Diversity, Abundance and Distribution of Birds in Tāmaki Makaurau / Auckland 2009-2019. State of the Environment Reporting

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

February 2021 Technical Report 2021/08

Research and Evaluation Unit RIMU

Auckland Council
Te Kaunihera o Tāmaki Makaurau

Diversity, abundance and distribution of birds in Tāmaki Makaurau / Auckland 2009-2019. State of the environment reporting

February 2021 Technical Report 2021/08

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

*Auckland Council, Research and Evaluation Unit (RIMU)
**AUT – Auckland University of Technology

Auckland Council
Technical Report 2021/08

ISSN 2230-4525 (Print)
ISSN 2230-4533 (Online)

ISBN 978-1-99-002298-2 (Print)
ISBN 978-1-99-002299-9 (PDF)

This report has been peer reviewed by the Peer Review Panel.
Review completed on 5 February 2021 Reviewed by three reviewers
Approved for Auckland Council publication by: Name: Eva McLaren Position: Manager, Research and Evaluation (RIMU)
Name: Megan Carbines Position: Manager, Air, Land and Biodiversity (RIMU)
Date: 5 February 2021

Recommended citation
Landers, T. J., H. Allen, C. D. Bishop, G. J. K. Griffiths, J. Khin, G. Lawrence and M. R. Ludbrook (2021). Diversity, abundance and distribution of birds in Tāmaki Makaurau / Auckland 2009-2019. State of the environment reporting. Auckland Council technical report, TR2021/08

Executive summary

Auckland Council collects a variety of bird data across Auckland as part of its regional Bird Monitoring Programme (BMP), which contributes to reporting on the State of Environment for Auckland, as well as contributing to other environmental reporting obligations. Birds are useful indicators for evaluating biodiversity and are commonly surveyed in New Zealand using the standard five-minute bird count method, which is the basis of the ten-minute bird count method used in this study. This report details the results from the two major land bird programmes in the BMP, each of which takes five years to survey a full rotation: forest (2009-2018) and wetlands (2011-2019).

The majority of birds counted in forest (70%) and wetlands (55%) were indigenous species. Four of the top five bird species counted in forest were indigenous whereas in wetlands, only two of the top five species were indigenous. Tūī (*Prosthemadera novaeseelandiae novaeseelandiae*) was the most commonly counted species at forest sites, followed by silvereye (*Zosterops lateralis lateralis*), grey warbler (*Gerygone igata*), North Island fantail (*Rhipidura fuliginosa placabilis*) and Eurasian blackbird (*Turdus merula*), all detected in >50 per cent of counts. Silvereye was the most commonly counted species at wetland sites, followed by common myna (*Acridotheres tristis*), grey warbler, European goldfinch (*Carduelis carduelis*) and house sparrow (*Passer domesticus*), all detected in >30 per cent of counts.

Species richness (i.e. diversity) and abundance varied significantly across the region when looking at different Land Classes, ecological districts, large sub-regional areas, and highly managed areas. Sites that were mostly indigenous ecosystems and/or were near large forested areas (Hunua and Waitākere Ranges, Aotea/Great Barrier Island [Aotea] and Te Hauturu-o-Toi/Little Barrier Island [Hauturu]), had the highest indigenous dominance (mean proportion indigenous species of total species), whereas sites in urban and rural areas had the lowest percentages. The highest percentages of indigenous birds were found at well-protected or highly managed forest areas, both on offshore islands and in mainland sanctuaries. Hauturu had the highest percentage where almost all birds counted were indigenous, followed by Glenfern and Windy Hill on Aotea, and the Kōkako Management Area in the Hunua Ranges, where on average ~90 per cent of individual birds counted were indigenous. This shows the high value of these sites as reserves for indigenous birds. No differences were detected between the two completed wetland rotations over this study (Note: forest rotations were not compared; see Methods). Overall, the numbers of introduced species varied more than indigenous species, which generally explained the variation seen in indigenous dominance across the region.

This study identified the importance of large-forested and highly managed areas in the region, and hence the value of these for maintaining high proportions of indigenous species, which in turn contribute to ecological integrity in these areas. These places also function as important sources of indigenous birds, which can spill over into neighbouring areas as more of these are restored. Future completed full rotations in the regional BMP will allow longer-term trends to be assessed so that we can track if bird populations are stable, improving or decreasing, and thus adjust management actions accordingly.

Table of contents

List of figures

List of tables

List of acronyms and abbreviations

10MBC	10-minute bird count
5MBC	First five minutes of 10MBC
ANOVA	Analysis of variance
Aotea	Aotea/Great Barrier Island
ARC	Auckland Regional Council
BMP	Bird Monitoring Programme
CBP	Coastal Bird Programme
DOC	Department of Conservation
ED	Ecological district
Hauturu	Te Hauturu-o-Toi/Little Barrier Island
MUL	Auckland Council Metropolitan Urban Limit
KMA	Kōkako Management Area
SSMRP	Seabird and Shorebird Monitoring and Research Programme
TBMP	Terrestrial Biodiversity Monitoring Programme

1.0 Introduction

The land area of Tāmaki Makaurau / the Auckland region comprises ~4520km^2 on the mainland and ~500km^2 on the Hauraki Gulf islands. The region encompasses a diverse range of natural ecosystems and habitats comprising forest, scrub and shrubland vegetation (hereafter collectively referred to as 'forest') from sea level to over 700m, along with freshwater wetlands, lakes, rivers, salt marshes, estuaries and duneland ecosystems in lowland and coastal areas (Auckland Council 2015). Indigenous forest once covered much of the region, but historical deforestation, agriculture and growth of New Zealand's largest urban area (Meurk and Swaffield 2000), mean that today, forest covers less than 30 per cent of the Auckland region (Singers et al. 2017). On the mainland, existing forests include small urban remnants, rural forest fragments north and south of the city and large, intact forests in the Waitākere and Hunua Ranges. Large, contiguous forests also exist on Aotea/Great Barrier Island (Aotea) and the pristine, pest-animal-free Te Hauturu-o-Toi/Little Barrier Island (Hauturu). Auckland's existing freshwater wetland ecosystems comprise a tiny fragment of their former extent, with just four per cent of the original wetlands remaining (Lawrence and Bishop 2017). Wetlands are of particular importance given the biodiversity they support and the variety of resources they provide for people (Barbier et al. 1997; Zedler and Kercher 2005; Ministry for the Environment 2007; Ministry for the Environment and Stats NZ 2019).

Auckland's ecosystems and habitats support a wide variety of biodiversity (Cameron et al. 2008). Although birds form only a small proportion of total biodiversity, they are commonly used as indicators for monitoring the status and trends of biodiversity (Temple and Wiens 1989; Furness and Greenwood 1993; Gill 2006; Monks et al. 2013). In New Zealand, diurnal land birds are useful indicators because they are usually conspicuous and easy to identify. They are also high in the food chain and thus may rely on multiple trophic levels below them to survive (MacLeod 2014). People also tend to have a strong connection with birds and public interest in surveying and interacting with local birds is very high in New Zealand (Galbraith et al. 2014; Brandt et al. 2020).

Birds are an important group to monitor given the significant ecological roles they play. Indigenous birds are well known to be key pollinators and seed dispersers of indigenous plants (Clout and Hay 1989; Kelly et al. 2010; Young et al. 2012). A classic example is the kererū, which is the only native bird capable of dispersing the seeds of some indigenous plants with large fruits. Birds are also important subjects to monitor given the huge declines that have occurred across the world and in New Zealand, as a result of anthropogenic effects (Butchart et al. 2010; Waldron et al. 2017; Belder et al. 2018). Almost a third of New Zealand's original avifauna has become extinct since humans arrived (Worthy and Holdaway 2002; Tennyson and Martinson 2006; Innes et al. 2010; Robertson et al. 2017). Pressures on birds are also believed to be increasing as a result of climate change, which is likely to cause more extreme weather events, increased numbers of some pest animals, and various habitat changes (Pearce et al. 2018; Bishop and Landers 2019; Auckland Council 2020).

1.1 Regional Bird Monitoring Programme

Auckland Council collects a variety of bird data across Auckland as part of its regional Bird Monitoring Programme (BMP), which contributes to reporting on the state of the environment for Auckland under the Resource Management Act 1991. The BMP is also important for evaluating and reporting on key council plans and strategies, such as the Auckland Unitary Plan and Indigenous Biodiversity Strategy (Auckland Council 2012). It began as part of the Terrestrial Biodiversity Monitoring Programme (TBMP) in 2009 when the former Auckland Regional Council (ARC) commenced systematic, landscape-scale monitoring of Auckland's forest assets (hereafter referred to as the 'forest' programme), which included a variety of vegetation monitoring conducted in standard 20m by 20m plots (Allen 1993; Hurst and Allen 2007; McNutt 2012), as well as pest animal and bird monitoring. In 2010 the TBMP, including the BMP, was transferred to the newly formed Auckland Council and subsequently expanded in 2010 to include additional plot-based vegetation monitoring of wetlands across the region (hereafter referred to as the 'wetland' programme), including bird count-based monitoring, which was added from 2011.

The BMP has had some additions over time, with the largest change being the establishment of a Coastal Bird Programme (CBP). The CBP formed out of a number of seabird research and monitoring projects that have occurred over the last decade, which have primarily focussed on collaborative work with the University of Auckland, Auckland Museum, the Department of Conservation (DOC) and other seabird groups and researchers (e.g. Northern New Zealand Seabird Trust) on Hauraki Gulf/Tīkapa Moana seabirds (Rayner et al. 2013; Ismar et al. 2014; Dunphy et al. 2015; Mischler et al. 2015; Rayner et al. 2015; Ranjard et al. 2016; Zhang et al. 2017; Zhang et al. 2019; Dunphy et al. 2020). More recently, mainland seabird projects have been established, including some key seabird survey work on the Waitākere Ranges coast, which has led to a number of seabird and shorebird projects there (Landers 2017). In 2018, a comprehensive regional seabird and shorebird programme was approved as part of the new Natural Environment Targeted Rate, called the Seabird and Shorebird Monitoring and Research Programme (SSMRP). The SSMRP began late in 2018, with the first major field surveys conducted in 2019 (results from the SSMRP will be reported in a future technical report). A Dune Monitoring Programme is also being developed, which has thus far focussed on plant surveys; however, Auckland Council is currently investigating the inclusion of dune bird monitoring in this programme.

Auckland Council conducts other bird monitoring in the region, most of which is either species-specific or site-based, implemented to address specific local questions; however, that information is not included in this report as the focus here is to provide a comprehensive regional picture of the state of birds across the Auckland region.

1.2 Report purpose and scope

The purpose of this report is to assess the current status of land birds in Auckland using the regional bird data currently available from the Auckland Council's regional BMP. We have elected to use only the BMP data, as this is the most comprehensive dataset available that provides systematic coverage across the majority of the Auckland region. Although there are other sources of bird data (e.g. eBird, iNaturalist and other site-specific projects), the BMP not only provides the comprehensive coverage required for state of environment reporting (MacLeod 2014), but it has also been collected by relatively few observers, all of whom are experts, and uses standard protocols. Observer experience and methodological consistency helps to ensure high quality data. The two major components of the BMP, forest and wetland birds, are the focus of this report. We plan to include additional environments (i.e. coastal and dune birds) in future reports when sufficient information has been collected. Given the limited time series so far, no trends are reported (see Methods).

This report's spatial focus is on both large-scale sub-regional areas and smaller areas of interest in Auckland (i.e. large forested and urban areas, and sites that are highly protected or have high levels of pest management; see Methods). For the largest-scale analyses we used the following broad 'Land Class' categories, which we calculated using combinations of Landcover database (LCDB) categories (Landcare Research 2020) (see Methods): Indigenous, Mixed, Rural and Urban. To investigate how birds varied in ecologically similar areas, we used the existing Auckland region ecological districts (EDs), which were defined by McEwen (1987), with some minor changes since then (Brook 1996; Lux and Beadel 2006). The region contains a mix of geographically and topographically diverse features that are quite distinct and these differences are adequately captured by the ED framework. There is also a wide variation in development pressures in different parts of the region, which are also captured to some extent by the ED framework. We also investigated using the national ecosystem classification system developed by DOC (Singers and Rogers 2014), however, since our programme was designed to monitor at the regional and ED scale, more work is required to determine the applicability of reporting on ecosystems due to issues with levels of replication and representation. The usefulness of this approach, and possible modifications required to the monitoring programme, will be the subject of a subsequent report.

2.0 Methods

2.1 Study area

Both the forest and wetland components of the BMP include sites dispersed across the Auckland region, established using a grid-based approach as described below (Figure 1). Both programmes take five years to sample the full set of sites (i.e. ~1/5 of each programme is sampled each year), and thus at the time of writing this report there were two complete rotations for the majority of sites for each programme as shown in Table 1 (the exception was for wetlands which had no bird counts conducted the first year in 2010). The forest programme sites are all surveyed in established forest, scrub, and shrubland vegetation across the region based on the national 8km x 8km grid used by both the DOC and Ministry for the Environment. Several 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 2. Forest sites were surveyed from late October to December (with the following exceptions: Hauturu had four of the 15 Rotation 1 sites surveyed in late March and all of the seven Rotation 2 sites in February; Tāwharanui had six of the 19 Rotation 1 sites surveyed in March). A large number of sites in Rotation 2 were not re-surveyed as planned because of staff and funding shortages.

Table 1: Bird monitoring by programme showing the five-year Rotation time period.

Programme	Rotation	Rotation time period
Forest	1	2009-2013
	2	2014-2018
Wetlands	1	2011-2014
	2	2015-2019

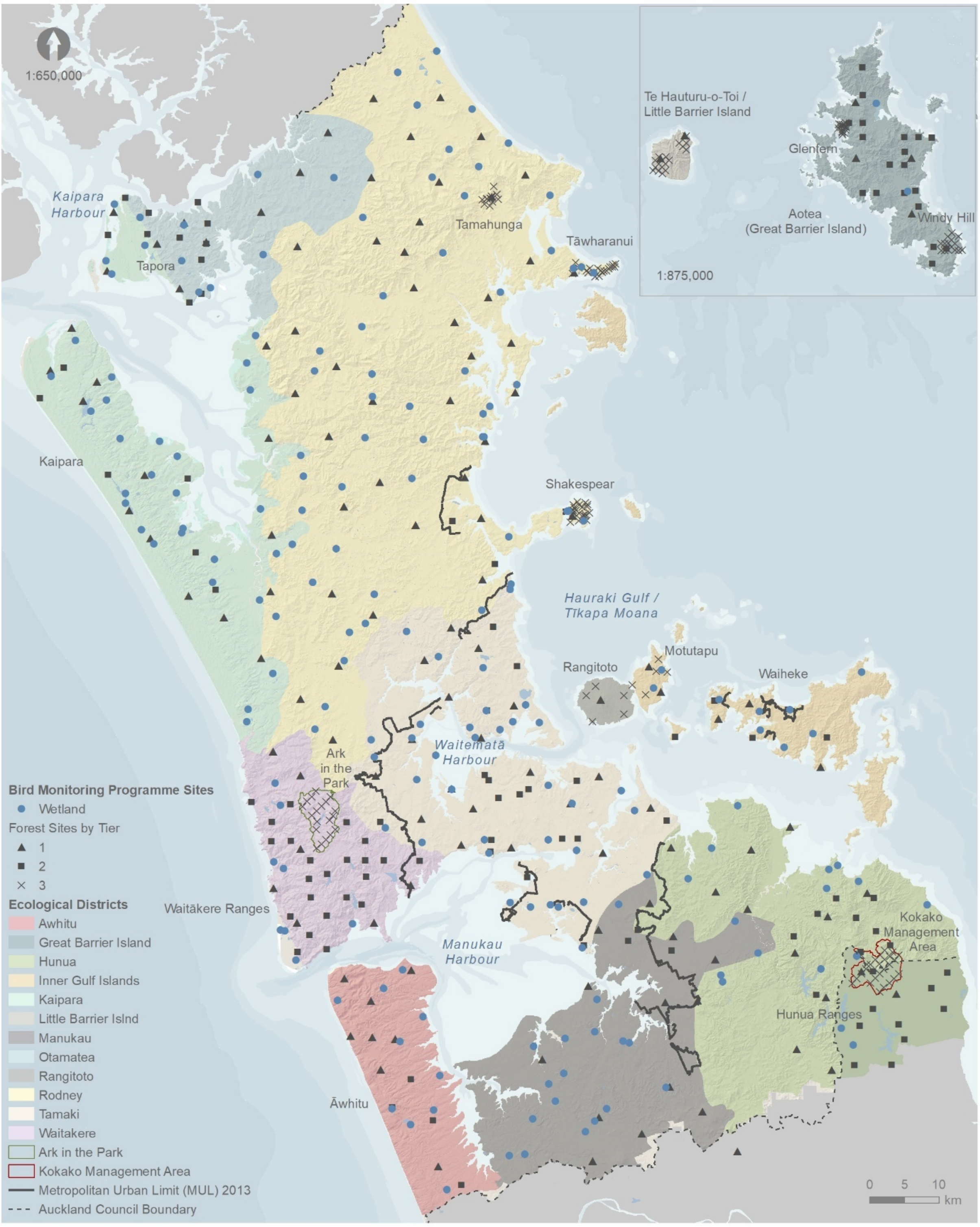


Figure 1: Regional Bird Monitoring Programme forest and wetland sites showing major spatial categories used in analyses (e.g. tiers, ecological districts, Areas).

Table 2: Forest programme tier structure. All Tier 1-3 sites are confined to forest, scrub or shrubland vegetation types.

Tier	Spatial grid size	Number of plots with bird counts		Location details (including 'Areas' used in analyses)
		Rotation 1	Rotation 2	
1	4km x 4km	118	50	Comprehensive regional coverage
2	2km x 2km	91	45	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, Tapora, Waiheke Island, Waitākere Ranges
3	Various (mostly 500-700m)	104	83	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
	Totals:	313	178	The total individual sites used in the 'Total species summary' (3.1.1) totalled 400, given this included additional, new sites added to Rotation 2

*MUL = Auckland Council Metropolitan Urban Limit.

The regional BMP contains 187 sites in wetlands across the region using a 4km x 4km grid (again, based on the national 8km x 8km 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 15m x 15m vegetation plot, in which bird surveys were conducted, as described below. All wetland sites generally have been surveyed in March, however, in some years this varied slightly, with some sites surveyed in early April.

2.2 Bird surveys

Birds were surveyed at all sites by conducting three 10-minute bird counts (10MBCs). These were always conducted on the same day for a given rotation (i.e. Rotation 1 or Rotation 2). The three counts were carried out between the first hour after sunrise and before 13:00 hours, with at least one hour in between each count, and where each count began after two minutes of silence. The first five minutes of each 10MBC closely follows the standard ‘five-minute’ bird count methodology commonly used in New Zealand bird surveys (Dawson and Bull 1975; Elliott et al. 2010; Hartley 2012; MacLeod et al. 2012; Miskelly 2018; Fitzgerald et al. 2019) where all birds heard and seen are noted over a five minute period. During the second five minutes of the 10MBC, only new species not detected in the first five minutes are recorded. This provides extra time for assessing species richness at that site. All birds were included in counts regardless of their distance from the observer. Given that wind and rain can affect bird count results (Dawson and Bull 1975; Aubert 2016), counts were only performed in ideal weather (a judgement call made by the observers at the site on the day of the survey).

2.3 Analyses

Three main dependent variables were used for the majority of analyses in this study: Indigenous Dominance (proportion of indigenous species of total species counted), Indigenous (indigenous species only) and Introduced (introduced species only). These three variables can be calculated in two ways, from abundance data (mean number of individual birds per count) and from richness data (mean number of species per count). Hence, a total of six main variables was calculated for all analyses (listed in Table 3). Abundance variables were calculated using the first five minutes of the 10MBC (hereafter called 5MBC) and richness variables using the full 10MBC. All variables are means per count, calculated by averaging the totals from each of the three bird counts conducted at each plot on the same day. In the ‘Total species summary’ sections (3.1.1, 3.2.1), full species lists were calculated for each of the two programmes (forest, wetlands), including the following variables calculated for each species: Mean Species Abundance (mean number of individuals per 5MBC) and Probability of Detection (per cent of 5MBCs that contained the species) (Table 6 and 28). Total Species Richness was also calculated for each programme (forest, wetlands), which is the total number of species from all counts.

