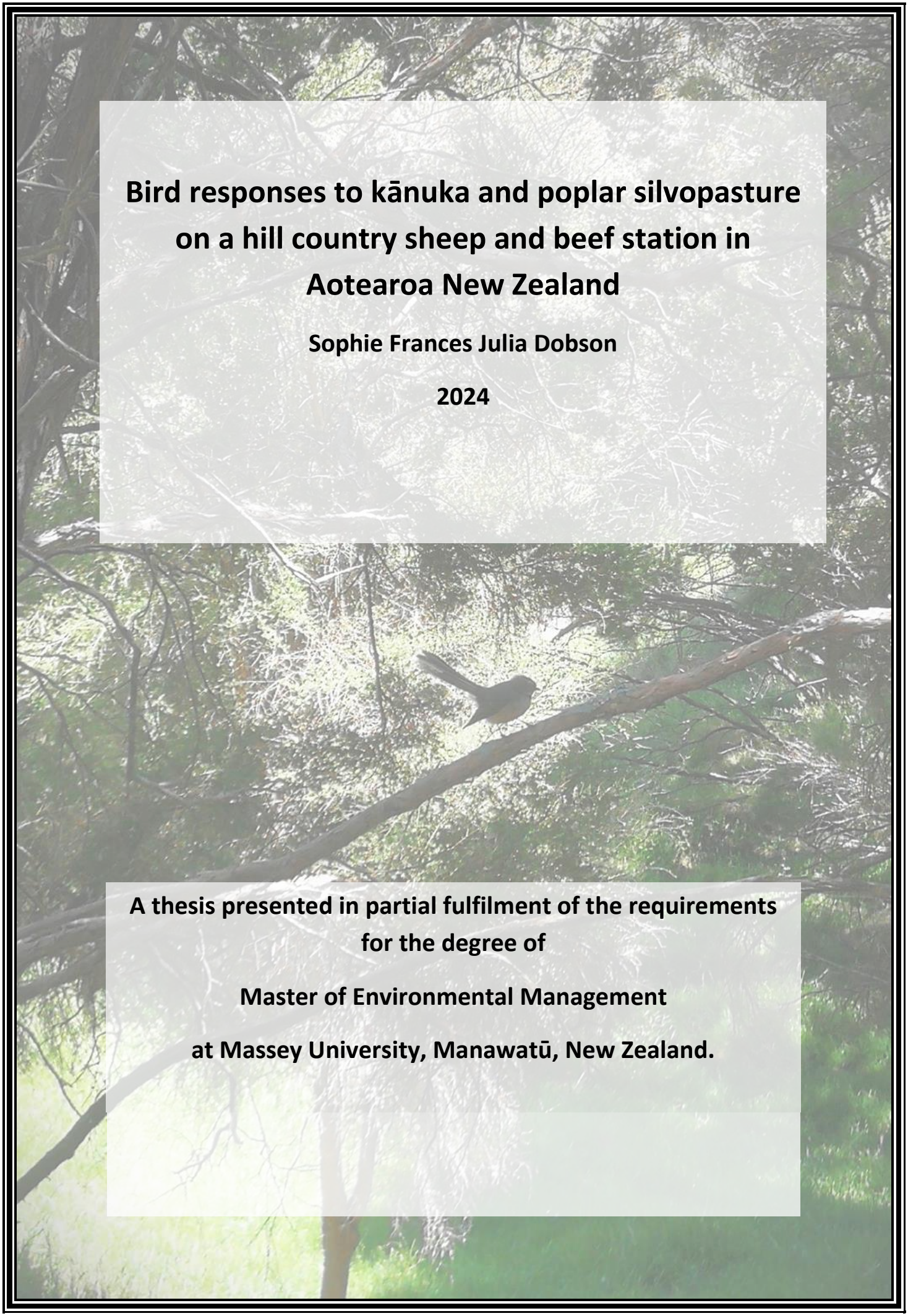

Bird responses to kānuka and poplar silvopasture on a hill country sheep and beef station in Aotearoa New Zealand

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Abstract

Historically, agriculture in Aotearoa New Zealand has been associated with mass deforestation and subsequent erosion. A popular way to counter erosion in hill country sheep and beef agricultural systems has been to plant exotic poplar or willow silvopastoral systems, however recent studies have explored the use of low density kānuka plantings as a potential native alternative.

This study explored how both current poplar/willow and proposed kānuka plantings affect the movements of birds in a hill country sheep and beef station. It analysed the density of trees in various poplar/willow and kānuka groves via the use of a GIS dataset of individual trees across the Wairarapa region. Tree densities were used to generate four sampling categories (Open Pasture, Poplar/Willow, Low Density Kānuka, and High Density Kānuka), and 5-minute bird counts were undertaken in each of these categories.

Results show that native and endemic bird counts grew significantly as kānuka density increased but counts of native and endemic birds in Poplar/Willow sites were often lower than those in Open Pasture. Introduced birds showed a similar increase in counts in Poplar/Willow as in Low Density Kānuka.

Overall, the native species the benefitted the most from the presence of kānuka were the small insectivorous passerines: grey warbler (*Gerygone igata*), silvereye (*Zosterops lateralis*), and fantail (*Rhiphidura fuliginosa*). No native birds favoured Poplar/Willow sites, however native birds were sometimes witnessed moving through the canopy when poplar plantings bordered kānuka groves. Introduced European starlings (*Sturnus vulgaris*), chaffinches (*Fringilla coelebs*) and yellowhammer (*Emberiza citrinella*) all benefitted from the presence of both poplar/willow plantings and kānuka groves. Significant numbers of introduced Eurasian skylark (*Alauda arvensis*) and endemic New Zealand pipit (*Anthus novaeseelandiae*) were present on Open Pasture sites.

Given the positive response of on-farm native bird populations to the presence of kānuka, its use as a silvopastoral plant has great potential to align conservation goals with the economic realities of agriculture. There is long term potential to form bird corridors out of silvopastoral

erosion mitigation, however more work still needs to be done to fully understand the complexities of on-farm birdlife.

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Contents

1. Introduction

Before humans arrived in Aotearoa New Zealand 80% of the country was covered in native forest; by 2018 this number was down to just 27% with little indication the trend will change in the immediate future (Ministry for the Environment & Stats NZ, 2022). Much of this mass deforestation was the result of converting land for agricultural use; however, it also came with the associated habitat loss and decline of many of New Zealand's native and endemic bird species (Meadows, 2012). As a result, the traditional view of agriculture in New Zealand has been that of one opposed to conservation values, with conservation efforts being focused on natural areas and agricultural research focusing primarily on productivity and exotic species (Mackay-Smith et al., 2024).

In recent years there has been a change of attitudes, with an increasing body of research looking at how conservation could potentially be integrated into an agricultural context through processes that are mutually beneficial to landowners. In particular, there has been research released about the potential use of native tree species in New Zealand silvopastoral systems.

This literature review aims to examine the current research regarding the state of silvopastoralism in New Zealand, particularly in regard to the use of native plant species, and the potential value of New Zealand agricultural landscapes as a habitat for native bird species.

1.1. Hill country sheep and beef farms and silvopastoralism

Hill country beef and sheep farms are one of the largest forms of land use in New Zealand, with beef and sheep pastoral farming taking up 39.7% of the country's land area (Norton & Pannell, 2018). They are typified by steep dry pasture lands that primarily run sheep and cattle for the use of beef, lamb and wool products (Dodd et al., 2016). Hill country pastures are typically heavily deforested, however 25% of the total native vegetation remaining in New Zealand still exists in these areas in the form of remnant native bush and scrub remnant native growing in hard to access gullies and steep slopes (Norton & Pannell, 2018). These remaining native patches have to potential to be a significant asset to conservation as there is very little public conservation land located within hill country regions (Case et al., 2022).

Unfortunately, even with the remnant vegetation being present, deforestation has led to significant problems with erosion, which poses a major threat to agriculture in these regions (Basher, 2013). Since the 1960s, hill country land managers have combatted erosion via the planting of exotic trees along erosion prone slopes(Wilkinson, 1999). The process of using these trees in conjunction with an agricultural system (usually involving livestock such as sheep and cows) is defined as silvopasture (Mackay-Smith et al., 2024). A number of species are utilized for silvopasture in New Zealand; however, the majority of hill country land managers use exotic poplar (*Populus* spp.) and willow (*Salix* spp.) (Mackay-Smith et al., 2024; Wilkinson, 1999).

Poplar and willow silvopastoral systems

Poplar and willow have been cultivated in New Zealand for over 180 years and are the most widely used trees in sheep and beef silvopastoral systems (Kemp et al., 2018; Mackay-Smith et al., 2024; Wilkinson, 1999). They are a popular choice due to being fast growing, easy to clone, and having extensive root systems that are effective at holding together erosion-prone slopes, even during periods of intense rainfall (Benavides et al., 2009; Wall et al., 2006; Wilkinson, 1999). They are often cultivated into easy to plant poles that can be transported to site using trucks or lifted in place via helicopter, and quickly planted via the use of a post rammer (Kemp et al., 2018; Wilkinson, 1999). Sheep can graze in paddocks immediately after planting (provided poles are protected with a plastic sleeve), and when trees are grown their leaves provide shelter and an additional source of fodder to both sheep and cows (Benavides et al., 2009; Charlton et al., 2007; Wilkinson, 1999). Poplar and willow are usually used in unison with each other, with poplar being planted on higher slopes and willow being used in damp gullies and swampy regions of the farm where their high evapotranspiration rate can be taken advantage of to dry out soils (Charlton et al., 2007; Wilkinson, 1999).

Poplar/willow silvopastoral systems have received extensive institutional support, with over two million poplars being planted in the 1960s and 1970s for government-led erosion control initiatives (Benavides et al., 2009; Wilkinson, 1999). Today they are widely supported through regional council planting schemes, where poles are provided to rural landowners for erosion stabilisation (Charlton et al., 2007). Additionally, they are eligible for carbon credits under the

Emissions Trading Scheme (ETS), providing an added financial incentive for planting (Ministry for Primary Industries., 2017).

In addition to institutional support, poplar and willow have been extensively researched, resulting in a very well-developed system of planting and cultivation for use of these species in the agricultural environment (Mackay-Smith et al., 2021). However, there are still a number of drawbacks relating to the use of these species. Poplars are large trees that frequently grow well in excess of 30 m tall (Mackay-Smith et al., 2023). Due to their height, they require frequent pruning and management, as overgrown trees can be easily damaged during storms and pose risks for livestock and people though falling branches (Benavides et al., 2009; Charlton et al., 2007; Mackay-Smith et al., 2021). Because of this instability it is recommended that trees be removed once they reach the age of 40 years, a management strategy that becomes problematic if they are being incorporated into the ETS, as some of their carbon capture potential is reduced by removal (Charlton et al., 2007; Mackay-Smith et al., 2021).

Another issue relating to poplar and willows large sizes is their negative effects on pasture productivity, as these trees increasingly block light from reaching large sections of pasture as they grow (Benavides et al., 2009; Wall et al., 2006). A number of studies have analysed pasture production under poplar and found significant reductions in pasture growth compared to open pasture environments. Wall et al. (2006) found that poplar trees had higher percentages of incident photosynthetically active radiation (PAR) under 5-year old poplar trees compared to 25-year old trees, as the older trees' larger sizes and bigger rates of canopy closure blocked more light from reaching pasture, resulting in losses in pasture production of up to 50%. Guevara-Escobar et al. (2007) found similar results, with pasture under younger poplar trees displaying growth similar to that of open pasture, while pasture under mature trees showed a 40% reduction in growth. They also suggested that the feed quality of open pasture was better than that under the poplar canopy. Douglas et al. (2001) also found reduction in pasture growth under poplar, however there was regional variation between results, with their South Island site demonstrating a 20–34% reduction in pasture growth and their North Island site only demonstrating a 7–14% reduction. This was thought likely to be due to differences in pasture species, with the South Island pasture site consisting of 85% *Lolium perenne* (perennial ryegrass, a shade intolerant species) and the North Island site

displaying significant botanical differences between pasture under the canopy and in the open.

The economic impacts of poplar/willow silvopastoral systems relating to soil conservation and pasture production have received much attention, but the same cannot be said about their ecological impacts (Mackay-Smith et al., 2024). Very few studies in New Zealand have looked at poplar/willow from an ecological perspective, and none focus on birds (Mackay-Smith et al., 2021).

Native plants and silvopasture

Poplar and willow have a long history of use as a silvopastoral plant in New Zealand, and alongside *Pinus radiata* they have received the majority of scientific attention regarding research into their use, effectiveness, and optimal planting strategies (Mackay-Smith et al., 2021, 2024). As a result, native plants have received little attention about their potential as commercial or silvopastoral species (Buckley et al., 2023). Over last decade, however, there has been growing public and expert support for the use of natives in planting initiatives and for use in economic development (Buckley et al., 2023). Native plants are now commonly used for planting riparian margins and Mānuka (*Leptospermum scoparium*) is being utilised for its specialised honey production qualities and is beginning to be investigated for its use in erosion management (Dairy NZ, 2014; Marden et al., 2020). Kānuka (*Kunzea ericoides*) in particular has been receiving new attention over the last 5 years and there is a growing body of research demonstrating that it has potential to be a silvopastoral species that rivals poplar/willow systems.

Kānuka as a potential silvopasture species

Kānuka is endemic to New Zealand and is commonly found growing naturally in the paddocks and gullies of hill country stations and farms. It is a coloniser species that represents the first stage of regeneration in native forests, a trait that enables it to grow well in barren, steep, and heavily modified environments (Lambie et al., 2021). It is currently estimated that around 70%

of regenerating forest in New Zealand consists of mixed kānuka-mānuka scrubland (Lambie et al., 2021; Ministry for Primary Industries., 2017).

Historically, kānuka has been thought of as an agricultural weed; however, its uses are now being explored in riparian planting, as a replacement for retired erosion-prone pine forestry, and as a native silvopastoral species in beef and sheep hill country stations (Dairy NZ, 2014; Lambie et al., 2021; Mackay-Smith et al., 2021). A study utilizing new modelling techniques to quantify the effectiveness of landslide prevention on two hill country sites noted that kānuka was particularly abundant in the area and commonly located more frequently on the steeper, more erosion-prone slopes than the exotic poplar silvopastoral plantings (Spiekermann et al., 2021). This was noted as a positive sign, as kānuka had demonstrated good potential for slope stabilization in the model.

Other studies have analysed the relationship between kānuka and pasture production. In a 2022 study comparing kānuka to open pasture in New Zealand hill country, kānuka plots were found to have higher levels of available soil phosphorus and potassium, more organic matter, greater porosity, and did not appear to compete with pasture species for water (Mackay-Smith et al., 2022). Livestock were also more attracted to kānuka patches for shade and shelter, likely contributing to the high levels of soil nutrients from dung and urine deposition. This study found that pasture production under kānuka was 107.9% higher than open pasture (Mackay-Smith et al., 2022). A follow up study published one year later indicates the conditions under the kānuka led to selection that favoured more competitive fast-growing pasture species (Mackay-Smith et al., 2023). This contrasts with the previous poplar centric studies that demonstrated important pasture species (such as perennial ryegrass) decreased or remained at the same level under poplar compared to open pasture (Guevara-Escobar et al., 2007; Mackay-Smith et al., 2023).

1.2. Current data regarding on-farm bird populations in New Zealand

Biodiversity in New Zealand farmed landscapes has historically received very little study, which has been cited as an issue due to public conservation land favouring mountainous

highlands as opposed to warmer and more productive lowlands (Blackwell et al., 2005; MacLeod et al., 2012; Moller et al., 2008). This has been suggested by some to be a missed opportunity due to farmland generally taking up more productive environments that could, with the right land management strategies, potentially nurture threatened species (Blackwell et al., 2005; Moller et al., 2005).

Minimal research has been undertaken on the impact of silvopasture on bird populations within New Zealand; however, a study in 2005 investigated bird numbers and diversity across a range of orchards and hill country sheep/beef farms, the latter landscape being where the majority of silvopasture is used (Blackwell et al., 2005). It found that although the majority of farm and orchards supported very low native bird diversity, and predominantly introduced finches and songbirds were counted, these habitats did support higher bird abundance than on public native reserves. Additionally, the variety, type, and extent of different habitat types within farms had a strong influence on what species of birds were present on farms, with scrub (the category including kānuka) heavily favouring native species.

Research on hedgerows in Canterbury farms found that the vegetation type affected bird populations more than neighbouring crop type (Lemmers et al., 2014). The study primarily focused on introduced birds as 99% of birds recorded came from the same 12 exotic species. Interestingly, all these species were more populus on hedgerows primarily consisting of exotic pine and macrocarpa, than those that predominantly included mixtures of various native plant species (Lemmers et al., 2014). This indicates there could possibly be a trend for common introduced farm birds (some of which are considered pests) to prefer non-native vegetation. Another survey done on house sparrows (*Passer domesticus*) and European greenfinches (*Chloris chloris*) also indicated that the hedgerows and shelterbelts had the most significant influence on these species' populations during breeding season, though it did not specify what plant species were present (MacLeod et al., 2011). The study also noted that the composition of habitats alone was not enough to account for variation in bird densities across the farms sampled.

A Central Otago study looking at the effects of successional shrubland regeneration on "anthropogenic grasslands" found that the most common exotic passerines were unaffected by it, with only yellowhammer (*Emberiza citrinella*), goldfinch (*Carduelis carduelis*), and redpoll (*Acanthis flammea*) likely to be negatively impacted by continued succession (Wilson

et al., 2014). Native silvereyes (*Zosterops lateralis*) and grey warblers (*Gerygone igata*) were also present but at much lower numbers than those reported in forest.

Kānuka as a habitat for birds

There are few studies specifically focused on bird populations within kānuka in New Zealand pastoral landscapes. Some inference can, however, be made using studies that have focused on bird populations within kānuka-dominated habitats.

Studies done in the South Island found that grey warbler and fantail (*Rhipidura fuliginosa*) frequently nest in kānuka, with grey warbler demonstrating a particular preference for kānuka (Gill, 1983; Powlesland, 1982).

