Aotea Bird Count

Results of the December 2019 survey

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Prepared by Serena Simmonds

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Acknowledgments

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For copies of this report please contact:

Aotea Great Barrier Environmental Trust
contact.gbiet@gmail.com
www.gbiet.org

Executive summary

In December 2019, the first Aotea Bird Count (ABC) was conducted across Aotea Great Barrier Island (Aotea) by 42 trained community volunteers, organised by the Aotea Great Barrier Environmental Trust, Auckland Council and the sanctuaries located on the island. The ABC aimed to assess the presence of all bird species across the island to help fill gaps in previous research by covering as wide a range of locations, habitat and species as possible. Other objectives of the survey were to help in understanding how bird populations across the island might be responding to different levels of pest management and degree of human impact, as well as factors such as elevation. The count focused particularly on the presence of tui, kākā, kererū, and kākāriki and was the first of what is planned to be annual or potentially twice-yearly bird counts.

The ABC builds on previous island-wide counts and those conducted at Windy Hill Sanctuary and Glenfern Sanctuary over many years, as well as more recent counts in the Okiwi Valley. Some of these previous counts used different methodologies, so while they can be compared within surveys, they cannot be readily compared between the different surveys.

The ABC used a standard five-minute bird count methodology used widely throughout New Zealand that can be readily repeated, and results compared with future surveys. The method involves observers counting for five minutes all species seen and heard, within 25m and outside of 25m, at five points along a transect. Survey points are spaced apart by about 200m. Sixteen transects were located across the island to give a total of 80 survey points. These aspects of the method aimed to replicate the approach used in the 2006-07 island-wide bird count.

A total of 3,078 individual birds were recorded as seen and heard during the survey, both at the survey points and between five-minute surveys. During the actual five-minute counts at each point, 41 species that were positively identified and six species (62 individuals) were identified to the genus/family/common name (for example, tern sp. and finch sp.). A further 67 individuals were recorded as 'unknown'.

Species diversity (the number of different species observed per transect) ranged from eight at the Cooper's Castle transect to 26 at Okupu. The Tryphena transect, in the more populated southern end of Aotea, had the highest average density of birds per hectare (78.45), the highest number of individual birds counted (271), and the highest number of introduced bird species. The Cooper's Castle transect had both the lowest number of species observed (8), and lowest number of individual birds counted (74). The Glenfern transect had the lowest average density of birds per hectare (6.11).

Of the four key species of interest, an average of 230 individual kākā, 222 tui, 29 kererū, and eight kākāriki were observed during the five-minute bird counts across all the transects. The species with the highest frequency of occurrence during the survey was tui (recorded in about 66% of all survey points and all transects). The species with the lowest frequency was kākāriki (counted in only one transect, and just over 1% of survey points).

The highest maximum flock size was recorded for kākā (12 birds). Other species with high overall densities were silvereye, house sparrow, grey warbler and fantail.

Multiple linear regression models (MLM) were used to analyse the data for potential correlations between bird density and factors such as elevation, level of pest management and degree of human impact. Each transect was assigned a 'level' for these factors to use in the model. For all species combined, the MLM results showed that bird density was at its highest in areas of lower altitude and higher assigned levels of pest management, while levels of human impact seemed to have little effect. A MLM was created for each of the four key species and the four most common species.

The results of the individual models show that kererū, fantail and grey warbler density decreased with elevation increases, and the density of tui and house sparrows increased with increased levels of pest management. Kererū, kākā and fantail density decreased with increases in the degree of human impact, while the density of house sparrow and grey warbler increased.

Some caution is needed in interpreting the results of the MLM analysis, which are based on a single survey and broad assumptions about the different levels of human impact and pest management at each survey location. Further surveys, refinement of the parameters used in the analysis, and consistency in the use of trained counters, will all assist in discerning any trends or patterns in the data over the coming years.

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The Aotea Bird Count focused on the presence of kākā, kererū, tui and kakariki.

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1. Introduction

This report presents the results of an island-wide bird count undertaken on Aotea Great Barrier Island (Aotea) in December 2019. The count is intended to be the first of what is hoped to be annual or bi-annual bird surveys across the island, largely carried out by trained community volunteers. The ABC reflect a desire by the Aotea community to understand the state of bird populations on the island and how they may be changing over time.

1.1 Island environments and birds

Island environments around the world are home to unique assemblages of fauna and flora that are often restricted in their distribution. The geographic separation that island species experience mean they are more susceptible to the risks posed by the introduction of exotic predators than their closest mainland relatives (Blackburn et al., 2004; Butchart et al., 2006; Johnson & Stattersfield, 1990). When island endemic species lack the ability to adapt to the challenges posed by introduced predators, population decline is more likely for those endemic species (Blackburn et al., 2004).

Close to 40% of the worlds threatened bird species are located on islands (Johnson & Stattersfield, 1990). This figure is likely to have increased over the last 30 years as more bird species have come under threat from introduced predators and habitat loss. Data shows that over the last 400 years, approximately 90% of bird extinctions have occurred on islands, with just over half of those occurring on the islands of the Pacific Ocean (Johnson & Stattersfield, 1990). These historic extinctions have been largely driven by the presence of introduced predators (Blackburn et al., 2004; Loehle & Eschenbach, 2012).

1.2 Aotea Great Barrier Island

Aotea is New Zealand's fourth largest island, and has a range of introduced mammalian predators including two species of rats (*Rattus rattus and R. exulans*), and feral cats (*Felis catus*) (Ogden & Gilbert, 2011). These introduced species pose a significant threat to the endemic and native bird life of Aotea, especially to species for which the island houses a large portion of their total population, such as the pāteke/brown teal (*Anas chlorotis*) and the takoketai/black petrel (*Procellaria parkinsoni*) (E. A. Bell et al., 2016; Ogden & Gilbert, 2011).

Various surveys assessing the abundance and/or presence of different bird species have occurred across Aotea over the last 20 years. Some surveys focused on specific areas, such as Glenfern and Windy Hill sanctuaries, and others on certain species, two such examples being takoketai/black petrel and kererū (*Hemiphaga novaeseelandiae*) (Anderson & Ogden, 2003; Elizabeth A Bell et al., 2011; Ogden, 2011, 2018). The data these surveys provide give detailed information on species trends including in pest managed and unmanaged areas. They do not generally provide a way to compare between different sites across the island for the same species, as the methodologies used vary between each study.

1.3 Objectives of the Aotea Bird Count

The Aotea Bird Count (ABC) was primarily developed to provide an island-wide assessment of the birds of Aotea by covering a wide range of locations and species. The count may also provide data and information to help understand how bird populations across the island might be responding to differing levels of pest management and human impact. The ABC uses a standard five-minute bird count method and is planned to be repeated biannually or annually. The count builds on a previous island-wide bird count undertaken in 2006-7 that also used a five minute count methodology (Ogden, 2009). Comparisons will be made with this earlier data at a later date.

1.4 Key target species

Four bird species were identified by various island stakeholders as key target species for the ABC: kākā (*Nestor meridionalis*), kererū, kākāriki (*Cyanoramphus novaezelandiae)*, and tui (*Prosthemadera novaeseelandiae).* Where they are found, these species are often noisy and active (Allen & Holdaway, 2010), making them easily identifiable during bird counts.

Kākā is an at-risk bird (Robertson et al., 2017) that are conspicuousness on Aotea. They thrive on Aotea and are numerous, due largely to the absence on the island of known threat species, such as possums (*Trichosurus vulpecula*) and stoats (*Mustela erminea*) (Moorhouse et al., 2003; Ogden & Gilbert, 2011). Tui is one of New Zealand's most recognisable birds as they are a visually and audibly conspicuous species, and as such can be easily identified and counted. Tui population sizes on Aotea differ markedly between those found inside predator-managed areas, such as Windy Hill Sanctuary, and those in unmanaged areas (Ogden, 2018), and make them a potential indicator of predator abundance.

Little data is available on the abundance of kererū on Aotea. These birds are at risk of predation from cats and rats, especially during the nesting season when eggs, chicks, and adults can be targeted (Innes et al., 2010). Kererū show a suggested increase in population size in areas of pest management compared to unmanaged areas (Ogden, 2018; Ruffell & Didham, 2017) and can be regarded as an indicator of forest health. They also play an important role in the distribution of the seeds of key forest species such as taraire (*Beilschmiedia tarairi*) and puriri (*Vitex lucens*) (Clout & Hay, 1989; Wotton & Kelly, 2012), both of which are common throughout the forests of Aotea (Lewington, 2008).

Kākāriki was once widespread across New Zealand. Habitat destruction and predator incursions mean the species' current strongholds are predator free areas such as offshore islands and mainland locations with predator fences (Ortiz-Catedral & Brunton, 2009). The remnant population of kākāriki on Aotea is unique as they are mainly confined to a small area in the north and have continued to survive, even with the constant threat of predation. While there are occasionally reports of kākāriki on other parts of the island (e.g., Armitage, 2001; B. Bell pers comms), a breeding population has only been confirmed in Okiwi. This species may return to areas that are free of rats and cats, or where active pest management is in place, as was seen on Motuhaku after the eradication of rats in 2008 (Aotea Great Barrier Environmental Trust, pers comms).

2. Methodology

2.1 Study site

Aotea is situated 100km to the north-east of central Auckland, New Zealand, in the Hauraki Gulf (Figure 1). The main island has several smaller islets and rock stacks offshore, including Motu Kaikoura and Rakitu, that altogether cover an area of 28,500ha (Towns, 1987). The highest point of the island is Hirakimata (Mount Hobson), at 621m above sea level, located on the mountain range that traverses the centre of the island (Ogden & Gilbert, 2011).

Conservation land is largely contained within the Aotea Conservation Park which covers more than 12,000ha and is home to many native and endemic species of flora and fauna.