Table 3: List of variables used in analyses.

Variable group	Variable names	Variable definition
Abundance	Mean Indigenous Dominance (Species Abundance)	Mean percentage of individuals that were indigenous species of the total individuals counted
	Mean Indigenous Species Abundance	Mean number of individuals that were indigenous species
	Mean Introduced Species Abundance	Mean number of individuals that were introduced species
Richness	Mean Indigenous Dominance (Species Richness)	Mean percentage of indigenous species of total species counted
	Mean Indigenous Species Richness	Mean number of indigenous species
	Mean Introduced Species Richness	Mean number of introduced species
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	Per cent of 5MBCs that contained the species

Given the very short time period of this study (only two independent measures, each five years apart), and also that the majority of forest sites were not re-surveyed in Rotation 2, statistical analyses of forest data were performed only on Rotation 1. Both Rotations are graphed in all figures for assessing general tendencies but no statistical analysis for trends was possible.

To analyse for regional scale differences in abundances and species richness we ran one-way analysis of variance (ANOVA) models for Tier 1 (regional) forest data and Repeated Measures ANOVA for wetland data (including Rotation as a factor), using the factors Land Class and ED, all in separate analyses.

Land Class was calculated for each bird count site by summing all LCDB categories in a 1000m radius and then grouping the results into the following classes:

- Indigenous: >50% coverage of LCDB categories: Broadleaved Indigenous Hardwoods, Fernland, Flaxland, Herbaceous Freshwater Vegetation, Herbaceous Saline Vegetation, Indigenous Forest, Mangrove, Manuka and/or Kanuka, Matagouri or Grey Scrub (Note: matagouri is absent in Auckland);
- Rural: >50% coverage of LCDB categories: Gorse and/or Broom, High Producing Exotic Grassland, Low Producing Grassland, Mixed Exotic Shrubland;
- Urban: >50% coverage of LCDB categories: Built-up Area (settlement) or Transport Infrastructure;
- Mixed: All other LCDB categories.

We also conducted the following one-way ANOVAs for all variables on the forest data using the following sub-regional Areas: Tier 2 – factor Tier 2 ‘Area’; Tier 3 – factor Tier 3 ‘Area’ (Table 2). Due to low sample sizes and patchy coverage, Tier 1 and 2 sites were included for all Tier 2 ‘Areas’, except for the Hunua and Waitākere Ranges, which both had higher sample sizes with sites distributed regularly across the area of interest.

The assumptions for ANOVA (independent observations, normality, homogeneity via Levene’s Test) were checked for all data and any data failing these were transformed as required (see Results). If transformation still did not fulfil the ANOVA assumptions, we analysed those data using the non-parametric Kruskal-Wallis test. For all significant ANOVAs, post-hoc tests were run to determine which factor pairs were significant (Tukey HSD tests for ANOVAs and Multiple Comparison Z-Value tests for Kruskal-Wallis tests).

Only categories that had at least five replicates were included in analyses. All statistical tests were done in STATISTICA 12 (StatSoft 2014) to assess significance ($\alpha < 0.05$).

3.0 Results

3.1 Forest birds

3.1.1 Total species summary (Tiers 1-3, Rotations 1 and 2)

A total of 1,452 bird counts was completed at 400 forest (forest, scrub, shrubland vegetation) sites over the time frame of this study (2009-2018), during which 23,019 individual birds were counted. The majority of these were endemic and indigenous species, with only about one third of all birds counted being introduced species (Table 4). Only a small percentage (7%) of total birds counted were 'Threatened' or 'At Risk' species (Table 5) (Robertson et al. 2017). Total Species Richness comprised 64 species, and four out of the five most abundant species were indigenous (i.e. tūī, silvereye, grey warbler, and North Island fantail – Eurasian blackbird was the 5th most abundant species), and these occurred in at least 50 per cent of all counts (Table 6).

Table 4: Status of species counted at 400 forest sites (1452 total bird counts conducted from 2009-18) in the Auckland region.

Status	Count	Percentage of total birds
Endemic	10,757	46.7%
Indigenous	5,071	22.0%
Introduced	7,191	31.2%
TOTAL	23,019	

Table 5: Conservation status (Robertson et al. 2017) of indigenous species counted at forest sites (1452 total bird counts from 2009-18) in the Auckland region.

Conservation Status	Count	Percentage of total birds
Threatened	38	0.2%
At Risk	1,557	6.8%
Not Threatened	14,235	61.8%
TOTAL	15,830	

Table 6: Mean Species Abundance and Probability of Detection of all bird species counted (1452 total bird counts conducted from 2009-18) at forest sites (n = 400) in Auckland; *indigenous; **endemic.

Species counted			Mean Species Abundance	Probability of Detection
Tūī	tūī	*Prosthemadera novaeseelandiae novaeseelandiae***	2.40 ± 0.11	76
Silvereye	tauhou	*Zosterops lateralis lateralis**	2.22 ± 0.09	73
Grey warbler	riroriro	*Gerygone igata***	1.70 ± 0.06	80
North Island fantail	pīwakawaka	*Rhipidura fuliginosa placabilis***	0.91 ± 0.05	53
Eurasian blackbird		*Turdus merula*	0.90 ± 0.04	53
Chaffinch		*Fringilla coelebs*	0.88 ± 0.05	44
Common myna		*Acridotheres tristis*	0.72 ± 0.05	33
Sacred kingfisher	kōtare	*Todiramphus sanctus vagans**	0.66 ± 0.03	42
Bellbird	korimako	*Anthornis melanura melanura***	0.58 ± 0.10	14
Eastern rosella		*Platycercus eximius*	0.55 ± 0.04	30
European goldfinch		*Carduelis*	0.37 ± 0.04	19
New Zealand pigeon	kererū	*Hemiphaga novaeseelandiae***	0.31 ± 0.02	23
Kākā	kākā	*Nestor meridionalis***	0.30 ± 0.05	11
Whitehead	pōpokatea	*Mohoua albicilla***	0.27 ± 0.04	8
North Island tomtit	miromiro	*Petroica macrocephala toitoi***	0.25 ± 0.03	16
European greenfinch		*Carduelis chloris*	0.21 ± 0.02	15
House sparrow		*Passer domesticus*	0.20 ± 0.03	9
Song thrush		*Turdus philomelos*	0.20 ± 0.02	14
Eurasian skylark		*Alauda arvensis*	0.19 ± 0.03	11
Shining cuckoo	pīpīwharauroa	*Chrysococcyx lucidus**	0.19 ± 0.02	15
Common pheasant		*Phasianus colchicus*	0.17 ± 0.02	14
North Island saddleback	tīeke	*Philesturnus rufusater***	0.16 ± 0.03	6
North Island robin	toutouwai	*Petroica longipes***	0.13 ± 0.03	6
Pūkeko	pūkeko	*Porphyrio melanotus melanotus**	0.12 ± 0.02	9
Yellowhammer		*Emberiza citrinella*	0.11 ± 0.02	8
Australian magpie		*Gymnorhina tibicen*	0.09 ± 0.01	7
Common starling		*Sturnus vulgaris*	0.08 ± 0.02	5
Welcome swallow		*Hirundo neoxena neoxena**	0.06 ± 0.01	4

Red-crowned parakeet	kākāriki	*Cyanoramphus novaezelandiae novaezelandiae***	0.05 ± 0.01	3
Dunnock		*Prunella modularis*	0.04 ± 0.01	3
Long-tailed cuckoo	koekoeā	*Eudynamys taitensis***	0.04 ± 0.01	2
Spur-winged plover		*Vanellus miles novaehollandiae**	0.04 ± 0.01	3
Paradise shelduck	pūtangitangi	*Tadorna variegata***	0.03 ± 0.01	2
Peafowl		*Pavo cristatus*	0.03 ± 0.01	1
Red-billed gull	tarapunga	*Larus novaehollandiae scopulinus**	0.03 ± 0.01	2
Swamp harrier	kāhu	*Circus approximans**	0.03 ± 0.01	2
California quail		*Callipepla californica*	0.02 ± 0.01	2
North Island kokako	kōkako	*Callaeas wilsoni***	0.02 ± 0.01	1
Rock pigeon		*Columba livia*	0.02 ± 0.01	1
Southern black-backed gull	karoro	*Larus dominicanus dominicanus**	0.02 ± 0.01	1
Spotted dove		*Streptopelia chinensis tigrina*	0.02 ± 0.01	1
Stitchbird	hihi	*Notiomystis cincta***	0.02 ± 0.01	1
Sulphur-crested cockatoo		*Cacatua galerita*	0.02 ± 0.01	1
Variable oystercatcher	tōrea pango	*Haematopus unicolor***	0.02 ± 0.01	1
Chicken		*Gallus gallus domesticus*	0.01 ± 0.01	1
North Island rifleman	titipounamu	*Acanthisitta chloris granti***	0.01 ± 0.004	<1
South Island pied oystercatcher	tōrea	*Haematopus finschi***	0.01 ± 0.01	<1
Yellow-crowned parakeet	kākāriki	*Cyanoramphus auriceps***	<0.01	<1
Australasian gannet	tākapu	*Morus serrator**	<0.01	<1
Barbary dove		*Streptopelia risoria*	<0.01	<1
Black shag	kawau	*Phalacrocorax carbo novaehollandiae**	<0.01	<1
Brown quail		*Coturnix ypsilophora*	<0.01	<1
Canada goose		*Branta canadensis*	<0.01	<1
Caspian tern	taranui	*Hydroprogne caspia**	<0.01	<1
Mallard		*Anas platyrhynchos*	<0.01	<1
Morepork	ruru	*Ninox novaeseelandiae novaeseelandiae**	<0.01	<1

North Island fernbird	mātātā	*Bowdleria punctata vealeae***	<0.01	<1
North Island weka		*Gallirallus australis greyi***	<0.01	<1
Northern New Zealand dotterel	tūturiwhatu	*Charadrius obscurus aquilonius***	<0.01	<1
Pied stilt	poaka	*Himantopus himantopus leucocephalus**	<0.01	<1
Spotless crake	pūweto	*Porzana tabuensis tabuensis**	<0.01	<1
White-faced heron	matuku moana	*Egretta novaehollandiae novaehollandiae**	<0.01	<1
White-fronted tern	tara	*Sterna striata**	<0.01	<1
Wild turkey		*Meleagris gallopavo*	<0.01	<1

3.1.2 Tier 1: Regional patterns

3.1.2.1 Land Classes: Species Richness

Mean Indigenous Dominance (Species Richness) varied across Land Classes (one-way ANOVA, $F_{3,131} = 22.98$, $p<0.001$, $\eta^2 = 0.35$, Log transformed; Figure 2), with the highest Indigenous Dominance found in Indigenous Land Class sites, which were all significantly different from Mixed, Urban and Rural sites (Table 7). These differences were because of the reduced Introduced Species Richness found in Indigenous Land Class sites (one-way ANOVA, $F_{3,131} = 24.44$, $p<0.001$, $\eta^2 = 0.36$, Figure 2, Table 8).

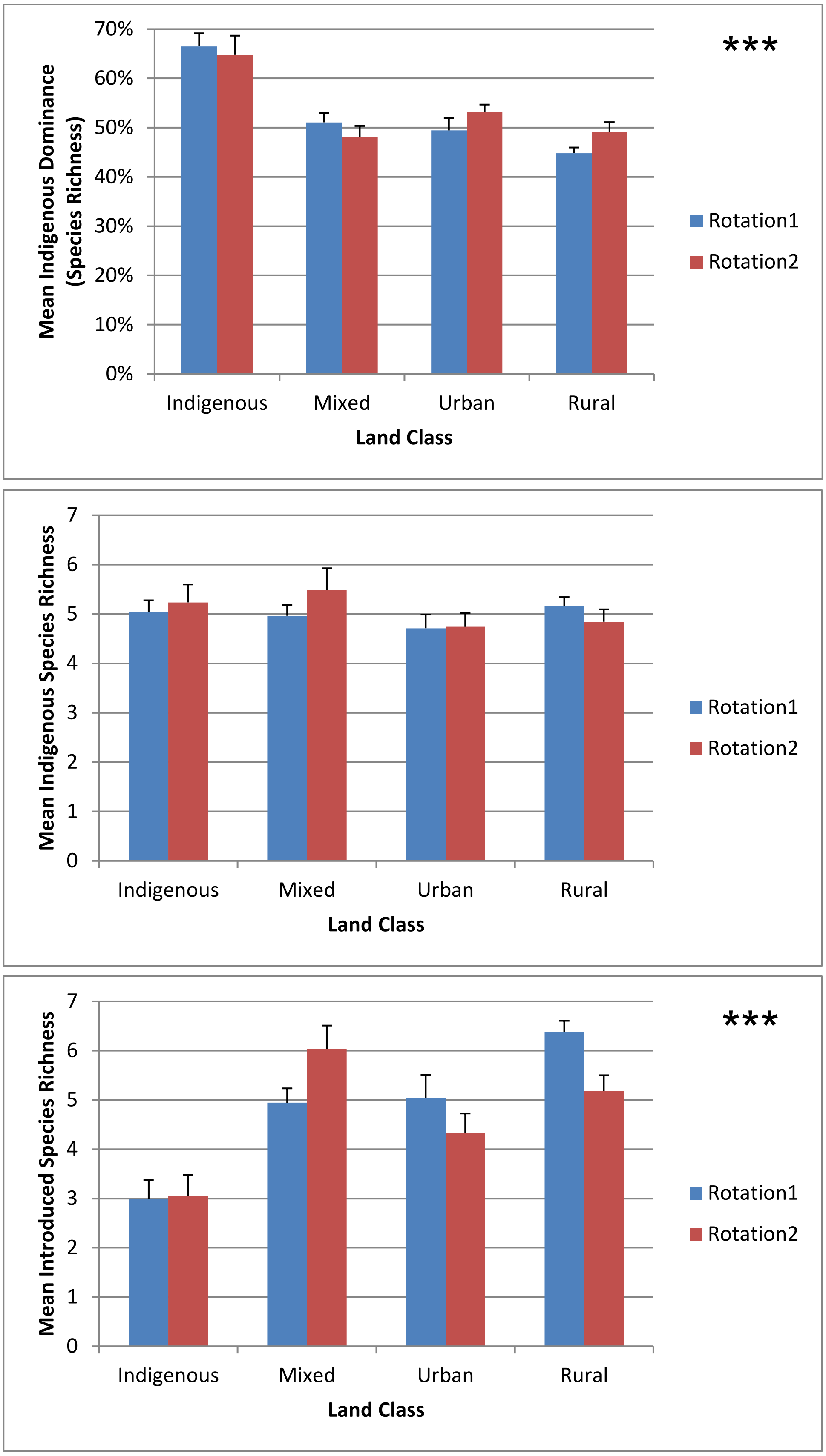


Figure 2: Mean Indigenous Dominance (Species Richness), Indigenous and Introduced Species Richness for birds counted at Tier 1 (regional) forest sites by Land Class and Rotation. Bars = Standard Error. Overall ANOVA: ***p<0.001.

Table 7: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Richness) for birds counted at Tier 1 (regional) forest sites by Land Class.

Land Class	n	p values		
		Mixed	Indigenous	Rural
Mixed	29			
Indigenous	35	**p<0.001**		
Rural	56	**p<0.05**	**p<0.001**	
Urban	15	**p<0.05**	**p<0.001**	0.420

Table 8: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Richness for birds counted at Tier 1 (regional) forest sites by Land Class.

Land Class	n	p values		
		Mixed	Indigenous	Rural
Mixed	29			
Indigenous	35	**p<0.001**		
Rural	56	**p<0.01**	**p<0.001**	
Urban	15	0.998	**p<0.01**	0.060

3.1.2.2 Land classes: Species Abundance

Mean Species Abundance varied similarly to the Species Richness measures with Indigenous Dominance (Species Abundance) varying across Land Classes (one-way ANOVA, $F_{3,131} = 24.89$, $p<0.001$, $\eta^2 = 0.36$, Figure 3). The highest Indigenous Dominance was found in the Indigenous Land Class, which was significantly different from Mixed, Urban and Rural sites (Table 9). These differences were due to reduced Introduced Species Abundance found in Indigenous Land Class sites (one-way ANOVA, $F_{3,131} = 14.53$, $\eta^2 = 0.25$, $p<0.001$, Table 10).

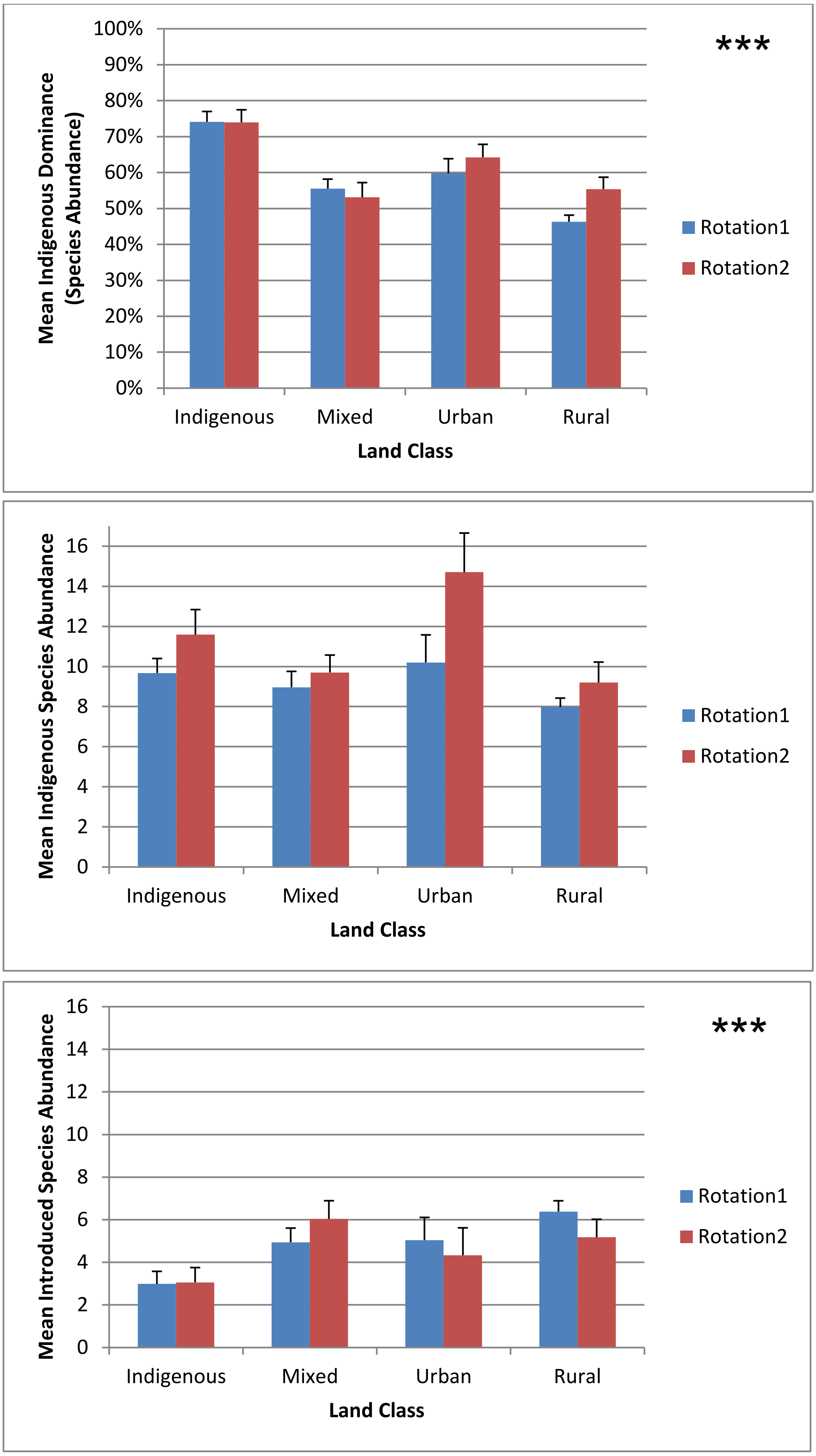


Figure 3: Mean Indigenous Dominance (Species Abundance), Indigenous and Introduced Species Abundance for birds counted at forest sites by Land Class and Rotation. Bars = Standard Error. Overall ANOVA: ***p < 0.001.