Birds surveyed at Kennedy Bush Scenic Reserve; a section of remnant bush with plentiful kānuka growth within the Port Hills (near Christchurch). This study identified the most frequently recorded birds to be silvereye, grey warbler, bellbird (*Anthornis melanura*), fantail, chaffinch (*Fringilla coelebs*), blackbird (*Turdus merula*) and redpoll (Freeman, 1999). Chaffinch numbers were noted as being particularly high during the spring breeding season, and native species were noted as being less abundant than in less established forest in Reefton sites (Freeman, 1999). At Kowhai Bush in Kaikoura the less mature kānuka-dominated habitat commonly featured riflemen (*Acanthisitta chloris*), brown creepers (*Mohoua novaeseelandiae*), fantails, chaffinches, goldfinches, redpolls, silvereye and grey warblers, with the latter two recorded feeding on kānuka and mānuka trees 70-80% of the time (Gill, 1980). A dense kānuka stand accessible via farm track near Nelson was found to have high bellbird, brown creeper, grey warbler, silvereye and fantail populations, with birds in the insectivorous category showing the largest preference to kānuka when compared to a nearby gorse stand (Williams & Karl, 2002).

Overseas context

With data lacking in New Zealand, it is important to look further afield to see what international research has produced and whether any significant trends hold for bird populations across silvopasture or agroforestry landscapes.

Research on Italian vineyards saw overall positive results with scrub patches having beneficial effects on both native warbler populations and erosion control (Brambilla et al., 2017). In south-eastern Kenya, results were mixed as it was found that traditional agroforestry systems were particularly species rich, with 80% of all bird species observed being supported there; however the noticeable exception was forest specialists, whose numbers significantly decreased the further they got from intact primary forest (Norfolk et al., 2017). Likewise, a study in the British Isles found that birds' responses to silvopasture were generally positive, with the presence of trees attracting invertebrates, that in turn attracted the birds that fed on them. However, results did vary across geographic region, with sites in Northern Wales having more birds in grassland plots than in silvopastoral ones (Mcadam et al., 2007). Some negative effects were found for migratory flocking species in Andean forests north of Colombia, with the lack of vegetative density and diversity of silvopastures being less suitable for the species studied than other forested agricultural habitats in the region, although they did benefit more from silvopasture than open pasture (McDermott & Rodewald, 2014).

Overall, overseas studies presented silvopasture (or landscape uses similar to silvopasture) as having a range of different outcomes for birds in their respective regions. Results appear to vary depending on geography and species studied, although there was a general trend in most reports of silvopasture having at least some positive impacts.

Values and cultural attitudes of farmers and landowners

It is important when undertaking research on a potential vector for conservation strategy to consider the attitudes of those directly affected by potential changes. Studies looking into the attitudes of New Zealand farmers towards native biodiversity have indicated that there is a desire amongst many to work as the environmental stewards or custodians of the land (Blackwell et al., 2005; Meadows, 2012). A national survey of farmers done in 2012 found that 82% of respondents rated maintaining or increasing native bird species biodiversity as being

important or very important, and 78% rated maintaining or increasing native plant species biodiversity as being important or very important (Guenther et al., 2012). Additionally, when asked what sustainability elements they considered during their current practice, 81% answered yes to protection of indigenous flora and fauna and 65% believed this would become more important in the future (Guenther et al., 2012).

Another 2012 study ascertained that New Zealand beef and sheep farmers viewed birds as indicators of a healthy farm environment, however it also raised the issue of finances (Meadows, 2012). It was found that farmers surveyed often linked their willingness to take on the responsibility of birdlife on farms to financial constraints and that due to the lack of external financial support, New Zealand farmers take on conservation projects at their own expense (Meadows, 2012). Case et al., (2022) also raised the issue of financial expense for landowners, and pointed out that currently the ETS is set up to financially favour exotic forestry, rather than the small patches of native vegetation that agricultural environments are able to nurture. Currently only 11% of forest reGIStered under the ETS is native (Buckley et al., 2023). Additionally, this study raised the issue of rural landowners currently lacking a way to access the knowledge or advice needed to successfully improve the biodiversity and conservation value of their farms.

1.3. **Study goals**

Currently there is a lack of available data on bird populations within farmland in New Zealand and none specifically on the impact that kānuka or poplar silvopastures have on bird populations within farms. My study aims to fill a research gap by analysing how kānuka silvopasture affects bird populations on a beef and sheep hill country farm. It will also compare and contrast this to existing poplar-willow silvopastures more widely utilised by hill country farms.

2. Methods

2.1. Study site selection

This study took place in the Wairarapa district in the lower North Island, New Zealand. To investigate how birds used a farmed landscape and responded to low density kānuka plantings, I planned to make bird counts in the following land cover categories:

1) **Low density kānuka:** Areas with kānuka growing at densities low enough to allow for pasture growth and sheep and cattle grazing. Other trees species must be not present or are only present at low numbers (see Section 2.1.2 "Generating sample locations") (**Figure 2.1a**).
2) **High density native bush**: Areas with mixed native bush consisting of kānuka mixed with a range of other species. These sites could not be grazed regularly due to the density of tree species and steep slopes creating a barrier for stock access. The purpose of this category was to provide the closest possible analogy to native bush within the farmed landscape **(Figure 2.1b).**
3) **Poplar/Willow:** As these are common silvopastoral species used to control erosion within hill country farms, this category has been included to analyse the difference between native and exotic plantings. These sites have similar requirements to low density kānuka; they feature little undergrowth or tree diversity and have grazed pasture underneath the canopy (**Figure 2.1c**).
4) **Open pasture:** Open pasture with no trees present within the sampling radius were used to set a baseline for birdlife on farms if no plantings are present **(Figure 2.1d**).

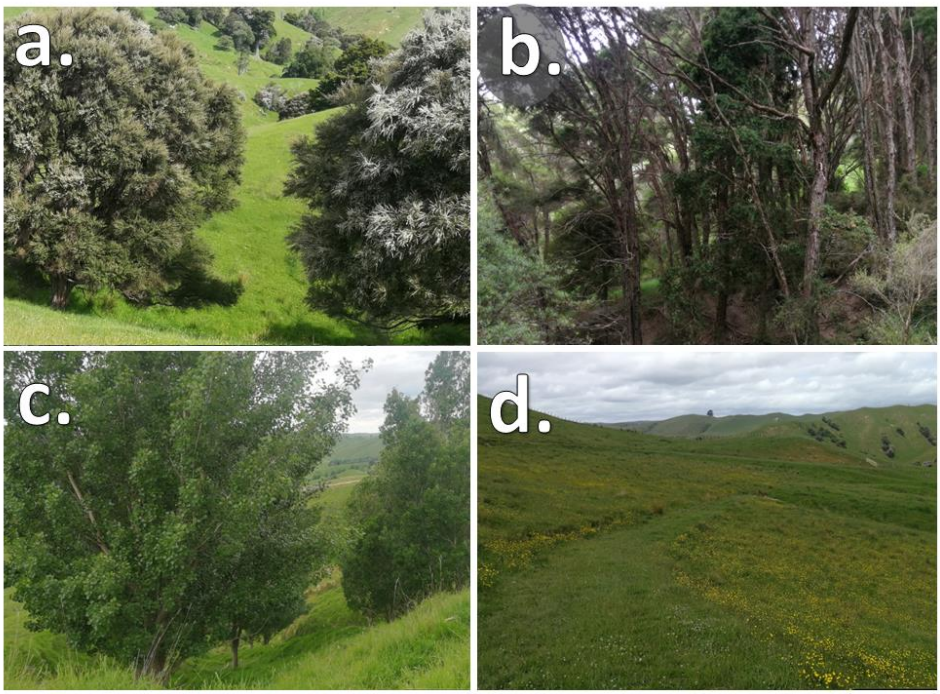


Figure 2.1 *Examples of each landcover type. (a) Low Density Kanuka, (b) High Density Kanuka, c) Poplar/Willow and d) Open Pasture.*

To select an appropriate farm for the study with the targeted land cover types represented, an existing tree distribution dataset was examined (Spiekermann et al., 2021). The dataset was for an 843 km^2 area of the Wairarapa, Wellington Region. It used aerial orthophotos and LiDAR data, with field validation, to identify and map out individual trees and their likely species or genus. It resulted in a single datapoint for every detectable (i.e., large or established) tree. The individual datapoints were classified into one of four categories: poplar/willow, eucalyptus, kānuka, and pine. These categories represent the most abundant tree species groups located in the region. Less abundant tree species in the region were assigned to one of the four categories, with native species falling into the "Kānuka" category, since kānuka was the dominant native species. While the chosen categories do lose some species information, these broad groupings were deemed suitable for the purposes of the current study.

To identify suitable farms within the area, the tree distribution dataset was visually assessed in ArcGIS Pro 2.8.0, with tree species relevant to this study (poplar-willow and kānuka) colour coded. A suitable farm located within the study area (**Figure 2.2**) was identified based on its

mixture of readily accessible high density native bush, low density kānuka, poplar/willow plantings and open pasture habitat types contained within the single farm/station boundary.

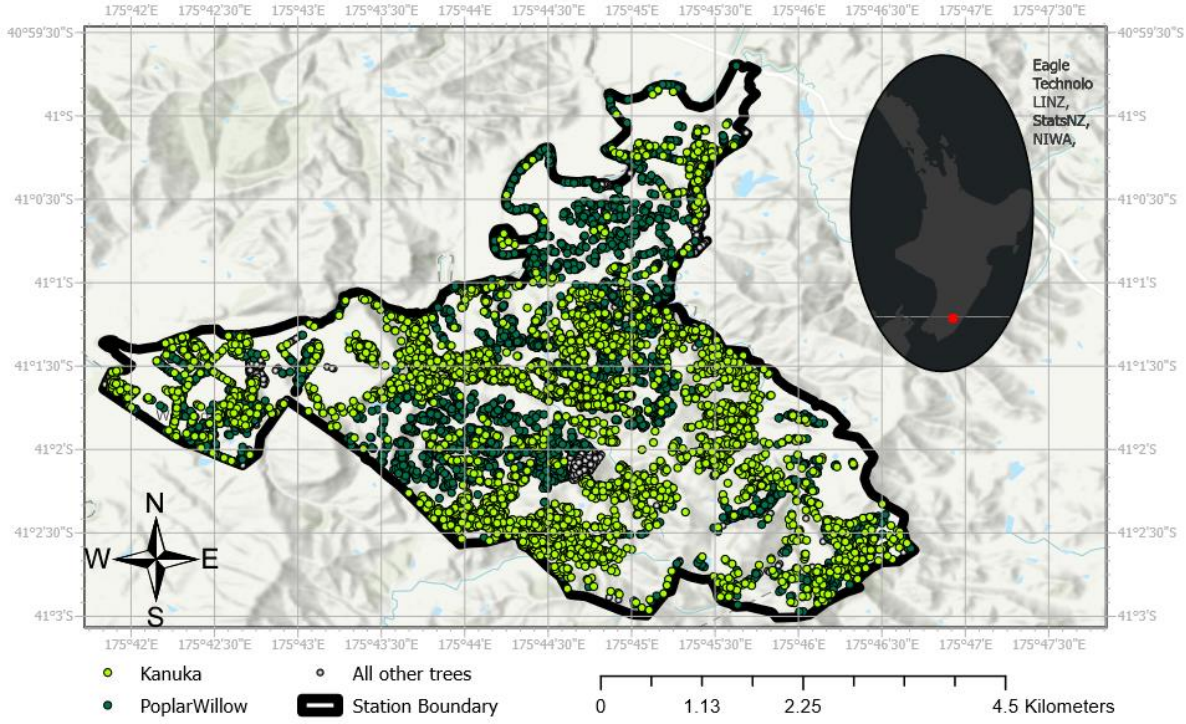


Figure 2.2 *Map of the study site, showing a good spread of kānuka trees, poplar/willow plantings and areas of open pasture.*

Description of study site

The 1700 ha farm station selected for the study (Figure 2.2) is a productive hill country sheep and beef agricultural enterprise, aligning with the focus of previous studies involving low density kānuka plantings for silvopastoral use (Mackay-Smith et al., 2022). The farm is located 10 km southeast of Masterton at 41°S, 175°E and is predominantly steep, hilly topography interspersed with two large gullies where most of the remnant native forest persists. A regional-scale soil map indicates the soils in this area are a mixture of pallic, gley and brown (**Table 2.1**) (Manaaki Whenua - Landcare Research, 2019). The climate of the site has been described as seasonally dry, with summer droughts being a regular occurrence (Rosser & Ross, 2011). According to long-term data from the NIWA cliFlo database, average annual rainfall nearby (climate station 2613, elevation 111 m above sea level, approximately 4 km away from site) from 1991–2021 was 871.6 mm (National Institute of Water and Atmospheric Research, 2011).

Table 2.1 *Soil types most likely present at the study site according to regional scale data sourced from S-map online.*

Smap name	Depth	Texture	Drainage class	PAW (mm)	Order
Templeton_1a.3	Deep	Silt	Moderately well drained	156.8	Pallic
Taihape_10a.1	Moderately Deep	Silt	Poorly drained	126.6	Gley
Bushcroft_16a.1	Deep	Silt	Imperfectly drained	153.2	Brown

Generating sample locations

To generate bird count sampling locations that met the requirements of the study and minimised bias, the following steps were undertaken:

Step 1: The "Point Density" tool in ArcGIS was used to generate tree-density rasters for the four vegetation categories. Density was calculated on a cell-by-cell basis (cell size set to 10) as the number of trees per hectare within a radius of 50 m of each cell, which was to be the same size as the planned sampling radius. This radius was deemed to provide a suitable distance for establishing bird count locations, because 50 m was deemed to be the maximum distance from which an observer could reliably identify birds in the study area (see below).

The four categories were defined as follows in the model:

1. Low Density Kānuka: Kanuka densities with <18 trees per hectare and other tree densities of <2 trees per hectare.
2. High Density Kānuka: Kānuka densities with >18 trees per hectare and there was no restriction on density of other tree species within the radius. The cut off point of >18 trees per hectare was decided based on the natural breaks/jenks options in ArcGIS and later confirmed with site visits.
3. Low Density Poplar/Willow: Poplar-willow densities with >1 trees per hectare and all other tree densities <2 trees per hectare.
4. Open pasture: All tree species were at 0 density.

Step 2: After density values were added to the map, the ArcGIS "Create Random Points" tool was used to create a large range of randomly generated potential bird count sites within the study area (**Figure 2.3a**; pink circles). These random points were then overlain with the density values given in accordance with each of the four categories and the "Extract Values to Points" tool was used to extract the tree density raster values from Step 1 to each of the random points (**Figure 2.3b**).

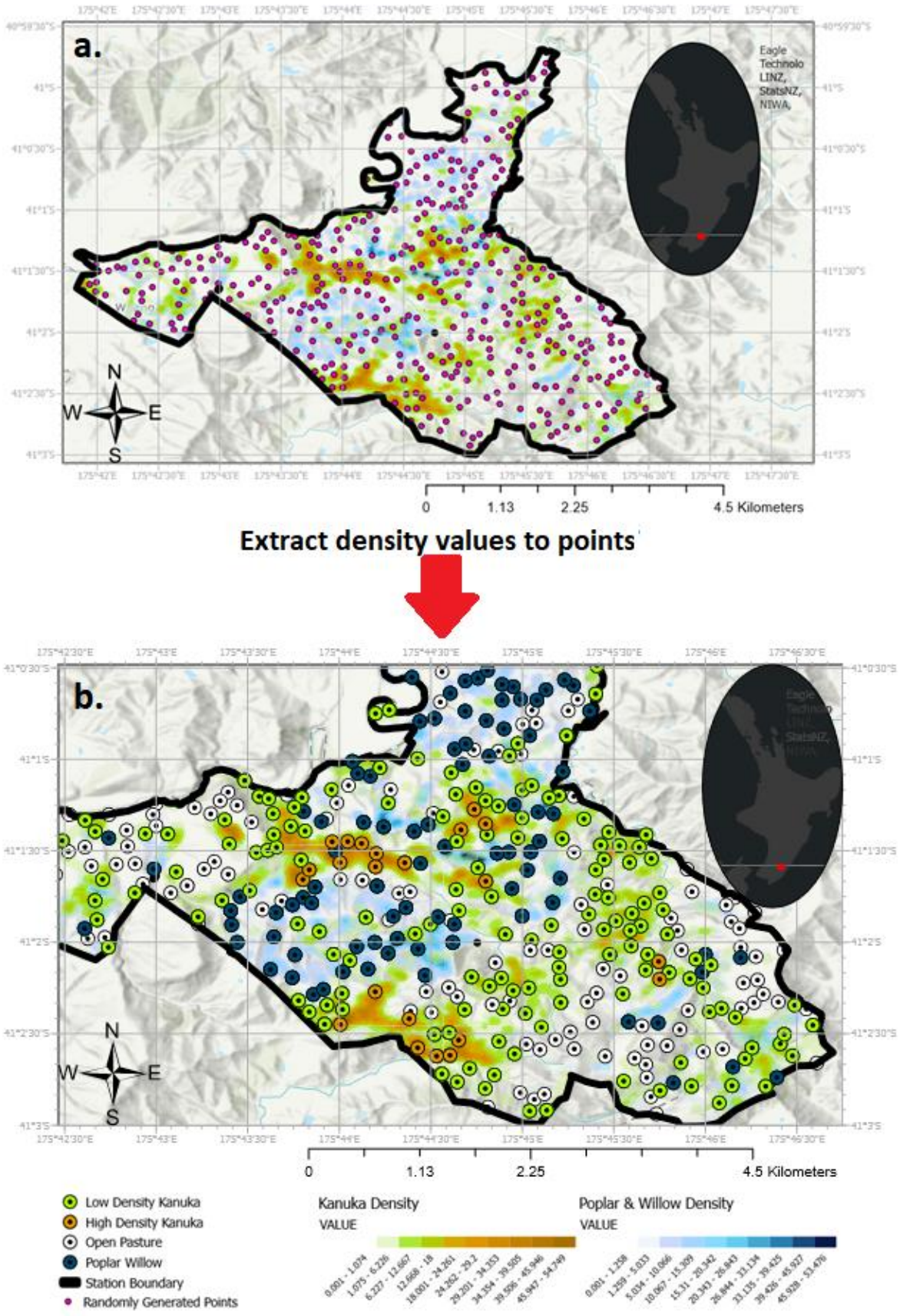


Figure 2.3 *(a) Randomly generated points overlaying densities of kanuka (orange/green) and poplar/willow (blue); (b) random points sorted into one of the four landscape categories.*

Step 3: All random points that did not clearly fit one of the four category definitions were removed, along with any points that would not be practicable to access. After this process was complete, a random number generator was used to select 35 potential research site points within each category, with the exception of High Density Native Bush. High Density Native Bush only covered a very small portion of the farm, so in total only 27 sites were able to be generated.