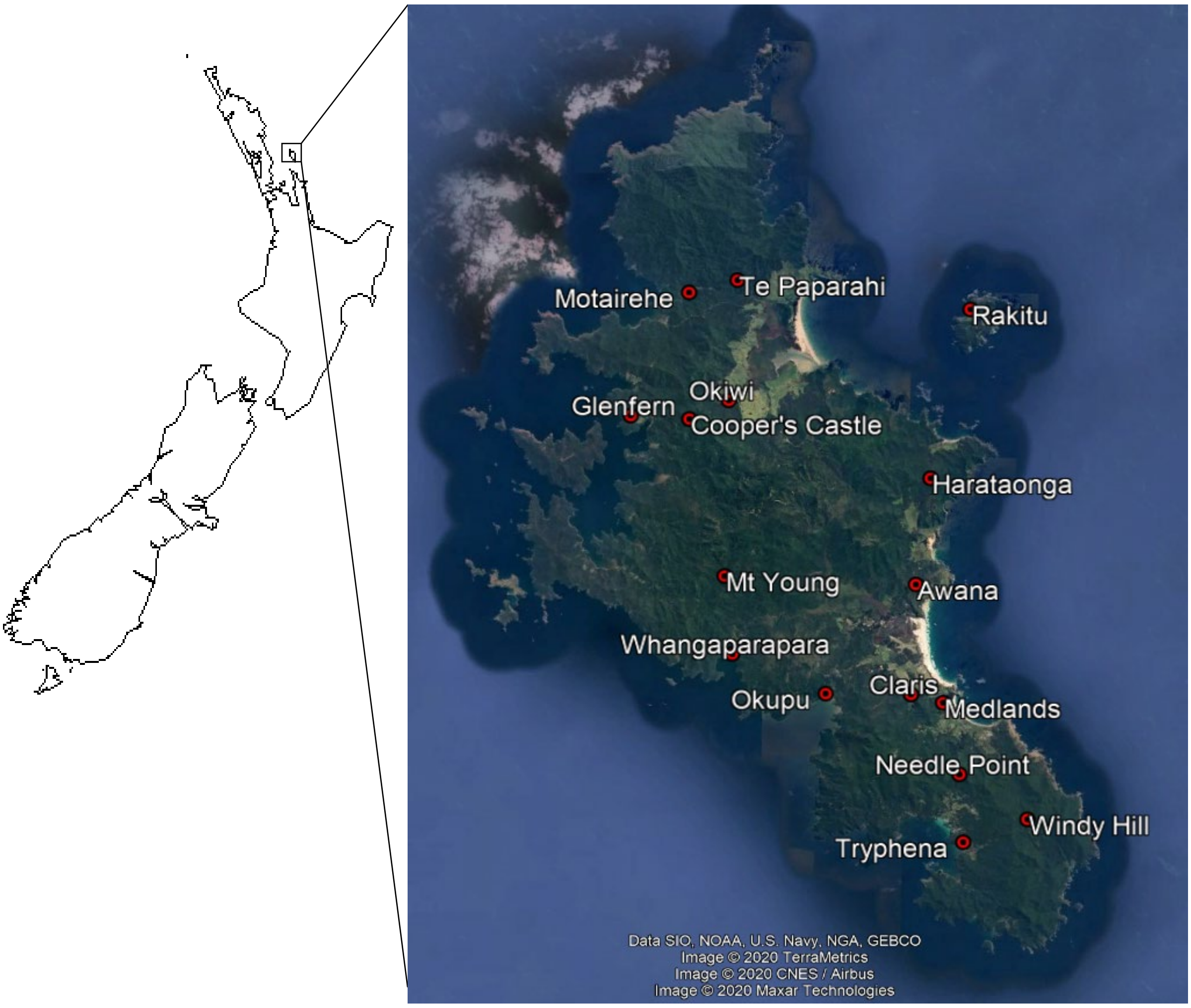


Figure 1. Location of Aotea Great Barrier Island and Aotea Bird Count transects

2.2 Data collection

Across Aotea, 80 permanent count stations were established and surveyed along 16 transect lines during December 2019 (Figure 2). These locations included Rakitu (Arid Island) off Aotea's northeast coast. The transect lines covered a range of elevations and vegetation types, areas with differing levels of pest management, and human occupation.

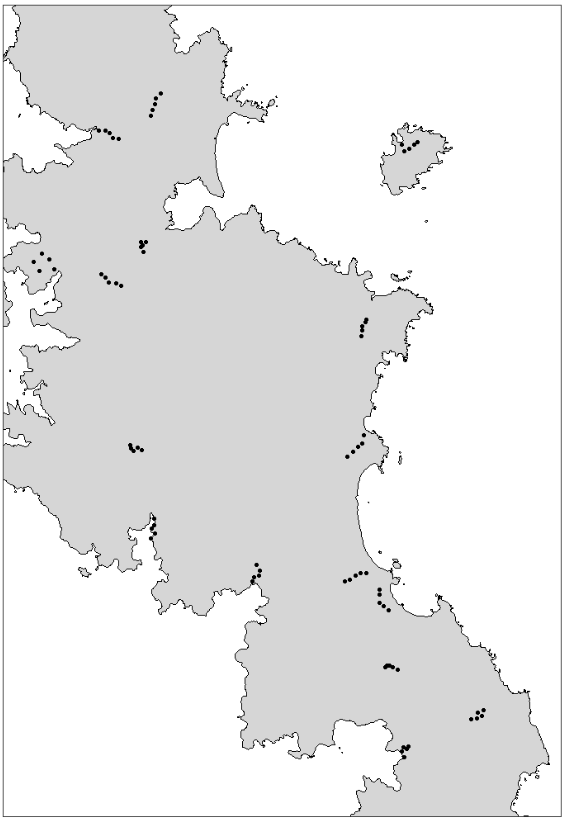


Figure 2. Permanent survey points established for the Aotea Bird Count

Each transect line consisted of five points that were spaced approximately 200m apart. The transect bird surveys were conducted by a group of up to three observers, with at least one person being trained in bird identification techniques. A replicate of each transect was surveyed by the same group of observers, with at least a one-hour interval between each replicate.

At the commencement of each transect, the conditions of wind, rain, noise, temperature and cloud were recorded. If at any point during the survey the conditions changed and compromised bird detection, the observers would cease the count, continuing at a time when those levels had returned to normal. If significant temporary noise (for example, a car driving past) occurred during the five-minute count, the observers would pause the count until the noise had passed, observe a two-minute silence, and then continue.

Upon arrival at each survey point, a two-minute period of silence was observed to minimise any disturbance caused by the approach of the observers. The time of survey was noted, and the observers then spent five minutes recording all the birds seen and heard during that time, with care being taken not to record the same individual bird more than once at that point. For each observation, a record was taken of the species, number of individuals, if it was seen or heard, and if it was within or outside of a 25m radius of the observer. Any species unable to be identified was recorded as 'unknown'. Birds flying overhead were also recorded.

While travelling between points, all kākā, kererū, tui and kākāriki were recorded, along with any bird species not recorded during the five-minute count at the previous point ('off-survey' data).

2.3 Statistical analyses

The ABC is hoped to be the first of an ongoing series of counts that will be used as a baseline to compare with the results of future surveys. A simplified approach was used for this initial bird count on Aotea that can be easily replicated in both the field methodology and approach to the statistical analysis of the recorded data.

The data was analysed using the average of the two paired replicates at each point, giving 80 points of data for each species (i.e., average of the two counts at each of five points on 16 transects). Observation of birds seen and heard at each point were combined for the analyses. Observations made between points were not included in this analysis but are commented on in the results section of this report (Table 4).

Two methods of data summary (frequency and density) were used to report on species occurrence patterns. One set of data (density) was used in multiple linear regression models to help understand the potential influences behind differences in observed birds (species and numbers) across the island.

The software package R (Version 1.2.5019) was used for all statistical analyses, maps and graphs created in the analysis presented in this report.

Frequency

Species frequency reflects the number of times a species is recorded as present at a survey point, divided by the total number of counts undertaken (80 count stations or points in the ABC). The formula used is: $f_s = n_s / N$, where f_s = frequency for species *s*, n_s = number of points where species *s* was observed (at the survey point), and N = total number of points surveyed. For example, if the counts for a species at 10 points were as follows: 2,0,3,0,1,1,0,2,0,0, its frequency would be 5/10 i.e. the species was recorded at five of the 10 survey points.

Frequencies were calculated for all species recorded (excluding those recorded between points) and converted to percentages. Frequency varies between 0% and 100%, where 0% represents no occurrence of the species on any survey point, and 100% represents occurrence of that species on all points surveyed. When based on a large sample size, the percentage value relates directly to the probability of recording the species at a site. Other advantages of frequency calculated in this way is that comparisons between sites and surveys undertaken at different times (seasons or years) are relatively straightforward. Frequency is also a robust analysis when counts are carried out by different observers (Ogden, 2009).

Frequency can be influenced by how conspicuousness a species is and tends to give higher records for more conspicuous species such as tui, kingfisher and kākā. Conspicuousness can vary with season depending on the species life history, time of day, and factors like weather conditions (Ogden, 2009). Further surveys should aim to replicate the time of year and day, and other factors as much as possible if comparisons are intended between data sets.

Density

Density provides an indication of the number of birds present per hectare and can be calculated overall for all species, and for each species. The density per hectare of each bird species was calculated for each of the 80 survey points using the formula: $D_i = s_i / A$, where D_i = density at point *i* expressed as the number of birds per hectare, s_i = number of individuals observed within 25m at survey point *i*, and A= area of the survey point in hectares (0.1963ha).

The density for each species individually was calculated as the average of the densities at each survey point. An average density for the combined species per transect was also presented as it represents a measure of relative difference in bird presence across the island. This measure was calculated by taking the sum of the densities for all species at each of the five points in the transect, and then finding the average of those five points. The overall density for all species, island-wide, was also calculated, as the sum of each species average density.

Multiple linear regression models

Multiple linear regression models can be used to estimate the effects that different factors (predictor variables) can have on observed differences in bird density at different locations. For this first ABC, three potential factors were chosen; elevation, assigned categories (levels) of pest management, and the level of human disturbance/impact at each survey point. Pest management and human impact levels are indicative only and more work is needed to refine the classifications for each survey point for future surveys.

Elevation data for each survey point was acquired from GPS data collected at each point.

Pest management information was collected from the Trap Library accessed from Trap NZ. Five levels of pest management were defined - pest free, high, medium, low and none as defined in Table 1.

Table 1. Definitions of pest management levels across Aotea

Level	Description
Pest free	No pests
High	Predator proof fence with large number of traps that are regularly checked
Medium	100-1000 traps that are regularly checked
Low	0-100 traps
None	No recorded pest management

Information on human disturbance/impact at each site was gathered from Google Earth Pro (Version 7.3.2.5776) and knowledge of the sites. Human impact was categorised as one of four levels - high, high-medium, low-medium, and low, as defined in Table 2.

Table 2. Definitions of levels of human impact/disturbance across Aotea

Level	Description
High	High density of traffic, houses nearby, other activity
High-medium	Large foot traffic and/or some cars
Low-medium	Some foot traffic with little to no vehicle traffic
Low	No or low foot traffic, no vehicle traffic

When one predictor variable increases at the same rate as another, this indicates that the two are highly related (multicollinearity) and will give the same result, if placed in a model together. The purpose of creating multiple linear regression models is to explain how changes in predictor variables affect the values of a response variable (for example, how does bird density change in response to variation in elevation and human impact?). It is therefore necessary to remove one or more of the related variables from any model to prevent using redundant data. To test if multicollinearity existed between the predictor variables, a statistical method called the variance inflation factor was used. Several tests were then run to see if the data set followed a normal distribution. Square-root transformed data was used for the analyses and any outliers to the data set were removed.

The statistical method Akaike's information criterion (AIC) was used to determine which variables contributed to the explanation of the variance in bird density (for example, does elevation have any measurable impact on tui density?). If a predictor variable was determined not to have provided such information, it was removed from that species model. The predictor variables were also modelled against density for each of the focal species to assess if any of those species were sensitive to changes in those variables.

3. Results

The full data set collected during the December 2019 count is provided in Appendix A.

3.1 Observations

A total of 2,310 observations were made, comprised of 3,078 individual birds which were seen/heard during the survey period (all observations, both during the five-minute counts and 'off-survey' i.e., between counts).

Forty-three different species were positively identified during the survey, along with eight unknown species. During the five-minute surveys, 41 bird species were positively identified not including flying birds. Two species were seen only while travelling between survey points, an unidentified tern species and yellowhammer (Table 4). Three species (brown teal, Caspian tern and paradise shelduck) were noted with more individuals between points than were noted during the surveys (Table 4).

The number of individuals (abundance) of each species recorded across the whole survey is presented in Figure 3. The species with the largest number of individuals observed was kākā (230 birds), closely followed by tui (222 birds). Five species were only observed once during the five-minute counts - Caspian tern, duck sp., fernbird, ruru and tomtit.