Table 9: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Abundance) for birds counted at Tier 1 (regional) forest sites by Land Class.

Land Class	n	p values		
		Mixed	Indigenous	Rural
Mixed	29			
Indigenous	35	**p<0.001**		
Rural	56	**p<0.05**	**p<0.001**	
Urban	15	0.807	**p<0.05**	0.011

Table 10: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Abundance for birds counted at Tier 1 (regional) forest sites by Land Class.

Land Class	n	p values		
		Mixed	Indigenous	Rural
Mixed	29			
Indigenous	35	**p<0.01**		
Rural	56	0.079	**p<0.001**	
Urban	15	0.998	**p<0.05**	0.159

3.1.2.3 Ecological districts: Species Richness

Mean Indigenous Dominance (Species Richness) varied across EDs (one-way ANOVA, $F_{7,118} = 4.83$, $p<0.001$; $\eta^2 = 0.22$, Figure 4), with the highest Indigenous Dominance in sites in the Waitākere ED, which were significantly higher than Āwhitu, Kaipara and Manukau ED sites (Table 11). Sites in the Hunua ED also had a significantly higher Indigenous Dominance (Species Richness) compared with Kaipara ED sites. These differences were a result of the reduced Introduced Species Richness found in Waitākere compared with all other EDs, except for Hunua ED sites, which had less Introduced Species Richness than sites in the Kaipara ED (one-way ANOVA, $F_{3,118} = 5.21$, $p<0.001$; $\eta^2 = 0.24$; Figure 4; Table 12).

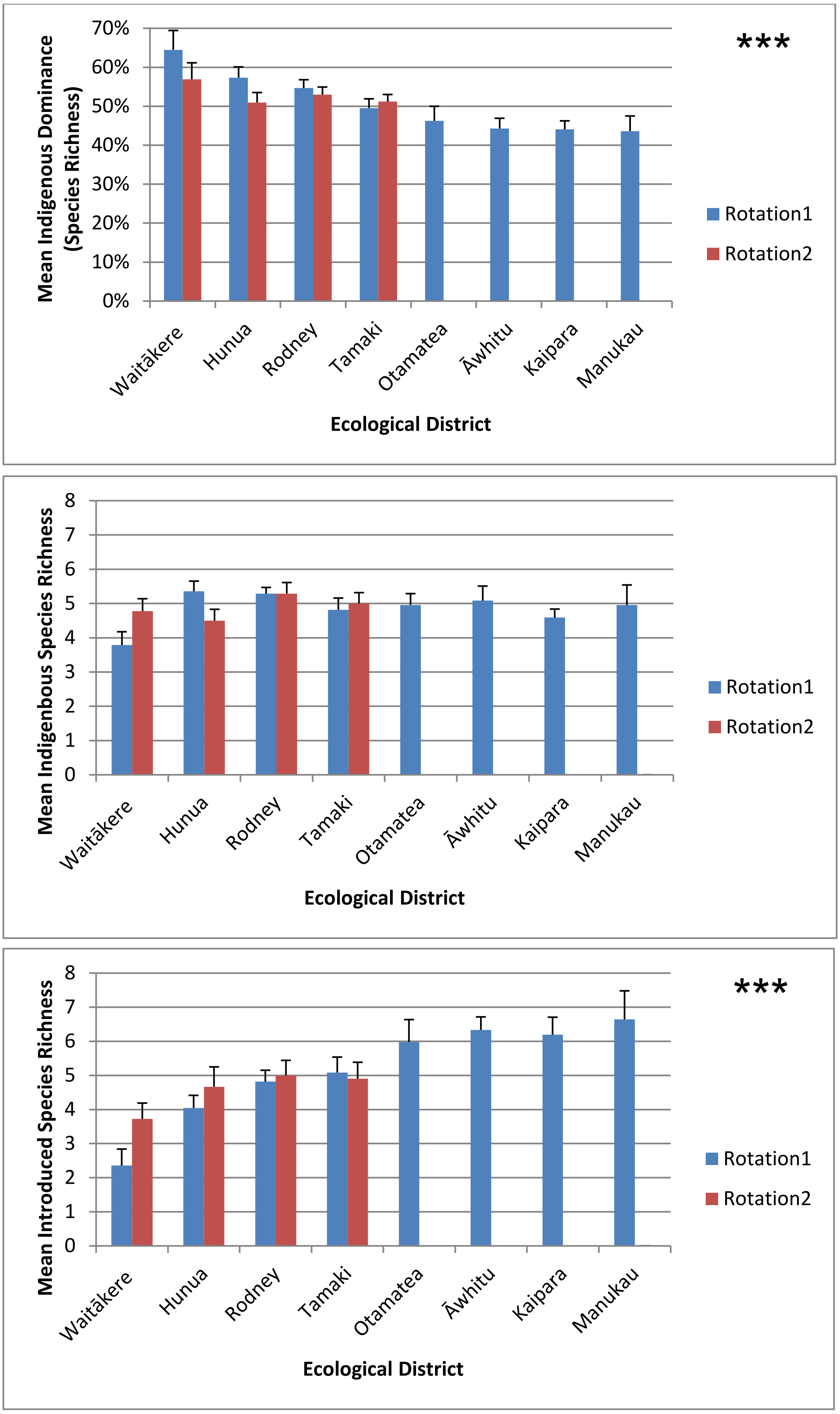


Figure 4: Mean Indigenous Dominance (Species Richness), Indigenous and Introduced Species Richness for birds counted at Tier 1 (regional) forest sites by ecological district and Rotation. Bars = Standard Error. Overall ANOVA: ***p<0.001.

Table 11: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Richness) for birds counted at Tier 1 (regional) forest sites by ecological district.

ecological district	n	p values						
		Kaipara	Otamatea	Rodney	Waitākere	Tamaki	Āwhitu	Manukau
Kaipara	19							
Otamatea	8	1.000						
Rodney	40	**p<0.05**	0.562					
Waitākere	7	**p<0.01**	0.053	0.429				
Tamaki	18	0.831	0.998	0.769	0.078			
Āwhitu	12	1.000	1.000	0.121	**p<0.01**	0.922		
Manukau	7	1.000	1.000	0.280	**p<0.05**	0.942	1.000	
Hunua	15	**p<0.05**	0.357	0.994	0.874	0.527	0.075	0.164

Table 12: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Richness for birds counted at Tier 1 (regional) forest sites by ecological district.

ecological district	n	p values						
		Kaipara	Otamatea	Rodney	Waitākere	Tamaki	Āwhitu	Manukau
Kaipara	19							
Otamatea	8	1.000						
Rodney	40	0.183	0.777					
Waitākere	7	**p<0.001**	**p<0.01**	**p<0.05**				
Tamaki	18	0.657	0.958	1.000	**p<0.05**			
Āwhitu	12	1.000	1.000	0.259	**p<0.001**	0.664		
Manukau	7	1.000	0.998	0.299	**p<0.01**	0.613	1.000	
Hunua	15	**p<0.05**	0.310	0.890	0.549	0.785	0.054	0.074

3.1.2.4 Ecological districts: Species Abundance

Species Abundance had a similar pattern to the Species Richness variables with significant one-way ANOVAs for Mean Indigenous Dominance (Species Abundance) (one-way ANOVA, $F_{7,118} = 4.71$, $p<0.001$; $\eta^2 = 0.22$, Figure 5) and Introduced Species Abundance (one-way ANOVA, $F_{7,118} = 3.40$, $p<0.01$; $\eta^2 = 0.17$). Sites in the Waitākere ED had higher Mean Indigenous Dominance (Species Abundance) than Āwhitu, Kaipara, Manukau and Otamatea ED sites (Table 13). These differences were a result of the reduced Introduced Species Abundance found in sites in the Waitākere ED compared with Āwhitu, Kaipara, and Manukau ED sites (Table 14).

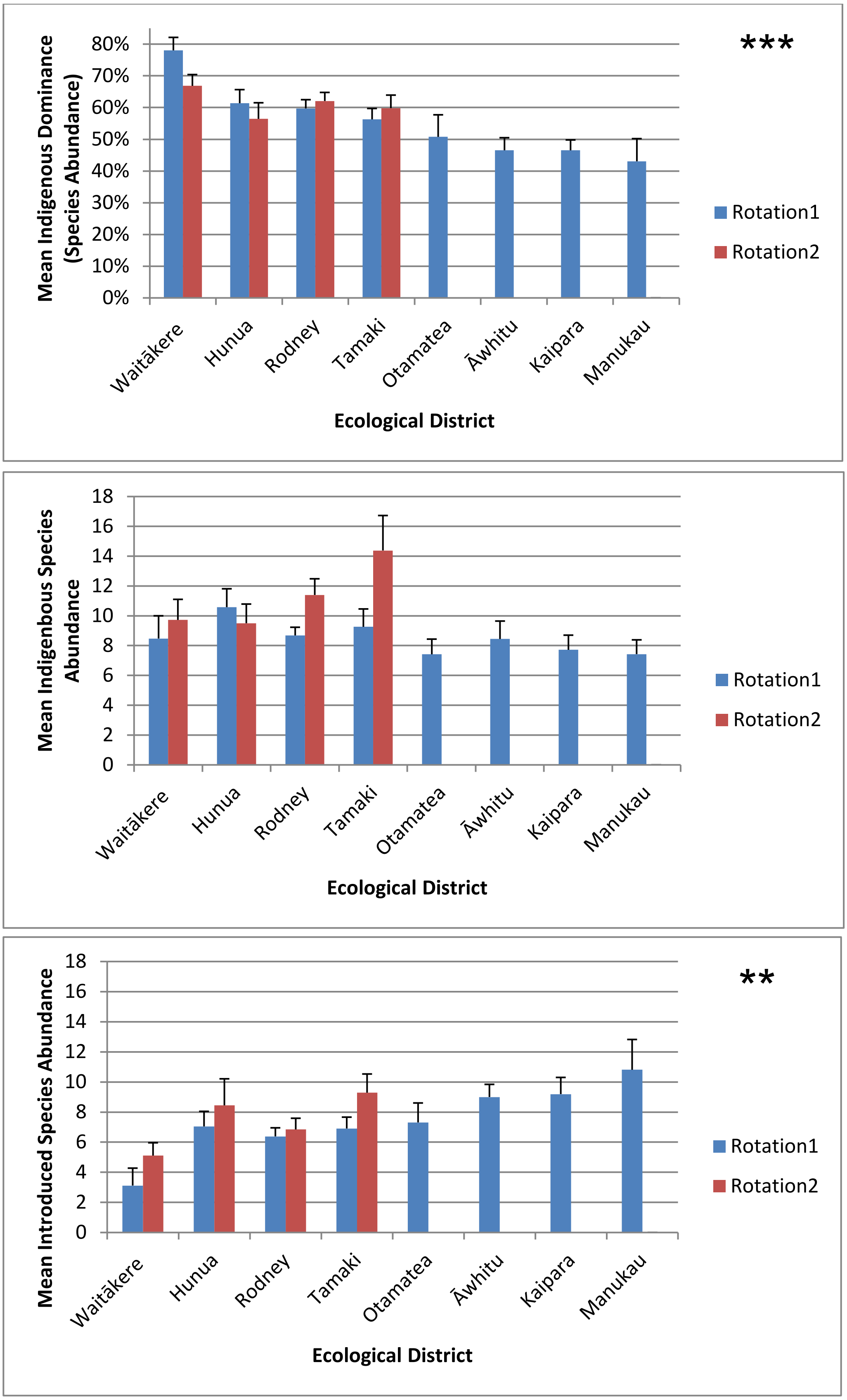


Figure 5: Mean Indigenous Dominance (Species Abundance), Indigenous and Introduced Species Abundance for birds counted at forest sites by ecological district and Rotation. Bars = Standard Error. Overall ANOVA: **p < 0.01; ***p < 0.001.

Table 13: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Abundance) for birds counted at Tier 1 (regional) forest sites by ecological district.

ecological district	n	p values						
		Kaipara	Otamatea	Rodney	Waitākere	Tamaki	Āwhitu	Manukau
Kaipara	19							
Otamatea	8	0.999						
Rodney	40	0.073	0.838					
Waitākere	7	**p<0.001**	**p<0.05**	0.111				
Tamaki	18	0.593	0.992	0.995	0.058			
Āwhitu	12	1.000	0.999	0.211	**p<0.05**	0.735		
Manukau	7	1.000	0.983	0.195	**p<0.01**	0.592	1.000	
Hunua	15	0.143	0.803	1.000	0.324	0.985	0.262	0.213

Table 14: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Abundance for birds counted at Tier 1 (regional) forest sites by ecological district.

ecological district	n	p values						
		Kaipara	Otamatea	Rodney	Waitākere	Tamaki	Āwhitu	Manukau
Kaipara	19							
Otamatea	8	0.940						
Rodney	40	0.154	0.998					
Waitākere	7	**p<0.05**	0.41049	0.433				
Tamaki	18	0.611	1.000	1.000	0.347			
Āwhitu	12	1.000	0.978	0.436	**p<0.05**	0.823		
Manukau	7	0.980	0.645	0.099	**p<0.01**	0.309	0.975	
Hunua	15	0.734	1.000	0.999	0.336	1.000	0.890	0.390

3.1.3 Tier 2: Large sub-regional 'Areas' of interest

3.1.3.1 Species Richness

All three Mean Species Richness one-way ANOVAs for Tier 2 Areas were significant: Indigenous Dominance ($F_{5,83} = 19.95$, $p<0.001$, $\eta^2 = 0.55$); Indigenous ($F_{5,83} = 2.84$, $p<0.05$, $\eta^2 = 0.15$); Introduced ($F_{5,83} = 18.09$, $p<0.001$, $\eta^2 = 0.52$); Figure 6.

Aotea and the Hunua and Waitākere Ranges had significantly higher Mean Indigenous Dominance (Species Richness) compared with Tapora, Urban and Waiheke Areas (Table 15). The only significantly different Areas for Indigenous Species Richness were Urban and Waitākere, with the latter having a higher Mean Indigenous Species Richness (Table 16). The significant results in Indigenous Dominance were the result of reduced Introduced Species Richness on Aotea and in the Hunua and Waitākere Ranges Areas (Table 17).

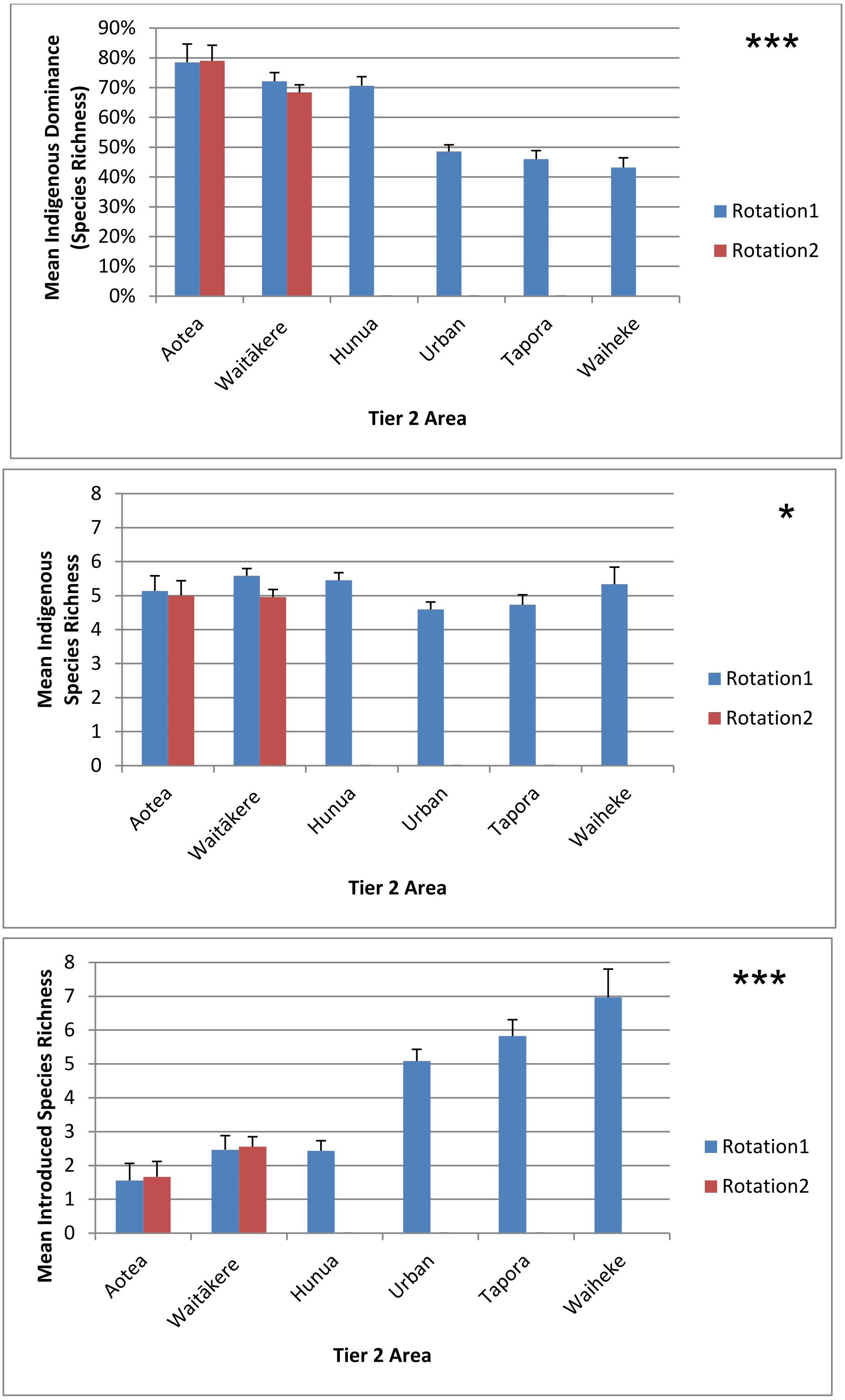


Figure 6: Mean Indigenous Dominance (Species Richness), Indigenous and Introduced Species Richness for birds counted at forest sites by Tier 2 Area and Rotation. Bars = Standard Error. Overall ANOVA: *p<0.05; ***p<0.001.

Table 15: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Richness) for birds counted at forest sites by Tier 2 Area.

Tier 2 Area	n	p values				
		Tapora	Waitākere	Urban	Hunua	Waiheke
Tapora	15					
Waitākere	20	**p<0.001**				
Urban	23	0.987	**p<0.001**			
Hunua	20	**p<0.001**	0.999	**p<0.001**		
Waiheke	5	0.998	**p<0.001**	0.946	**p<0.001**	
Aotea	6	**p<0.001**	0.869	**p<0.001**	0.733	**p<0.001**

Table 16: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Species Richness for birds counted at forest sites by Tier 2 Area.

Tier 2 Area	n	p values				
		Tapora	Waitākere	Urban	Hunua	Waiheke
Tapora	15					
Waitākere	20	0.169				
Urban	23	0.999	**p<0.05**			
Hunua	20	0.339	0.999	0.087		
Waiheke	5	0.872	0.997	0.701	1.000	
Aotea	6	0.965	0.940	0.861	0.987	1.000

Table 17: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Richness for birds counted at forest sites by Tier 2 Area.

