequently recorded bird species (Hill et al. 2015, Landers et al. 2021). Following tauhou, common Myna, riroriro, house sparrow, and tūī ranked as the next four most abundant wetland birds. Notably, four of the five most abundant bird species in wetlands were indigenous, contrasting with Landers et al. (2021), which only identified three native species (tauhou, riroriro and tūī) among the top five. This apparent improvement in native species ranking may be attributed to pest control and the restoration and protection of indigenous plant communities in wetland regions (Anderson & Ogden, 2003; Robertson, 2016). Nonetheless, it could also result from natural yearly variations in bird populations observed over the past five years, underscoring the need for long-term bird counting studies to assess trends reliably (Keith et al., 2015; Lovegrove & Parker, 2023). Additionally, tūī are very noticeable birds, easily heard and seen during monitoring, which might introduce observer bias in their reporting. It is also important to note that none of the specific wetland native species (mātātā, spotless crake and banded rail) ranked among the 10 most abundant species over this 15-year monitoring period. This pattern aligns with previous findings from bird count monitoring at Kaitoke wetland on Great Barrier Island {Anderson, 2003 #7;Ogle, 1980 #71}. Despite the area's intact vegetation sequence, most species recorded in high numbers were those with broad habitat ranges (e.g., tauhou, riroriro) (Anderson & Ogden, 2003). Therefore, the high numbers of non-wetland-specific species may stem from their natural lower abundance due to habitat and behaviour, but also due to historical and ongoing degradation of wetland habitats caused by development and the invasion of exotic species {Owen, 1985 #72}. Anderson & Ogden (2003) noted a rise in common

Mynas at Kaitoke wetland, and our monitoring program corroborates the prevalence of common Mynas in wetlands. These birds are dominant and may be detrimental to New Zealand's indigenous bird communities {Baker, 2016 #73}.

In the TBMP, resident wetland species exhibited expected preferences for land cover types. Native bird species recorded in regular 5MBC were more numerous in indigenous land classes, which also hosted a higher diversity of native species. Conversely, introduced species thrived more in rural and urban settings, with notably greater numbers found in those wetlands. Overall, species richness of introduced species surpassed that of indigenous species, indicating a pronounced dominance of introduced species in Auckland's wetland habitats.

Results across ecological districts indicated that areas with a greater proportion of indigenous vegetation cover (e.g., Inner Gulf Islands, Hunua, Rodney) supported a higher abundance of native species in wetlands compared to the predominantly rural Āwhitu Ecological District. It is noteworthy that some species classified as Regionally Vulnerable were recorded in these more indigenous Ecological Districts, implying that these habitats are valuable to species of conservation concern (Woolly et al., 2024). Furthermore, Landers et al. (2021) observed after two monitoring rotations in 2021 that the Waitākere and Hunua Ecological Districts consistently exhibited the highest Mean Indigenous Dominance values across all Ecological Districts. Our findings echoed this suggested trend, although neither observation achieved statistical significance. The greater abundance of wetland birds in indigenous versus rural-dominated ecological districts reinforces the results of the land cover classification analysis, reflecting the preference of native birds for indigenous habitats.

An interesting and hopeful trend emerged from the data, showing a significant rise in native bird populations in rural and urban wetland areas in recent years, indicating a positive shift towards restoring native species abundance in modified habitats. Native species richness has also grown compared to the initial TBMP cycle, suggesting an increase in the number of native species occupying wetlands. Rural areas have been identified as crucial refuge habitats for native biodiversity in New Zealand, with shelterbelts, riparian zones, and scrublands fostering ecological functionality and even the restoration of native plant and pollinator species {Walker, 2008 #74}. Urban environments can offer food and shelter in gardens and managed wetland areas {MacLeod, 2022 #53} and our results may reflect improvements in wetland habitat quality and connectivity in both urban and rural green spaces in the Auckland region. Auckland has seen growing awareness and positive outcomes from community-led programmes focused on restoration initiatives {B, 2010 #76;Galbraith, 2013 #77}. Alongside an expansion of government-based approaches {Sullivan, 2016 #75}, pest management may have contributed to improvements in both rural and urban habitats. However, the reasons behind increasing native abundance in these spaces require further investigation.