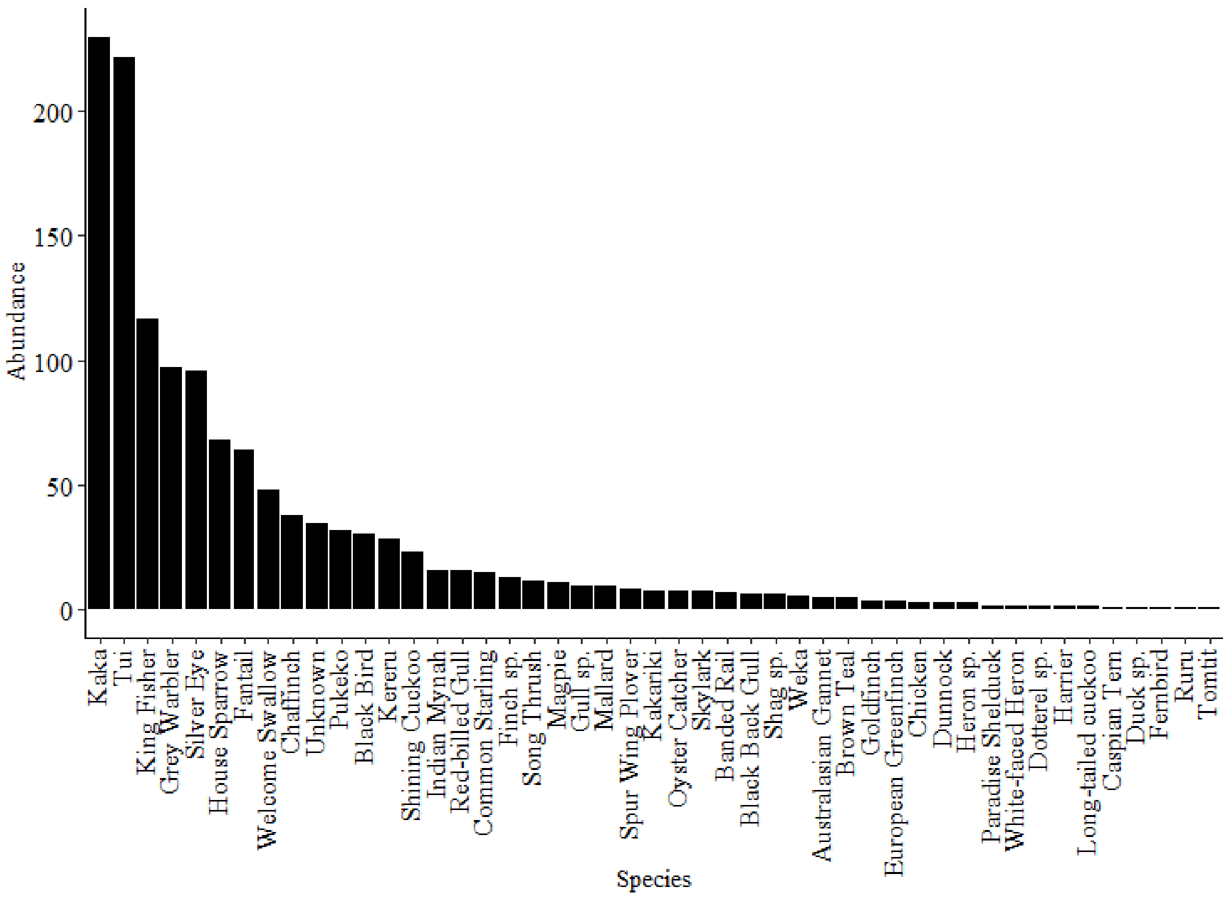


Figure 3. Number of individuals of all species observed during five-minute counts (both within and outside of 25m, excluding flying birds)

3.2 Frequency

Five species were recorded in all 16 transects - tui, silvereye, grey warbler, kākā, and kingfisher. Five species (shining cuckoo, kererū, fantail, chaffinch, and blackbird) were recorded in between 10 and 15 transects (Table 3, Table 4).

Figure 4 illustrates how the frequency of occurrence varied between each transect, as did the species present. Kākā was amongst the most frequently observed species in 11 transects, with 100% occurrence at survey points in nine of those transects. Tui were amongst the most frequent species in eight transects, with 100% occurrence at survey points in seven of those transects. Grey warbler, welcome swallow, blackbird, kingfisher and fantail were also identified as frequently occurring species (Table 3).

Aotea Bird Count (ABC) survey points were marked along transects across Aotea Great Barrier

Table 3. Frequency of occurrence for each species at each transect

Species	Frequency of occurrence (%)															
	Awa	Cla	Coo	Gle	Har	Med	Mot	You	Nee	Oki	Oku	Rak	TeP	Try	Wha	Win
Australasian gannet	0	0	0	0	0	0	0	0	0	0	30	10	0	0	0	0
Banded rail	10	0	0	0	0	10	0	0	0	0	0	0	0	20	0	0
Black back gull	0	30	0	0	0	0	0	0	0	0	0	10	0	0	10	0
Blackbird	60	20	10	20	30	90	30	10	60	40	60	0	0	20	0	20
Brown teal	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0
Caspian tern	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0
Chaffinch	60	20	0	90	60	80	0	30	10	0	60	0	20	40	0	10
Chicken	0	10	0	0	0	0	0	0	0	10	0	0	0	10	0	0
Common starling	0	0	0	0	0	10	0	0	0	0	50	40	0	0	0	0
Dotterel sp.	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0
Duck sp.	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0
Dunnock	0	0	0	50	0	0	0	0	0	0	0	0	0	0	0	0
European greenfinch	0	0	0	0	0	30	0	0	0	0	10	0	0	0	0	0
Fantail	0	50	0	40	60	0	100	80	20	70	30	80	70	0	10	60
Fernbird	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Finch sp.	10	60	0	0	0	0	30	0	0	0	70	0	0	0	0	10
Goldfinch	0	0	0	0	0	20	0	0	0	0	40	0	0	0	0	0
Grey warbler	**80**	**50**	**90**	**100**	**90**	**40**	**80**	**90**	**40**	**50**	**40**	**60**	**90**	**30**	**50**	**60**
Gull sp.	0	10	0	0	0	0	10	0	0	0	10	0	0	10	50	0
Harrier	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Heron sp.	0	0	0	0	0	0	10	0	0	0	0	0	0	30	0	0
House sparrow	0	0	0	0	0	20	0	0	0	90	60	0	0	80	60	0
Indian mynah	0	10	0	0	0	0	10	0	0	70	10	0	0	80	30	0
Kaka	**20**	**20**	**100**	**100**	**100**	**60**	**100**	**100**	**90**	**100**	**50**	**90**	**100**	**100**	**50**	**100**
Kakariki	0	0	0	0	0	0	0	0	0	60	0	0	0	0	0	0

Species	Frequency of occurrence (%)															
	Awa	Cla	Coo	Gle	Har	Med	Mot	You	Nee	Oki	Oku	Rak	TeP	Try	Wha	Win
Kereru	0	0	60	10	0	30	30	50	40	40	20	30	40	30	10	40
Kingfisher	**70**	**70**	**50**	**100**	**90**	**90**	**70**	**100**	**80**	**80**	**60**	**90**	**70**	**90**	**80**	**100**
Long-tailed cuckoo	10	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
Magpie	20	20	0	10	0	20	0	0	0	40	0	0	0	0	0	30
Mallard	0	0	0	0	0	0	0	0	0	0	30	0	0	20	0	0
Oystercatcher	0	40	0	0	0	0	0	0	0	0	10	0	0	30	0	0
Paradise shelduck	0	0	0	0	0	10	10	0	0	0	0	0	0	0	0	0
Pukeko	50	60	0	10	0	70	20	0	0	20	10	0	0	0	0	0
Red-billed gull	0	0	0	10	0	20	0	0	0	0	0	0	0	0	10	0
Ruru	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10
Shag sp.	0	0	0	0	0	0	0	0	0	0	0	10	0	0	40	0
Shining cuckoo	30	40	20	20	30	20	0	40	0	40	20	30	20	30	0	40
Silvereye	**10**	**50**	**70**	**30**	**70**	**80**	**50**	**70**	**80**	**40**	**20**	**40**	**20**	**50**	**10**	**50**
Skylark	10	20	0	0	0	30	0	0	0	0	0	80	0	0	0	0
Song thrush	0	10	0	10	0	80	0	10	0	0	0	0	0	30	10	0
Spur-wing plover	0	40	0	10	0	20	0	0	0	0	0	0	0	10	0	0
Tomtit	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0
Tui	**80**	**40**	**100**	**100**	**90**	**80**	**70**	**100**	**80**	**100**	**100**	**80**	**90**	**90**	**100**	**100**
Unknown	60	60	0	0	40	10	50	70	0	0	50	0	90	0	0	20
Weka	0	0	0	0	0	0	0	0	0	0	0	40	0	0	0	0
Welcome swallow	0	80	0	0	0	80	20	0	0	0	10	50	0	30	40	0
White-faced heron	0	10	0	0	0	0	0	0	0	0	0	0	0	0	10	0

Notes: Awa: Awana, Coo: Cooper's Castle, Gle: Glenfern, Har: Harataonga, Med: Medlands, Mot: Motairehe, You: Mt Young, Nee: Needle Rock, Oku: Okupu, Rak: Rakitu, TeP: Te Paparahi, Try: Tryphena, Wha: Whangaparapara, Win: Windy Hill. Numbers given are the frequency of occurrence expressed as a percentage and calculated as the number of points (out of ten total, five points each surveyed twice) the species was observed at along that transect, divided by ten and multiplied by 100. Bold text is species recorded at all 16 transects.

Figure 4. Frequency of occurrence for each species at each transect (presented as percentages)

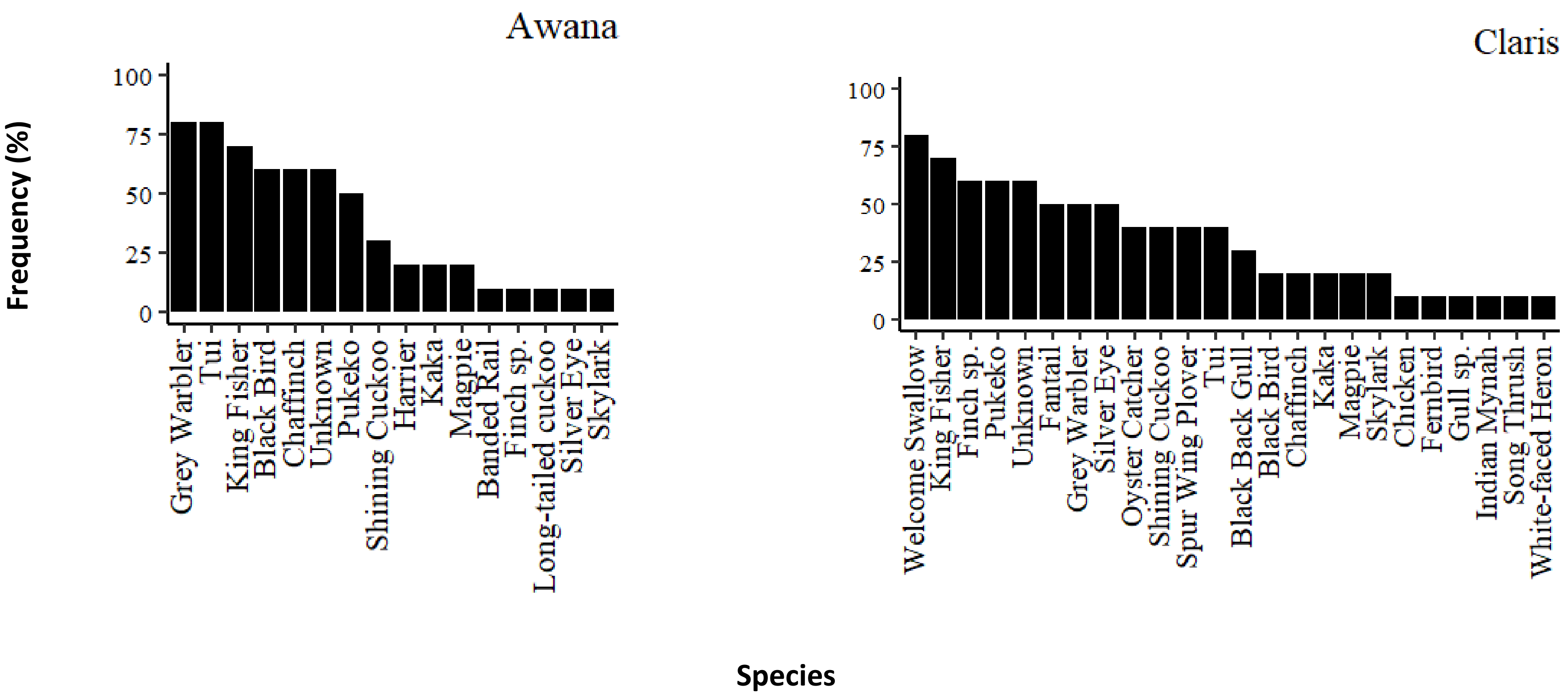


Figure 5. Frequency of occurrence for each species at each transect (presented as percentages) cont..