Tier 2 Area	n	p values				
		Tapora	Waitākere	Urban	Hunua	Waiheke
Tapora	15					
Waitākere	20	**p<0.001**				
Urban	23	0.769	**p<0.001**			
Hunua	20	**p<0.001**	1.000	**p<0.001**		
Waiheke	5	0.769	**p<0.001**	0.213	**p<0.001**	
Aotea	6	**p<0.001**	0.849	**p<0.001**	0.868	**p<0.001**

3.1.3.2 Species Abundance

Mean Indigenous Dominance (Species Abundance) ($F_{5,83}$ = 10.15, p<0.001, η^2 = 0.34) and Introduced Species Abundance ($F_{5.83}$ = 14.92, p<0.001, η^2 = 0.47, square root transformed) one-way ANOVAs were significant for Tier 2 Areas (Figure 7). Post-hoc tests showed similar patterns as the Species Richness results, with Aotea and the Hunua and Waitākere Ranges Areas having higher Indigenous Dominance (Species Abundance) and lower Introduced Species Abundances compared with Tapora, Urban and Waiheke Areas (Table 18 and 19).

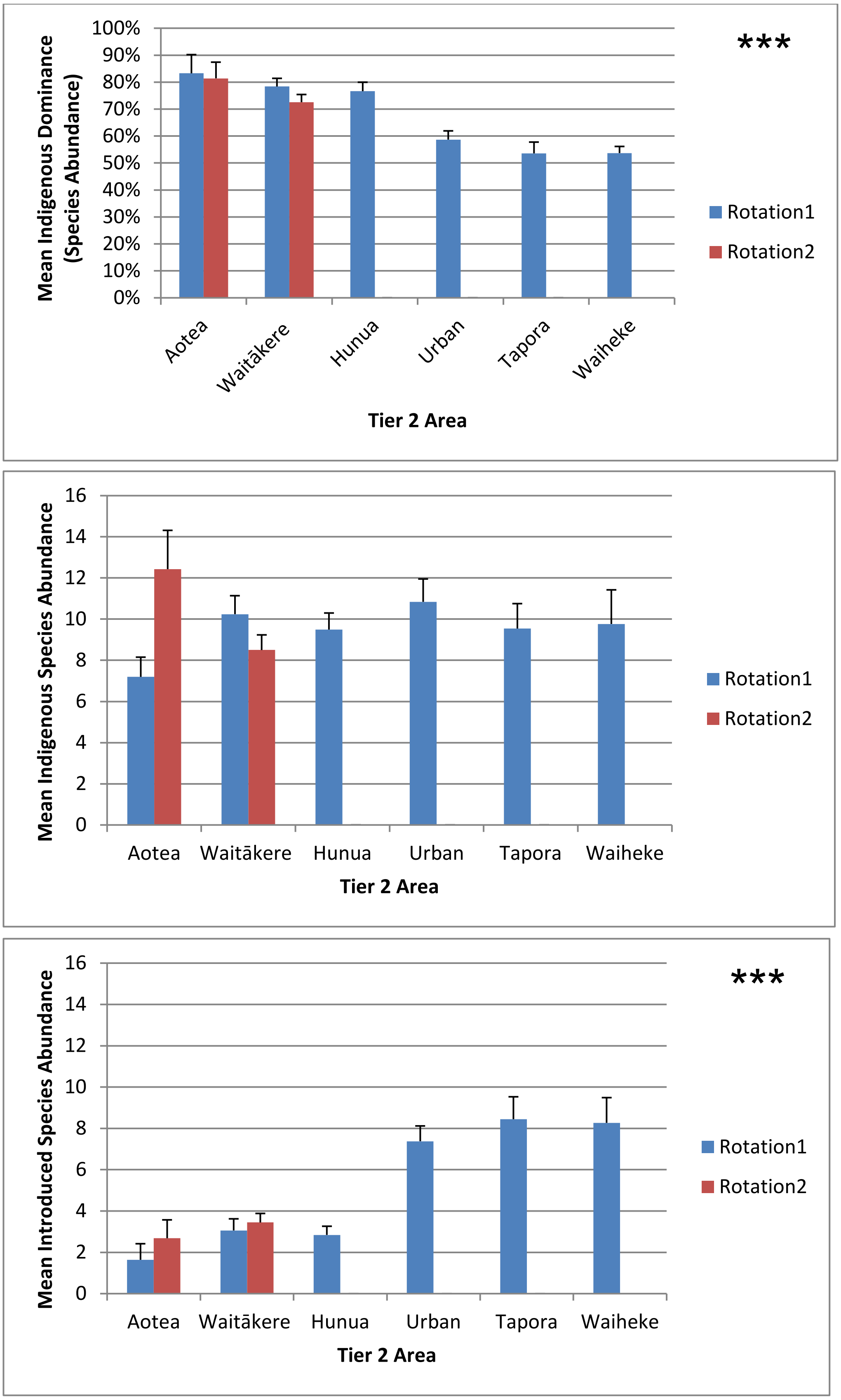


Figure 7: Mean Indigenous Dominance (Species Abundance), Indigenous and Introduced Species Abundance for birds counted at forest sites by Tier 2 Area and Rotation. Bars = Standard Error. Overall ANOVA: ***p<0.001.

Table 18: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Richness) for birds counted at forest sites by Tier 2 Area.

Tier 2 Area	n	p values				
		Tapora	Waitākere	Urban	Hunua	Waiheke
Tapora	15					
Waitākere	20	**p<0.001**				
Urban	23	0.904	**p<0.001**			
Hunua	20	**p<0.001**	0.999	**p<0.01**		
Waiheke	5	1.000	**p<0.05**	0.984	**p<0.05**	
Aotea	6	**p<0.01**	0.981	**p<0.01**	0.929	**p<0.05**

Table 19: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Richness for birds counted at forest sites by Tier 2 Area.

Tier 2 Area	n	p values				
		Tapora	Waitākere	Urban	Hunua	Waiheke
Tapora	15					
Waitākere	20	**p<0.001**				
Urban	23	0.969	**p<0.001**			
Hunua	20	**p<0.001**	1.000	**p<0.001**		
Waiheke	5	1.000	**p<0.01**	0.989	**p<0.01**	
Aotea	6	**p<0.001**	0.468	**p<0.001**	0.539	**p<0.001**

3.1.4 Tier 3: Key managed 'Areas'

3.1.4.1 Species Richness

All three Species Richness Kruskal-Wallis tests for Tier 3 Areas were significant: Indigenous Dominance ($H7 = 52.46$, $p<0.001$); Indigenous ($H7 = 48.70$, $p<0.001$); Introduced ($H7 = 42.86$, $p<0.001$) (Figure 8). Hauturu had the highest Mean Indigenous Dominance, which was almost 100%. This was significantly different from all the Tier 3 Areas except for the Aotea sanctuaries at Glenfern and Windy Hill, and also the highly managed area of the Hunua Ranges in the Kōkako Management Area (KMA) (Table 20). The main driver for this was high Indigenous Species Richness (Table 21) in these Areas in contrast to low Introduced Species Richness (Table 22).

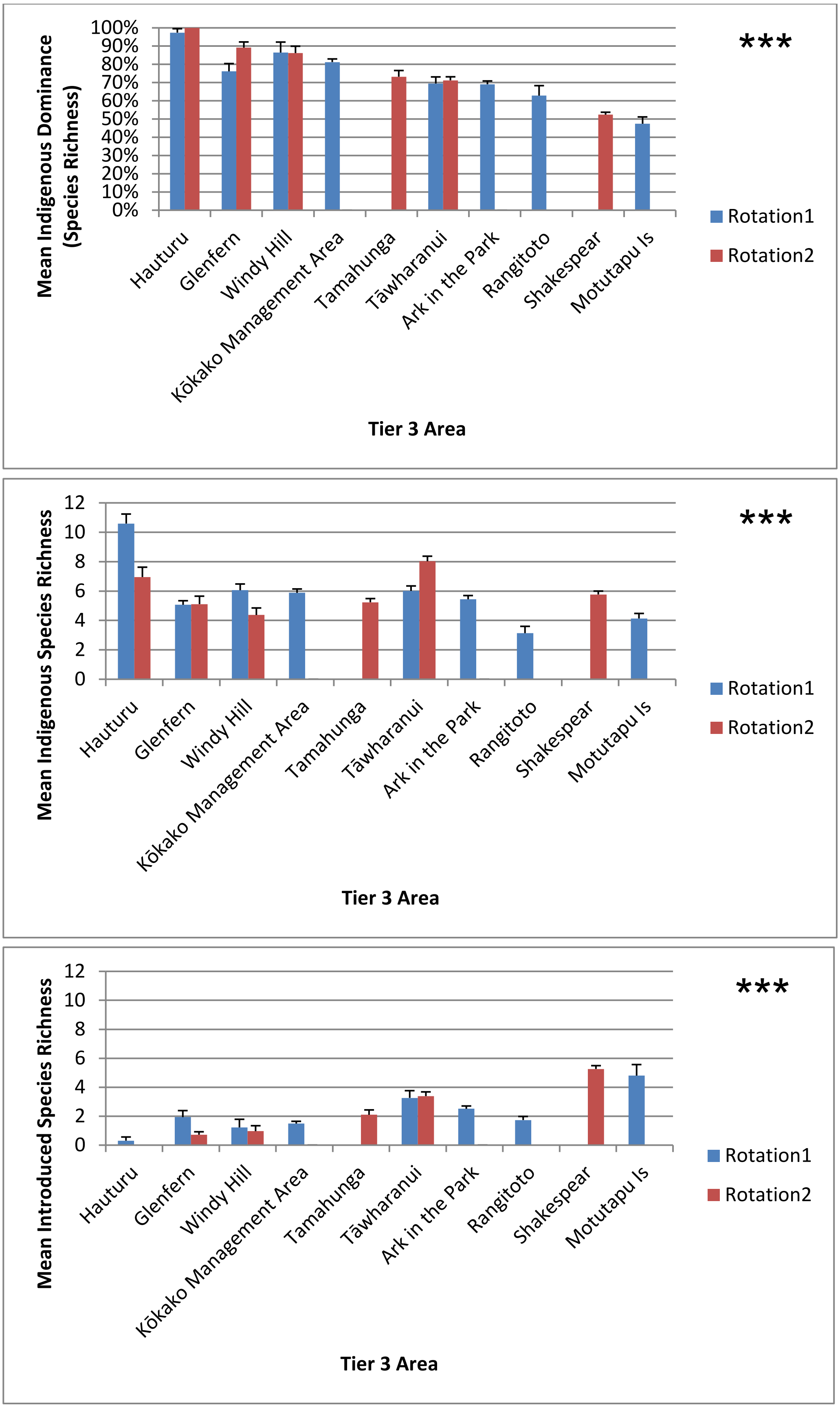


Figure 8: Mean Indigenous Dominance (Species Richness), Indigenous and Introduced Species Richness for birds counted at forest sites by Tier 3 Area. Bars = Standard Error. Overall Kruskal-Wallis test: ***p<0.001.

Table 20: Post-hoc comparisons of mean ranks of all pairs of Mean Indigenous Dominance (Species Richness) for birds counted at forest sites by Tier 3 Area.

Tier 3 Area	n	p values						
		Ark in the Park	Rangitoto	Motutapu Is	Hauturu	KMA	Glenfern	Windy Hill
Ark in the Park	19							
Rangitoto	5	1.000						
Motutapu Is	5	0.942	1.000					
Hauturu	13	**p<0.001**	**p<0.01**	**p<0.001**				
KMA	26	0.124	0.439	**p<0.01**	0.178			
Glenfern	10	1.000	1.000	0.116	0.064	1.000		
Windy Hill	6	0.539	0.539	**p<0.01**	1.000	1.000	1.000	
Tāwharanui	19	1.000	1.000	0.993	**p<0.001**	0.111	1.000	0.507

Table 21: Post-hoc comparisons of mean ranks of all pairs of Mean Indigenous Species Richness of birds counted at forest sites by Tier 3 Area.

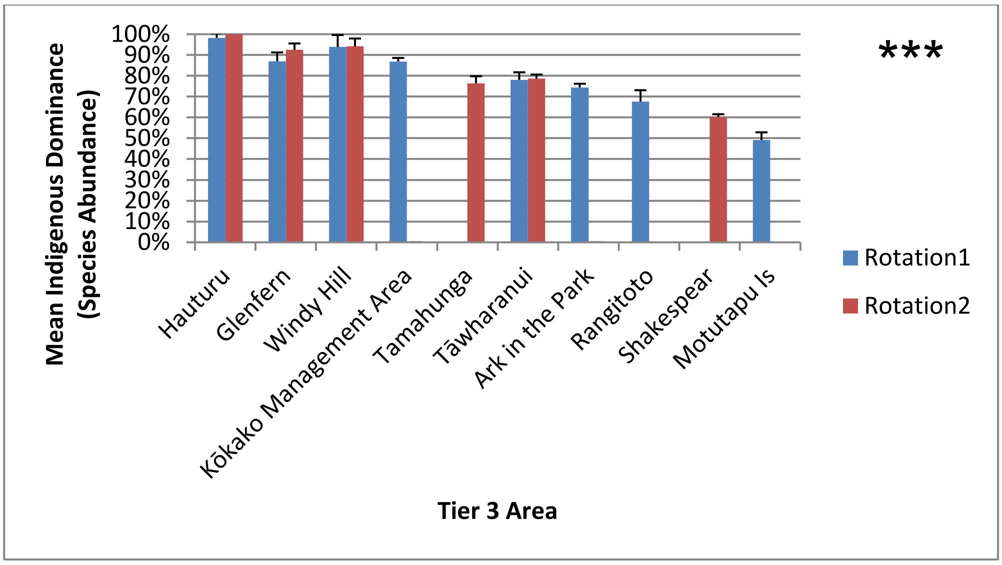
Tier 3 Area	n	p values						
		Ark in the Park	Rangitoto	Motutapu Is	Hauturu	KMA	Glenfern	Windy Hill
Ark in the Park	19							
Rangitoto	5	0.335						
Motutapu Is	5	1.000	1.000					
Hauturu	13	**p<0.001**	**p<0.001**	**p<0.001**				
KMA	26	1.000	0.062	0.432	**p<0.001**			
Glenfern	10	1.000	1.000	1.000	**p<0.001**	1.000		
Windy Hill	6	1.000	0.203	0.837	0.227	1.000	1.000	
Tāwharanui	19	1.000	0.060	0.401	**p<0.01**	1.000	1.000	1.000

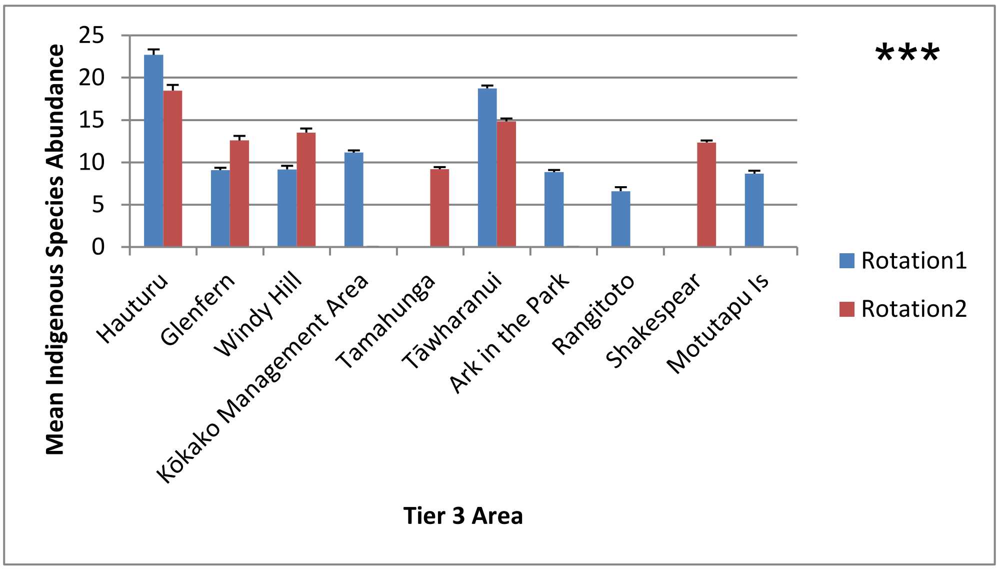
Table 22: Post-hoc comparisons of mean ranks of all pairs of Mean Introduced Species Richness of birds counted at forest sites by Tier 3 Area.

Tier 3 Area	n	p values						
		Ark in the Park	Rangitoto	Motutapu Is	Hauturu	KMA	Glenfern	Windy Hill
Ark in the Park	19							
Rangitoto	5	1.000						
Motutapu Is	5	1.000	0.658					
Hauturu	13	**p<0.001**	0.979	**p<0.001**				
KMA	26	0.389	1.000	**p<0.05**	0.169			
Glenfern	10	1.000	1.000	0.317	0.169	1.000		
Windy Hill	6	1.000	1.000	0.071	1.000	1.000	1.000	
Tāwharanui	19	1.000	1.000	1.000	**p<0.001**	0.098	1.000	0.525

3.1.4.2 Species Abundance

The Species Abundance Kruskal-Wallis tests for Tier 3 Areas were also all highly significant: Indigenous Dominance (H_7 = 51.02, p<0.001); Indigenous (H_7 = 51.84, p<0.001); Introduced (H_7 = 46.75, p<0.001) (Figure 9). The highest Mean Indigenous Dominance (Species Abundance) percentages were again found on Hauturu, at Glenfern and Windy Hill Sanctuaries, and the Kokako Management Area in the Hunua Ranges (Table 23). Hauturu had the highest Mean Indigenous Species Abundance and the lowest Mean Introduced Species Abundance (Table 24 and 25). Tāwharanui had the second highest Mean Indigenous Species Abundance. The highest Mean Introduced Species Abundances were found at Shakespear and Motutapu Island.





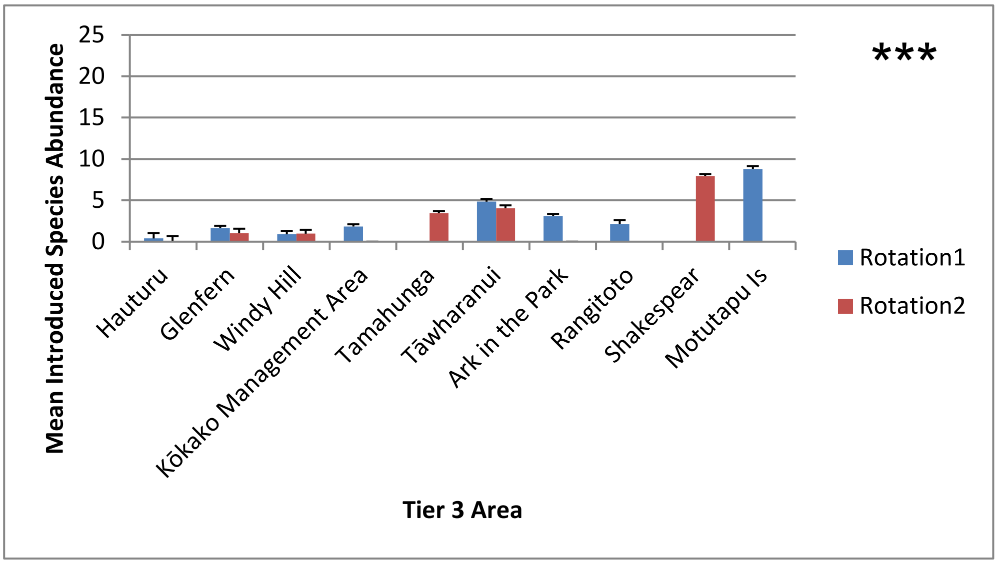


Figure 9: Mean Indigenous Dominance (Species Abundance), Indigenous and Introduced Species Abundance for birds counted at forest sites by Tier 3 Area and Rotation. Bars = Standard Error. Overall Kruskal-Wallis test: ***p<0.001.

Table 23: Post-hoc comparisons of mean ranks of all pairs of Mean Indigenous Dominance (Species Abundance) for birds counted at forest sites by Tier 3 Area.