Step 4: After the potential sampling sites were identified, a field visit was conducted to assess each site for its suitability for the fieldwork, and sites that were inaccessible or generated through modelling errors were removed from the map and subsequent study. The final number of sampling sites was 32 Low Density Kānuka, 22 High Density Native Bush, 30 Poplar/Willow and 30 Open Pasture sites (**Figure 2.4**).

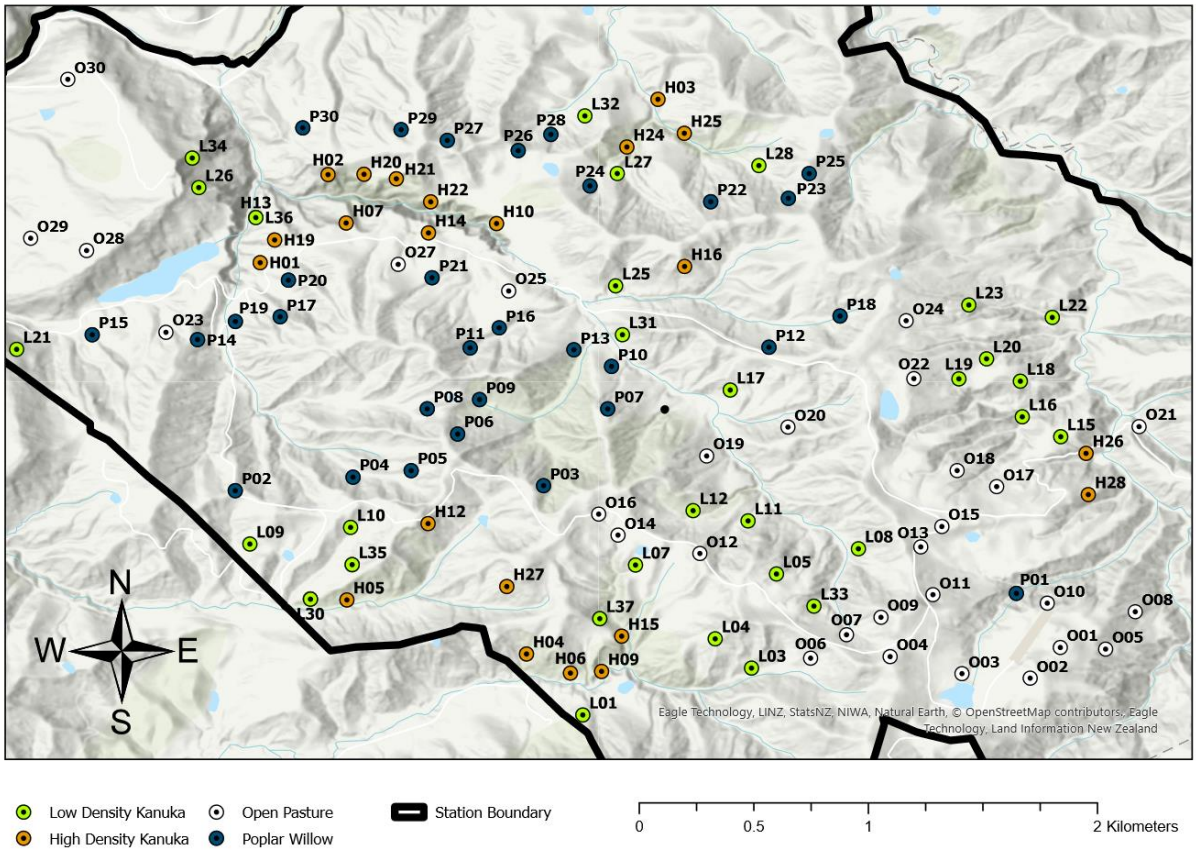


Figure 2.4 *Location of sampling sites. Sites beginning with "L" and "H" represent Low and High Density Kānuka sites respectively, sites beginning with "P" represent Poplar/Willow and sites beginning with "O" are open Pasture. Numbering was assigned through GIS during the process of filtering sites into categories and is not significant beyond identifying individual sites.*

2.2. Bird counts

The bird count sampling method used for the study was a modified version of the 5-minute bird count in which I recorded every bird heard or seen over a 5-minute period, with supplementary observations of behaviour, direction of movement, and environmental features of the birds recorded location (Hartley & Greene, 2012). Additional visual observations made on site during each count included weather/visibility, temperature, precipitation, and windspeed (see **Appendix A: Example of data collection sheet** for scale). These were recorded during the 2-minute stand-down period (designed to allow birds to resettle if disturbed by surveyor movement) at the start of each count. Unlike regular 5-minute bird counts which do not have a cut off distance, the radius in which birds were counted in this study was limited to 50 m. This was due both to the high density kānuka category only covering narrow margins of bush and that the primary focus of the research was on hill country (steep slopes) and forested areas with limited sight lines.

All surveys were conducted by the same experienced bird watcher who received additional specialist instruction on bird identification over the 3-month period leading up to the survey date. Observations took place at the coordinates of each sampling site (**Figure 2.4**) over the period of October 2021–December 2021.

Sampling times were in the morning between 7 am and 12 pm, and in the afternoon between 3 pm and 7 pm (when birds are more vocally active) and sites were generally sampled three times over the study period to capture data at different times of day. To do this, a spreadsheet was set up dividing sampling times into three periods: early morning (7:00–10:30 am), midday (10:30 am–12:00 pm, 3:00–4:30 pm) and evening (4:30–7:00 pm) and each site was marked off as surveys were completed within these time periods. Due to the time constraints and challenges of conducting research on a working farm, some sites were only sampled twice and there were a small number of sites that were sampled twice at similar time periods. Overall, 103 sample locations were sampled three times, 10 locations were sampled twice, and one location was sampled four times. These inconsistencies were taken into account when creating statistical models for the study.

2.3 Statistical analysis

Data aggregation for different analyses

After the data collection period, all bird counts were aggregated into a single document, alongside additional information on each survey site, including landcover category (Open Pasture, Poplar/Willow, Low Density Kānuka, or High Density Kānuka), poplar/willow, kānuka, and combined tree density values in units of "trees per hectare", number of times the survey site had been counted, and survey date. A single black-backed gull (*Larus dominicanus*) flying over was removed from the dataset as it was not considered to be part of the farm bird community.

Birds were then categorised by New Zealand native status and assigned to three categories: native (including endemics as they are a subcategory of natives), exclusively endemics, and introduced. Classification of birds into status groups was done in reference to information provided by "The Field Guide to the Birds of New Zealand" (Heather et al., 2015).

The total number of birds counted within each count was then calculated for each status category. When this was done the total number of birds for each site was calculated, to give a value for numbers of birds counted across the survey period.

The bird count data were analysed to evaluate if there were statistically significant differences in bird numbers between the different land cover categories using two methods: Linear models to explore the relationship between landcover, tree density values, and bird counts, and non-metric multidimensional scaling to explore community responses to land cover variation.

Generalised Linear Mixed Effects Modelling

Generalised linear mixed effect models (GLMs) were used to test the influence of land cover category and tree densities on bird counts. These models enable the inclusion of random and fixed variables and can account for multiple observations at the sampling sites.

Modelling was done in R version 4.3.3, using the package lme4 (Function = glm, model family = poisson) to provide the primary code and ggplot2 was used to create graphs used for additional visual presentation. Prior to the modelling beginning, the plugin "forcats" was used to reorder the landcover categories in the following way: 1) open pasture, 2) poplar/willow 3) low density kānuka 4) high density kānuka. This was done to ensure "open pasture" would work effectively as the zero tree-density control, as GLM models always treat the first fixed variable as the intercept against which all other models are compared.

The initial models were structured to test different combinations of the fixed variables (land cover category, poplar/willow tree density, kānuka tree density and combined tree density) and covariates (weather/visibility, temperature, precipitation, site location, and survey day). The latter two variables were used to account for the uneven numbers of survey repeats for each site and different conditions between the first and last survey day respectively. A fifth random variable (wind speed) was initially trialled; however, this variable was missing a significant number of entries resulting in skewed counts in which some blocks of sites or dates were missing from analyses that involved wind speed. To evaluate the impact of this reduction, models were run using the reduced data set with wind speed included as a variable, and the same data set but without wind speed included as a variable. There was no substantial difference between models with and without wind speed and therefore wind speed was not used in further analyses, enabling the whole data set to be used.

To compare different combinations of model variables, modelling started with the most complicated models containing all factors and covariates before being progressively simplified towards models that had the lowest (and therefore most optimal) scores in the Akaike Information Criterion (AIC). Models within 2 AIC units of the lowest value were considered meaningful.

After AIC had been taken into consideration, the final set of models were assessed for best fit to the purpose of the research question. Priority was given to low AIC models that contained poplar/willow and kānuka densities over those that featured combined tree densities. This was because specifying tree species gave more detailed results than what could be provided by a general density measure.

Additionally, any models that contained covariates that had no significant impact on results were removed in favour of similar models that only utilised covariates that impacted results

in a meaningful way. The inclusion of environmental variables (weather/visibility, temperature, and precipitation) made no effective improvement to models that did not include them (these were probably partly accounted for by 'day' in the models) so these models are not presented in the results. Random variables that were retained were the day the survey was recorded, and site number.

Fixed variables that were kept were the landscape category, kānuka density, and poplar/willow density, with combined/all tree density being rejected from the final models due to it not adding any additional useable information beyond what was provided by the tree species variables.

The output of the models includes differences in bird counts between the land cover categories and any influence of tree density on bird counts, when controlling for the other factors. Output for fixed effects gives the IRR (incidence rate ratio) on a log scale, which were exponentiated using the model_parameters function of the package "parameters". The results therefore give the change in predicted birds counted, as a proportion, from the pasture category, when holding other effects constant. For example, "Category (Low-density Kānuka)" gives than expected change from pasture to low density kānuka, while "Kānuka density" gives the predicted increase in bird count for each additional increase in kānuka trees per hectare.

To gain a deeper understanding of how different land cover categories and planting densities affected different types of birds, the modelling process was repeated for subsets of native birds, endemic birds, and introduced birds.

Graphing of bird counts in Chapter 3 was done using GGPlot2 in R, with the jitter function used to aid visualising overlapping data points in scatter plots (Wickham, 2016).

Community Analyses

While GLMs are good for analysing the responses of broad groupings of birds to different landscape categories, they do not identify the communities or individual species that are most strongly associated with certain land covers or tree densities. To examine the communities present on site, Non-Metric Multi-Dimensional Scaling (NMDS) was used to visualise the similarities between the bird communities within each landscape category, as well as the

dissimilarities between differing landscape categories. This analysis uses the species composition and relative abundance at each site to characterise the community present at each site, and to test whether there are differences in species composition that are associated with land cover.

NMDS was done using PRIMER 7.0 with the PERMANOVA+ package, with the Bray-Curtis Dissimilarity being used to quantify results. To prepare the dataset, individual species counts were averaged for each site. This effectively reduced noise by decreasing the number of individual points on the NMDS visualisations and removes the issue of there being different numbers of counts across sites.

NMDS data were first generated in a visual form via mapping individual sample locations onto a scaled grid with each point colour coded in accordance with what landscape category the site fell under. This provided a visual display of how similar sampling site communities were, with tightly clustered points indicating close community relationships and widely spaced ones representing more distant associations. This visualisation was also overlain with the 11 most populous bird species, with their position on the grid in relation to each other showing how closely associated individual species were to each other.

After the NMDS visualisation was created, the program SIMPER (Similar Percentage) was used to tabulate the community similarity values within each land cover category and then the dissimilarity values between the land cover categories.

The first analyses of the similarity within categories provided information of the average similarity between the sites in that category (in which a higher average similarity value represents more uniform communities across sites within that category) and also the bird species that contributed most heavily to each landcover category (giving information on these individual species' average abundance and percentage contribution to the community).

The next analyses evaluated the average dissimilarity between each land cover category and every other land cover category. This generated six pair-wise comparisons of the land cover categories (e.g., Low Density Kānuka and High Density Kānuka), where a larger average dissimilarity value represents a larger difference between communities. These analyses also provided information on the bird species that contributed the most to how different landcover communities were from each other. Birds that had higher abundance dissimilarities between

categories were the ones that contributed the most towards the configuration of different communities.

3. Results

3.1. Total bird counts

Over the duration of the research period, 333 bird surveys were completed, counting 2726 birds, including 542 endemic, 413 native and 1728 introduced individuals (**Table 3.1**; this gives all scientific names). The High Density Kānuka category accounted for the most birds (926), with the Open Pasture category having the least (388). In total, 30 species were identified, with European Starling being present in the greatest numbers. In general, native, and endemic species occurred in kānuka categories at much higher frequencies, with introduced species displaying more variation across all landcover categories (**Figure 3.1**).

***Table 3.1**: Summary of bird species identified on farm including total number of birds counted by species, habitat category, and status (endemic, native or introduced). Numbers refer to the total number of individuals counted across all surveys in each category.*

Species		High Density Kānuka	Low Density Kānuka	Open Pasture	Poplar/Willow	Total
Endemic		**256**	**171**	**73**	**42**	**542**
Bellbird	*Anthornis melanura*	3	1	0	0	4
Fantail	*Rhiphidura fuliginosus*	83	44	0	19	146
Grey Warbler	*Gerygone igata*	131	86	0	4	221
Kererū	*Hemiphaga novaeseelandiae*	3	2	0	0	5
New Zealand Pipit	*Anthus novaeseelandiae*	4	17	68	8	97
Paradise Shelduck	*Tadorna variegata*	2	2	5	2	11
Sacred Kingfisher	*Todiramphus sanctus*	9	6	0	5	20
Tūī	*Prosthemadera novaeseelandiae*	21	13	0	4	38
Native		**230**	**128**	**24**	**31**	**413**
Pūkeko	*Porphyrio melanotus*	0	0	1	0	1
Shining Cuckoo	*Chrysococcyx lucidus*	9	1	0	1	11
Silvereye	*Zosterops lateralis*	202	104	3	19	328
Swamp Harrier	*Circus approximans*	4	1	1	0	6
Welcome Swallow	*Hirundo neoxena*	15	22	18	10	65
White-faced Heron	*Egretta novaehollandiae*	0	0	1	0	1
Introduced		**432**	**445**	**287**	**564**	**1728**
Australian Magpie	*Gymnorhina tibicen*	7	10	35	21	73
Blackbird	*Turdus merula*	51	41	1	36	129
California Quail	*Callipepla californica*	1	1	1	0	3
Chaffinch	*Fringilla coelebs*	83	59	2	100	244
Dunnock	*Prunella modularis*	10	14	0	6	30
Eastern Rosella	*Platycercus eximius*	6	8	0	23	37
Eurasian Skylark	*Alauda arvensis*	2	17	84	21	124
European Starling	*Sturnus vulgaris*	89	101	67	104	361
Goldfinch	*Carduelis carduelis*	51	42	33	71	197
Greenfinch	*Chloris chloris*	21	15	13	19	68
House Sparrow	*Passer domesticus*	26	21	6	51	104
Mallard Duck	*Anas platyrhynchos*	1	8	3	1	13

Species		High Density Kānuka	Low Density Kānuka	Open Pasture	Poplar/Willow	Total
Peafowl	*Pavo cristatus*	5	0	0	0	5
Song Thrush	*Turdus philomelos*	23	12	2	12	49
Turkey	*Meleagris gallopavo*	4	0	3	0	7
Yellowhammer	*Emberiza citrinella*	52	96	37	99	284
Unknown		**8**	**18**	**4**	**13**	**43**
Unidentified		8	18	4	13	43
Grand Total		**926**	**762**	**388**	**650**	**2726**