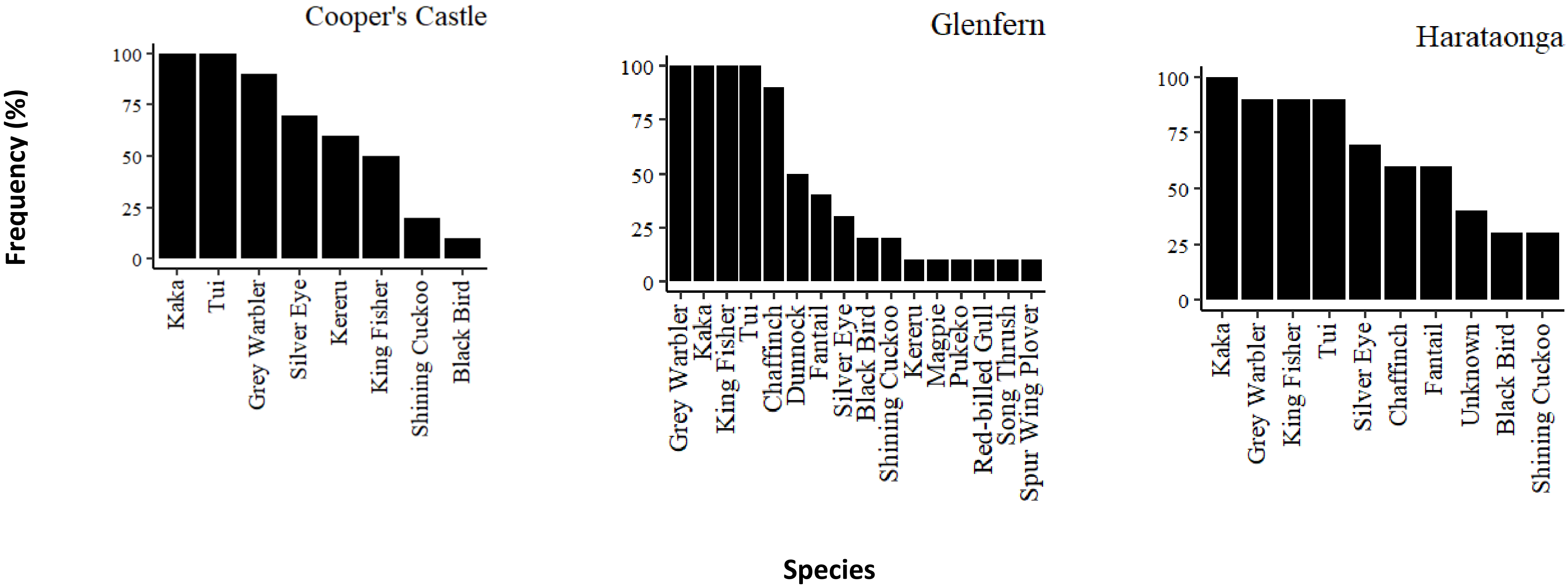


Figure 6. Frequency of occurrence for each species at each transect (presented as percentages) cont...

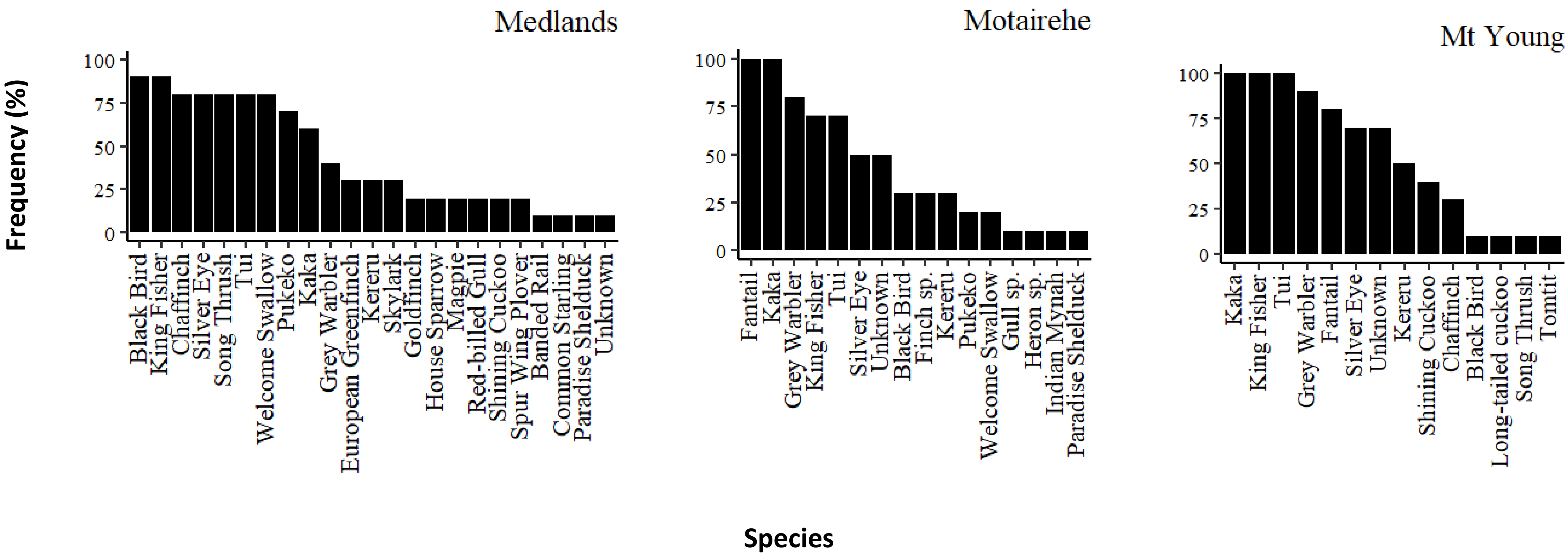


Figure 7. Frequency of occurrence for each species at each transect (presented as percentages) cont...

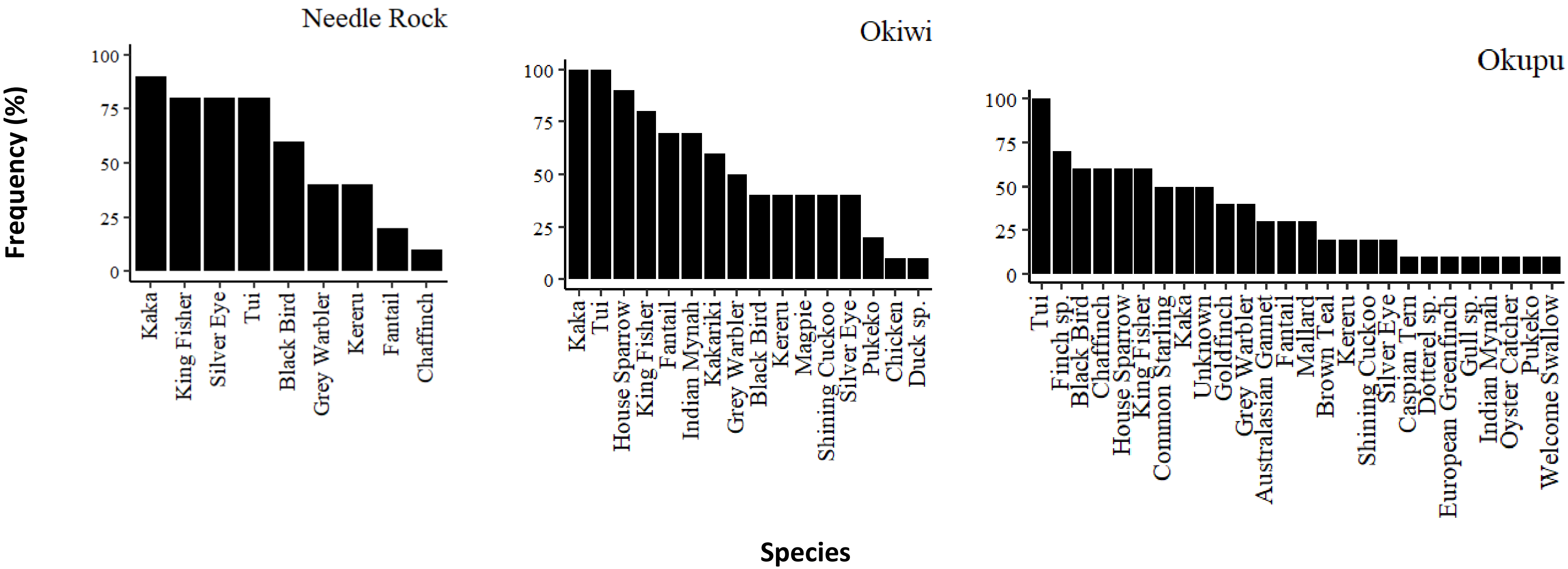


Figure 8. Frequency of occurrence for each species at each transect (presented as percentages) cont...