Playback results concentrate on cryptic wetland species that typically go unrecorded in standard monitoring. Their low counts and absence of abundance distribution trends might be linked to: (1) the monitoring methods used, and (2) variations in species abundance across different vegetation types (e.g., forest, freshwater) and wetland forms (e.g., saltmarsh, lagoons, mudflat) observed in these habitats {Anderson, 2003 #7}. Past research has shown that wetland bird abundance varies with the wetness gradient or the characteristics of the plant community, and predator pressure further influences habitat selection within wetland sites {Elliot, 1987 #78;Andrews, 1995 #79;Onley, 1982 #80}. For instance, habitat preferences for spotless crakes have been linked to vegetation variations {Ogle, 1980 #71;Kaufmann, 1987 #81} and predator pressure {Onley, 1982 #80}. Therefore, the uniformity of habitats within our plots and the seasonal monitoring aimed at capturing subtle differences in species behaviour may also contribute to the observed low counts.

Future playback monitoring should consider a broader array of bird monitoring stations in wetland areas to better represent wetland bird diversity. The elusive nature of wetland bird species results in substantial knowledge gaps regarding their status and trends (Hill et al 2015), highlighting the need for improved monitoring. The mātātā, the only species showing a significant positive correlation with indigenous land cover, has previously been linked to wetland habitat quality (Anderson & Ogden 2003, Hill et al 2015), indicating that it may serve as a strong indicator of wetland habitat quality in the Auckland region.

4.2.1. Indicator species: Interannual variation

The apparent recovery of welcome swallow populations in the Auckland region from 2017 to 2021, in contrast to 2015, may result from intensified legislation and restoration efforts targeting vulnerable wetland ecosystems in recent years {Robertson, 2016 #69}. Since this bird is more frequently seen in rural wetland areas and considering the earlier mentioned increase in native wetland biodiversity in these regions, these findings suggest that the welcome swallow could be a potential indicator of the effectiveness of pest control and restoration strategies in transitioning wetland habitats. Previously, Anderson & Ogden (2003) found no significant impact of vegetation type on welcome swallow abundance, and little additional data have since been gathered on this topic. Further research is essential to determine whether the variations in welcome swallow abundance are related to the recovery of ecological functions or to a natural preference for rural wetlands, particularly regarding the capacity of rural wetland landscapes to support breeding swallows and insect populations (Elgin et al 2020).

4.3. Study limitations

Standard bird counts are known to overdetect vocal and conspicuous birds while underestimating cryptic ones (between 60% and 80% of birds detected in this study for wetland and forest were heard but not seen) {Hartley, 2012 #44}. Accordingly, our results demonstrated that variations among observers modestly but significantly influenced our models. However, the results of this monitoring period revealed notable patterns in the state and trends of terrestrial birds in the Auckland region when compared using repeated monitoring over time. The 5MBC does not aim to provide accurate census data, but merely an index of bird numbers {Dawson, 1975 #43;Hartley, 2012 #44}, which can still offer a useful measure in that context.

Further, this study is limited by a small sample size in the trend data. Although this report adds a full rotation of monitoring for the TBMP sites compared to the last published report (Landers et al., 2021) each site has only been monitored three times in 15 years. Results from three counts in any single site over time may miss a range of single events in between cycles (e.g. transitioning effects of weather events), may be limited in differentiating real changes in populations from variation in conspicuousness between communities {Hartley, 2012 #44;Dawson, 1975 #43}, or may be unable to uncover underlying processes. Lastly, certain variables, such as pest management, pest monitoring data and forest fragmentation, were not part of the TBMP at the time of this report and could significantly influence data interpretation in the future. Most of the variation in bird abundance and richness can only be partially explained by the available data to the Terrestrial Biodiversity Monitoring Programme (TBMP).