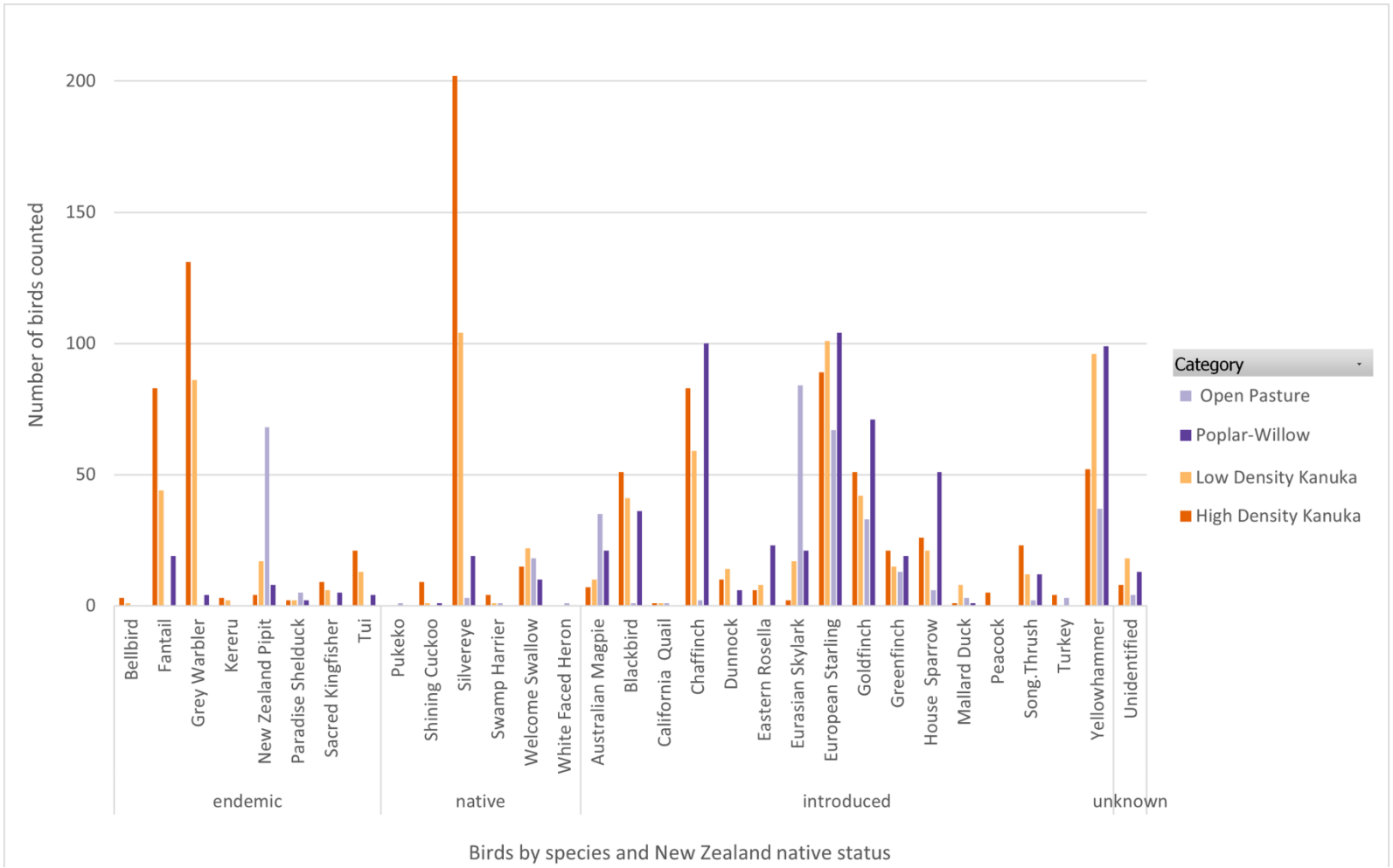


Figure 3.1 *Total bird species counts grouped by Endemic, Native and Introduced species by habitat category classed as Open Pasture, Poplar/Willow, Low Density Kānuka and High Density Kānuka.*

3.2. Relationships of counts to habitat characteristics

Relationships between total bird counts (combining native and introduced species) in the survey and tree densities are plotted in **Figure 3.2**, with different habitat category points distinguished by colour. Bird numbers tended to increase with tree density within habitat categories. The number of birds counted increased as kānuka density increased in the Low Density Kānuka category, followed by the trend line levelling out and results becoming more variable in the High Density category. In Poplar/Willow areas, counts increased more gradually as the density of poplars and willows increased. When evaluated against all tree species combined, the surveys conducted in the kānuka categories consistently had higher bird counts than those in the Poplar/Willow surveys at a similar tree density value. Pasture sites set along the 0-density line, range from having the lowest counts to counts which were similar to the High Density Kānuka category.

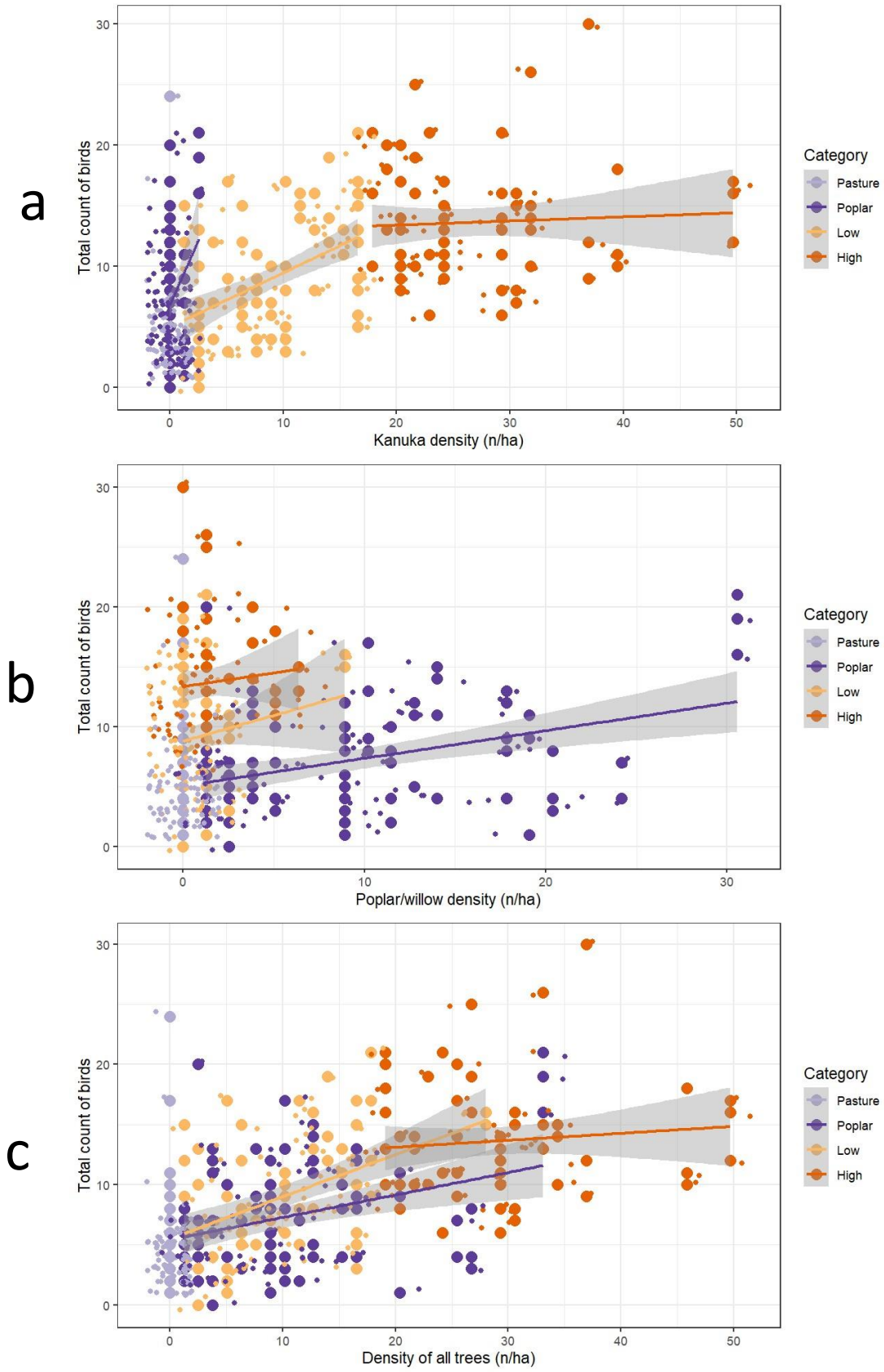


Figure 3.2 *Total count of birds in every survey plotted against the density of kānuka (a), poplar/willow (b), and the combined density of all trees (c). Points are identified by their respective categories. Smoothing curves using the generalised linear model function are shown for each habitat type. The jitter function was used to offset overlapping points.*

Linear mixed modelling confirmed these patterns. Of the candidate models tested, three were similarly supported (AIC 1794.3–1794.9; **Table 3.2**) and each combined the landscape category with some additional combination of tree densities (AllTrees density, Kanuka_dens + PoplarWillow_dens, or Kanuka_dens + PoplarWillow_dens + AllTrees_dens). All three models gave equivalent findings, and results from the model of Category + Kanuka_dens + PoplarWillow_dens are shown in **Table 3.3**. The model predicted that, compared to Open Pasture (the intercept), bird numbers would be 1.65 times higher in Low Density Kānuka habitat (P<0.001) and 1.86 times higher in High Density Kānuka (P=0.003). The Poplar/Willow increase of 1.24 times higher than the intercept was less strongly supported (P<0.1). Additionally, when controlling for differences in habitat categories, bird counts would be expected to increase by 2% for every additional kānuka tree added to the sampling area or by 3% for every poplar or willow tree added to the study zone (P<0.01).

Table 3.2 *Candidate models considered for total bird counts. Category refers to the classification of landcover (Open Pasture, Poplar/Willow, Low Density Kānuka and High Density Kānuka); Kanuka_dens, PoplarWillow_dens and AllTrees_dens refer to the density of trees (per ha) estimated at each count site. All models had Site and Survey Day as random factors. Npar gives the number of parameters, and the lowest AIC scores (those within 2 AIC units of the lowest value) are shaded.*

Model	npar	AIC
Category + Kanuka_dens + PoplarWillow_dens + AllTrees_dens	9	1794.9
Category + Kanuka_dens + PoplarWillow_dens	8	1794.3
Category + Kanuka_dens + AllTrees_dens	8	1796.9
Category + Kanuka_dens	7	1803.2
Category + PoplarWillow	4	1799.6
Category + AllTrees_dens	7	1794.9
Category	7	1808.8
Kanuka_dens + PoplarWillow_dens + AllTrees_dens	6	1806.2
Kanuka_dens + PoplarWillow_dens	5	1804.7
Kanuka_dens	4	1820.9
PoplarWillow_dens	4	1884.6

Table 3.3 *Mixed-model linear analyses of total bird numbers within different landcover categories and additional effects of kānuka and poplar/willow density. IRR displays the ratio rate compared to the intercept.*

Parameter	IRR	SE	95% CI	Z	P
Intercept (Open Pasture)	4.22	0.33	(3.62, 4.92)	18.30	<0.001
Category (Poplar/Willow)	1.24	0.16	(0.96, 1.60)	1.68	0.093
Category (Low Density Kānuka)	1.65	0.19	(1.31, 2.08)	4.25	<0.001
Category (High Density Kānuka)	1.86	0.39	(1.23, 2.81)	2.93	0.003
Kānuka Density	1.02*	0.00718	(1.01, 1.03)	2.74	0.006
Poplar/Willow Density	1.03*	0.00816	(1.01, 1.04)	3.43	<0.001
	*Increase is cumulative with every increase of density unit				

3.3. Natives and endemics

When counts were filtered to comprise only native bird numbers (endemics included) results showed notable differences. As with the combined bird counts, native birds increased steadily with increasing kānuka density in the Low Density Kānuka sites and levelled off in High Density Kānuka Sites (**Figure 3.3a**). In comparison, **Figure 3.3b** showed limited change in native counts as poplar/willow density increased (with the exception of a single low density kānuka site that had some increase in counts) and **Figure 3.3c** demonstrated much higher counts in the kānuka categories than under poplar/willow.

When only endemic birds were counted, relationships between endemic bird counts and tree density displayed a similar pattern to the native birds with a key difference being that the endemic birds appeared to reach a peak in population at approximately 20 kānuka trees/ha (**Figure 3.4a**).

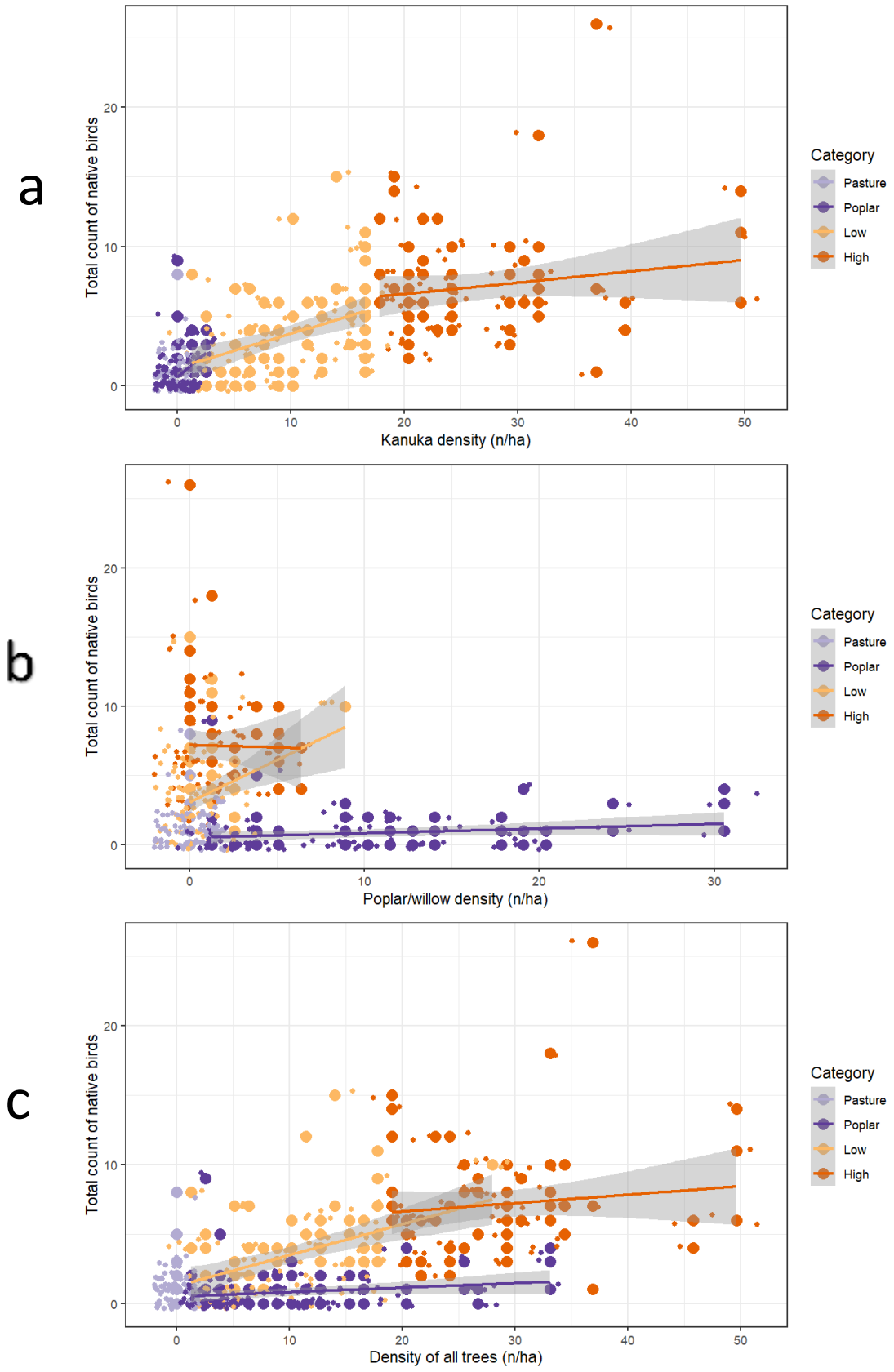
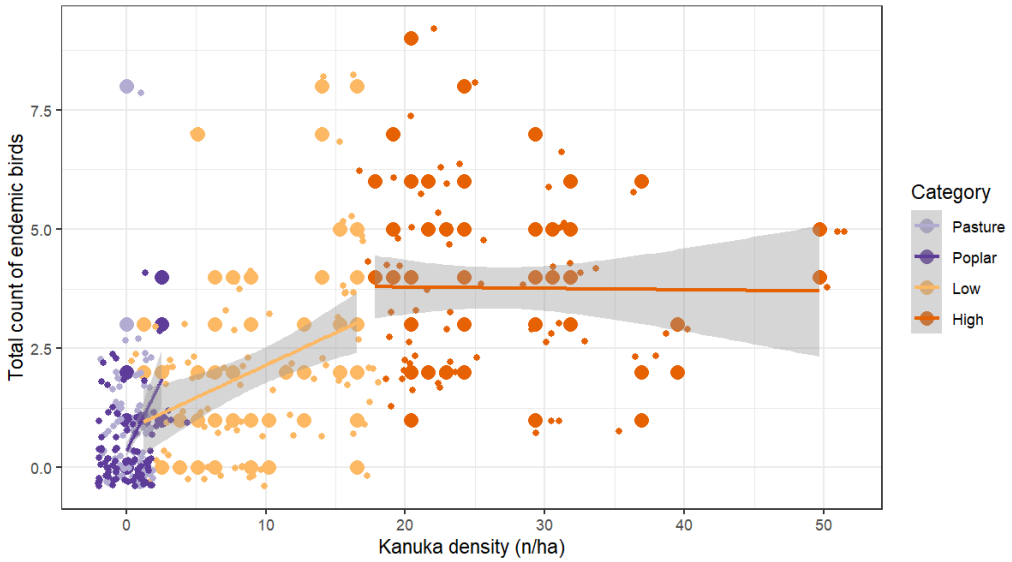
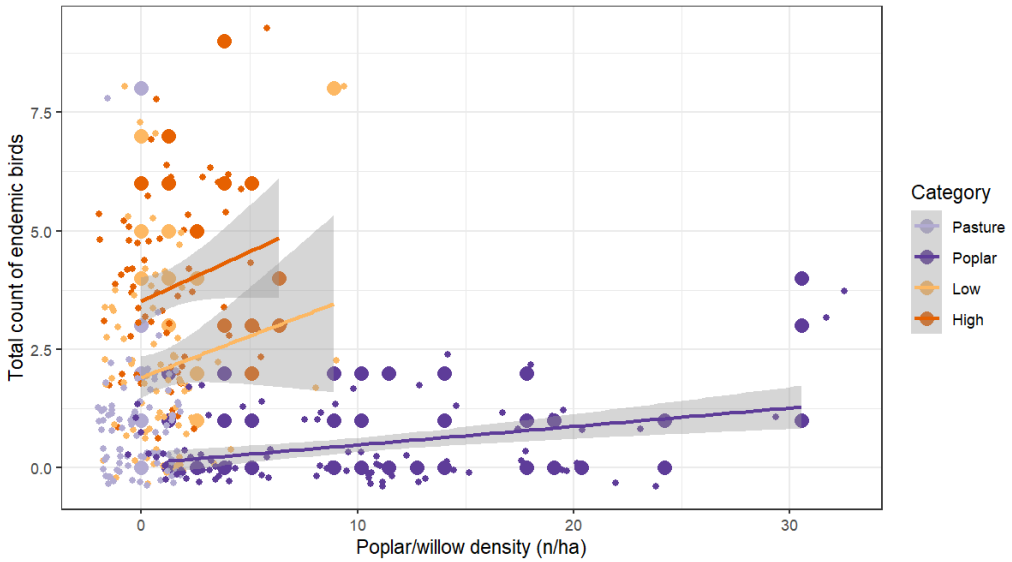