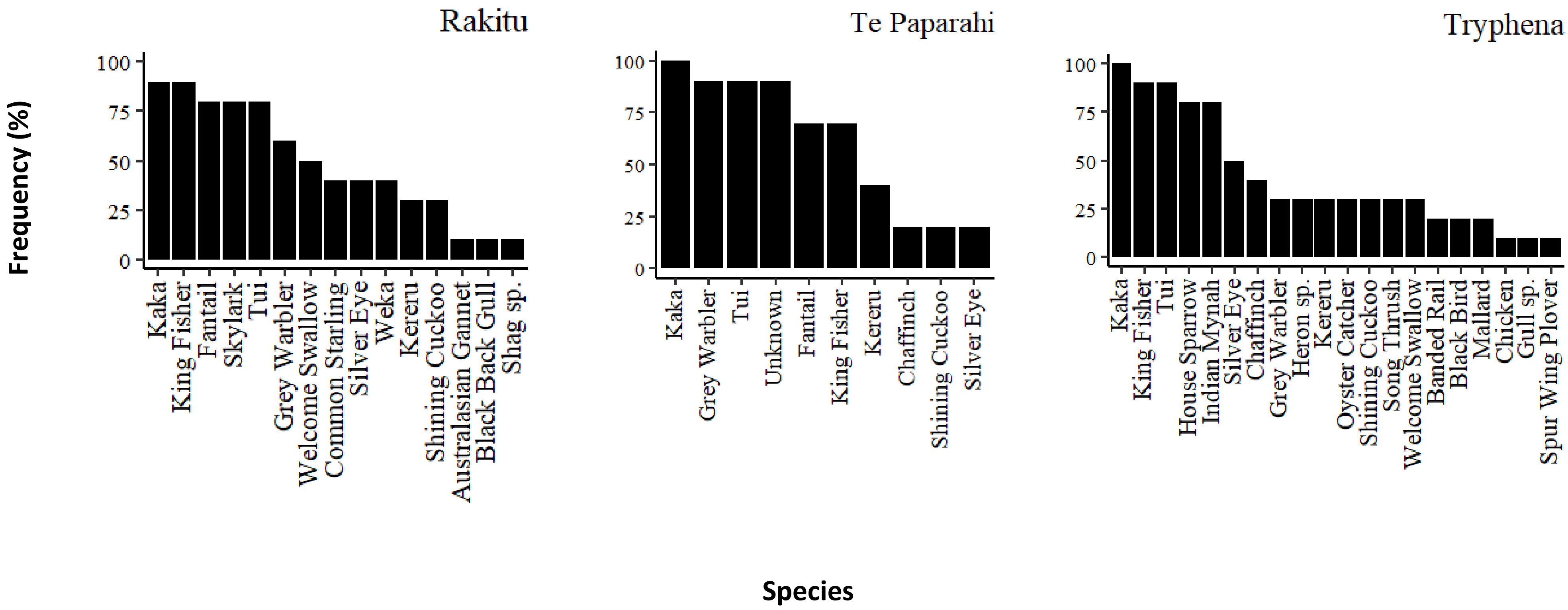
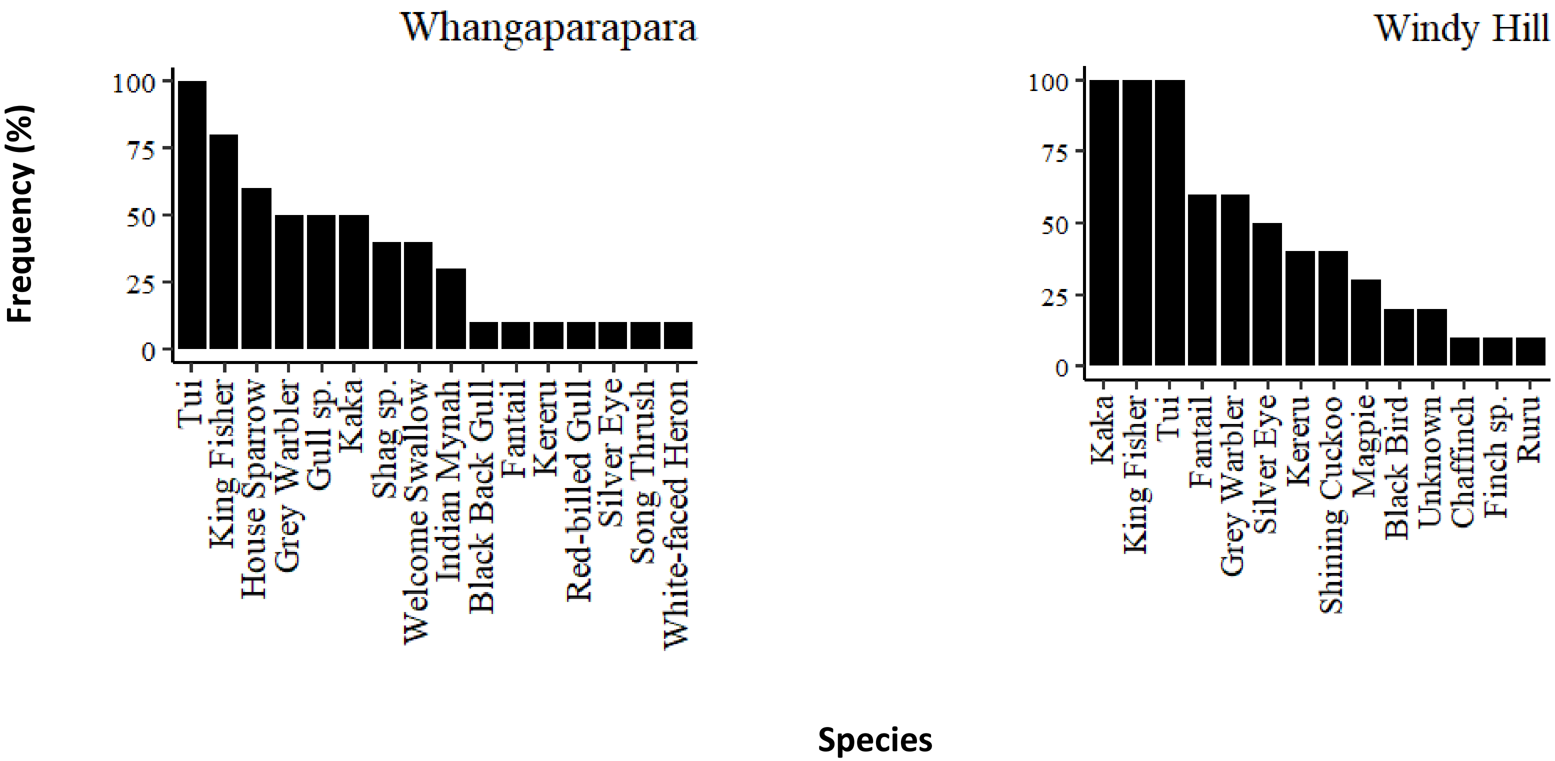


Figure 9. Frequency of occurrence for each species at each transect (presented as percentages) cont...



3.2 Density

Average, maximum and minimum densities of birds per hectare were calculated across all survey points. The five species with the highest overall density per hectare were tui, silvereye, grey warbler, fantail and house sparrow (Table 4). The combined average density of these five species was 16.21 individuals per hectare. This figure is influenced by the flocking nature of silvereyes (up to 20 individuals in a single observation) and house sparrows (up to 10 individuals). The four key species, tui, kākā, kererū and kakariki had a combined average density of 7.55 individuals per hectare. Kākāriki were only observed on-survey at a single point (two observations), so no average value is presented.

The total density of birds per hectare was calculated for each species. Nineteen species contributed to less than 10% of the total bird density of the on-survey observations across Aotea (see Table 4). The overall average density per survey point, for all birds combined, was 28.88 ± 5.79 birds/hectare. The large deviation from the mean (average) was likely due to the presence of conspicuous flocking species such as silvereyes and house sparrows.

Table 4. Summary of bird species occurrence in transects

Species (common name)	Number of transects observed on	Average density per hectare	Maximum flock size	Average abundance (on survey)	Abundance (between points)
Australasian gannet	2	N/A	2	5	0
Banded rail	4	0.35	3	7	9
Black back gull	3	0.06	4	6	3
Blackbird	13	0.96	2	31	6
Brown teal	3	N/A	5	5	18
Caspian tern	1	N/A	1	1	3
Chaffinch	11	0.83	3	38	0
Chicken	3	N/A	3	3	0
Common starling	3	0.51	3	15	3
Dotterel sp.	1	N/A	1	1	0
Duck sp.	1	N/A	1	1	0
Dunnock	1	N/A	1	3	0
European greenfinch	2	0.13	1	3	0
Fantail	12	2.55	4	1	23
Fern bird	1	N/A	1	1	0
Finch sp.	5	0.54	3	13	5
Goldfinch	2	0.22	2	4	1
Grey warbler	16	2.23	3	97	25
Gull sp.	4	0.16	2	10	0
Harrier	1	N/A	1	1	2
Heron sp.	1	0.06	2	3	4
House sparrow	5	2.61	10	68	4
Indian mynah	6	0.48	2	16	4
Kākā	16	1.24	12	230	107

Species (common name)	Number of transects observed on	Average density per hectare	Maximum flock size	Average abundance (on survey)	Abundance (between points)
Kākāriki	1	0.22	4	8	4
Kererū	14	1.02	3	29	23
Kingfisher	16	1.50	3	117	31
Long-tailed cuckoo	2	N/A	1	1	0
Magpie	6	0.41	2	11	0
Mallard	2	0.03	8	10	3
Oyster catcher	4	0.03	4	8	3
Paradise shelduck	2	0.06	2	2	4
Pukeko	7	0.35	5	32	10
Red-billed gull	3	N/A	25	16	0
Ruru	1	N/A	1	1	1
Shag sp.	2	0.22	7	6	3
Shining cuckoo	13	0.19	2	23	10
Silver eye	16	3.76	20	96	14
Skylark	4	0.03	1	8	0
Song thrush	6	0.25	2	12	2
Spur wing plover	4	0.03	4	8	1
Tern sp.*	0	N/A	N/A	0	4
Tomtit	1	N/A	1	1	0
Tui	16	5.06	3	222	70
Unknown	9	0.99	3	35	12
Weka	1	0.10	2	6	0
Welcome swallow	7	1.66	12	48	29
White-faced heron	2	0.03	1	2	2
Yellowhammer*	0	N/A	N/A	0	1

Notes:* Birds seen or heard only when transiting between survey points (i.e., not within the five-minute survey period). N/A: No density estimates available - only observed further than 25m from observer. Average density: Calculated using distance data (observations within 25m) across all transects. Average abundance (on survey): Number of individuals observed, calculated as average of replicates for all on-survey observations (rounded up). Abundance (between points): Number of individuals observed while travelling between points.

3.3 Transects

Of the 16 transects, Tryphena had the highest number of total individuals (271), followed by Rakitu (259), Okiwi (251), Okupu (196) and Medlands (191) (Table 5). The Okupu transect contained the highest number of species (26, followed by Claris (24), Medlands (23) and Tryphena (20).

Needle Rock, Cooper's Castle and Awana all had under 100 observed birds at the points in the transect, and Needle Rock and Cooper's Castle both had the lowest number of species observed on survey (nine and eight, respectively) (Table 5).

Table 5. Summary of survey data by transect

Transect	Number of birds	Number of species	Average density (birds/ha)	Most common species	% of transect records (most common sp)
Tryphena	271	20	78.45	Kākā	23
Rakitu	259	15	49.41	Tui	18
Okiwi	251	16	46.87	House sparrow	22
Okupu	196	26	47.38	Tui	20
Medlands	191	23	45.85	Welcome swallow	13
Mt Young	189	14	15.79	Kākā	19
Claris	181	24	15.28	Welcome swallow	16
Windy Hill	176	14	26.49	Kākā	30
Glenfern	150	16	6.11	Kākā	29
Whangaparapara	141	16	23.94	Tui	28
Motairehe	129	16	25.98	Blackbird	24
Harataonga	128	10	19.36	Kākā	34
Te Paparahi	123	10	24.45	Kākā	25
Needle Rock	87	9	16.81	Kākā	29
Awana	75	16	9.68	Tui	17
Cooper's Castle	74	8	10.19	Tui	27

Kākā was the most commonly observed species in seven of the 16 transects, with tui the most common in five transects (see Table 5), welcome swallow in two (Medlands and Claris) and house sparrow and blackbird in one each (Okiwi and Motairehe, respectively).

Average density per transect was calculated by taking the average of the sum of densities for each species at each of the five survey points in that transect (see Table 5). The majority of the transects ranged between 6 and 27 birds per hectare (average 28.88 birds/ hectare). Five transects had higher than normal densities, as compared with previous estimates (Ogden, 2009).

Tryphena had the highest average density (78.45 birds/hectare), followed by Rakitu (49.41 birds/hectare), Okupu (47.38 birds/ hectare), Okiwi (46.87 birds/ hectare) and Medlands (45.85 birds/ hectare) (Table 5). Potential reasons for these estimates are addressed in Section 4: Discussion of this report.