Tier 3 Area	n	p values						
		Ark in the Park	Rangitoto	Motutapu Is	Hauturu	KMA	Glenfern	Windy Hill
Ark in the Park	19							
Rangitoto	5	1.000						
Motutapu Is	5	1.000	1.000					
Hauturu	13	**p<0.001**	**p<0.05**	**p<0.001**				
KMA	26	0.092	1.000	**p<0.01**	0.094			
Glenfern	10	0.655	1.000	**p<0.05**	0.496	1.000		
Windy Hill	6	**p<0.05**	0.536	**p<0.01**	1.000	1.000	1.000	
Tāwharanui	19	1.000	1.000	0.421	**p<0.001**	1.000	1.000	0.296

Table 24: Post-hoc comparisons of mean ranks of all pairs of Mean Indigenous Species Abundance of birds counted at forest sites by Tier 3 Area.

Tier 3 Area	n	p values						
		Ark in the Park	Rangitoto	Motutapu Is	Hauturu	KMA	Glenfern	Windy Hill
Ark in the Park	19							
Rangitoto	5	1.000						
Motutapu Is	5	1.000	1.000					
Hauturu	13	**p<0.001**	**p<0.01**	**p<0.01**				
KMA	26	1.000	1.000	1.000	**p<0.001**			
Glenfern	10	1.000	1.000	1.000	**p<0.001**	1.000		
Windy Hill	6	1.000	1.000	1.000	**p<0.01**	1.000	1.000	
Tāwharanui	19	**p<0.001**	**p<0.05**	0.145	1.000	**p<0.05**	**p<0.05**	0.087

Table 25: Post-hoc comparisons of mean ranks of all pairs of Mean Introduced Species Richness of birds counted at forest sites by Tier 3 Area.

Tier 3 Area	n	p values						
		Ark in the Park	Rangitoto	Motutapu Is	Hauturu	KMA	Glenfern	Windy Hill
Ark in the Park	19							
Rangitoto	5	1.000						
Motutapu Is	5	1.000	0.765					
Hauturu	13	**p<0.001**	0.531	**p<0.001**				
KMA	26	0.738	1.000	**p<0.05**	0.168			
Glenfern	10	1.000	1.000	**p<0.05**	1.000	1.000		
Windy Hill	6	0.291	1.000	**p<0.01**	1.000	1.000	1.000	
Tāwharanui	19	1.000	1.000	1.000	**p<0.001**	0.075	0.402	0.061

3.2 Wetland birds

3.2.1 Total species summary (Rotations 1 and 2)

In total, 913 bird counts were completed at 187 wetland sites during this study (2011-2019), and 14,513 individual birds were counted. The majority were introduced, followed by indigenous and endemic species (Table 26). Only a small percentage (~8%) of total birds counted were 'Threatened' or 'At Risk' species (Table 27) (Robertson et al. 2017). Total Species Richness comprised 61 species, with half of the 10 most abundant species being indigenous, and these occurred in a third of all counts (Table 27).

Table 26: Status of species counted at 187 wetland sites (913 total bird counts from 2011-19) in the Auckland region.

Status	Count	Percentage of total birds
Endemic	3,521	24.3%
Indigenous	4,565	31.5%
Introduced	6,427	44.3%
TOTAL	14,513	

Table 27: Conservation status (Robertson et al. 2017) of indigenous species counted at wetland sites (913 total bird counts from 2011-19) in the Auckland region.

Conservation Status	Count	Percentage of total birds
Threatened	5	<0.1%
At Risk	653	8.1%
Not Threatened	7,450	91.9%
TOTAL	8,108	

Table 28: Mean Species Abundance and Probability of Detection of all bird species counted (913 total bird counts from 2011-19) at wetland sites in Auckland; *indigenous; **endemic.

Species counted			Mean Species Abundance	Probability of detection
Silvereye	tauhou	*Zosterops lateralis lateralis**	2.42 ± 0.10	76
Common myna		*Acridotheres tristis*	1.56 ± 0.09	63
Grey warbler	riroriro	*Gerygone igata***	0.97 ± 0.05	59
European goldfinch		*Carduelis carduelis*	0.86 ± 0.09	35
House sparrow		*Passer domesticus*	0.81 ± 0.08	31
Tui	tūī	*Prosthemadera novaeseelandiae novaeseelandiae***	0.79 ± 0.07	36
Common starling		*Sturnus vulgaris*	0.78 ± 0.17	17
North Island fantail	pīwakawaka	*Rhipidura fuliginosa placabilis***	0.67 ± 0.06	37
Australian magpie		*Gymnorhina tibicen*	0.64 ± 0.05	37
Pūkeko	pūkeko	*Porphyrio melanotus melanotus**	0.61 ± 0.05	33
Eurasian blackbird		*Turdus merula*	0.53 ± 0.05	34
Welcome swallow		*Hirundo neoxena neoxena**	0.51 ± 0.06	24
Paradise shelduck	pūtangitangi	*Tadorna variegata***	0.45 ± 0.10	9
Eastern rosella		*Platycercus eximius*	0.45 ± 0.04	25
South Island pied oystercatcher	tōrea	*Haematopus finschi***	0.42 ± 0.28	1
Spur-winged plover		*Vanellus miles novaehollandiae**	0.29 ± 0.06	13
Chaffinch		*Fringilla coelebs*	0.25 ± 0.03	18
Sacred kingfisher	kōtare	*Todiramphus sanctus vagans**	0.19 ± 0.02	17
Black swan		*Cygnus atratus**	0.16 ± 0.11	1
Mallard		*Anas platyrhynchos*	0.16 ± 0.04	6
European greenfinch		*Carduelis chloris*	0.15 ± 0.03	10
Swamp harrier	kāhu	*Circus approximans**	0.13 ± 0.01	12
Southern black-backed gull	karoro	*Larus dominicanus dominicanus**	0.11 ± 0.04	5
Yellowhammer		*Emberiza citrinella*	0.10 ± 0.02	6
Bellbird	korimako	*Anthornis melanura melanura***	0.09 ± 0.04	2
New Zealand pigeon	kererū	*Hemiphaga novaeseelandiae***	0.08 ± 0.01	6
Spotted dove		*Streptopelia chinensis tigrina*	0.07 ± 0.01	6

Eurasian skylark		*Alauda arvensis*	0.06 ± 0.01	4
Grey teal	tētē	*Anas gracilis**	0.06 ± 0.06	<1
White-faced heron	matuku moana	*Egretta novaehollandiae novaehollandiae**	0.06 ± 0.03	3
Variable oystercatcher	tōrea pango	*Haematopus unicolor***	0.05 ± 0.03	2
North Island fernbird	mātātā	*Bowdleria punctata vealeae***	0.05 ± 0.01	4
Pied stilt	poaka	*Himantopus himantopus leucocephalus**	0.04 ± 0.02	1
Song thrush		*Turdus philomelos*	0.04 ± 0.01	4
Pied shag	kāruhiruhi	*Phalacrocorax varius varius**	0.04 ± 0.02	1
Rock pigeon		*Columba livia*	0.03 ± 0.01	2
Dunnock		*Prunella modularis*	0.03 ± 0.02	1
Chicken		*Gallus gallus domesticus*	0.03 ± 0.01	2
Spotless crake	pūweto	*Porzana tabuensis tabuensis**	0.02 ± 0.01	2
Wild turkey		*Meleagris gallopavo*	0.02 ± 0.02	1
North Island tomtit	miromiro	*Petroica macrocephala toitoi***	0.02 ± 0.01	1
Canada goose		*Branta canadensis*	0.02 ± 0.01	1
Red-billed gull	tarāpunga	*Larus novaehollandiae scopulinus**	0.02 ± 0.01	1
Red-crowned parakeet	kākāriki	*Cyanoramphus novaezelandiae novaezelandiae***	0.02 ± 0.01	1
Little black shag	kawau tūī	*Phalacrocorax sulcirostris**	0.02 ± 0.01	<1
Common pheasant		*Phasianus colchicus*	0.01 ± 0.004	2
Bar-tailed godwit	kuaka	*Limosa lapponica**	0.01 ± 0.01	<1
Barbary dove		*Streptopelia risoria*	0.01 ± 0.01	1
Banded rail	Moho pererū	*Gallirallus philippensis philippensis**	0.01 ± 0.01	<1
Australasian shoveler	kuruwhengi	*Anas rhynchotis**	0.01 ± 0.01	<1
New Zealand pipit	pīhoihoi	*Anthus novaeseelandiae novaeseelandiae***	<0.01	1
Black shag	kawau	*Phalacrocorax carbo novaehollandiae**	<0.01	1
Common redpoll		*Carduelis flammea*	<0.01	<1
Peafowl		*Pavo cristatus*	<0.01	1
New Zealand dabchick	weweia	*Poliocephalus rufopectus***	<0.01	<1

Black-billed gull	tarapunga	*Larus bulleri***	<0.01	<1
California quail		*Callipepla californica*	<0.01	<1
Brown teal	pāteke	*Anas chlorotis***	<0.01	<1
Kaka	kākā	*Nestor meridionalis***	<0.01	<1
Caspian tern	taranui	*Hydroprogne caspia**	<0.01	<1
North Island saddleback	tīeke	*Philesturnus rufusater***	<0.01	<1

3.2.2 Regional patterns

3.2.2.1 Land classes: Species Richness

Wetland Mean Species Richness varied significantly across Land Classes for the Indigenous Dominance (Repeated Measures ANOVA, $F_{3,130}$ = 22.98, p<0.001, η^2 = 0.20) and Introduced variables (Repeated Measures ANOVA, $F_{3,130}$ = 22.39, p<0.001, , η^2 = 0.13), with the highest Indigenous Dominance found in Indigenous Land Class sites, which were significantly different from Rural sites in Rotation 1 and from Rural and Urban sites in Rotation 2 (Figure 10; Table 29). There was higher Introduced Species Richness in Rural sites compared with Indigenous and Mixed Land Classes, but only during Rotation 2 (Table 30).

A time effect was found only in the Mean Indigenous Species Richness when comparing Rotation 1 with 2, but this was negligible given the low partial eta-squared value (Repeated Measures ANOVA, $F_{3,130}$ = 4.67, p<0.05, η^2 = 0.03).

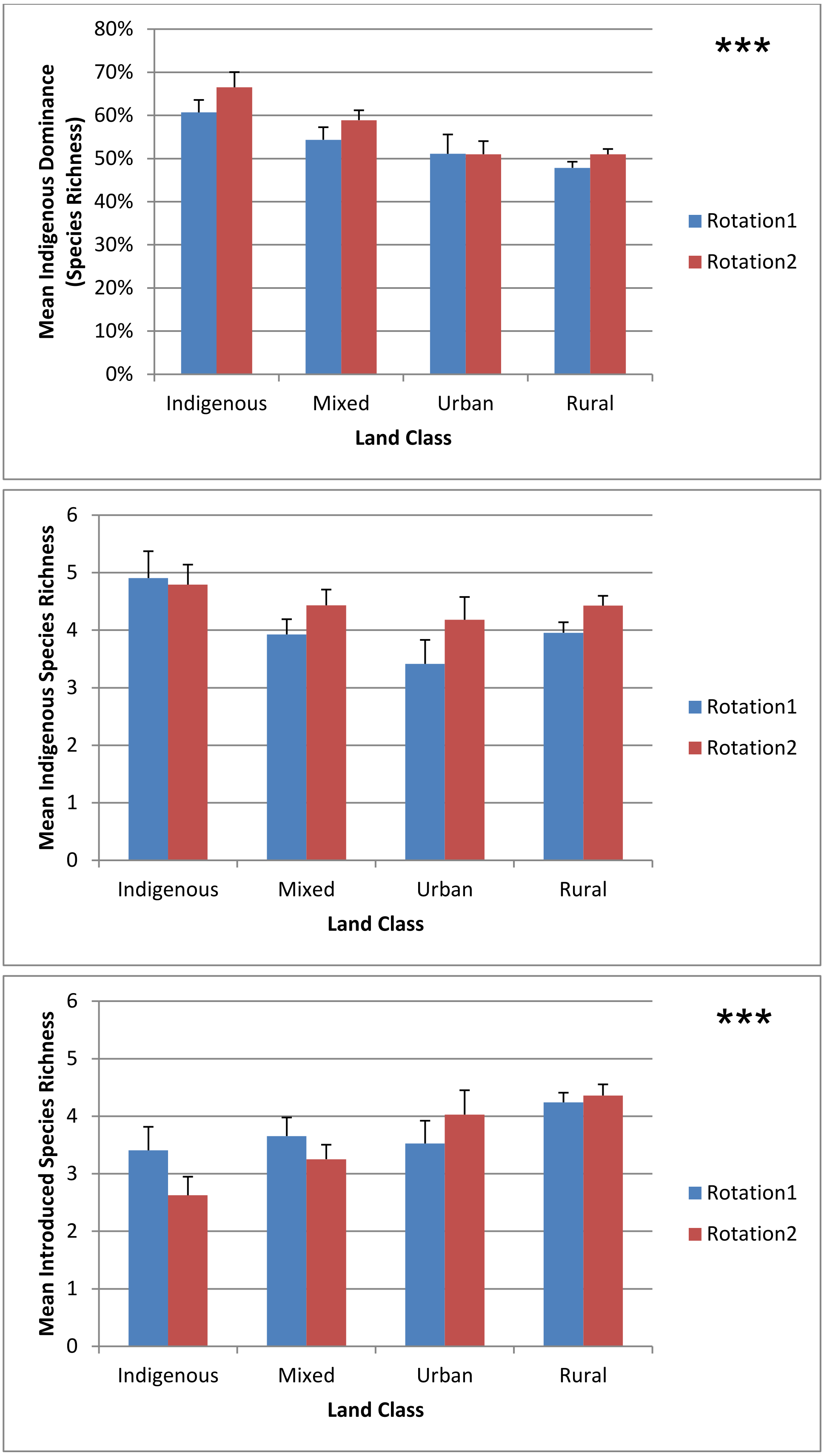


Figure 10: Mean Indigenous Dominance (Species Richness), Indigenous and Introduced Species Richness for birds counted at wetland sites by Land Class and Rotation. Bars = Standard Error. Overall ANOVA: ***p<0.001.

Table 29: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Richness) for birds counted at wetland sites by Land Class and Rotation (R1 = Rotation 1; R2 = Rotation 2).

Land Class-Rotation	**n**	**p values**						
		Mixed-R1	Mixed-R2	Rural-R1	Rural-R2	Indigenous-R1	Indigenous-R2	Urban-R1
Mixed-R1	27							
Mixed-R2	27	0.792						
Rural-R1	79	0.276	**p<0.01**					
Rural-R2	79	0.928	0.083	0.630				
Indigenous-R1	16	0.745	1.000	**p<0.01**	0.085			
Indigenous-R2	16	**p<0.05**	0.530	**p<0.001**	**p<0.001**	0.805		
Urban-R1	12	0.995	0.617	0.991	1.000	0.473	**p<0.05**	
Urban-R2	12	0.995	0.604	0.992	1.000	0.461	**p<0.05**	1.000

Table 30: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Richness for birds counted at wetland sites by Land Class and Rotation (R1 = Rotation 1; R2 = Rotation 2).

Land class-Rotation	**n**	**p values**						
		Mixed-R1	Mixed-R2	Rural-R1	Rural-R2	Indigenous-R1	Indigenous-R2	Urban-R1
Mixed-R1	27							
Mixed-R2	27	0.792						
Rural-R1	79	0.276	**p<0.01**					
Rural-R2	79	0.928	0.083	0.630				
Indigenous-R1	16	0.745	1.000	**p<0.01**	0.085			
Indigenous-R2	16	**p<0.05**	0.530	**p<0.001**	**p<0.001**	0.805		
Urban-R1	12	0.995	0.617	0.991	1.000	0.473	**p<0.05**	
Urban-R2	12	0.995	0.604	0.992	1.000	0.461	**p<0.05**	1.000

3.2.2.2 Land classes: Species Abundance

Only the Indigenous Species Abundance data required transformation as its distribution was positively skewed, and hence square root transformation was applied.

Wetland Mean Species Abundance varied significantly across Land Classes for all three variables analysed in the Repeated Measures ANOVAs: Indigenous Dominance ($F_{3,130} = 14.63$, $p<0.001$, $\eta^2 = 0.25$); Indigenous ($F_{3,130} = 3.32$, $p<0.05$, $\eta^2 = 0.07$, square root transformed); Introduced variables ($F_{3,130} = 5.00$, $p<0.01$, $\eta^2 = 0.10$, square root transformed). Mean Indigenous Dominance (Species Abundance) was significantly higher in Indigenous Land Classes in comparison to Rural sites for both Rotations (Table 31). This pattern appears to be the result of Mean Indigenous Species Abundances being significantly higher in sites in the Indigenous Land Class in Rotation 1 (Table 32) and Mean Introduced Species Abundances being significantly higher in Rural sites in Rotation 2 (Table 33).

There was no significant difference found between Rotation 1 vs 2 for any of the three variables.

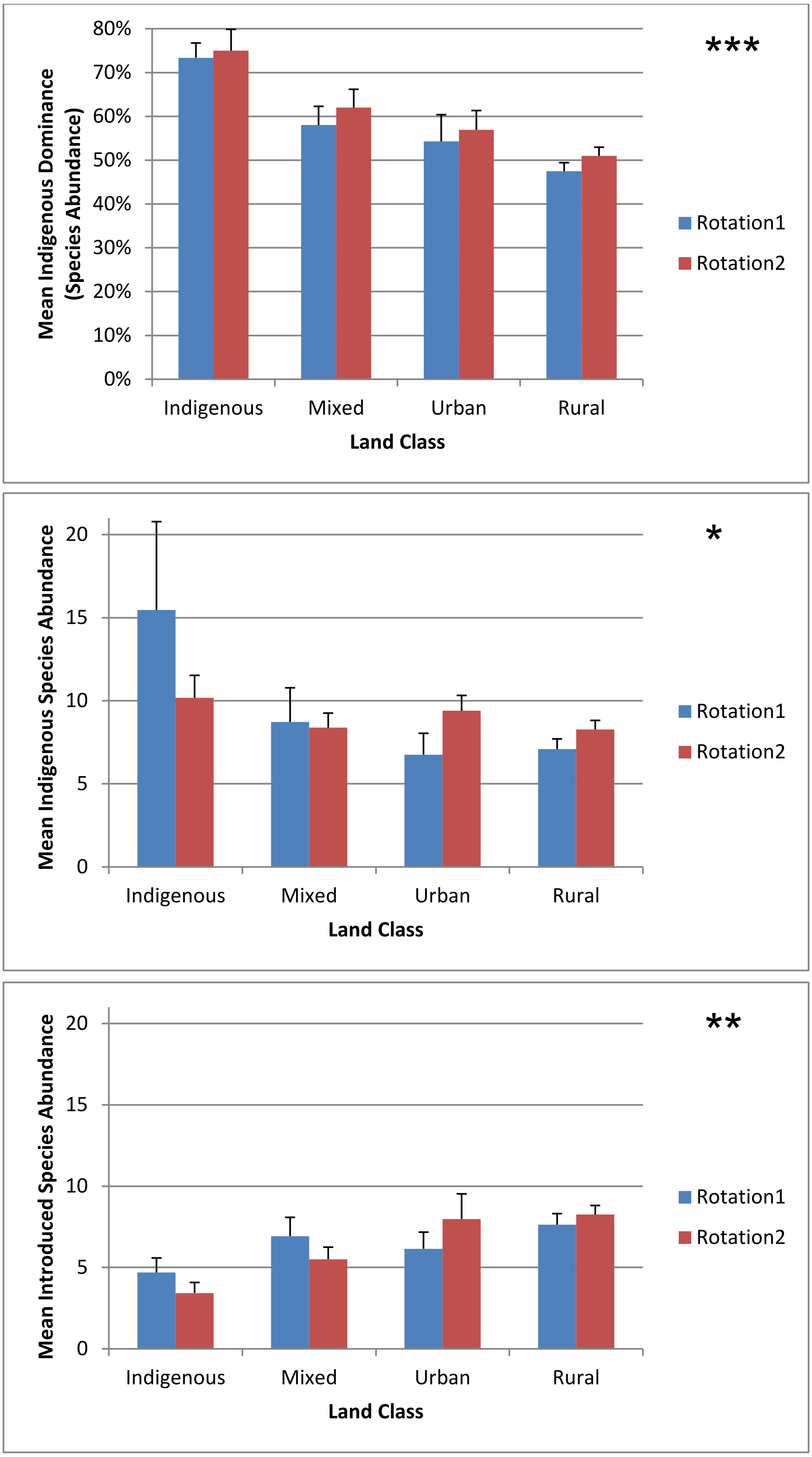


Figure 11: Mean Indigenous Dominance (Species Abundance), Indigenous and Introduced Species Abundance for birds counted at wetland sites by Land Class and Rotation. Bars = Standard Error. Overall ANOVA: *p<0.05; **p<0.01; ***p<0.001.