Figure 3.3 *Total count of native birds (including endemics) in every survey plotted against the density of kānuka (a), poplar/willow (b), and the combined density of all trees (c). Points are broken up into their respective categories to demonstrate where each survey took place.*

a



b



c

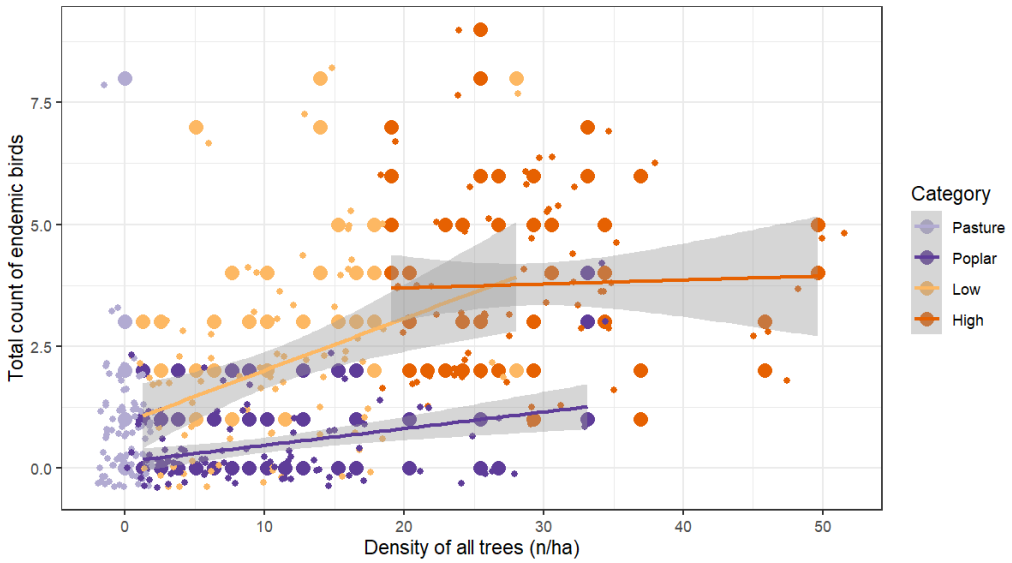


Figure 3.4 *Total count of endemic birds in every survey plotted against the density of kanuka (a), poplar/willow (b), and the combined density of all trees (c). Counts are broken up into their respective categories to demonstrate where each survey took place.*

Linear mixed models were again used to check trends found in plots, with the "Category + Kanuka_dens + PoplarWillow_dens" candidate model being chosen for both native and endemic modelling due to its low AIC value and inclusion of all information relevant to the research (**Table 3.4 and Table 3.5**).

For native bird counts (endemics included) the increase of bird populations with kānuka density was confirmed, as there was a 2.2 times increase in low density kānuka sites compared to open pasture (P<0.001) and a 2.9 times increase in high density kānuka (P=0.001, **Table 3.6**). The poplar/willow category had fewer native birds than open pasture, with poplar/willow counts being 49% of that measured in open pasture (P<0.016). This indicates that native birds have a preference for kānuka over poplar/willow in the farm environment. When controlling for landscape category, however, there was an additional increase in native bird counts as poplar/willow density increases, of 4% increase in native bird numbers for every additional tree present (P<0.016).

A similar trend was shown when only endemic birds are included in the analyses (**Table 3.7**). There were 1.93 times more endemic bird numbers in Low Density Kānuka (P<0.001) compared to open pasture and a 2.59 times increase under high density kānuka (P=0.003). The poplar/willow category displayed an even greater decrease in endemic birds from open pasture than when non-endemic natives were included in analyses, with poplar/willow having only 29% of the numbers of endemics that open pasture had (P<0.001). Once again there was a 6% increase in the number of birds per additional poplar or willow tree present, indicating there is some benefit of poplar/willow presence for endemic bird species (P<0.001).

Table 3.4 *Candidate models considered for native bird counts. Category refers to all landcover categories. Kanuka_dens, PoplarWillow_dens and AllTrees_dens refer to the density of trees (per ha) estimated at each count site. All models had Site and Survey Day as random factors. Npar gives the number of parameters, and the lowest AIC scores (those within 2 AIC units of the lowest value) are shaded.*

Model	npar	AIC
Category + Kanuka_dens + PoplarWillow_dens + AllTrees_dens	9	5151.9
Category + Kanuka_dens + PoplarWillow_dens	8	5150.7
Category + Kanuka_dens + AllTrees_dens	8	5152.2
Category + Kanuka_dens	7	5154.3
Category + PoplarWillow_dens	7	5156.4
Category + AllTrees_dens	7	5150.2
Category	6	5160.4
Kanuka_dens + PoplarWillow_dens + AllTrees_dens	6	5177.0
Kanuka_dens + PoplarWillow_dens	5	5175.0
Kanuka_dens	4	5173.4
PoplarWillow_dens	4	5265.1

Table 3.5 *Candidate models considered for endemic bird counts. Category refers to all landcover categories (Open Pasture, Poplar/Willow, Low-density Kānuka and High-density Kānuka); Kanuka_dens, PoplarWillow_dens and AllTrees_dens refer to the density of trees (per ha) estimated at each count site. All models had Site and Survey Day as random factors. Npar gives the number of parameters, and the lowest AIC scores (those within 2 AIC units of the lowest value) are shaded.*

Model	npar	AIC
Category + Kanuka_dens + PoplarWillow_dens + AllTrees_dens	9	2835.3
Category + Kanuka_dens + PoplarWillow_dens	8	2835.5
Category + Kanuka_dens + AllTrees_dens	8	2839.2
Category + Kanuka_dens	7	2845.7
Category + PoplarWillow_dens	7	2837.1
Category + AllTrees_dens	7	2839.0
Category	6	2847.8
Kanuka_dens + PoplarWillow_dens + AllTrees_dens	6	2868.8
Kanuka_dens + PoplarWillow_dens	5	2867.0
Kanuka_dens	4	2865.1
PoplarWillow_dens	4	2937.2

Table 3.6 *Generalised linear model of native bird populations within different habitat categories and additional effects of kānuka and poplar/willow density. IRR for the intercept displays the mean.*

Parameter	IRR	SE	95% CI	Z	P
Intercept (Open Pasture)	0.07	0.01	(0.05, 0.09)	-18.61	<0.001
Category: Poplar/Willow	0.49	0.13	(0.29, 0.83)	-2.66	0.008
Category: Low Density Kānuka	2.20	0.44	(1.49, 3.25)	3.98	<0.001
Category: High Density Kānuka	2.91	0.98	(1.51, 5.62)	3.18	0.001
Density: Kānuka	1.03*	0.01	(1.01, 1.05)	2.82	0.005
Density: Poplar/Willow	1.04*	0.02	(1.01, 1.07)	2.42	<0.016
*Increase is cumulative with every increase of density unit					

Table 3.7 *Generalised linear model of endemic bird populations within different habitat categories and additional effects of kānuka and poplar/willow density. IRR displays the ratio rate compared to the intercept.*

Parameter	IRR	SE	95% CI	Z	P
Intercept (Open Pasture)	0.10	0.01	(0.07, 0.13)	-16.49	<0.001
Category (Poplar/Willow)	0.29	0.09	(0.15, 0.53)	-4.01	<0.001
Category (Low Density Kānuka)	1.93	0.38	(1.32, 2.83)	3.37	<0.001
Category (High Density Kānuka)	2.59	0.82	(1.39, 4.82)	3.00	0.003
Kānuka Density	1.02*	0.01	(1.00, 1.04)	1.92	0.055
Poplar/Willow Density	1.06*	0.02	(1.03, 1.10)	3.66	<0.001
*Increase is cumulative with every increase of density unit					

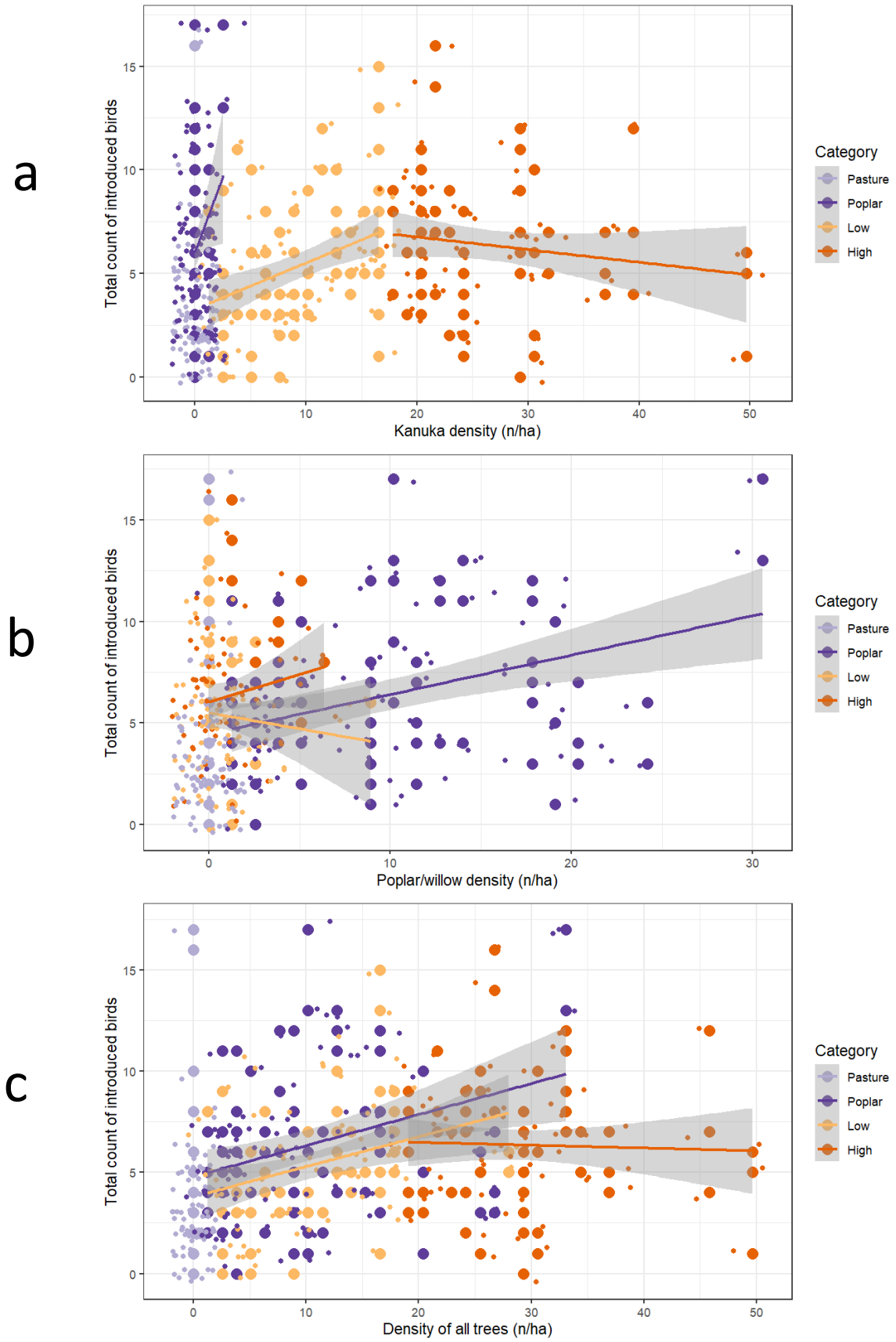


Figure 3.5 *Total count of introduced birds in every survey plotted against the density of kānuka (a), poplar/willow (b), and the combined density of all trees (c). Counts are broken up into their respective landcover categories to demonstrate where each survey took place.*

3.4. **Introduced birds**

When bird counts were filtered to only include introduced species, the number of birds still increased with kānuka density initially, however there was a decline in numbers counted within higher density sites (**Figure. 3.5a**). Both poplar/willow and open pasture categories recorded higher counts compared to either kānuka category and **Figure.3.5b** demonstrates a possible trend towards introduced bird populations increasing with poplar/willow density.

Linear modelling confirmed some of these trends. Once again, the candidate model "Category + Kanuka_dens + PoplarWillow_dens" was chosen due to its lower AIC and best model fit (**Table 3.8**). This model confirmed that in contrast to the native and endemic bird count results, introduced bird numbers increased at similar levels over different landcover categories, with Poplar/Willow counts 1.47 times higher than the Open Pasture and Low Density Kānuka increasing by 1.45 times higher (**Table 3.9**).

Additionally, although the trend of decreasing introduced bird populations at higher kānuka densities wasn't evident in the statistical analyses, introduced bird counts were 1.52 times higher when comparing High Density Kānuka to Open Pasture, which was less of an increase than with the native bird populations. Tree density results also displayed an interesting trend, with poplar/willow density displaying an additional 3% increase in introduced bird counts per every extra tree present, compared to kānuka density, where no significant additional increase in birds was measured with increased kānuka density.

Table 3.8 *Candidate models considered for native bird counts. Category refers to classification of landcover (open pasture, poplar/willow, low-density kānuka and high-density kānuka); Kanuka_dens, PoplarWillow_dens and AllTrees_dens refer to the density of trees (per ha) estimated at each count site. All models had Site and Survey Day as random factors. Npar gives the number of parameters, and the lowest AIC scores (those within 2 AIC units of the lowest value) are shaded*

Model	npar	AIC
Category + Kanuka_dens + PoplarWillow_dens + AllTrees_dens	9	8547.3
Category + Kanuka_dens + PoplarWillow_dens	8	8545.3
Category + Kanuka_dens + AllTrees_dens	8	8545.9
Category + Kanuka_dens	7	8551.2
Category + PoplarWillow	7	8544.4
Category + AllTrees_dens	7	8545.1
Category	6	8550.6
Kanuka_dens + PoplarWillow_dens + AllTrees_dens	6	8551.5
Kanuka_dens + PoplarWillow_dens	5	8549.5
Kanuka_dens	4	8571.9
PoplarWillow_dens	4	8567.1

Table 3.9 *Generalised linear model of introduced bird populations within different landcover categories and additional effects of kānuka and poplar/willow density. IRR displays the ratio rate compared to the intercept.*

Parameter	IRR	SE	95% CI	Z	P
Intercept (Open Pasture)	0.19	0.02	(0.16, 0.23)	-18.27	<0.001
Category (Poplar/Willow)	1.47	0.21	(1.11, 1.94)	2.67	0.008
Category (Low Density Kānuka)	1.45	0.20	(1.11, 1.91)	2.71	0.007
Category (High Density Kānuka)	1.52	0.39	(0.93, 2.51)	1.66	0.096
Kānuka Density	1.01*	0.00864	(0.99, 1.03)	1.06	0.291
Poplar/Willow Density	1.03*	0.00906	(1.01, 1.04)	2.89	0.004
	*Increase is cumulative with every increase of density unit				

3.5. Community analyses

Although linear mixed model analyses are effective for analysing broad trends in the data, they are unable to account for the unique community make-up of each habitat. To examine communities of species and their preferences for particular land cover categories, type multidimensional scaling and SIMPER analyses were used to compare habitats and categorise in terms of what species were most strongly associated with specific land cover categories.

Multidimensional scaling

A non-metric Multidimensional scaling mapped associations between different habitat categories and showed that low and high density kānuka were predictably closely associated with each other, with low density kānuka showing less dense clustering and some association with the poplar/willow category (**Figure. 3.6**). Open pasture was the most distinct of all land cover categories, having very limited overlap with all the forested habitats.

These analyses also show the community relationships between the 11 most frequently counted bird species on site (**Figure. 3.6**). Noticeably, the majority of native bird species (tūī, silvereye, grey warbler and fantail) are closely associated with one another, while the native

pipit is associated with other common pasture dwelling bird species such as skylark and magpie. Other exotic species such as starling, yellowhammer, blackbird and chaffinch, are not associated with each other, indicating their own separate place within the community relationships.

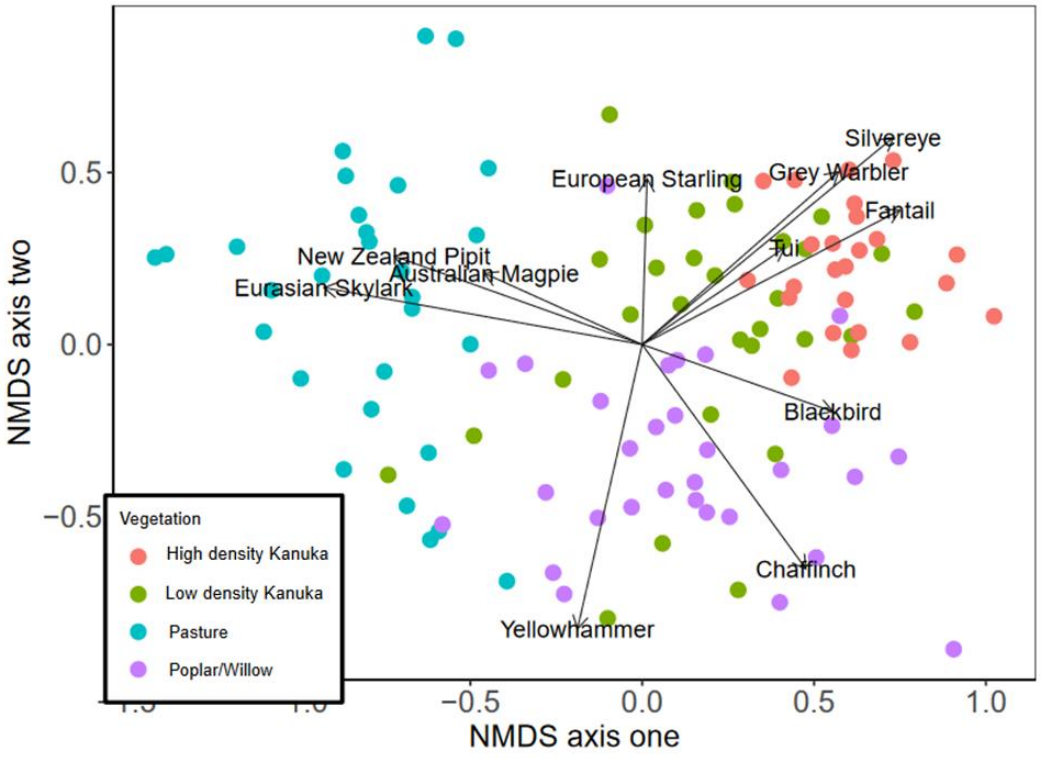


Figure 3.6 *Non-metric Multidimensional scaling displaying community relationships. Category symbols represent community relationships between individual sampling sites. Radial spokes display individual bird species associations.*

SIMPER Analysis

The SIMPER analysis displays what species had the largest contribution to each habitats community make up and the similarities between each group (**Table 3.10**). Yellowhammer, Chaffinch, and Starlings each appeared in three out of four categories, with their outsized contribution to each community likely the result of their general abundance onsite. Of the native birds, silvereye and grey warbler featured heavily in both kānuka categories, with Fantail contributing to 11% of the community make up in high density sites. Open pasture

dwelling pipits appeared to be the only native bird species to influence a category where kānuka was not abundant.