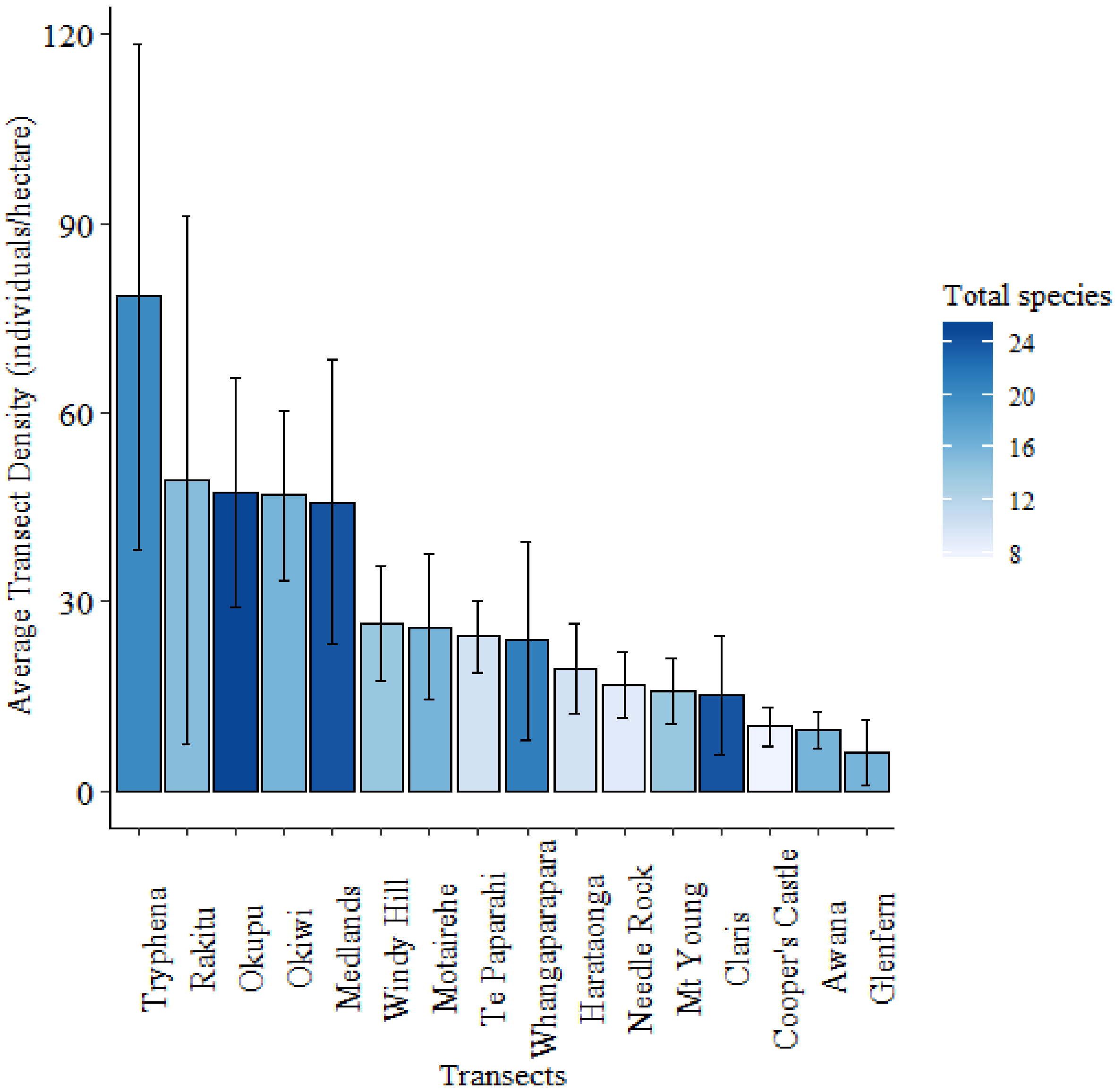


Figure 10. The average density for all species at each transects. Error bars display the 95% confidence intervals.

3.3 Multiple linear regression models

The variable inflation factor indicated that there was no multicollinearity between predictor variables. The results of the Akaike's information criterion stepwise regression showed that varying levels of human impact do not explain any of the variation present in the average species density per point, when modelled for all bird species. However, this varied when models were created for different species individually.

A multiple linear regression was calculated that predicted the number of birds per hectare (density) as a response to varying levels of pest management and elevation. When density was predicted for all bird species combined, across all survey points, higher altitudes were found to have fewer species (β = -0.007, p < 0.01), while different levels of pest management only had a small effect on density (β = 0.23, p = 0.15). Elevation and pest management explained approximately 17% of the variance found in bird densities across the different survey locations (Table 6).

Table 6. Summary of multiple linear regression model for all species

	β	**SE**	**CI (0.05, 0.95)**	**p**
Intercept	5.16	0.35	(4.58, 5.74)	2.0×10^{-16}***
Elevation	-0.007	0.002	(-0.01, -0.003)	0.0016**
Pest management	0.23	0.16	(-0.035, 0.49)	0.15
R^2 = 0.17, F (2,75) = 7.45, p = 0.001				

Notes: β: the increase or decrease in the predictor variable per single unit of density increase; SE: standard error; CI: 95% confidence intervals; p: probability of β being due to chance; *: significance of p value (*** high, **medium, * low)

3.4 Key target species

A summary of the survey results for each of the four target bird species is presented below.

North Island kākā (Nestor *meridionalis septentrionalis*)

New Zealand threat status: At risk (recovering) (Roberston et al, 2017).

Kākā was found in all 16 transects surveyed (Figure 6). They had the highest density of any species in seven of the transects they were found in. The highest density of kākā in a single observation occurred on the Okiwi transect (d = 12.74). The average density of this species was 1.24 per hectare and ranged from three to 13 birds per hectare (rounded up). The flock size was between one and 12 individuals (Table 4).

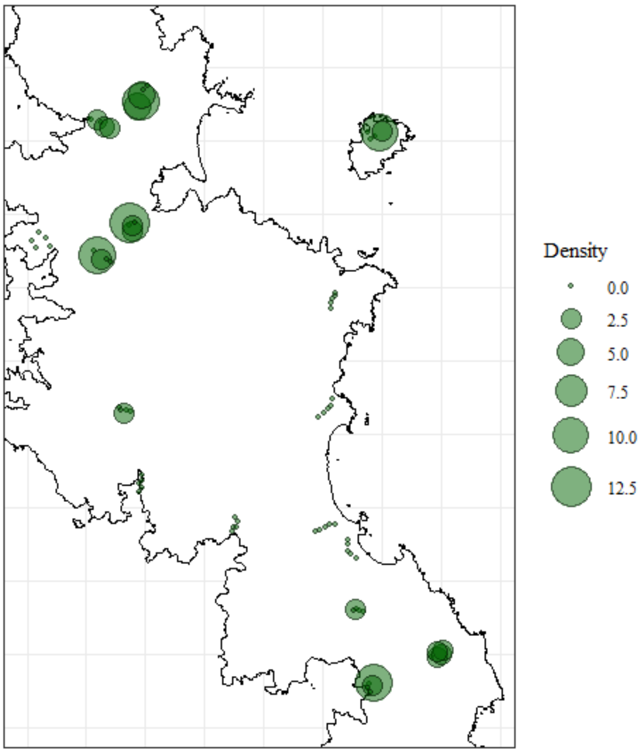


Figure 11. Kākā density across Aotea at each of the transects surveyed

A multiple linear regression model predicted that kākā density decreased as the level of human impact increased (β = -0.27, p = 7.33 x 10^{-4}). Human impact explained 14% of the variance of kākā density (Table 7).

Table 7. Summary of multiple linear regression model for kākā

	β	SE	CI (0.05, 0.95)	P
Intercept	1.23	0.22	(0.86, 1.60)	$3.83x10^{-7}$ ***
Human impact	-0.27	0.08	(-0.40, -0.14)	$7.33x10^{-4}$ ***
R^2 = 0.14, F(1, 78) = 12.36, p = $7.33x10^{-4}$				

Notes: β: the increase or decrease in the predictor variable per single unit of density increase; SE: standard error; CI: 95% confidence intervals; p: probability of β being due to chance; *: significance of p (*** high, **medium, * low).

Tui (*Prosthemadera novaeseelandiae novaeseelandiae*)

New Zealand threat status: Not threatened (Roberston et al, 2017).

Tui was found in all 16 transects surveyed (Figure 7) and had the highest density of any species in five of the transects that they were found in. The highest density of tui in a single observation occurred on the Tryphena transect (d = 33.11). The average density for this species was 5.06 per hectare and ranged between three and 33 birds per hectare. The flock size was between one and three individuals (Table 4).

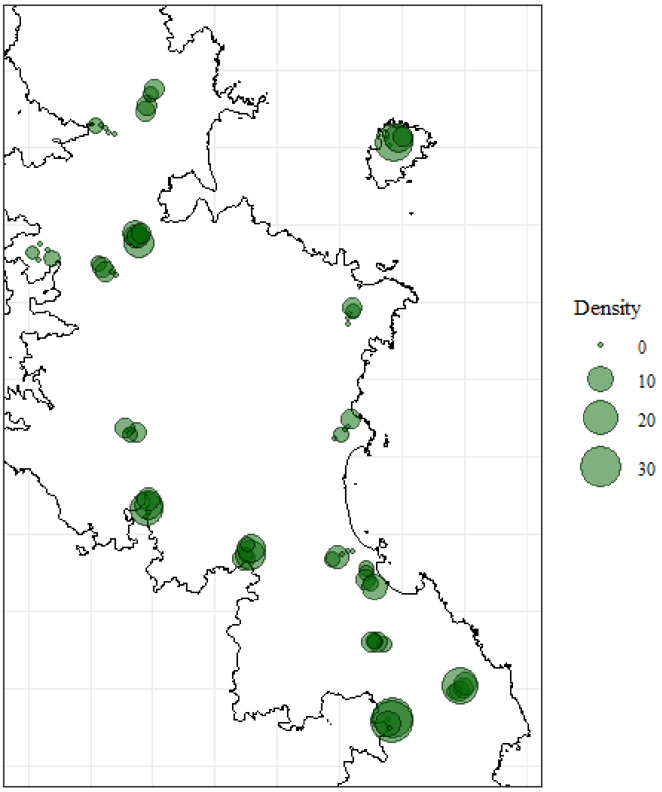


Figure 12. Tui density across Aotea at each of the transects surveyed

A multiple linear regression model predicted that tui density was significantly affected by pest management (*β* = 0.27, *p* = 0.04). Pest management explained 5% of the variance of tui density (Table 8).

Table 8. Summary of multiple linear regression model for tui at each of the transects surveyed

	β	SE	CI (0.05, 0.95)	p
Intercept	1.35	0.23	(0.96, 1.73)	1.18×10^{-7}***
Pest management	0.27	0.13	(0.055, 0.49)	0.04*
R^2 = 0.05, $F(1, 78)$ = 4.35, p = 0.04				

Notes: *β*: the increase or decrease in the predictor variable per single unit of density increase; SE: standard error; CI: 95% confidence intervals; *p*: probability of *β* being due to chance; *: significance of *p* (*** high, **medium, * low).

Kākāriki/red-crowned parakeet (*Cyanoramphus novaezelandiae novaezelandiae*)

New Zealand threat status: At risk (relict) (Roberston et al, 2017).

Kākāriki was only found at one survey point in the Okiwi transect (Figure 8). The density of this species was 17.83per hectare. The flock size was between one and four individuals (Table 4).

While a total of four observations of kākāriki were recorded within 25m during this survey, all of the observations were at a single survey point. Consequently, no information could be gathered on the potential influence the predictor variables may have had on the density of kākāriki.

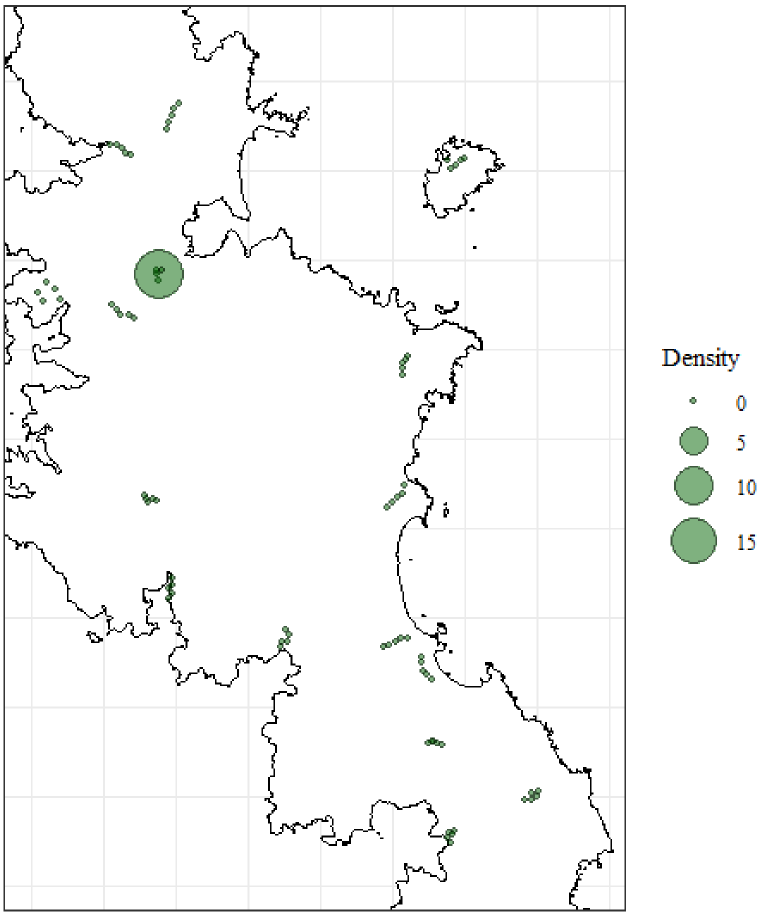


Figure 13. Kākāriki density across Aotea at each of the transects surveyed

Kererū/wood pigeon (*Hemiphaga novaeseelandiae*)

New Zealand threat status: Not threatened (Roberston et al, 2017).