Table 31: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Dominance (Species Abundance) for birds counted at wetland sites by Land Class and Rotation (R1 = Rotation 1; R2 = Rotation 2).

Land class-Rotation	n	p values						
		Mixed-R1	Mixed-R2	Rural-R1	Rural-R2	Indigenous-R1	Indigenous-R2	Urban-R1
Mixed-R1	27							
Mixed-R2	27	0.986						
Rural-R1	79	0.173	**p<0.01**					
Rural-R2	79	0.684	0.132	0.878				
Indigenous-R1	16	0.145	0.518	**p<0.001**	**p<0.001**			
Indigenous-R2	16	0.071	0.336	**p<0.001**	**p<0.001**	1.000		
Urban-R1	12	0.999	0.931	0.936	0.999	0.121	0.066	
Urban-R2	12	1.000	0.994	0.721	0.969	0.278	0.172	1.000

Table 32: Post-hoc comparisons using Tukey HSD test of Mean Indigenous Species Abundance for birds counted at wetland sites by Land Class and Rotation (R1 = Rotation 1; R2 = Rotation 2).

Land class-Rotation	n	p values						
		Mixed-R1	Mixed-R2	Rural-R1	Rural-R2	Indigenous-R1	Indigenous-R2	Urban-R1
Mixed-R1	27							
Mixed-R2	27	1.000						
Rural-R1	79	0.987	0.882					
Rural-R2	79	1.000	1.000	0.515				
Indigenous-R1	16	0.103	0.218	**p<0.01**	0.059			
Indigenous-R2	16	0.923	0.985	0.389	0.932	0.716		
Urban-R1	12	0.997	0.974	1.000	0.976	0.065	0.710	
Urban-R2	12	0.979	0.998	0.674	0.987	0.852	1.000	0.675

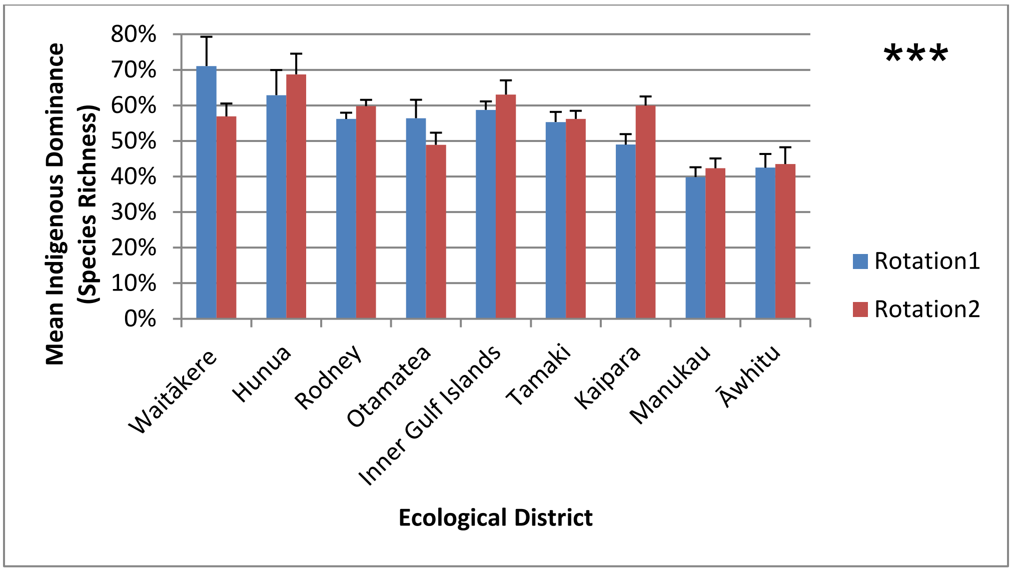
Table 33: Post-hoc comparisons using Tukey HSD test of Mean Introduced Species Abundance for birds counted at wetland sites by Land Class and Rotation (R1 = Rotation 1; R2 = Rotation 2).

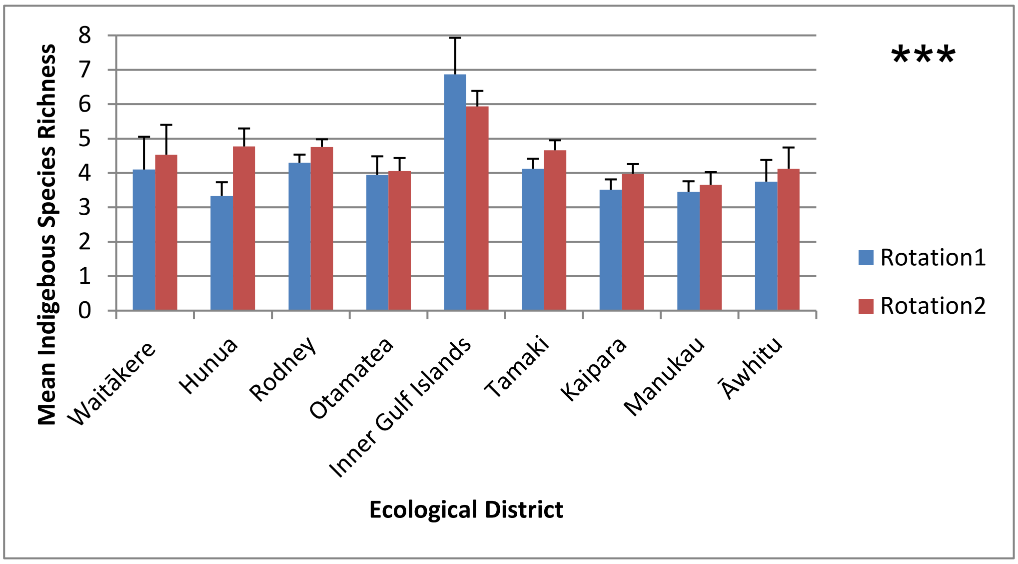
Land class-Rotation	**n**	**p values**						
		Mixed-R1	Mixed-R2	Rural-R1	Rural-R2	Indigenous-R1	Indigenous-R2	Urban-R1
Mixed-R1	27							
Mixed-R2	27	0.959						
Rural-R1	79	0.999	0.583					
Rural-R2	79	0.943	0.242	0.992				
Indigenous-R1	16	0.869	1.000	0.427	0.185			
Indigenous-R2	16	0.378	0.906	0.057	**p<0.05**	0.995		
Urban-R1	12	1.000	1.000	0.983	0.891	0.996	0.863	
Urban-R2	12	0.999	0.862	1.000	1.000	0.704	0.281	0.982

3.2.2.3 Ecological districts: Species Richness

When looking at regional differences between EDs for Mean Species Richness variables, all three Repeated Measures ANOVAs were significant (Indigenous Dominance : $F_{8,125} = 4.44$, $p<0.001$, $\eta^2 = 0.22$; Indigenous: $F_{8,125} = 3.58$, $p<0.001$, $\eta^2 = 0.19$; Introduced: $F_{8,125} = 3.80$, $p<0.001$, $\eta^2 = 0.20$) (Figure 12). The post-hoc comparisons revealed this reflected the following differences: Mean Indigenous Dominance (Species Richness) was greater in Rotation 2 data for the Hunua ED compared with the more rural/urban EDs Kaipara, Āwhitu and Manukau; there were higher levels of Mean Indigenous Species Richness for sites in the Inner Gulf Islands ED compared with Kaipara, Rodney, Āwhitu, Tamaki and Manukau EDs, the latter mostly all rural/urban areas; and there were higher levels of Mean Introduced Species Richness for sites in the Inner Gulf Islands ED compared with Kaipara and Hunua ED sites (Appendix A).

There were no significant effects of time (Rotation 1 vs 2) for any of the three variables.





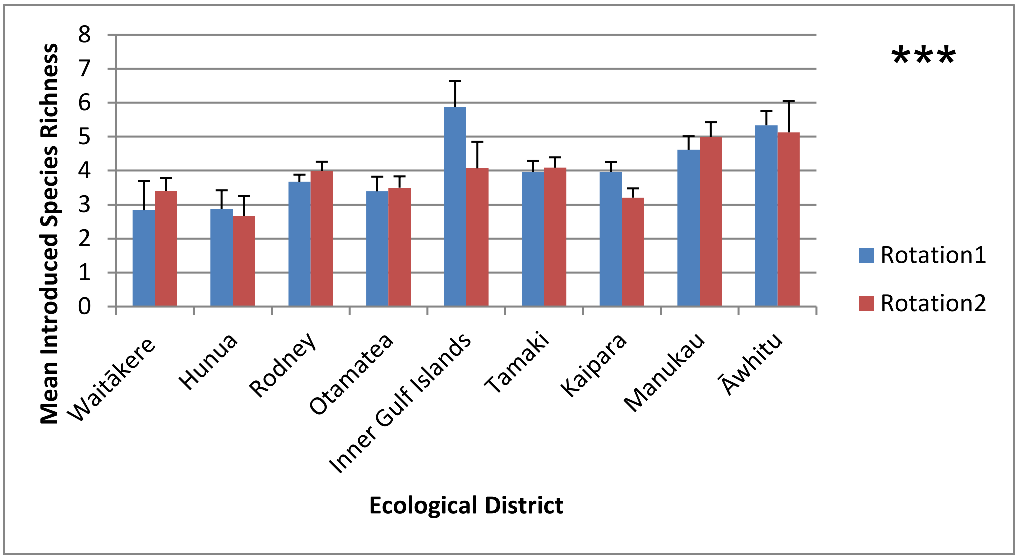


Figure 12: Mean Indigenous Dominance (Species Richness), Indigenous and Introduced Species Richness for birds counted at wetland sites by ecological district and Rotation. Bars = Standard Error. Overall ANOVA: ***p<0.001.

3.2.2.4 Ecological districts: Species Abundance

Mean Species Abundance data differed significantly for Indigenous Dominance (Repeated Measures ANOVA, $F_{8,125} = 2.83$, $p<0.05$, $\eta^2 = 0.15$) and Introduced (Repeated Measures ANOVA, $F_{8,125} = 3.56$, $p<0.001$, $\eta^2 = 0.19$, square root transformed) variables (Figure 13). However, this appeared to be quite minor for these variables as there were no significant pair-wise comparisons for Mean Indigenous Dominance (Species Abundance), and only one for Introduced Species Abundance: sites in the Manukau ED during Rotation 1 had significantly higher Mean Introduced Species Abundance compared with sites in the Hunua ED during Rotation 2 (Appendix A).

Again, there was no significant difference found between Rotation 1 vs 2 for any of the three variables.

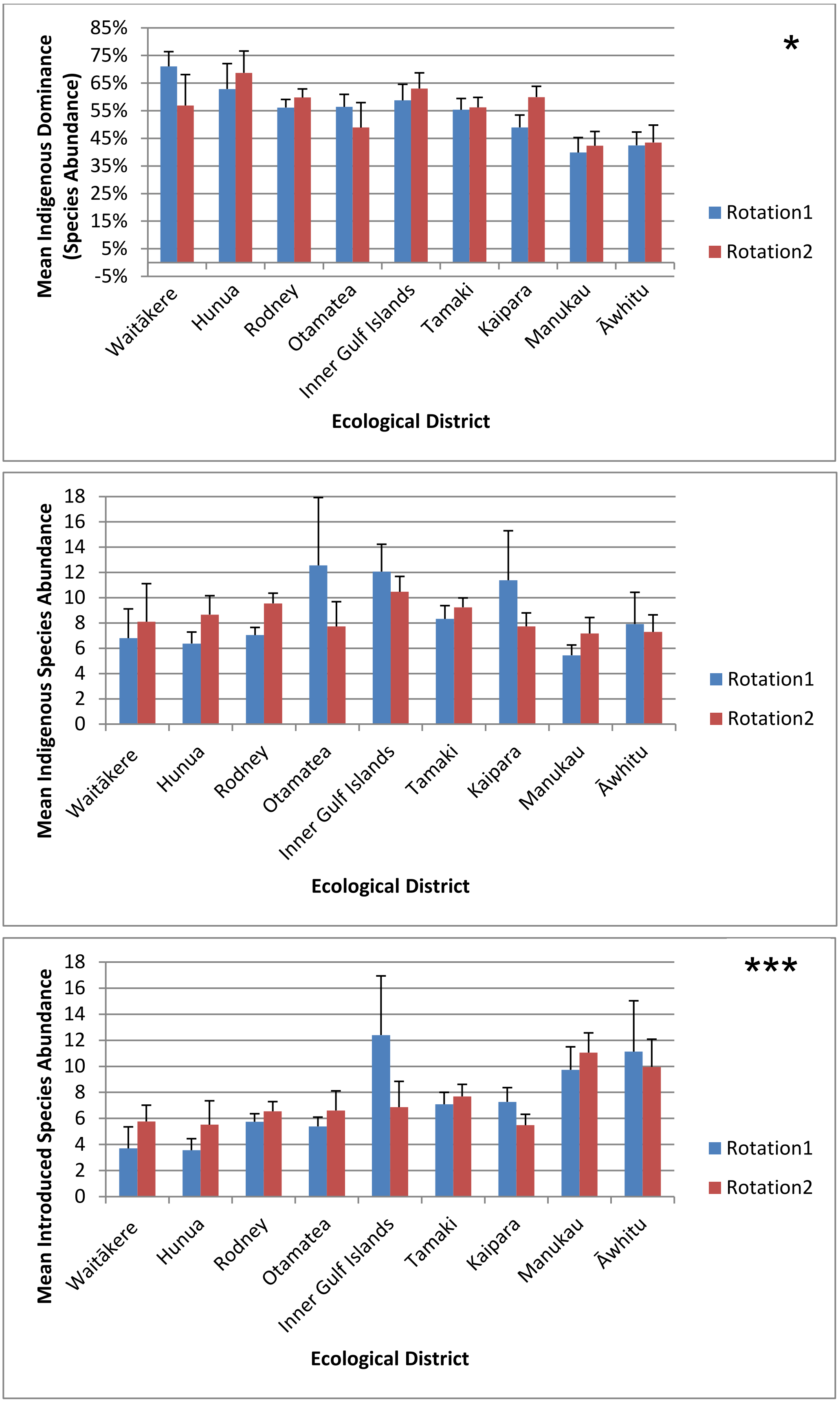


Figure 13: Mean Indigenous Dominance (Species Abundance), Indigenous and Introduced Species Abundance for birds counted at wetland sites by ecological district and Rotation. Bars = Standard Error. Overall ANOVA: *p<0.05; ***p<0.001.

4.0 Discussion

4.1 Limits of this study

This comprehensive 10-year study of forest and wetland birds has revealed significant variation across the region, and it shows the value of using the standard 5MBC methodology. It is important to acknowledge that 5MBCs disproportionately detect more conspicuous birds while cryptic and quieter birds can be overlooked (Hartley 2012). However, as this study has analysed these data in similar environments (separately for forest and wetlands) where detectability will generally be consistent, robust inferences are achievable given the large sample sizes for most of the areas in this study.

A major limitation of this study is the lack of trend data. This is because only two independent time measures were available, with the two Rotations. This was further complicated in the forest data with two thirds of the forest Rotation 2 dataset not remeasured (as a result of the resourcing issues mentioned in the Methods). We were able to look for variation over time in the wetlands data, where two full rotations were completed, however, no major changes were found, probably because only two time measures were available to analyse. Future remeasures will allow us to conduct more robust trend analyses and thus identify what changes are occurring over time.

4.2 Forest birds

In total, 64 species were counted in the forest component of this study with almost 70 per cent of all birds detected being indigenous species (Table 2). Tūī was the most commonly counted bird, but silvereye and grey warbler were very commonly counted as well. These three species were detected in >70 per cent of all counts at forest sites. The next two most common species were the indigenous North Island fantail and the introduced Eurasian blackbird, both detected in 53 per cent of all forest counts. These five species are all conspicuous as they are vocal and thus easily detected. A bird study in the heavily forested Waitākere Ranges using a similar five-minute bird count method to this study found the same top five species (T. Lovegrove and K. Parker, unpubl. data). Their 22-year study found all these species to have increased, except for fantail, which had changed very little.

There was considerable variation in Indigenous Dominance when calculated from both Mean Species Richness and Abundance data across all our spatial independent variables (Land Class, ED, Tier 2 and 3 sites). Sites that were predominantly indigenous ecosystems had the highest Indigenous Dominance compared with Rural, Mixed and Urban sites. Our findings were similar for the range of EDs in the region. Districts with the largest indigenous forests (Hunua and Waitākere) had higher Indigenous Dominance compared with the more rural and urban areas (Āwhitu, Kaipara and Manukau). When we looked specifically at the key forested areas in the region using our Tier 2 site network, compared with the smaller forest patches in the Urban, Tapora and Waiheke Areas, we again saw that the Waitākere and Hunua Ranges have higher Indigenous Dominance (~70%), and that Aotea's large forested environment had the highest levels (~80%), when calculated from either Mean Species Richness or Abundance data. The other Areas, which generally have smaller forest patches with more fragmentation, were all below 50 per cent Indigenous Dominance when calculated from Species Richness data and between 50 and 60 per cent when calculated using Species Abundance data.

There was an interesting high value for Mean Indigenous Species Abundance for the Urban Land Class in Rotation 2. It may be that urban sites have been benefitting from increased pest animal management, however, this is difficult to confirm without additional evidence. Hence, we can only consider this as a tendency at this stage, given the incomplete sampling for Rotation 2 as discussed in the Methods. We intend to examine how robust this pattern is after we complete Rotation 3 in 2023.

Auckland's largest highly managed areas (Tier 3 sites) showed the highest levels of Indigenous Dominance for the whole programme, with Hauturu on top with the highest percentages when calculated from both Mean Species Richness and Abundance data (close to 100%). This is not that surprising given Hauturu historically lacked most predatory mammals, apart from feral cats (*Felis catus*) and Pacific rats (*Rattus exulans*), and the island has been totally pest-animal free for over 15 years (Rayner et al. 2007; Veitch and Wade 2019), moreover Hauturu has the most intact forest ecosystems in the region (Cameron et al. 2008). Interestingly, these values were not significantly different from the counts conducted in the Glenfern and Windy Hill Sanctuaries and in the Hunua KMA on the mainland, although the values tended to be slightly lower (>85% for Glenfern/Windy Hill and ~80/90% for KMA for Mean Species Richness and Abundance). All of these areas are well above the mean values for the region; for example, Mean Indigenous Dominance values for Mixed, Urban and Rural Tier 1 Areas are generally in the 50 per cent range when calculated from Mean Species Richness or Abundance. These results show the high value of both the highly managed Tier 2 Areas on islands and also on the mainland (namely in the KMA). The large intact forested areas also stood out as important bird sites, again both on the islands (i.e. Aotea) and the mainland (Hunua and Waitākere). It is important to maintain high levels of management at these island and mainland sites so they can continue to act as reserves for our indigenous species. These places also have a very important role as sources of indigenous birds to colonise nearby habitats, as they are restored through regeneration, plantings of indigenous species and pest mammal control. Our findings also highlight the importance of connecting areas through restoration and management to allow landscape-scale processes like dispersal to occur, as well as enhancing year-round food sources for birds and other fauna (Ogle 1987; Hobbs and Norton 1996; Norton and Miller 2000; Lucas et al. 2004; Sullivan et al. 2009; Norton et al. 2018). Auckland Council has a number of joint programmes with the community (e.g. North-West Wildlink and Pest Free Auckland 2050), which aim to restore new areas and increase connectivity as part of its objectives under the Indigenous Biodiversity Strategy (Auckland Council 2012).