5 Conclusions

Overall findings

This study reinforces the conclusions from Landers et al. (2021) regarding the value of large-scale bird surveys, which become clearer and more relevant over time. The continuation of the regional Terrestrial Biodiversity Monitoring Programme (TBMP) is essential for validating trend analyses, which will guide and enhance decision-making and management practices. This is particularly important given the increasing pressures on birds from urbanisation, land use changes, and climate change.

Land Classes

The comprehensive bird count data collected from forest and wetland sites during the 15-year monitoring program have highlighted significant variation in the richness and abundance of terrestrial birds across the Auckland region. Native forest and wetland birds consistently preferred sites predominantly composed of indigenous Land Classes. This aligns with the understanding that native birds in the Auckland region prefer environments that support ecological functions beneficial for native species {Singers, 2017 #52}. In contrast, introduced forest and wetland bird species favoured urban and rural land classes, confirming findings from the last terrestrial bird State of the Environment report (Landers et al. 2021). While the results indicate a lack of suitable conditions in urban and rural areas for many native species, species such as tūī and tauhou can occur in substantial numbers in both indigenous and urban settings.

Our results also show increases in the abundance of native bird species in both Tier 1 and Tier 2 forest sites, as well as in wetland areas, indicating positive trends for native birds in Auckland. Notably, the number of native birds in wetlands has recently increased in both rural and urban areas, although native bird numbers remain modest compared to those of introduced species. This highlights that well-managed indigenous habitats, as well as restored rural and urban environments, serve as sanctuary pockets for the restoration and recovery of native biodiversity in forests and wetlands.

Unfortunately, this positive trend in native birds primarily involves broad-habitat, non-threatened species that can thrive in urban areas (e.g., tūī and tauhou), indicating that more work is needed to support those threatened species that are highly dependent on managed habitats, which remain underrepresented in both urban and rural environments.

Ecological Districts

The Ecological District analysis revealed that regions surrounding healthy forests such as the Waitākere Ranges, Hunua Ranges, and Aotea/Great Barrier Island support a greater diversity of native bird species, especially in Tier 2 sites. We recognise that more connected forest and wetland areas serve as crucial sanctuaries for indigenous species, particularly threatened species, in the face of urban pressures. However, the observed high presence of native species in the Waitākere Ranges, contrasted with low kererū numbers and high counts of introduced birds, suggesting that pest control efforts may still be inadequate to support more vulnerable native species in that Ecological District.

Interesting patterns also emerged for specific Ecological Districts, such as the apparent higher kererū abundance in forest sites of rural Āwhitu than in any other Ecological District, possibly linked to reduced possum densities, or the increase in native bird populations in wetland habitats which may indicate successful restoration initiatives. However, given the complexity within the Ecological District classification, further research is warranted to clarify trends.

Further, elevated introduced bird populations in rural areas such as Āwhitu, coupled with high numbers of introduced birds in wetland sites within the Inner Gulf Islands, indicate insufficient wetland habitat quality for most wetland native abundance. This uncovers the need for enhanced management actions in wetlands in these areas of Auckland.

Indicator species

A few species such as pīwakawaka, kererū, kākā and mātātā could serve as indicators of habitat restoration success in forests and wetlands in the Auckland region. Having identified these potential indicator species is preliminary work, necessitating further studies to confirm trends in their abundance and relationships with signals of pest management and restoration project successes. This emphasises the need to invest in identifying reliable indicator variables and species that can be consistently monitored over time to confidently evaluate environmental changes.

Monitoring considerations

Long-term, region-wide monitoring of terrestrial birds cannot account for all ecological influences. Variations in bird abundance and richness were only partially explainable by the data available through the Terrestrial Biodiversity Monitoring Programme (TBMP). Many factors, including natural behaviours, predation, competition, and habitat loss, profoundly affect these populations. Habitat fragmentation is notably pressing in the Auckland region, influenced by urbanisation and development, but direct measures of fragmentation were not included in this report. A future report will integrate this information to better understand the relationship between habitat fragmentation and terrestrial bird biodiversity, and to promote restoration initiatives in modified habitats to support ecological processes such as dispersal.