Kererū was found in 14 surveyed (Figure 9). The highest density of kererū in a single observation occurred on the Windy Hill transect (d = 10.19). The average density for this species was 1.02 per hectare, and from three to 10 birds per hectare (rounded). The flock size was ranged between one and three individuals (Table 4).

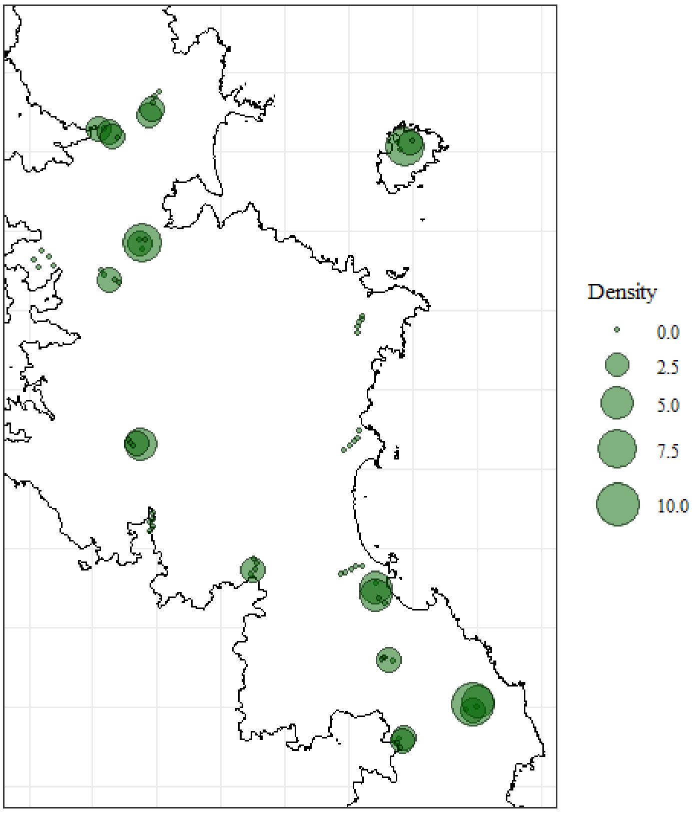


Figure 14. Kererū density across Aotea at each of the transects surveyed

A multiple linear regression model predicted that kererū density was significantly affected by elevation (*β* = -0.003, *p* = 0.06) and human impact (*β* = -0.27, *p* = 0.01). Elevation and human impact together explained 8% of the variance of kereru density (Table 9).

Table 9. Summary of multiple linear regression model for kererū

	β	**SE**	**CI (0.05, 0.95)**	**p**
Intercept	1.45	0.39	(0.80, 2.10)	0.0004 ***
Elevation	-0.003	0.001	(-0.005, -0.0004)	0.06
Human impact	-0.27	0.11	(-0.44, -0.09)	0.01*
R^2 = 0.08, $F(2, 77)$ = 3.28, p = 0.04				

Notes: *β*: the increase or decrease in the predictor variable per single unit of density increase; SE: standard error; CI: 95% confidence intervals; *p*: probability of *β* being due to chance; *: significance of *p* (*** high, **medium, * low).

3.5 Most commonly observed species

The five most commonly observed species were tui (see above), silvereye, fantail, house sparrow and grey warbler. A summary of the survey results for these four bird species is presented below.

Tauhou/ silvereye (*Zosterops lateralis lateralis*)

New Zealand threat status: Not threatened (Roberston et al, 2017).

Silvereye was found in all 16 transects surveyed (Figure 10). This species had the third highest density in two transects. The highest density of silvereye in a single observation occurred on the Rakitu transect (d = 78.96). The average density of this species was 3.76 per hectare and ranged between three and 79 birds per hectare (rounded). The flock size was between one and 20 individuals (Table 4).

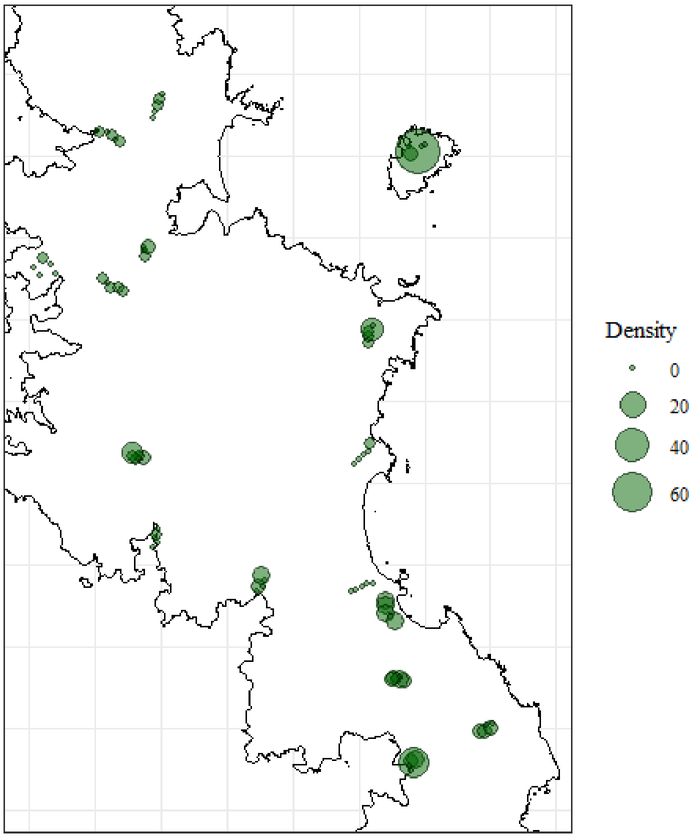


Figure 15. Silvereye density across Aotea at each of the transects surveyed

Neither human impact, elevation or pest management significantly explained any of the variation present in silvereye density.

House sparrow (*Passer domesticus*)

New Zealand threat status: Not threatened (Roberston et al, 2017).

House sparrow was found in five transects surveyed (Figure 11). This species had the highest density of any species in one transect. The highest density of house sparrow in a single observation occurred on the Tryphena transect (d = 53.49). The average density of this species was 2.61 per hectare and ranged between three and 53 birds per hectare (rounded). The flock size was between one and ten (Table 4).

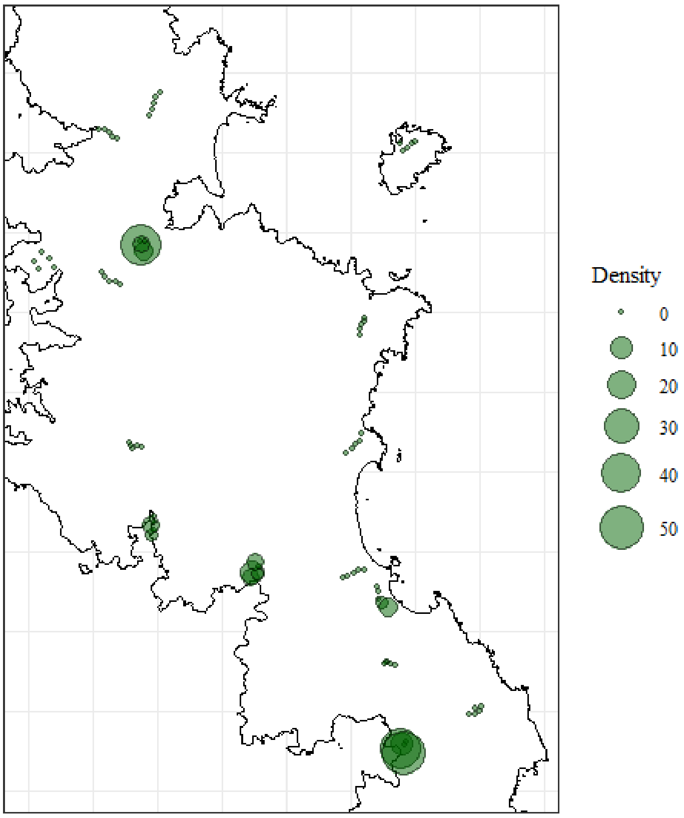


Figure 16. House sparrow density across Aotea at each of the transects surveyed

A multiple linear regression model predicted that the density of house sparrow was higher in areas with a low number of pests (β = 0.26, p = 0.05) and in areas with higher levels of human impact (β = 0.40, p = 0.001). Pest management and human impact together explained 14% of the variance of house sparrow density (Table 10).

Table 10. Summary of multiple linear regression model for house sparrow

	β	SE	CI (0.05, 0.95)	p
Intercept	-0.07	0.41	(-1.47, -0.09)	0.06
Pest management	0.26	0.13	(0.05, 0.48)	0.05*
Human impact	0.40	0.12	(0.20, 0.61)	0.001**
R^2 = 0.14, $F(2, 77)$ = 6.37, p = 0.003				

Notes: *β*: the increase or decrease in the predictor variable per single unit of density increase; SE: standard error; CI: 95% confidence intervals; *p*: probability of *β* being due to chance; *: significance of *p* (*** high, **medium, * low).

Piwakawaka/ North Island fantail (*Rhipidura fuliginosa placabiis)*

New Zealand threat status: Not threatened (Roberston et al, 2017).

Fantail was found in 12 transects surveyed (Figure 12). The highest density in a single observation occurred on the Motairehe transect (d = 22.92). The average density of this species was 2.55 per hectare and ranged between three and 23 birds per hectare (rounded). Fantail was observed in flocks between one and four individuals (Table 4).

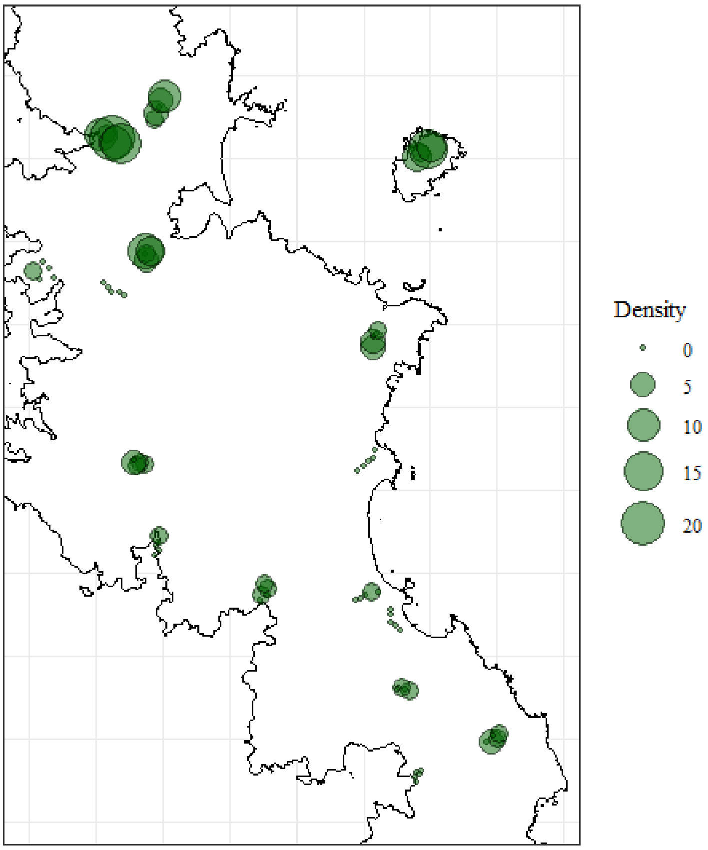


Figure 17. Fantail density across Aotea at each of the transects surveyed

A multiple linear regression model predicted that the density of fantails decreased with increases in elevation (*β* = -0.004, *p* = 0.03) and human impact (*β* = -0.38, *p* = 0.01). Elevation and human impact together both explained 8% of the variance of fantail density (Table 11).