4.3 Wetland birds

Approximately 55 per cent of all the birds counted at the 187 wetland sites were indigenous species, compared with 70 per cent at forest sites. Silvereye was the most commonly counted bird at wetland sites, followed by myna and grey warbler, with all three species detected in at least 59 per cent of all counts. In contrast to forest sites, the top five most abundant birds included three introduced species (myna, European goldfinch, house sparrow); however, birds counted at wetland sites varied similarly to forest sites across Land Classes, with sites comprising mainly indigenous vegetation having higher Mean Indigenous Dominance (>60%) compared with Rural and Urban sites (~50%) when calculated from either Species Richness or Abundance. This pattern was seen when comparing EDs, with the Waitākere and Hunua EDs tending to have the highest Mean Indigenous Dominance values, although these were not statistically significant. Further sampling may show these patterns are real. An interesting outlier can be seen in all values for the Inner Gulf Islands, which tended to have elevated Mean Species Abundance and Richness values for both Indigenous and Introduced species compared with the other EDs. However, given these data are based on a small sample size with only five sites for each Rotation, and in two quite different locations (three on Waiheke and two on Motutapu), additional replication is required to show whether this elevated Abundance and Richness is real.

We found no difference when comparing Rotation 1 with Rotation 2. This result may mean that generally wetland birds have not changed overall; however, it may also mean that the time span of this 10-year study may be too short to detect changes. A recent study using a similar count methodology in the Waitākere Ranges over a 22-year period highlighted the importance of carrying out long-term monitoring, as the numbers of many bird species only changed very slowly and some not changing at all

(T. Lovegrove and K. Parker, unpubl. data). Thus, long-term changes may require decades of data to detect the overall trend.

4.4 Forest and wetland birds – overall findings

The full set of bird count data in forest and wetland sites over this 10-year study has revealed broad variation in bird species richness and abundance across the region. There are areas with high levels of indigenous birds, both on the islands and the mainland. The results also show a decline in Mean Indigenous Dominance from larger forest areas to smaller forest fragments in rural and urban environments, which is not surprising. Moreover, the Land Class analyses showed that sites predominantly comprising indigenous vegetation tended to have higher proportions of indigenous birds and fewer introduced birds. Bird assemblages clearly vary across Auckland and this is likely the result of a number of factors which are described below.

Many factors influence bird numbers, including behaviour and demography, predation, competition and food resources (Newton 1998; Newton 2007; Innes et al. 2010). Habitat loss and fragmentation (patch size, edge effects, connectivity, etc.) are also important factors that influence the spatial makeup of biodiversity; the importance of each of these is still debated (Trzcinski et al. 1999; Banks-Leite et al. 2010; Smith et al. 2011; Barbaro et al. 2012; Villard and Metzger 2014; Haddad et al. 2015; Pfeifer et al. 2017; Bain et al. 2020). It is difficult to explain how each of these factors has specifically affected the overall regional bird patterns we found in this study, but we can infer that since indigenous birds evolved in a predominantly forested landscape (Singers et al. 2017), higher Indigenous Dominance would be expected in places with the most intact indigenous vegetation. This has also been seen in Australia where there are strong positive correlations between indigenous vegetation and indigenous birds (Sewell and Catterall 1998; White et al. 2005; Daniels and Kirkpatrick 2006). This pattern was also apparent for wetland and forest birds when comparing sites in and around the larger forested areas in the region (e.g. Waitākere and Hunua Ranges, outer islands). These had high Mean Indigenous Dominance compared with rural and urban areas (e.g. Kaipara, Manukau, Āwhitu) with more fragmented forest landscapes. A study using the available data at the time (a portion of Rotation 1 as permission to use some sites was not always given on privately owned land and other sites were omitted as they had few to no pest mammals, a key factor in the aims of their study) of the forest programme, found that areas with >10 per cent forest cover had relatively stable numbers of indigenous birds (for species abundance and total species richness measures) compared with smaller patches (forest cover below ~5-10%), where there was more variation in indigenous bird numbers (Ruffell and Didham 2017).

The drivers of the variation seen in Indigenous Dominance at the larger spatial scales for forest (Tier 1 and 2) and wetland sites are another interesting finding in this study. The numbers of indigenous birds generally didn't vary as much as introduced birds between Land Class and ED Areas (Indigenous analyses had lower p-values, many which were not significant). For example, comparing both the richness and abundance variations in the means of introduced and indigenous birds in Tier 2 Areas, there is much greater variation in Mean Introduced Species per count, which ranged from ~1-7 compared with ~4-5 mean species per count for Mean Indigenous species (Figure 6).

In our study, Mean Indigenous Abundance and Richness were reasonably consistent across Land Classes, which contrasts with studies elsewhere that show urban areas tended to have the lowest species richness overall, often dominated by a few exotic species (Chace and Walsh 2006). However, this contrasts with a Dunedin study (van Heezik et al. 2008), which like our study, found relatively high (~50%) percentages of introduced species at urban sites.

The variation in introduced species we found raises the question of what effects do higher proportions of introduced species have on indigenous species and other biodiversity. As described in overseas studies, introduced birds can have a variety of negative impacts on indigenous species (reviewed in Baker et al. 2014). A number of introduced birds in New Zealand are known to have detrimental effects on indigenous birds (Krull et al. 2015; Auckland Council 2020). For example, common mynas have negative effects on indigenous birds through competition (e.g. food resources and nest cavities) along with other aspects related to their aggressive behaviour (Tindall et al. 2007; Dhami and Nagle 2009; Grarock et al. 2012). Mynas are of particular concern given they were one of the most common birds counted in this study, being detected in a third of forest sites and almost two-thirds of wetland sites. Mynas are very common in other environments, including on Auckland's maunga (volcanic cones) (Landers et al. 2019), and their numbers have increased over time in the annual garden bird surveys (Brandt et al. 2020). In Auckland, introduced birds have also been shown to have negative impacts on some indigenous birds as a result of people feeding birds (Galbraith et al. 2015), which is a very common activity in the region (Galbraith et al. 2014). The overall effects of introduced birds on New Zealand's indigenous avifauna is a relatively unstudied subject that clearly needs more attention (Krull et al. 2015), especially in light of the high numbers of introduced birds in rural and urban areas.

5.0 Summary

- Indigenous birds formed the greater proportion of common birds counted in this 10-year survey of forest and wetland areas of Auckland.
- Our highly managed Tier 3 Areas (e.g. Hauturu, Glenfern, Windy Hill, KMA, Tāwharanui) and large forested areas with indigenous vegetation hold the highest proportions of indigenous birds, and hence are important reserves for indigenous species. They also provide sources of birds for neighbouring areas being restored through programmes such as Pest Free Auckland and the North-West Wildlink.
- Sites that predominantly comprise indigenous Land Classes had higher percentages of indigenous birds, with rural classes having the lowest. To increase the numbers and diversity of indigenous birds in the region and to maintain all the ecological functions they provide in indigenous ecosystems (e.g. pollination, dispersal, predation), we need to ensure the Tier 3 and large forest areas (namely the Hunua and Waitākere Ranges) are protected and enhanced. We also need to create more restored areas, along with linkages between them, especially in the rural and urban areas of the region to allow indigenous birds to increase and flourish.
- The levels of introduced species may explain some of the variation we found in Indigenous Dominance; however, we don't have a good understanding of what effects many introduced species have on indigenous birds and other biodiversity in the Auckland region. This is an area that needs further research. This may allow us to take the most strategic approach and help prioritise future management actions.
- This study highlights the value of large-scale bird surveys, which increase in value the longer they run. It is important the regional Bird Monitoring Programme continues so that trend analyses can be achieved over time, which can inform decisions and management. This aspect is especially important given increased pressures on birds from urbanisation, land use changes and climate change.
- Future regional analyses should explore the use of citizen-derived bird data, such as eBird and NatureWatch to improve the temporal and spatial limitations of the data in our study. These citizen-science initiatives also stimulate more of the community to become engaged with their local biodiversity.
- Given the large amount of private land in the rural and urban areas of Auckland, members of the regional community can play a crucial role in achieving

biodiversity gains. Some relatively easy contributions that we can all make is to replace pest plants with appropriate indigenous plants, control pest mammals (e.g. rats, stoats, possums), and join a local community restoration group.

6.0 Acknowledgements

The Auckland Council regional Bird Monitoring Programme would not exist without the original designer of the programme, Matt Baber, who developed the first iteration of the Terrestrial Biodiversity Monitoring Programme when he worked at the former ARC. We would also like to thank all participants in the bird surveys: Jane Andrews, Sally Armstrong, Hugo Baynes, Steph Borrelle, Ursula Brandes, Doug Bridge, Susan Carrodus, Kirsty Denny, Karen Denyer, Melanie Duplain, Kirstin Foster, Richard Gillies, Nick Goldwater, Sharen Graham, Melinda Habgood, Wendy Hare, Sam Hill, Leigh Joyce, Amanda Kirk, Helen Lindsay, Stacey Lockie, Doug Lockyear, Jeff McCauley, Virginia Moreno, Danielle Munster, Kevin Parker, Sarah Peters, Ian Price, Mags Ramsey, Jessica Reaburn, Kate Richardson, Sarah Roth, Mark Seabrook, Su Sinclair, Carolina Stavert, Maheshi Wadasinghe, Andy Warneford, Claire Webb, Sarah Wells, Fiona Wilcox, and Vanessa Wood.

7.0 References

Allen, R. B. 1993. A Permanent Plot Method for Monitoring Changes in Indigenous Forests: A Field Manual. Christchurch, New Zealand: Manaaki Whenua Landcare Research NZ Ltd.

Aubert, M. 2016. *Effects of forest fragmentation on plant-bird mutualisms in New Zealand lowland forests [Unpublished PhD Thesis].* PhD Thesis, University of Canterbury.

Auckland Council 2012. Auckland Council's Indigenous Biodiversity Strategy. Aucklan: Environmental Policy and Strategy, Auckland Council.

Auckland Council 2015. The Health of Auckland's Natural Environment In 2015: Te Oranga O Te Taiao O Tāmaki Makaurau. *State of Environment Report 2015.* Auckland.

Auckland Council 2020. Mahere ā-Rohe Whakahaere Kaupapa Koiora Orotā mō Tāmaki Makaurau: Auckland Regional Pest Management Plan 2020-2030.

Bain, G. C., MacDonald, M. A., Hamer, R., Gardiner, R., Johnson, C. N. and Jones, M. E. 2020. Changing bird communities of an agricultural landscape: declines in arboreal foragers, increases in large species. *Royal Society Open Science,* 7**,** 200076.

Baker, J., Harvey, K. J. and French, K. 2014. Threats from introduced birds to native birds. *Emu – Austral Ornithology,* 114**,** 1-12.

Banks-Leite, C., Ewers, R. M. and Metzger, J.-P. 2010. Edge effects as the principal cause of area effects on birds in fragmented secondary forest. *Oikos,* 119**,** 918-926.

Barbaro, L., Brockerhoff, E. G., Giffard, B. and van Halder, I. 2012. Edge and area effects on avian assemblages and insectivory in fragmented native forests. *Landscape Ecology,* 27**,** 1451-1463.

Barbier, E. B., Acreman, M. and Knowler, D. Economic valuation of wetlands: a guide for policy makers and planners. 1997. Ramsar Convention Bureau, Gland.

Belder, D. J., Pierson, J. C., Ikin, K. and Lindenmayer, D. B. 2018. Beyond pattern to process: current themes and future directions for the conservation of woodland birds through restoration plantings. *Wildlife Research,* 45**,** 473-489.

Bishop, C. D. and Landers, T. J. 2019. Climate change risk assessment for terrestrial species and ecosystems in the Auckland region. Auckland Council technical report, TR2019/014. *Climate Change Risk Assessment series 2019.*

Brandt, A., MacLeod, C., Howard, S., Gormley, A. and Spurr, E. 2020. State of NZ Garden Birds 2019 | Te Ahoa o nga Manu o te Kari i Aotearoa. Manaaki Whenua – Landcare Research, Lincoln. ISBN 978-0-947525-67-5.

Brook, F. 1996. Classification of the ecological districts of Northland. *Unpublished report, Department of Conservation, Whangarei,* 431.

Butchart, S. H. M., Walpole, M., Collen, B., van Strien, A., Scharlemann, J. P. W., Almond, R. E. A., Baillie, J. E. M., Bomhard, B., Brown, C., Bruno, J., Carpenter, K. E., Carr, G. M., Chanson, J., Chenery, A. M., Csirke, J., Davidson, N. C., Dentener, F., Foster, M., Galli, A., Galloway, J. N., Genovesi, P., Gregory, R. D., Hockings, M., Kapos, V., Lamarque, J.-F., Leverington, F., Loh, J., McGeoch, M. A., McRae, L., Minasyan, A., Morcillo, M. H., Oldfield, T. E. E., Pauly, D., Quader, S., Revenga, C., Sauer, J. R., Skolnik, B., Spear, D., Stanwell-Smith, D., Stuart, S. N., Symes, A., Tierney, M., Tyrrell, T. D., Vié, J.-C. and Watson, R. 2010. Global Biodiversity: Indicators of Recent Declines. *Science,* 328**,** 1164-1168.

Cameron, E. K., Hayward, B. W. and Murdoch, G. J. 2008. *A Field Guide to Auckland: Exploring the Region's Natural and Historical Heritage*, Random House New Zealand.

Chace, J. F. and Walsh, J. J. 2006. Urban effects on native avifauna: a review. *Landscape and Urban Planning,* 74**,** 46-69.

Clout, M. N. and Hay, J. R. 1989. The importance of birds as browsers, pollinators and seed dispersers in New Zealand forests. *New Zealand Journal of Ecology,* 12**,** 27-33.

Daniels, G. D. and Kirkpatrick, J. B. 2006. Does variation in garden characteristics influence the conservation of birds in suburbia? *Biological Conservation,* 133**,** 326-335.

Dawson, D. G. and Bull, P. C. 1975. Counting birds in New Zealand forests. *Notornis,* 22**,** 101-109.

Dhami, M. K. and Nagle, B. 2009. *Review of the biology and ecology of the common myna (Acridotheres tristis) and some implications for management of this invasive species*, School of Biological Sciences, The University of Auckland.

Dunphy, B. J., Taylor, G. A., Landers, T. J., Sagar, R. L., Chilvers, B. L., Ranjard, L. and Rayner, M. J. 2015. Comparative seabird diving physiology: first measures of haematological parameters and oxygen stores in three New Zealand Procellariiformes. *Marine Ecology Progress Series,* 523**,** 187-198.

Dunphy, B. J., Vickers, S. I., Zhang, J., Sagar, R. L., Landers, T. J., Bury, S. J., Hickey, A. J. R. and Rayner, M. J. 2020. Seabirds as environmental indicators: foraging behaviour and ecophysiology of common diving petrels (*Pelecanoides urinatrix*) reflect local-scale differences in prey availability. *Marine Biology,* 167**,** 1-12.

Elliott, G. P., Wilson, P. R., Taylor, R. H. and Beggs, J. R. 2010. Declines in common, widespread native birds in a mature temperate forest. *Biological Conservation,* 143**,** 2119-2126.

Fitzgerald, N., Innes, J. and Mason, N. W. H. 2019. Pest mammal eradication leads to landscape-scale spillover of tūī (*Prosthemadera novaeseelandiae*) from a New Zealand mainland biodiversity sanctuary. *Notornis,* 66**,** 181-191.

Furness, R. W. and Greenwood, J. J. 1993. *Birds as monitors of environmental change*, Springer, Netherlands.

Galbraith, J. A., Beggs, J. R., Jones, D. N., McNaughton, E. J., Krull, C. R. and Stanley, M. C. 2014. Risks and drivers of wild bird feeding in urban areas of New Zealand. *Biological Conservation,* 180**,** 64-74.

Galbraith, J. A., Beggs, J. R., Jones, D. N. and Stanley, M. C. 2015. Supplementary feeding restructures urban bird communities. *Proceedings of the National Academy of Sciences,* 112**,** E2648-E2657.

Gill, F. B. 2006. *Ornithology*, W H Freeman & Co.

Grarock, K., Tidemann, C. R., Wood, J. and Lindenmayer, D. B. 2012. Is It Benign or Is It a Pariah? Empirical Evidence for the Impact of the Common Myna (*Acridotheres tristis*) on Australian Birds. *PLoS One,* 7**,** 1-12.

Haddad, N. M., Brudvig, L. A., Clobert, J., Davies, K. F., Gonzalez, A., Holt, R. D., Lovejoy, T. E., Sexton, J. O., Austin, M. P. and Collins, C. D. 2015. Habitat fragmentation and its lasting impact on Earth's ecosystems. *Science Advances,* 1**,** 1-9.

Hartley, L. J. 2012. Five-minute bird counts in New Zealand. *New Zealand Journal of Ecology,* 36**,** 268-278.

Hobbs, R. J. and Norton, D. A. 1996. Towards a conceptual framework for restoration ecology. *Restoration Ecology,* 4**,** 93-110.

Hurst, J. M. and Allen, R. B. 2007. A Permanent Plot Method for Monitoring Indigenous Forests: Field Protocols. Lincoln, Canterbury, New Zealand: Landcare Research.

Innes, J., Kelly, D., Overton, J. M. and Gillies, C. 2010. Predation and other factors currently limiting New Zealand forest birds. *New Zealand Journal of Ecology,* 34**,** 86-114.

Ismar, S. M. H., Baird, K. A., Gaskin, C. P., Taylor, G. A., Tennyson, A. J. D., Rayner, M. J., Bettesworth, D., Fitzgerald, N., Landers, T. J. and Imber, M. J. 2014. A case of natural recovery after the removal of invasive predators – community assemblage changes in the avifauna of Burgess Island. *Notornis,* 61**,** 188-195.

Kelly, D., Ladley, J. J., Robertson, A. W., Anderson, S. H., Wotton, D. M. and Wiser, S. K. 2010. Mutualisms with the wreckage of an avifauna: the status of bird pollination and fruit-dispersal in New Zealand. *New Zealand Journal of Ecology,* 34**,** 66-85.

Krull, C. R., Galbraith, J. A., Glen, A. S. and Nathan, H. W. 2015. Invasive vertebrates in Australia and New Zealand. *In:* Stow, A., Maclean, N. and Holwell, G. I. (eds.) *Austral Ark.* Cambridge University Press, United Kingdom.

Landcare Research 2020. Land Cover Database v5 – Land Cover Database version 5, Mainland New Zealand. https://lris.scinfo.org.nz/layer/104400-lcdb-v50-land-cover-database-version-50-mainland-new-zealand/ (accessed 30/01/2020).

Landers, T. J. 2017. Muriwai Beach to Te Henga (Bethells) 2016 grey-faced petrel and little penguin survey. Auckland Council technical report, TR2017/027.

Landers, T. J., Hill, S. D., Ludbrook, M. R., Wells, S. J. and Bishop, C. D. 2019. Avian biodiversity across Auckland's volcanic cone reserves. *New Zealand Journal of Zoology,* 46**,** 97-106.

Lawrence, G. and Bishop, C. 2017. Remapping the extent of Auckland's wetlands: methods and summary. Auckland Council technical report, TR2017/024.

Lucas, D., Head, J., King, S., Crippen, T., Byrd, J., Ferkins, C. and Bodmin, K. 2004. Native to the West. A guide for planting and restoring the nature of Waitakere City. 2nd edn. Auckland, Waitakere City Council.

Lux, J. and Beadel, S. 2006. Natural areas of Otamatea Ecological District: reconnaissance survey report for the Protected Natural Areas Programme. Whangarei, N.Z. Dept. of Conservation, Northland Conservancy.

MacLeod, C. J. 2014. Regional Council Terrestrial Biodiversity Monitoring Framework: Avian Representation. Landcare Research. https://www.envirolink.govt.nz/assets/Envirolink/Indicator20M320-20Avian20representation.pdf.

MacLeod, C. J., Greene, T. C., MacKenzie, D. I. and Allen, R. B. 2012. Monitoring widespread and common bird species on New Zealand's conservation lands: a pilot study. *New Zealand Journal of Ecology,* 36**,** 300-311.