On average, high density kānuka had the highest similarity score, which is likely a reflection of both the smaller number of sites across a geographically smaller area and the unique habitat present on these sites that were used as native bush analogues.

Table 3.10 *SIMPER analyses of each individual landcover category. AV.SIM is the average similarity of each individual species, CONTRIB% is the percentage contribution to the land cover category and CUM% is the cumulative percentage.*

Category	Species	Average Abundance	Av.sim	Contrib%	Cum.%
Open Pasture *Average similarity: 39.38*	Skylark	24.20	13.04	33.11	33.11
	Pipit	20.76	11.93	30.28	63.39
	Yellowhammer	13.60	4.95	12.56	75.96
Poplar-Willow *Average similarity: 39.60*	Yellowhammer	17.10	9.69	24.47	24.47
	Chaffinch	15.20	8.75	22.10	46.57
	Goldfinch	13.42	5.81	14.67	61.24
	Starling	11.69	4.97	12.55	73.79
Low Density Kānuka *Average similarity: 42.49*	Yellowhammer	16.59	9.02	21.24	21.24
	Silvereye	11.72	6.64	15.62	36.85
	Grey Warbler	11.49	6.34	14.93	51.78
	Starling	11.12	4.74	11.16	62.94
	Chaffinch	8.42	4.21	9.90	72.84
High Density Kānuka *Average similarity: 58.90*	Silvereye	19.67	14.56	24.72	24.72
	Grey Warbler	14.78	10.94	18.57	43.30
	Fantail	9.60	6.48	11.00	54.30
	Starling	9.86	5.74	9.74	64.04
	Chaffinch	8.25	5.53	9.40	73.44

SIMPER Comparisons between different landcover categories

SIMPER was also used to compare the differences between communities in each different habitat type, with **Table 3.11** demonstrating the similar percentage comparisons between different habitats. When Low Density Kānuka bird communities were compared against other

landcover categories, it was found that Open Pasture was the most dissimilar to Low Density Kānuka, with a dissimilarity score of 77.50%, while High Density Kānuka was most similar, with the dissimilarity score being only 54.25% (**Table 3.11**).

When compared to High Density Kānuka, native bird species were found to be less abundant in Low Density Kānuka, while introduced yellowhammers, starlings and finches were more common. This pattern was largely reversed when comparing Low Density to Poplar/Willow as although finches Yellowhammers and Starlings were abundant in both categories, they were noticeably more abundant in Poplar/Willow. Additionally, native grey warblers and silvereyes were barely apparent in the Poplar/Willow landcover category compared to the high levels of abundance in the Low Density Kānuka category.

Open Pasture communities looked very different from other land cover categories, with Pipits the only abundant native species present. Exotic Skylarks were also present in high numbers and consistently scored the highest species dissimilarity percentage across all landcover comparisons where open pasture featured. Another notable feature of open pasture communities in **Table 3.11** are the fact that Yellowhammer and Starlings had higher average abundances in low density kānuka and poplar/willow, despite being regularly associated with open pasture.

Comparing High Density Kānuka abundances to Open Pasture and Poplar/Willow had unsurprising results, as bush dwelling native Fantails, Silvereyes and Grey Warblers all had very high average abundances in High Density Kānuka and little to no abundance in Poplar/Willow and Open Pasture (**Table 3.11)**. Exotic bird species were also consistently higher in abundances in Open Pasture and Poplar/Willow, with the exception of Chaffinches that only had a 1.02 average abundance score in Open Pasture when compared to 8.25 in High Density Kānuka.

Table 3.11 *SIMPER comparisons between different landcover categories. Average dissimilarity is the average percentage of difference between the species communities of the categories being compared.*

Group Comparisons	Species	Low Density Kānuka Average Abundance	High Density Kānuka Average Abundance	Average Dissimilarity (species)
Low Density Kānuka + High Density Kānuka *Average dissimilarity:* 54.25	Yellowhammer	16.59	6.37	6.18
	Silvereye	11.72	19.67	5.94
	Starling	11.12	9.86	5.23
	Grey Warbler	11.49	14.78	4.70
	Fantail	4.89	9.60	3.62
	Chaffinch	8.42	8.25	3.47
	Goldfinch	6.91	4.44	3.20
	Blackbird	4.34	6.65	2.78
	Sparrow	2.74	2.38	2.05
	Unidentified	3.78	0.78	2.00
Group Comparisons	**Species**	**Low Density Kānuka Average Abundance**	**Open Pasture Average Abundance**	**Average Dissimilarity (species)**
Low Density Kānuka + Open Pasture *Average dissimilarity:* 77.50	Skylark	3.19	24.20	11.18
	Pipit	3.86	20.76	9.12
	Yellowhammer	16.59	13.60	8.21
	Starling	11.12	9.66	6.65
	Grey Warbler	11.49	0.00	5.75
	Silvereye	11.72	0.57	5.73
	Goldfinch	6.91	8.37	4.50
	Chaffinch	8.42	1.02	4.31
Group Comparisons	**Species**	**Low Density Kānuka Average Abundance**	**Poplar-Willow Average Abundance**	**Average Dissimilarity (species)**
Low Density Kānuka + Poplar-Willow *Average dissimilarity:* 64.89	Yellowhammer	16.59	17.10	7.40
	Starling	11.12	11.69	6.38
	Goldfinch	6.91	13.42	5.88
	Chaffinch	8.42	15.20	5.87
	Grey Warbler	11.49	0.26	5.68
	Silvereye	11.72	2.96	5.53
	Sparrow	2.74	8.38	4.45
	Blackbird	4.34	6.33	3.31
	Skylark	3.19	4.33	2.90
Group Comparisons	**Species**	**High Density Kānuka Average Abundance**	**Open Pasture**	**Average Dissimilarity (species)**
High Density Kānuka + Open Pasture *Average dissimilarity: 86.90*	Skylark	0.22	24.20	12.02
	Pipit	0.09	20.76	10.35
	Silvereye	19.67	0.57	9.55
	Grey Warbler	14.78	0.00	7.39
	Yellowhammer	6.37	13.60	6.28
	Starling	9.86	9.66	5.84
	Fantail	9.60	0.00	4.80
	Chaffinch	8.25	1.02	4.20
	Goldfinch	4.44	8.37	4.18

Group Comparisons	Species	High Density Kānuka Average Abundance	Poplar/Willow Average Abundance	Average Dissimilarity (species)
High Density Kānuka **+** ***Poplar/Willow*** *Average dissimilarity: 86.90*	Silvereye	19.67	2.96	8.74
	Grey Warbler	14.78	0.26	7.27
	Yellowhammer	6.37	17.10	6.63
	Goldfinch	4.44	13.42	5.81
	Chaffinch	8.25	15.20	5.36
	Starling	9.86	11.69	5.35
	Sparrow	2.38	8.38	4.13
	Fantail	9.60	3.09	4.06
Group Comparisons	**Species**	**Open Pasture Average Abundance**	**Poplar/Willow**	**Average Dissimilarity (species)**
Open Pasture **+** **Poplar/Willow** *Average dissimilarity:* 76.40	Skylark	24.20	4.33	11.07
	Pipit	20.76	1.64	9.84
	Yellowhammer	13.60	17.10	8.27
	Chaffinch	1.02	15.20	7.50
	Starling	9.66	11.69	6.84
	Goldfinch	8.37	13.42	6.56
	Sparrow	1.13	8.38	4.28

4. Discussion

4.1. Overview of bird responses

Bird populations generally increased with tree density, with isolated single tree sites having very low to zero counts and the densest vegetation cover generally having the highest counts and largest ranges of recorded species present (**Figure 3.2**). However, responses varied between communities of birds and species of trees.

Native

Native birds responded most strongly to the presence of kānuka trees, with populations increasing 2.20 times that of pasture in the Low Density Kānuka category and 2.91 times in the High Density category (**Table 3.6).** In comparison, native birds did not favour the Poplar/Willow landcover category, as native bird numbers counted were only 49% of those in Open Pasture; an increase in poplar density did, however, result in a small increase in native bird numbers. These results accord with previous studies that recorded native birds' preference for on-farm sites where native plants are present (Blackwell et al., 2005).

Endemic

Endemic bird numbers also followed similar trends to native bird numbers, with bird counts being 1.93 times higher in Low Density Kānuka compared to Open Pasture and 2.59 times higher in High Density Kānuka (**Table 3.7**). In comparison, counts in Poplar/Willow were only 29% of those in Open pasture, though there was an additional 4% increase in counts with each poplar or willow added to the tree density values for this category. This indicates that while the Poplar/Willow landcover category may not be favoured by endemics, there is some benefit to the increased tree cover. Additionally, fieldnotes recorded that endemic birds in Poplar/Willow areas often seemed to be moving from adjacent kānuka groves and using the poplar canopy as a corridor. Scatterplots (**Figure 3.4**) also indicated that many endemic bird counts actually peaked in number around the 20 trees per hectare mark. This indicates that further increases in the density of native trees may not have been beneficial to the on-farm

endemic species, a result which is likely to be heavily influenced by the endemic grey warblers that were found in high numbers around kānuka trees.

An exception to this trend was the endemic New Zealand Pipit, which was present in significant numbers, but predominantly in Open Pasture settings. This result was unsurprising given that the natural habitat of the Pipit is predominantly grasslands rather than forests (Heather et al., 2015; Higgins et al., 2001). Paradise shelduck were also predominantly seen on grassland, however only a small number were counted across the entire survey, likely due to survey sites generally being located away from water bodies.

Introduced

Counts of introduced bird were very different in comparison, with counts in Poplar/Willow being 1.47 times higher than Open Pasture, indicating that introduced birds had more to gain from this habitat types compared to (**Table 3.9**). Interestingly, counts showed a similar increase in Low Density Kānuka, with counts being 1.45 times that of Open pasture. This may indicate that the presence of the trees was more important to the majority of introduced species rather than the species of trees themselves. High Density Kānuka bird counts were 1.52 times higher than those in Open Pasture, meaning even the more diverse vegetation wasn't appealing to the exotic farm species. It should also be noted from the scatterplots of introduced bird counts in the high density categories that the trends of counts tended to be flat or decrease with tree density, indicating at a certain point the changes in vegetation density may not be conducive to many exotic species requirements. Given the apparent lack of preference exotic birds seem to have towards what tree species present, it can be theorised that exotics presence in the trees related more to their use as a perching spot or for shade, rather than any exclusive niche provided by each species.

4.2. Community composition within landcover categories.

When looking at community composition and species count proportions, it is evident that a handful of species have a substantial impact on the response of native and introduced birds groupings.

Within Low Density Kānuka categories, native silvereye and endemic grey warbler were the New Zealand birds that were present in the highest numbers, and therefore likely had the biggest influence on the positive response native and endemic bird counts had to increasing kānuka density within the Low Density Kānuka category.

Yellowhammer, starling, and chaffinch were the introduced species present on Low Density Kānuka sites and were the primary contributors to the positive response introduced species had to these sites. With the addition of goldfinches, these species also were the biggest contributors to community composition on Poplar/Willow sites. This is likely why introduced birds' responses to Low Density Kānuka and Poplar/Willow sites were so similar, as the same species were being drawn to both lower density landcover types for the same reasons.

High Density Kānuka had a similar profile to Low Density Kānuka, with silvereye, grey warbler, chaffinch, and starling being most common, alongside native fantails. The greater presence of fantails and lower occurrence of yellowhammers within the bird communities in High Density Kānuka sites is likely why the was such a substantial difference between the responses of native and introduced birds to these sites.

Being the only landcover category that lacked the presence of trees, the community present within Open Pasture sites was far less diverse than what was found in the other three categories. As discussed earlier, pipits were the only native/endemic birds present in high numbers within these sites and were also some of the biggest contributors to the community, alongside introduced skylarks and yellowhammers.

4.3. Observed behaviour influencing populations within each landcover category

During the course of field observations, additional observations on bird behaviour and interactions with vegetation were recorded every survey. These observations have been compiled and used to help give additional context to the differences in bird communities across sites.

Low Density Kānuka community and behaviour

Within Low Density Kānuka categories, community analyses showed that native silvereye and endemic grey warbler were the New Zealand birds that were most abundant, with yellowhammer, starling and chaffinch being the introduced species most typical of that category. Behavioural observations indicated that the abundance of grey warblers and silvereyes was influenced by their insectivorous feeding preferences. Much of their behaviour was recorded as "feeding in canopy" and they were predominantly seen to be located directly on kānuka plants (**Figure 4.1** and **Figure 4.2**) This indicates kānuka was providing a habitat for the insects these birds prey upon (Dugdale & Hutcheson, 1997; Harris et al., 2004).

Insectivorous native fantails were also frequently recorded feeding in the kānuka canopy, although their numbers had less of an impact on community analyses. Of the native birds recorded on low density sites, tūī were of note as their occurrence was less driven by kānuka's presence as most tūī were observed to be located on "other native flora" (**Figure 4.2**) This is likely driven by tūī's preference for nectar feeding, particularly during the spring season (Higgins et al., 2001).

Interestingly, factors driving introduced species presence in kānuka were different from the most abundant natives (**Figure 4.1**). European starlings were present in the greatest numbers, however behavioural records show them predominantly spending their time either moving about the site or feeding on the ground, indicating their associations with kānuka landcover were not driven by feeding habits within the trees themselves. Location observations indicate that starlings were interacting with kānuka in relatively high numbers (**Figure 4.2**) so it is likely kānuka was utilised as a perching spot or shade, if not for any other reason.

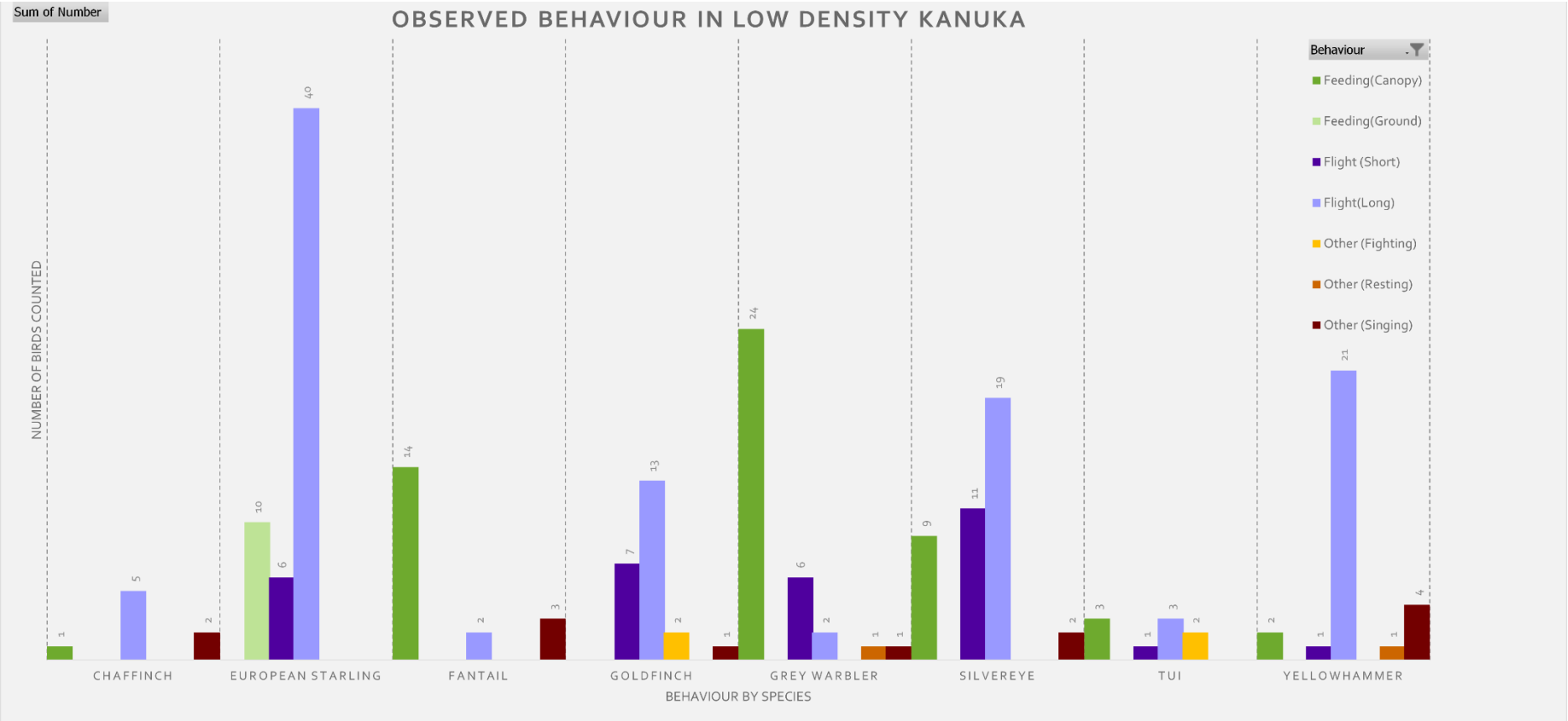


Figure 4.1 *Summary of behavioural records of selected bird species within Low Density Kanuka sites surveys.*