Table 11. Summary of multiple linear regression model for fantail

	β	SE	CI (0.05, 0.95)	p
Intercept	2.38	0.56	(1.45, 3.31)	5.74×10^{-5}***
Elevation	-0.004	0.002	(-0.008, -0.001)	0.03*
Human impact	-0.38	0.15	(-0.63, -0.13)	0.01*
R^2 = 0.08, *F*(2, 77) =3.35 , *p* = 0.04				

Notes: β: the increase or decrease in the predictor variable per single unit of density increase; SE: standard error; CI: 95% confidence intervals; p: probability of β being due to chance; *: significance of p (*** high, **medium, * low).

Riroriro/ grey warbler (*Gerygone igata*)

New Zealand threat status: Not threatened (Roberston et al, 2017).

Grey warbler was found in all 16 transects surveyed (Figure 13), and had the second highest density of any species in two transects. The highest density of grey warbler in a single observation occurred on the Claris transect (d = 15.28). The average density of this species was 2.23 per hectare and ranged between two and 15 birds per hectare (rounded). The flock size was between one and three individuals (Table 4).

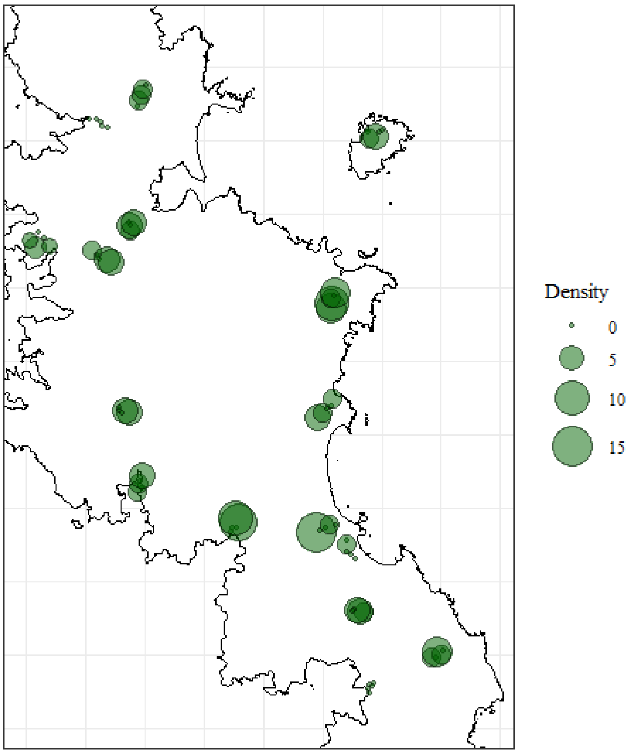


Figure 18. Grey warbler density across Aotea at each of the transects surveyed

A multiple linear regression model predicted that grey warbler density increased as elevation increased ($\beta = 0.003$, $p = 0.08$). Human impact did not significantly predict grey warbler densities ($\beta = 0.20$, $p = 0.15$). Elevation and human impact only explained 4% portion of the variance of grey warbler density (Table 12).

Table 12. Summary of multiple linear regression model for grey warbler

	β	SE	CI (0.05, 0.95)	p
Intercept	0.13	0.51	(-0.72, 0.98)	0.80
Elevation	0.003	0.002	(0.0002, 0.006)	0.08
Human impact	0.20	0.14	(-0.02, 0.43)	0.15
R^2 =0.04 , $F(2, 77)$ = 1.61 , p = 0.21				

Notes: β: the increase or decrease in the predictor variable per single unit of density increase; SE: standard error; CI: 95% confidence intervals; p: probability of β being due to chance; *: significance of p (*** high, **medium, * low).

4. Discussion

The transects surveyed across Aotea were each comprised of a different assemblage of bird species. The frequency of all species observed varied greatly (see Figure 4), as did the average densities of individuals at each transect (see Figure 5).

While the majority of transects had densities that were less than 27 birds per hectare, five transects had much higher density estimates (Table 13). One possible explanation is the presence of species with many individuals observed within a single transect. Most of these species are flocking birds that are usually found in larger groups. The survey was conducted during the breeding season for many of these species, which may have inflated the density estimates (Scofield & Stephenson, 2013). The Windy Hill transect had high estimates of density during this survey, as compared to previous estimates that used a similar methodology (Ogden, 2018), due to the high abundance of tui found in this transect.

Table 13. Transects with high average density

Transect	Species	Average number of individuals	Average density
Tryphena	House sparrow	9.75	78.45
	Silvereye	6.5	
	Mallard	6.0	
	Tui	5.2	
Rakitu	Silvereye	15.5	49.41
	Tui	5.0	
	Welcome swallow	3.5	
Okupu	Starling	5.0	47.38
	Tui	3.0	
Okiwi	House sparrow	8.5	46.87
	Kakariki	3.5	
	Tui	3.0	
Medlands	Welcome swallow	4.5	45.85

Notes: Transect: transects with high average density; Species: species that had a high number of individuals observed in that transect; Average number of individuals: the number of individuals of that species observed within that transect during the five-minute surveys; Average density: the number of birds per hectare from higher density transects.

For some species such as kingfisher and kākā, the number of individuals observed was high (individuals = 117 and 230, respectively) within the top five most abundant species, while average density estimates were comparatively low (d = 1.50 and 1.24, respectively) (Table 4). As density is an estimate that requires spatial bounds to calculate, this estimate excluded those observations that were outside of a 25m radius. Both kākā and kingfisher exhibit loud calls that can be heard over great distances and were often included as observations outside of 25m. Consequently, abundance for such species may have been over-estimated when compared to their relative average densities. Inversely, average densities for species of the finch family may have been under-estimated, as these small passerines are inconspicuous, and may not have been noticed when larger, louder birds were near.

The average density per survey point was calculated for all species (Table 4). Tui, silver eye, grey warbler, fantail and house sparrow had the highest densities. Tui and kākā were observed to be the most frequently occurring species (Table 3).

A proportion of the differences in species density could be accounted for by observing the effect of several predictor variables; pest management levels, elevation, and degree of human impact. Multiple linear regression models for the four focal species and additional four most common species reported individual responses to different levels of pest management levels, elevation and degree of human impact. A multiple linear regression model fitted for all bird species across all survey points indicated that elevation was the only significant predictor of bird density for all combined species. The model predicted that as elevation increased, the number of birds per hectare significantly decreased (see Table 6).

Silvereye was the only species for which the three predictor variables appeared to have no significant explanation of the response. The distribution of this species across all the transects and survey points was fairly even, apart from a large abundance recorded on Rakitu (see Figure 10).

The density of three species was found to be significantly predicted by one variable. The density of kākā decreased with increases in the degree of human impact (see Table 7). The density of tui was increased with increased levels of pest management (see Table 8). Grey warbler density was predicted to increase with increased elevation (see Table 12).

The density of three species was found to be significantly predicted by two variables. Kererū density was estimated to decrease with increases in elevation and human impact (see Table 9), although the effect of elevation was small. House sparrow density was predicted to increase in response to increases in pest management levels and degree of human impact (see Table 10). Fantail density was predicted to decrease as a response to elevation and human impact (see Table 11).

The degree of human impact was the most common predictor of density for the focal species, significantly predicting the density for four species; kākā, kererū, house sparrow and fantail. House sparrow was the only species where density significantly increased with increases in human impact, which can be seen by their high relative abundance at locations with higher human presence, such as around Tryphena and in Okiwi (see Figure 11).

Elevation was the second-most common predictor of density for the focal and common species, significantly predicting the density for three species; grey warbler, kererū and fantail. Grey warbler was the only species for which an increase in elevation significantly predicted for an increase in density. This result could be as a response to altitudinal variation in food resources, as has been observed in previous bird counts. In earlier surveys (Ogden, 2009), montane bush was recognised as distinct due to low bird diversity and the relatively high abundance of grey warbler, indicating the importance of vegetation type on species presence.

Pest management only significantly predicted the density of two species, tui and house sparrow. For both birds, increases in pest management predicted a significant increase in their respective densities. The level of pest management were retrieved from an online source (trap.nz) that may not have included all current Aotea pest management activity, and as such the models may be underestimating the effect of this predictor variable. Increases in pest management predict a greater increase in the number of birds per hectare than the other variables (*β* = 0.27, *β* = 0.26) (see Table 8, Table 10).

The relatively low R^2 value reported from the overall model (see Table 6), and in many of the individual models, indicated that there are other variables that affect the density of bird species on Aotea. Factors such as vegetation type (Mills et al., 1991), seasonal food abundance (Valle et al., 2017), and wind exposure (Chen et al., 2018) could influence the density of birds, and could be included as predictors in future models. Pest management has a positive effect on bird densities, for example, at Windy Hill Sanctuary the density of birds in managed areas was nearly twice as high compared to unmanaged areas (Ogden, 2018). As such, continued pest control efforts, especially in areas of high human habitation, may encourage a wider the distribution of Aotea's native and endemic bird species.

5. Survey and data limitations

For ease of access and observer safety, each transect was conducted along a path, track, road or other accessway. Consequently, each survey point was effectively located in an edge habitat i.e., along the boundary of a change in habitat type, such as from scrubland or forest, to a road, track or other open space. Such locations do not necessarily give an accurate estimate of bird abundance or density in each area, as was seen by the large number of observations made outside of 25m from each survey point.

Some records of species did not indicate if the observations were within or outside of the 25m radius and could not be included in the density estimates.

Three of the transects surveyed could not be included in the analyses due to slight variations in the methodology used.

Species such as tomtit, ruru, yellowhammer, and fernbird may have been observed in such low numbers (Figure 3) as they are inconspicuous birds. Calls of the tomtit and yellowhammer may have been misidentified as finch species, or otherwise labelled as unknown, due to their similarities.

Some caution is needed in interpreting the results of the MLM analysis, which are based on a single survey and broad assumptions about the different levels of human impact and pest management at each survey location. Further surveys, refinement of the parameters used in the analysis, and consistency in the use of trained counters will all assist in enabling any trends or patterns in the data to be discerned over the coming years.

Finally, it should be noted that the results cannot be extrapolated past the season that the survey occurred in, as the different bird species may exhibit seasonal patterns of occurrence and flock size due to the temporal abundance of food resources.

6. Recommendations for further surveys

In reviewing the survey design, and its implementation, as well as the results of the survey, several suggestions for improvements and additions were identified and are set out below:

- Observers conducting survey counts should be trained, or given refresher training as appropriate, prior to every count to ensure that both bird identification skills are current, and all observers are familiar and confident with the methodology and the types of observations to be recorded.

- An estimate of vegetation type at each survey point (in simple categories) should be included in future counts to account for habitat type and potential bird food sources. This aspect may have an impact on the presence/ absence of birds at different sites.

- An annual or biannual Aotea Bird Count would allow comparison of relative population trends for the key species at the different sites across the island, across years and different seasons (if biannual).

- Other areas on Aotea, such as Motu Kaikoura, and higher elevation areas, could be included in the count to provide further data and assist in investigating the potential effects of different levels of pest management, elevation and degree of human impact on bird occurrence and density.

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Appendix A – Raw survey data

Available upon request – 78 pages