Lastly, the significant impact of introduced pest pressures on terrestrial bird communities could not be quantified within this analysis. To improve the TBMP framework, pest monitoring should be included to provide critical insights that enhance our understanding of bird population trends and the success of pest management initiatives.

Further, the negative effects of invasive mammalian species on native birds are well-documented. However, the impact of introduced bird species is still not fully understood (Baker et al., 2014). This lack of knowledge may impede the recovery of native species that are less competitive in restored habitats. Future monitoring should focus on the role that introduced birds play in the dispersal and survival of native species and incorporate pest monitoring data to help develop more effective management strategies.

Management Considerations

These results highlight the role of urban and rural sites in forest and wetland bird biodiversity conservation. However, the enhancement of modified habitats in urban and rural regions relies on various economic and social factors {Jay, 2005 #83}. It is essential for policymakers, conservation managers, farmers, and the general public to recognise and share the importance of restoration and conservation of refuge habitats in modified landscapes (Blackwell et al., 2008).

Given the considerable amount of private land in the rural and urban areas of Auckland, members of the regional community can play a crucial role in achieving these biodiversity gains. Some relatively easy contributions include replacing pest plants with appropriate indigenous species, managing pest mammals, and joining a local community restoration group. Community-based restoration groups have expanded their reach significantly in the last decades {Silvertown, 2009 #82}, but more is needed from the conservation industry to support them with resources, data management and monitoring systems (Sullivan & Molles, 2016). These actions can significantly enhance the natural habitats around us and support the recovery of native wildlife.

6 Summary

- Indigenous forest birds preferred habitats primarily composed of native land classes, while introduced species favoured urban and rural areas.
- When analysing native species with fluctuating populations over the years, some indigenous species, such as tūī and tauhou, appear to be thriving in both urban and rural classified sites as well as on indigenous plots.
- Species like the pīwakawaka, riroriro, tauhou, kākā and kererū could serve as indicators of success for multi-species pest control efforts aimed at preserving indigenous landscapes and restoring urban forests.
- During the 15-year monitoring period, no wetland-specific native species ranked among the 10 most abundant species. Most native species found in wetlands exhibited broad habitat ranges, with introduced species dominating wetland habitats in the Auckland region.
- Native species living in wetlands showed a greater preference for indigenous land cover, but there has been an increase in the abundance of native birds in rural and urban sites over the last 15 years of monitoring.
- Refuge habitats such as urban forest fragments within highly modified landscapes in Auckland should be recognised by conservation managers and the public for their value in providing refuge, connectivity, and dispersal opportunities for indigenous species.
- The mātātā was the only species with significant results in the playback dataset, showing a strong positive relationship with indigenous land classes, suggesting it may be a relevant indicator for monitoring wetland habitat health in Auckland.
- Playback monitoring could benefit from including a broader range of bird monitoring stations within wetland plots to better reflect the diversity of wetland birds, and potentially improved technology for bird detection.
- An increase in the number of welcome swallows at rural wetland sites may indicate the success of pest control and restoration strategies in improving wetland habitats.
- Further research is needed on all species identified as potential indicators, along with their environmental gradients, to determine whether their variations are linked to the recovery of ecological functions and assess their value as indicator species.
- This study reinforces the conclusions from Landers et al. (2021) regarding the value of large-scale bird surveys, which become clearer and more relevant over time. It is crucial for the regional Terrestrial Biodiversity Monitoring Programme (TBMP) to continue so that trend analyses can be validated, thereby informing decision-making and management practices. This is particularly important given the increasing pressures on birds from urbanisation, land use changes, and climate change.
- Most of the variation in bird abundance and richness can only be partially explained by the available data to the TBMP. Future data analysis should incorporate more ecological integrity variables, such as pest monitoring and fragmentation analysis.

- Future regional analyses should consider utilising citizen-derived data, in addition to supporting and collaborating with community-led pest monitoring initiatives. This approach would help address the metadata limitations highlighted in our study, fill gaps in community resources and engage the community with their local biodiversity.

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8 Appendix

Appendix 1. Detailed breakdown of the calculation of study variables (mean abundance, richness and native dominance)

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