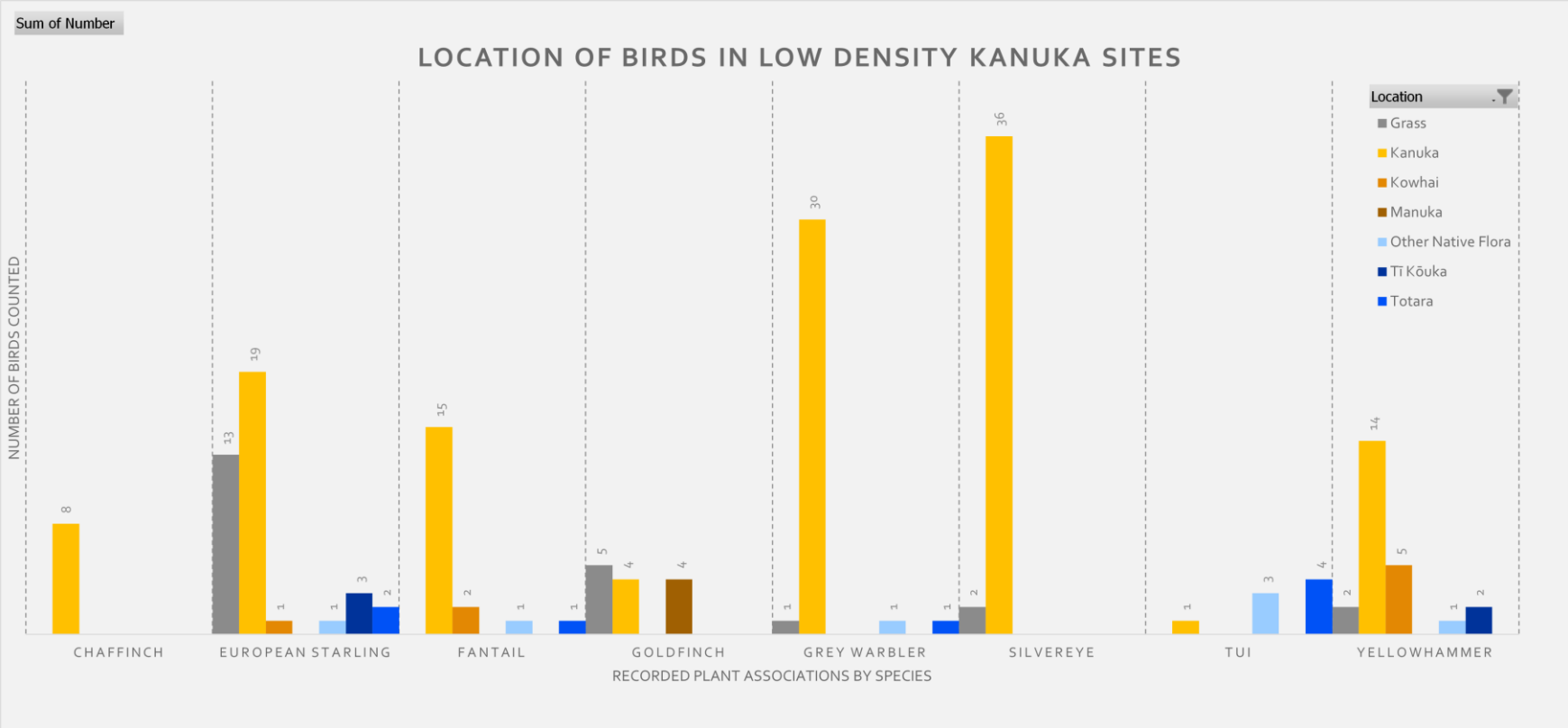


Figure 4.2 *Summary of records regarding what vegetation selected bird species were observed associating with during Low Density Kanuka site surveys.*

Yellowhammer and chaffinch were also a significant presence in low density sites (**Figure 4.1**) and also were the only common introduced species that were observed to feed in the canopy, likely influenced by data recording taking place during the breeding season, where invertebrates are used to feed chicks (Heather et al., 2015; Higgins et al., 2001). Regardless, most behavioural records indicate kānuka were primarily used as a perching spot rather than for anything else and yellowhammer in particular were less selective than grey warblers or silvereye in regards to what vegetation they were regularly sited on.

It should also be noted that yellowhammer and chaffinch are primarily ground feeders and often feed on seeds produced by pasture species (Heather et al., 2015)**.** Therefore, it is possible for these species to be drawn to kānuka not just for its food resources in the canopy, but also for what is growing in the pasture below low density kānuka groves.

High Density Kānuka community and behaviour

High Density Kānuka had a very similar community composition compared to Low Density Kānuka, with silvereye, grey warbler, chaffinch and starling also being present at high numbers in this habitat. The biggest variation in community composition came from the greatly reduced yellowhammer abundance and increased fantail abundance. This is likely reflective of the shift of habitat structure away from the more open and pasture-heavy Low Density Kānuka, which benefited yellowhammers that regularly nest and feed in pasture habitats, to the denser and more biodiverse High Density Kānuka, which provided a greater range of food sources birds like the fantail (Dugdale & Hutcheson, 1997; Heather et al., 2015). It is also of note that as the majority of High Density Kānuka sites included relatively untouched remnant forest patches, the kānuka in these areas was on average likely much older than some of the Low Density sites. As previous studies have found that old growth kānuka can sustain invertebrate communities that are as biodiverse as more mixed podocarp native forest, it is likely that fantails were also benefitting from a more diverse food source provided by older kānuka (Dugdale & Hutcheson, 1997).

As with Low Density Kānuka, High Density Kānuka sites favoured small insectivorous natives, with fantail, silvereye, and grey warbler all being observed feeding in the canopy (or air around

the canopy for fantails) at high rates (**Figure 4.3)**. These observations also predominantly took place around the kānuka trees present onsite (**Figure 4.4**). In comparison, no introduced bird was visibly seen to be foraging and they were seen to much more varied with what plant species they were associated with. Although the dense vegetation preventing clear sightlines could explain the lack of foraging observations, it is also possible that the greater amount of undergrowth High Density Kānuka sites feature shaded out the pasture plants and habitat these introduced birds favour. There were some records of starlings nesting in the area, however they were primarily using the cliff faces present on a small number of sites.

In addition to feeding in the area, grey warbler, fantail, and silvereye also demonstrated more territorial displays in High Density Kānuka, indicating these sites were of high value or sustained a greater density of birds. Tūī were also present onsite and displayed a range of behaviour, however as their counts were not high enough to impact the community analysis profile of High Density Kānuka (**Table 3.10**), it is likely that the remnant native forest amongst the predominantly kānuka landcover on the station wasn't enough to sustain a high population of tūī.

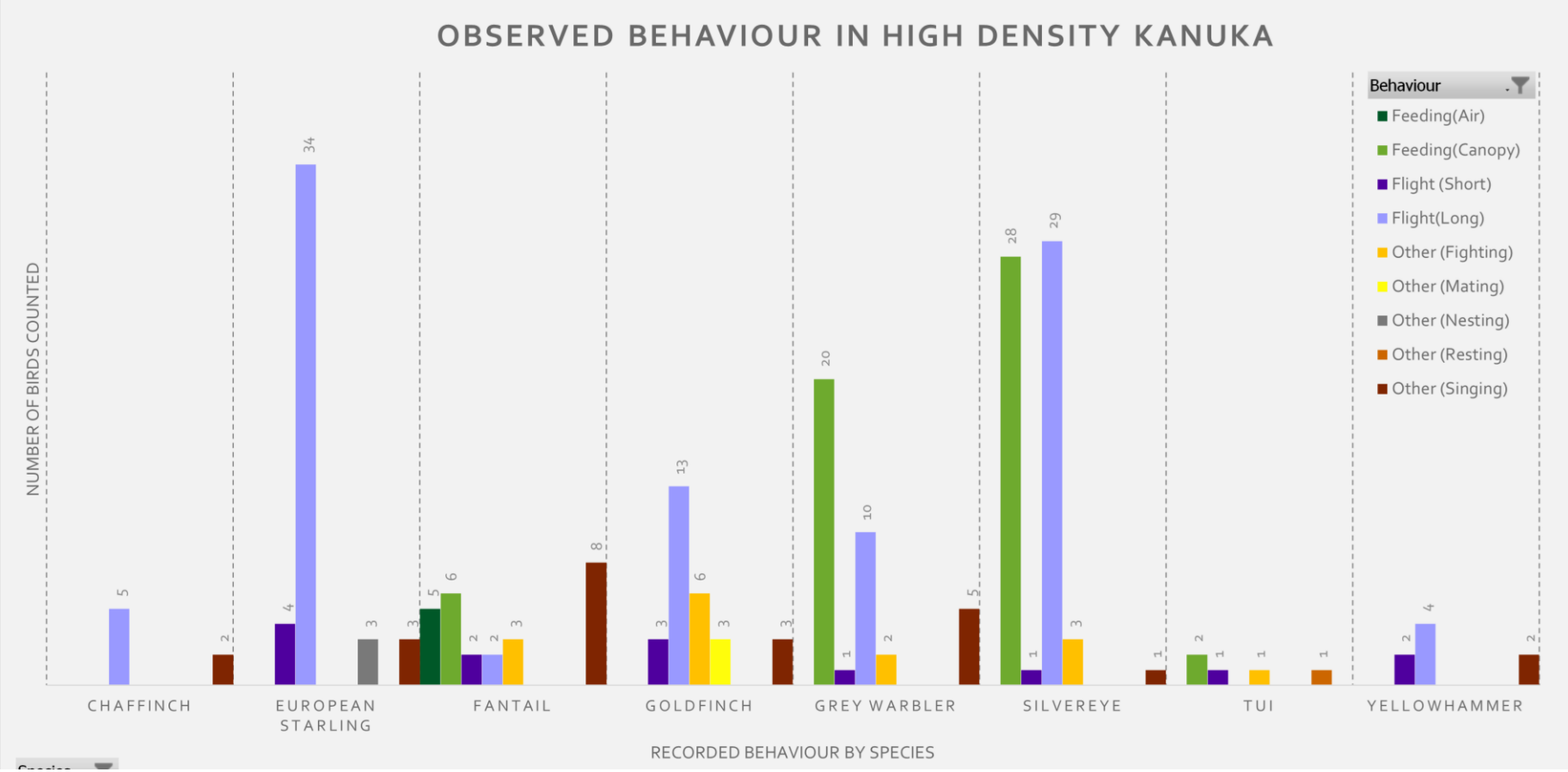


Figure 4.3 *Summary of behavioural records of selected bird species during High Density Kānuka site surveys.*

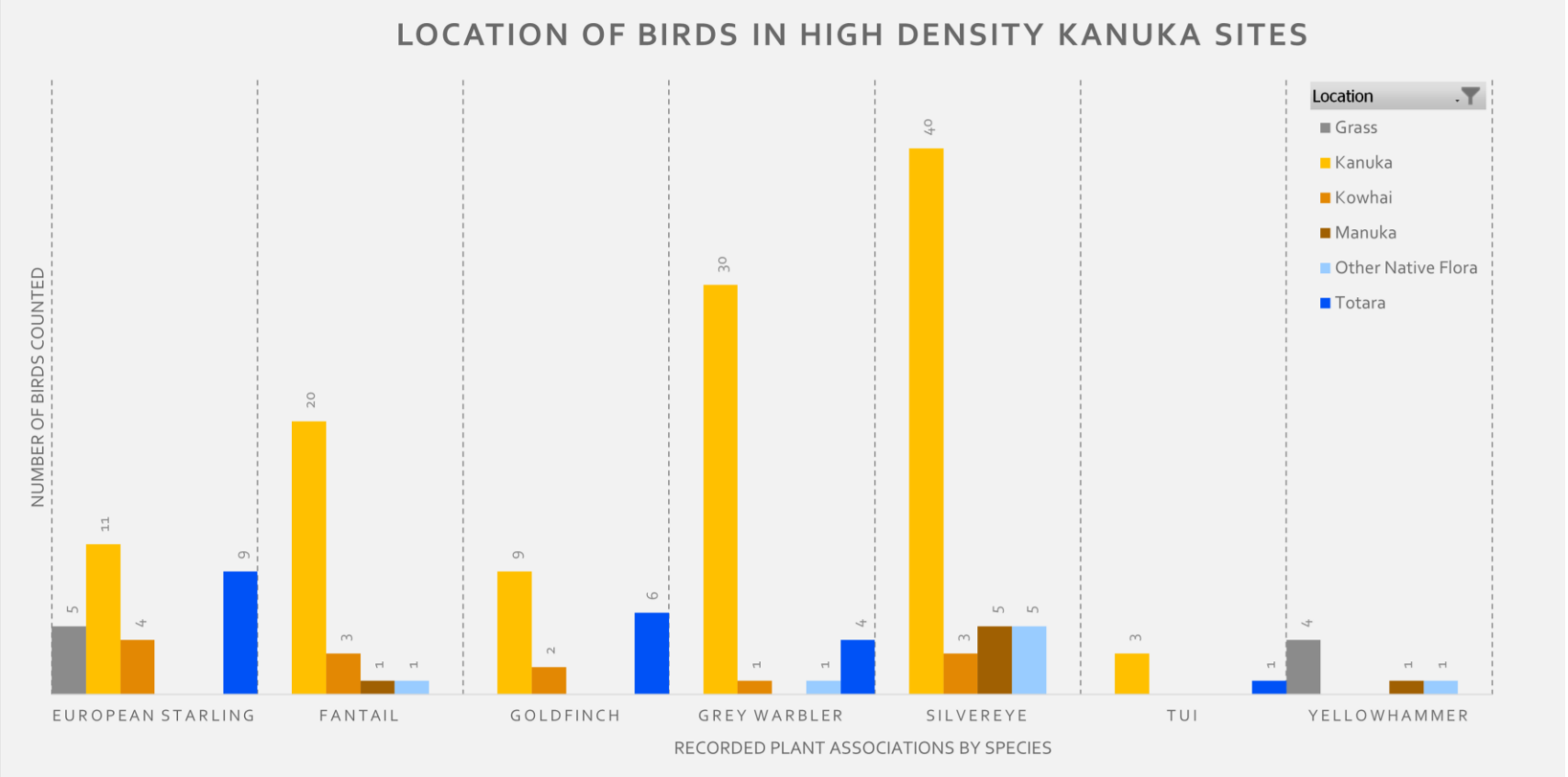


Figure 4.4: Summary of records regarding what vegetation selected bird species were observed associating with during High Density Kānuka site surveys.

Poplar/Willow community and behaviour

Poplar/Willow landcover had some similarities to the kānuka categories, with its high abundances of introduced yellowhammer, starling, and chaffinch (**Table 3.10**). However, natives were present at much lower numbers and introduced goldfinches contributed to the poplar/willow community in a far greater way.

Behavioural records of native birds show that the grey warblers, silvereyes and fantails that were present on site did still exhibit foraging behaviour and were seen interacting with both poplar and willow, so it is evident that they did at least gain some benefit from the plantings (**Figure 4.5** and **Figure 4.6**). However, due to their minimal contribution to bird communities in the Poplar/Willow landcover category, it can be inferred that they were not getting the same benefits from Poplar/Willow plantings as they were from kānuka stands. One potential explanation for this is nesting preferences, as the study took place during the breeding season and both fantail and grey warbler have demonstrated a particular preference for kānuka nesting sites (Gill, 1980, 1983; Heather et al., 2015; Higgins et al., 2001; Powlesland, 1982). It is also possible that the invertebrate communities that native birds primarily feed on were not as abundant in the Poplar/Willow stands, either due to these particular tree species not nurturing such rich native invertebrate communities, or due to human interference/pest control practices artificially lowering invertebrate biodiversity around this landcover category.

Goldfinches' heightened presence in Poplar/Willow communities appeared to be partially due to their preference for thistles that were growing under the canopy, as they were the only bird to be recorded regularly interacting with thistle, of which the seeds are known as an important food source for goldfinches (**Figure 4.6**) (Higgins et al., 2001). Additionally, when taking into account recorded vegetation associations across all forested landcover types (**Figure 4.2**, **Figure 4.4**, and **Figure 4.6**), it appears that goldfinches were seen in poplar or willow trees far more often than they were in kānuka. This could have been the result of the difference in pasture plants found under poplar and willow compared to kānuka, or it could have been a simple matter of the taller poplars and willows providing better sightlines overlooking the pastures where the goldfinches regularly foraged (Mackay-Smith et al., 2023) .

Most other introduced bird species behaved in similar ways in poplar/willow sites to how they had in low density kānuka, with the primarily granivorous species mainly feeding on the ground while using surrounding trees as perching spots. Interestingly, yellowhammer were recorded foraging on the ground and in association with the grass at greater numbers under Poplar/Willow than they were in Low Density Kānuka (**Figure 4.1**, **Figure 4.2**, **Figure 4.5**, and **Figure 4.6**). There are multiple factors that could be driving this change: 1) it could possibly indicate that the preferred invertebrates yellowhammer hunted in kānuka were not present (a possibility backed up by the low numbers of insectivorous native birds present), 2) it could reflect the fact that kānuka has been found to encourage the growth of different pasture species compared to poplar, or 3) it could be the result of reduced visibility under kānuka compared to poplar or willow groves (Dugdale & Hutcheson, 1997; Mackay-Smith et al., 2023).