McEwen, W. M. 1987. Ecological Regions and Districts of New Zealand. Third revised edition. New Zealand Biological Resources Centre publication no. 5. Department of Conservation, Wellington. *New Zealand Biological Resources Centre.* Wellington: Department of Conservation.

McNutt, K. 2012. Vegetation: permanent 20 × 20 m forest plots v1.0. DOCDM-359543. *Inventory and monitoring toolbox: vegetation.* Department of Conservation. https://www.doc.govt.nz/globalassets/documents/science-and-technical/inventory-monitoring/im-toolbox-20-x-20-forest-plots.pdf.

Meurk, C. D. and Swaffield, S. R. 2000. A landscape ecological framework for indigenous regeneration in rural New Zealand-Aotearoa. *Landscape and Urban Planning,* 50**,** 129-144.

Ministry for the Environment 2007. Protectiong our places: Introducing the national priorities for protecting rare and threatened native biodiversity on private land.: Ministry for the Environment. https://www.mfe.govt.nz/publications/biodiversity/protecting-our-places-information-about-national-priorities-protecting.

Ministry for the Environment and Stats NZ 2019. New Zealand's Environmental Reporting Series: Environment Aotearoa 2019. Available from www.mfe.govt.nz and www.stats.govt.nz.

Mischler, C. P., Bell, E. A., Landers, T. J. and Dennis, T. E. 2015. Sex determination of black petrels (*Procellaria parkinsoni*) using morphometric measurements and discriminant function analysis. *Notornis,* 62**,** 57-62.

Miskelly, C. M. 2018. Changes in the forest bird community of an urban sanctuary in response to pest mammal eradications and endemic bird reintroductions. *Notornis,* 65**,** 132-151.

Monks, J. M., O'Donnell, C. F. and Wright, E. F. 2013. Selection of potential indicator species for measuring and reporting on trends in widespread native taxa in New Zealand. DOC Research and Development Series 338. Department of Conservation, Wellington. 18 p. https://www.doc.govt.nz/documents/science-and-technical/drds338entire.pdf.

Newton, I. 1998. *Population limitation in birds*, Academic press, San Diego, California.

Newton, I. 2007. Population limitation in birds: The last 100 years. *British Birds,* 100**,** 518-539.

Norton, B. D. A. and Miller, C. J. 2000. Some issues and options for the conservation of native biodiversity in rural New Zealand. *Ecological Management & Restoration,* 1**,** 26-34.

Norton, D. A., Butt, J. and Bergin, D. O. 2018. Upscaling restoration of native biodiversity: A New Zealand perspective. *Ecological Management & Restoration,* 19**,** 26-35.

Ogle, C. 1987. The incidence and conservation of animal and plant species in remnants of native vegetation within New Zealand. *Nature conservation: The role of remnants of native vegetation. Surrey Beatty and Sons Pty Limited***,** 79-87.

Pearce, P., Bell, R., Bostock, H., Carey-Smith, T., Collins, D., Fedaeff, N., Kachhara, A., Macara, G., Mullan, B., Paulik, R., Somervell, E., Sood, A., Tait, A., Wadhwa, S. and Woolley, J.-M. 2018. Auckland Region climate change projections and impacts. Revised January 2018. Prepared by the National Institute of Water and Atmospheric Research, NIWA, for Auckland Council. Auckland Council Technical Report, TR2017/030-2.

Pfeifer, M., Lefebvre, V., Peres, C. A., Banks-Leite, C., Wearn, O. R., Marsh, C. J., Butchart, S. H. M., Arroyo-Rodríguez, V., Barlow, J., Cerezo, A., Cisneros, L., D'Cruze, N., Faria, D., Hadley, A., Harris, S. M., Klingbeil, B. T., Kormann, U., Lens, L., Medina-Rangel, G. F., Morante-Filho, J. C., Olivier, P., Peters, S. L., Pidgeon, A., Ribeiro, D. B., Scherber, C., Schneider-Maunoury, L., Struebig, M., Urbina-Cardona, N., Watling, J. I., Willig, M. R., Wood, E. M. and Ewers, R. M. 2017. Creation of forest edges has a global impact on forest vertebrates. *Nature,* 551**,** 187-191.

Ranjard, L., Reed, B. S., Landers, T. J., Rayner, M. J., Friesen, M. R., Sagar, R. L. and Dunphy, B. J. 2016. MatlabHTK: a simple interface for bioacoustic analyses using Hidden Markov Models. *Methods in Ecology and Evolution,* 8**,** 615-621.

Rayner, M. J., Gaskin, C. P., Fitzgerald, N. B., Baird, K. A., Berg, M., Boyle, D., Joyce, L., Landers, T. J., Loh, G., Maturin, S., Perrimen, L., Scofield, R. P., Simm, J., Southey, I., Taylor, G. A., Tennyson, A. J. D., Robertson, B. C., Young, M., Walle, R. and Ismar, S. M. H. 2015. Using miniaturized radiotelemetry to discover the breeding grounds of the endangered New Zealand Storm Petrel *Fregetta maoriana*. *Ibis,* 157**,** 754-766.

Rayner, M. J., Gaskin, C. P., Stephenson, B. M., Fitzgerald, N. B., Landers, T. J., Robertson, B. C., Scofield, R. P., Ismar, S. M. H. and Imber, M. J. 2013. Brood patch and sex-ratio observations indicate breeding provenance and timing in New Zealand Storm-petrel *Fregetta maoriana*. *Marine Ornithology,* 41**,** 107-111.

Rayner, M. J., Hauber, M. E., Imber, M. J., Stamp, R. K. and Clout, M. N. 2007. Spatial heterogeneity of mesopredator release within an oceanic island system. *Proceedings of the National Academy of Sciences of the United States of America,* 104**,** 20862-20865.

Robertson, H. A., Baird, K., Dowding, J. E., Elliott, G. P., Hitchmough, R. A., Miskelly, C. M., McArthur, N., O'Donnell, C. J., Sagar, P. M., Scofield, R. P. and Taylor, G. A. 2017. Conservation status of New Zealand birds, 2016. *New Zealand Threat Classification Series 19.* Wellington: Department of Conservation.

Ruffell, J. and Didham, R. K. 2017. Conserving biodiversity in New Zealand's lowland landscapes: does forest cover or pest control have a greater effect on native birds? *New Zealand Journal of Ecology,* 41**,** 23-33.

Sewell, S. R. and Catterall, C. P. 1998. Bushland modification and styles of urban development: their effects on birds in south-east Queensland. *Wildlife Research,* 25**,** 41-63.

Singers, N., Osborne, B., Lovegrove, T., Jamieson, A., Boow, J., Sawyer, J., Hill, K., Andrews, J., Hill, S. and Webb, C. 2017. Indigenous terrestrial and wetland ecosystems of Auckland. Auckland Council.

Singers, N. J. and Rogers, G. M. 2014. A classification of New Zealand's terrestrial ecosystems. *Science for Conservation 325. Department of Conservation, Wellington. 87 p.*

Smith, A. C., Fahrig, L. and Francis, C. M. 2011. Landscape size affects the relative importance of habitat amount, habitat fragmentation, and matrix quality on forest birds. *Ecography,* 34**,** 103-113.

StatSoft, I. 2014. STATISTICA (data analysis software system), version 12. www.statsoft.com.

Sullivan, J. J., Meurk, C., Whaley, K. J. and Simcock, R. 2009. Restoring native ecosystems in urban Auckland: urban soils, isolation, and weeds as impediments to forest establishment. *New Zealand Journal of Ecology,* 33**,** 60-71.

Temple, S. A. and Wiens, J. A. 1989. Bird populations and environmental changes: can birds be bio-indicators. *American Birds,* 43**,** 260-270.

Tennyson, A. J. D. and Martinson, P. 2006. *Extinct birds of New Zealand*, Te Papa Press.

Tindall, S. D., Ralph, C. J. and Clout, M. N. 2007. Changes in bird abundance following Common Myna control on a New Zealand island. *Pacific Conservation Biology,* 13**,** 202-212.

Trzcinski, M. K., Fahrig, L. and Merriam, G. 1999. Independent effects of forest cover and fragmentation on the distribution of forest breeding birds. *Ecological Applications,* 9**,** 586-593.

van Heezik, Y., Smyth, A. and Mathieu, R. 2008. Diversity of native and exotic birds across an urban gradient in a New Zealand city. *Landscape and Urban Planning,* 87**,** 223-232.

Veitch, C. R. and Wade, L. 2019. *Hauturu: The History, Flora and Fauna of Te Hauturu-o-Toi Little Barrier Island*, Massey University Press, Auckland.

Villard, M.-A. and Metzger, J. P. 2014. REVIEW: Beyond the fragmentation debate: a conceptual model to predict when habitat configuration really matters. *Journal of Applied Ecology,* 51**,** 309-318.

Waldron, A., Miller, D. C., Redding, D., Mooers, A., Kuhn, T. S., Nibbelink, N., Roberts, J. T., Tobias, J. A. and Gittleman, J. L. 2017. Reductions in global biodiversity loss predicted from conservation spending. *Nature,* 551**,** 364-367.

White, J. G., Antos, M. J., Fitzsimons, J. A. and Palmer, G. C. 2005. Non-uniform bird assemblages in urban environments: the influence of streetscape vegetation. *Landscape and Urban Planning,* 71**,** 123-135.

Worthy, T. H. and Holdaway, R. N. 2002. *The Lost World of the Moa: Prehistoric Life of New Zealand,* Christchurch, Canterbury University Press.

Young, L. M., Kelly, D. and Nelson, X. J. 2012. Alpine flora may depend on declining frugivorous parrot for seed dispersal. *Biological Conservation,* 147**,** 133-142.

Zedler, J. B. and Kercher, S. 2005. Wetland Resources: Status, Trends, Ecosystem Services, and Restorability. *Annual Review of Environment and Resources,* 30**,** 39-74.

Zhang, J., Dennis, T. E., Landers, T. J., Bell, E. and Perry, G. L. W. 2017. Linking individual-based and statistical inferential models in movement ecology: A case study with black petrels (*Procellaria parkinsoni*). *Ecological Modelling,* 360**,** 425-436.

Zhang, J., Rayner, M., Vickers, S., Landers, T., Sagar, R., Stewart, J. and Dunphy, B. 2019. GPS telemetry for small seabirds: using hidden Markov models to infer foraging behaviour of Common Diving Petrels (*Pelecanoides urinatrix urinatrix*). *Emu – Austral Ornithology,* 119**,** 126-137.

Appendix A Post-hoc comparisons

Post-hoc comparisons using Tukey HSD test of the following variables for birds counted at wetland sites by ecological districts:

A) Mean Indigenous Dominance (Species Richness)

B) Mean Indigenous Richness

C) Mean Introduced Richness

D) Mean Introduced Abundance

Superscripts: ^{1} = Rotation 1, ^{2} = Rotation 2

* = $p<0.05$; ** = $p<0.01$; *** = $p<0.001$

A	n	p values																
ecological district		Ka^{1} n=26	Ka^{2}	Ot^{1}	Ot^{2}	Ro^{1}	Ro^{2}	Wa^{1}	Wa^{2}	Aw^{1}	Aw^{2}	Ta^{1}	Ta^{2}	Ma^{1}	Ma^{2}	In^{1}	In^{2}	Hu^{1}
Kaipara^{2}	26	0.133																
Otamatea^{1}	6	0.999	1.000															
Otamatea^{2}	6	0.993	1.000	1.000														
Rodney^{1}	40	0.696	1.000	1.000	1.000													
Rodney^{2}	40	0.428	1.000	1.000	1.000	1.000												
Waitākere^{1}	5	0.297	0.998	0.997	0.999	0.968	0.990											
Waitākere^{2}	5	0.996	1.000	1.000	1.000	1.000	1.000	0.999										
Āwhitu^{1}	8	0.998	0.128	0.857	0.747	0.277	0.162	0.077	0.799									
Āwhitu^{2}	8	1.000	0.872	1.000	0.998	0.979	0.928	0.518	0.998	1.000								
Tamaki^{1}	23	0.990	1.000	1.000	1.000	1.000	1.000	0.904	1.000	0.651	0.999							
Tamaki^{2}	23	0.896	1.000	1.000	1.000	1.000	1.000	0.972	1.000	0.418	0.992	1.000						
Manukau^{1}	13	0.999	0.061	0.882	0.770	0.159	0.073	0.065	0.828	1.000	1.000	0.586	0.321					
Manukau^{2}	13	0.998	*	0.846	0.719	0.117	0.051	0.053	0.787	1.000	1.000	0.505	0.257	1.000				
Inner Gulf Islands^{1}	5	1.000	1.000	1.000	1.000	1.000	1.000	0.998	1.000	0.910	1.000	1.000	1.000	0.934	0.910			
Inner Gulf Islands^{2}	5	0.792	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.334	0.900	0.999	1.000	0.332	0.288	1.000		
Hunua^{1}	8	0.977	1.000	1.000	1.000	1.000	1.000	0.999	1.000	0.619	0.994	1.000	1.000	0.616	0.554	1.000	1.000	
Hunua^{2}	8	**	0.681	0.831	0.916	0.275	0.429	1.000	0.956	**	0.052	0.176	0.348	***	***	0.880	1.000	0.623

B	n	p values																
ecological district		Ka^1 n=26	Ka^2	Ot^1	Ot^2	Ro^1	Ro^2	Wa^1	Wa^2	Aw^1	Aw^2	Ta^1	Ta^2	Ma^1	Ma^2	In^1	In^2	Hu^1
Kaipara^2	26	0.996																
Otamatea^1	6	1.000	1.000															
Otamatea^2	6	1.000	1.000	1.000														
Rodney^1	40	0.810	1.000	1.000	1.000													
Rodney^2	40	0.075	0.810	0.999	1.000	0.965												
Waitākere^1	5	1.000	1.000	1.000	1.000	1.000	1.000											
Waitākere^2	5	0.995	1.000	1.000	1.000	1.000	1.000	1.000										
Āwhitu^1	8	1.000	1.000	1.000	1.000	1.000	0.953	1.000	1.000									
Āwhitu^2	8	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000								
Tamaki^1	23	0.994	1.000	1.000	1.000	1.000	0.975	1.000	1.000	1.000	1.000							
Tamaki^2	23	0.365	0.979	1.000	1.000	1.000	1.000	1.000	1.000	0.990	1.000	0.990						
Manukau^1	13	1.000	1.000	1.000	1.000	0.944	0.322	1.000	0.996	1.000	1.000	0.998	0.630					
Manukau^2	13	1.000	1.000	1.000	1.000	0.997	0.647	1.000	1.000	1.000	1.000	1.000	0.884	1.000				
Inner Gulf Islands^1	5	***	**	0.095	0.135	*	0.190	0.214	0.525	*	0.098	*	0.181	**	**			
Inner Gulf Islands^2	5	0.073	0.362	0.732	0.813	0.649	0.970	0.884	0.991	0.452	0.783	0.534	0.956	0.116	0.229	0.999		
Hunua^1	8	1.000	1.000	1.000	1.000	0.969	0.531	1.000	0.995	1.000	1.000	0.998	0.757	1.000	1.000	**	0.156	
Hunua^2	8	0.808	0.997	1.000	1.000	1.000	1.000	1.000	1.000	0.996	1.000	1.000	1.000	0.870	0.969	0.532	0.996	0.624

C	n	p values																
ecological district		Ka[1] n=26	Ka[2]	Ot[1]	Ot[2]	Ro[1]	Ro[2]	Wa[1]	Wa[2]	Aw[1]	Aw[2]	Ta[1]	Ta[2]	Ma[1]	Ma[2]	In[1]	In[2]	Hu[1]
Kaipara[2]	26	0.763																
Otamatea[1]	6	1.000	1.000															
Otamatea[2]	6	1.000	1.000	1.000														
Rodney[1]	40	1.000	0.999	1.000	1.000													
Rodney[2]	40	1.000	0.851	1.000	1.000	1.000												
Waitākere[1]	5	0.990	1.000	1.000	1.000	1.000	0.983											
Waitākere[2]	5	1.000	1.000	1.000	1.000	1.000	1.000	1.000										
Āwhitu[1]	8	0.746	0.060	0.649	0.746	0.314	0.715	0.277	0.747									
Āwhitu[2]	8	0.921	0.158	0.820	0.888	0.572	0.910	0.439	0.883	1.000								
Tamaki[1]	23	1.000	0.962	1.000	1.000	1.000	1.000	0.991	1.000	0.769	0.931							
Tamaki[2]	23	1.000	0.866	1.000	1.000	1.000	1.000	0.974	1.000	0.880	0.976	1.000						
Manukau[1]	13	0.999	0.376	0.979	0.992	0.901	0.999	0.749	0.990	1.000	1.000	0.999	1.000					
Manukau[2]	13	0.885	0.062	0.811	0.887	0.389	0.855	0.404	0.886	1.000	1.000	0.903	0.969	1.000				
Inner Gulf Islands[1]	5	0.497	*	0.404	0.494	0.192	0.472	0.145	0.498	1.000	1.000	0.518	0.646	0.987	1.000			
Inner Gulf Islands[2]	5	1.000	1.000	1.000	1.000	1.000	1.000	0.999	1.000	0.994	0.999	1.000	1.000	1.000	1.000	0.697		
Hunua[1]	8	0.956	1.000	1.000	1.000	0.997	0.919	1.000	1.000	0.118	0.234	0.962	0.903	0.512	0.171	0.062	0.997	
Hunua[2]	8	0.824	1.000	1.000	1.000	0.969	0.733	1.000	1.000	0.052	0.118	0.841	0.716	0.296	0.074	*	0.982	1.000

D	n	p values																
ecological district		Ka[1] n=26	Ka[2]	Ot[1]	Ot[2]	Ro[1]	Ro[2]	Wa[1]	Wa[2]	Aw[1]	Aw[2]	Ta[1]	Ta[2]	Ma[1]	Ma[2]	In[1]	In[2]	Hu[1]
Kaipara[2]	26	0.985																
Otamatea[1]	6	1.000	1.000															
Otamatea[2]	6	1.000	1.000	1.000														
Rodney[1]	40	0.999	1.000	1.000	1.000													
Rodney[2]	40	1.000	1.000	1.000	1.000	1.000												
Waitākere[1]	5	0.955	1.000	1.000	0.998	1.000	0.989											
Waitākere[2]	5	1.000	1.000	1.000	1.000	1.000	1.000	1.000										
Āwhitu[1]	8	0.986	0.517	0.976	0.999	0.595	0.879	0.443	0.987									
Āwhitu[2]	8	0.999	0.746	0.995	1.000	0.818	0.973	0.610	0.998	1.000								
Tamaki[1]	23	1.000	0.997	1.000	1.000	0.999	1.000	0.957	1.000	0.989	0.999							
Tamaki[2]	23	1.000	0.908	1.000	1.000	0.949	1.000	0.836	1.000	1.000	1.000	1.000						
Manukau[1]	13	0.993	0.457	0.989	1.000	0.525	0.881	0.474	0.995	1.000	1.000	0.995	1.000					
Manukau[2]	13	0.695	0.061	0.820	0.970	0.069	0.276	0.152	0.893	1.000	1.000	0.737	0.951	1.000				
Inner Gulf Islands[1]	5	0.961	0.512	0.939	0.992	0.588	0.834	0.384	0.961	1.000	1.000	0.966	0.996	1.000	1.000			
Inner Gulf Islands[2]	5	1.000	1.000	1.000	1.000	1.000	1.000	0.997	1.000	1.000	1.000	1.000	1.000	1.000	0.993	0.991		
Hunua[1]	8	0.817	1.000	1.000	0.993	0.996	0.933	1.000	1.000	0.221	0.372	0.830	0.563	0.205	*	0.214	0.991	
Hunua[2]	8	0.996	1.000	1.000	1.000	1.000	1.000	1.000	1.000	0.624	0.798	0.997	0.956	0.650	0.214	0.559	1.000	1.000

Find out more: phone 09 301 0101, email
rimu@aucklandcouncil.govt.nz or visit
aucklandcouncil.govt.nz and knowledgeauckland.org.nz