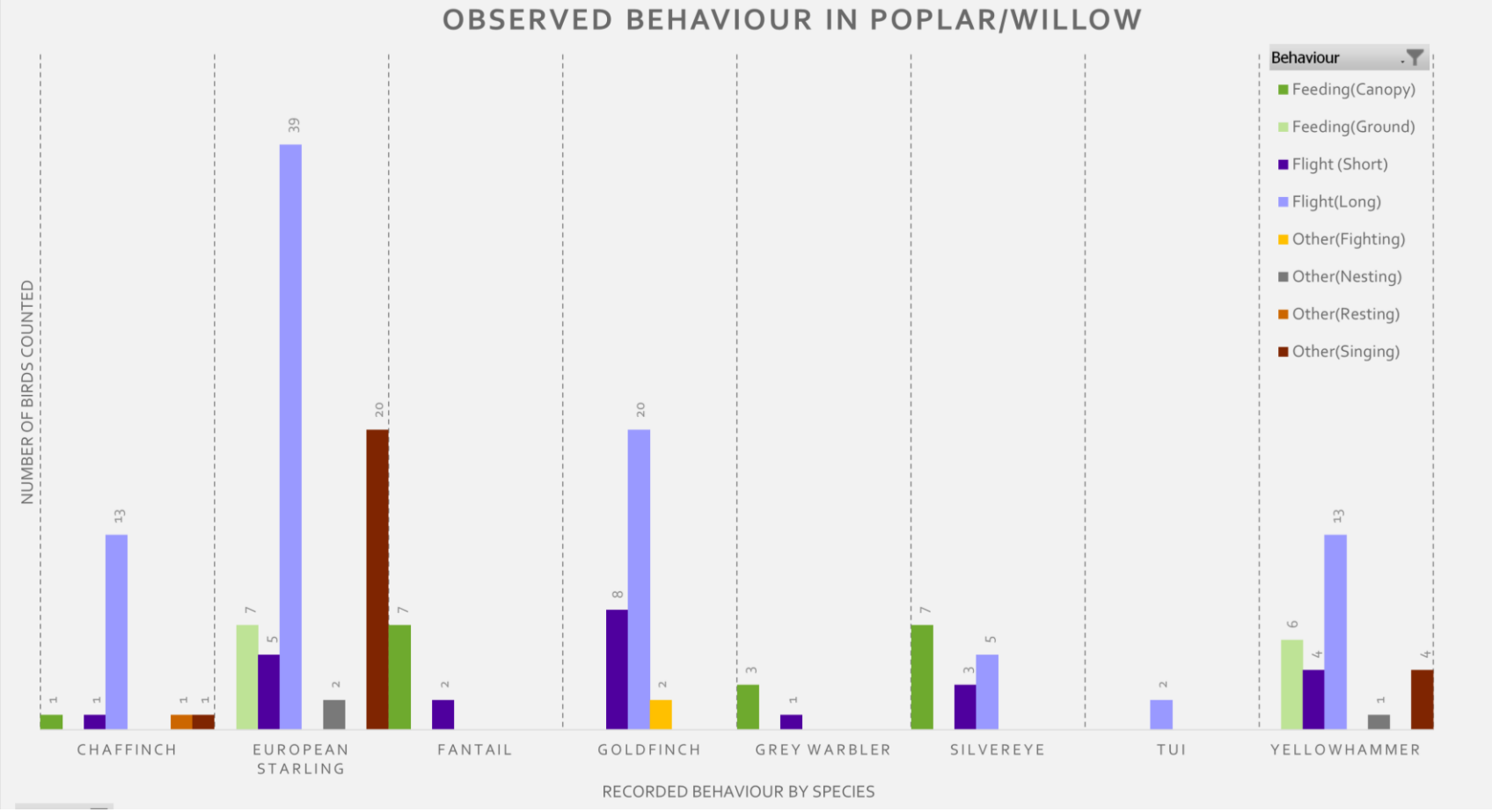


Figure 4.5 *Summary of behavioural records of selected bird species during Poplar/Willow site surveys.*

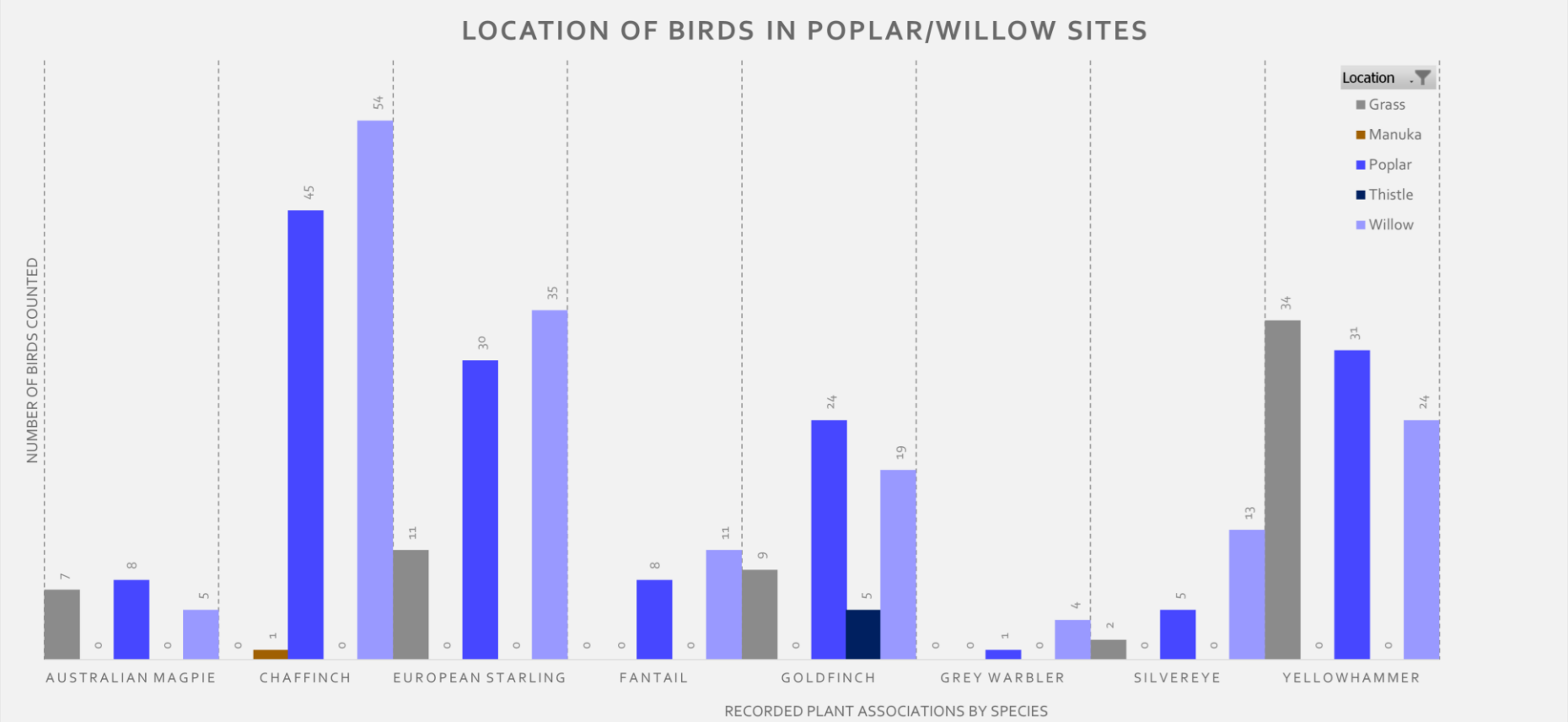


Figure 4.6 *Summary of records regarding what vegetation selected bird species were observed associating with during Poplar/Willow site surveys*

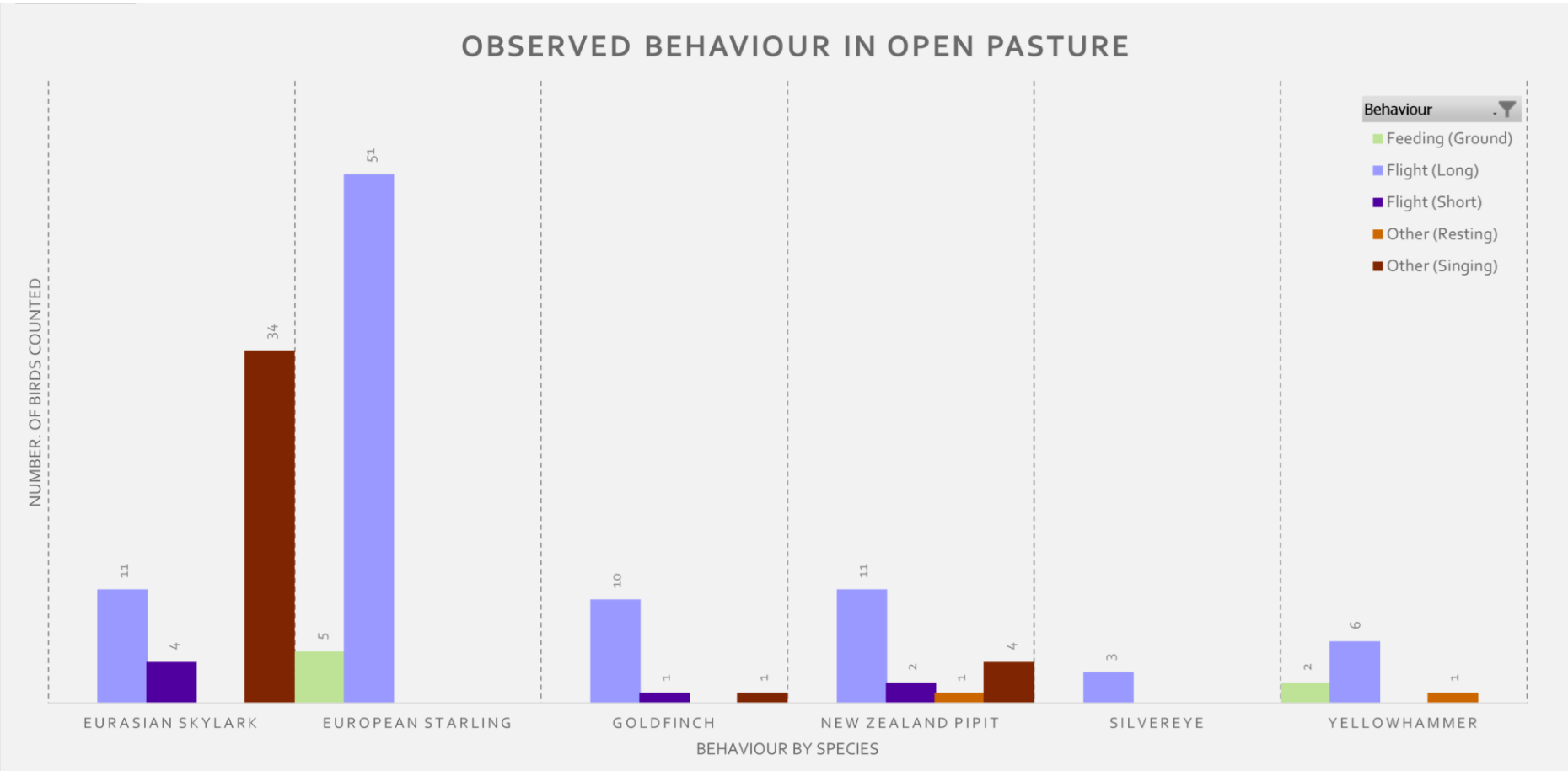


Figure 4.7 *Summary of behavioural records of selected bird species during Open Pasture site surveys.*

Open Pasture community and behaviour

Open pasture is a drastically different habitat to the forested landcover categories and therefore species communities present under this category were very different from in other categories. The species that were present in the highest numbers in Open Pasture were Eurasian skylarks, New Zealand pipits and yellowhammers, with starlings also being present in high numbers(**Figure 3.1** and **Table 3.10**).

Behaviour-wise, the reoccurring introduced species behaved similarly to in the forested landcover sites, although perching behaviour was naturally reduced due to the lack of available roosts in the open grassland environment (**Figure 4.7**).

Native silvereyes were the only of the three small insectivorous natives to be counted in Open Pasture, and all were in flight rather than interacting with the surrounding environment. This has interesting implications as it may indicate that grey warblers and fantails are less likely to travel longer distances through open areas than silvereyes are. So far very little research has been conducted regarding the gap crossing ability of fantails and grey warblers, particularly in regard to their ability to cross pasture land (as opposed to open water), however silvereyes are known for their ability to travel long distances, having recently colonised New Zealand from Australia in the 1800s, and have been recorded exhibiting migratory behaviour within New Zealand (Dennison et al., 1981; Innes et al., 2022).

The resident grassland species (endemic New Zealand pipit and introduced Eurasian skylark) were primarily observed singing, or in flight as their natural camouflage made them rather cryptic when foraging (Heather et al., 2015; Higgins et al., 2001). Although superficially similar in habitat and appearance, past research has shown that pipits and skylarks have very different diets, with pipits being primarily insectivorous and skylarks being primarily granivorous, so competition between species is limited, hence the reason both species could be recorded at high numbers (Garrick, 1981).

Uncommon species on site

It should also be noted what birds were generally absent within the landscape. Tūī and shining cuckoo were present on site but were counted relatively infrequently. Kererū were marked as present but had very few recorded counts. Behavioural records also demonstrated that all kererū observed were in transit and were not seen spending any time foraging on site. This could indicate that even the most densely vegetated and diverse parts of High Density Kānuka sites did not provide enough suitable resources to sustain a significant kererū population during the spring sampling period. Bellbirds were also present in minimal numbers, and forest birds such as whiteheads (*Mohoua albicilla*), tomtits (*Petroica macrocephala*) and riflemen were completely absent. This is likely a reflection of the barren landscape surrounding the farm station. Kererū, bellbirds, shining cuckoo, and tūī are all known to be proficient flyers over long distances, so even though the remnant native forest and regenerating kānuka left in the station didn't provide enough habitat for these species to maintain a significant presence in the area, birds were still able to make use of the forested habitat when crossing to more distant, but more desirable sites (Innes et al., 2022). In contrast, a recent review classified whiteheads, tomtits and riflemen as moderately-strongly "gap limited" in regard to their ability to cross open spaces to access new habitat, and therefore highly unlikely to be able to cross the 20–30 km of cleared farmland between the farm station and the nearest forest reserves (Innes et al., 2022).

Waterfowl were also not recorded in high numbers, although they were present on site. This was more likely the result of the sampling procedure, which avoided the significant water habitats on site. However, it was noted that there was limited water species movement outside of the main waterways. The dry conditions within the study area and the sampling period may have impacted their movement as damp areas observed during initial field investigations rapidly dried out during the initial weeks of the sampling, so this may have affected the presence of water-adapted species such as pūkeko and paradise ducks (Higgins et al., 2001).

4.4. Benefits of birds on farms

Prior to humans arriving in Aotearoa, an estimated 80% of the country was dense forest or scrubland (Ministry for the Environment & Stats NZ, 2022). After mass deforestation for industry and agriculture, native forest landcover has reduced to just 27% of the country- while an estimated

39.7% of the country consists of sheep and beef agriculture alone (Ministry for the Environment & Stats NZ, 2022; Norton & Pannell, 2018). Because of this mass deforestation event, and the introduction of pest mammals into the country, bird populations plummeted nationwide. Since then, considerable efforts have been put into restoring bird populations within national parks and predator-proof ecosanctuaries however the potential of farmland for conservation has remained largely neglected, with rural landowners being viewed as naturally opposed to conservation rather than potential allies in the fight to preserve and restore the country's biodiversity (Mackay-Smith et al., 2024; MacLeod et al., 2008). Within the agricultural landscape there is, however, untapped potential to utilise the landscape for conservation purposes. Encouraging the presence of birds in agricultural land would have a number of key benefits:

- **Cultural value**

  Native birds have high cultural value in Aotearoa New Zealand and past research has shown that rural landholders have a desire to increase the number of native birds on their properties (Guenther et al., 2012). Additionally in a 2019 survey on rural land managers found that 40.9% of respondents reported planting trees for the sake of increasing habitat/biodiversity, and 28% value being kaitiaki/guardians of the land (Stahlmann-Brown, 2019). Kaitiakitanga of native species is particularly important to tangata whenua, as Māori have long-standing cultural and spiritual ties to the native birds present in the environment. Thus, it can be argued that finding a way to align the economic realities of farming in New Zealand with the desire to see more native birds in the agricultural environment could greatly enhance the psychological and spiritual wellbeing of people living in these areas.

- **Ambassador species and ecological indicators**

  Due to the cultural significance of many native bird species in New Zealand, they also have the potential to be ambassador species for less charismatic fauna and flora in agricultural spaces. Maintaining a healthy bird population requires the input of a functioning ecosystem that can support a range of invertebrate species and flora to supply the necessary food, shelter and nesting materials birds need to survive and reproduce (Weller et al., 2012). On a similar note, the presence of birds in the agricultural system could

potentially be used as ecological indicators. Not only does their reliance on invertebrates and flora mean bird populations are likely to respond to changes in the wider ecosystem; birds are also easily identifiable to laymen; there is already a precedent set within New Zealand by "The New Zealand Garden Bird Survey" to involve citizen scientists in the reporting of bird populations (Hayman et al., 2024; Weller et al., 2012).

4.5. Applications/ benefits of silvopasture for conservation purposes

Kānuka silvopasture

Kānuka is one of the most common self-seeded hill-country species across New Zealand (Lambie et al., 2021; Ministry for Primary Industries., 2017). It has traditionally been considered a weed, however recent studies have indicated that it has potential use as a silvopastoral species that can be used in erosion prevention in hill country beef and sheep farms (Mackay-Smith et al., 2021; Spiekermann et al., 2021). Its shorter height and low canopy also make it a good species for providing shelter to livestock, and its presence could also be utilised for carbon capture under the emissions trading scheme (Mackay-Smith et al., 2024; Ministry for Primary Industries., 2017). There are many opportunities that kānuka's use as a silvopastoral species would present including:

- **Cohesion between conservation and economic factors**

  Studies have indicated that farmers in Aotearoa New Zealand feel very positively towards the presence of native bird species on the farm and would likely be interested in bird conservation, provided it does not come at the cost of their livelihood (Case et al., 2022; Guenther et al., 2012; Meadows, 2012). Given that native and endemic bird numbers demonstrated a clear positive response to the presence of kānuka, utilising it as a silvopastoral species could provide a vital opportunity to align the economic necessities of agriculture with the ecological needs of native species. Therefore, there is potential for a more enthusiastic uptake of this approach compared to more historically contentious environmental topics.

- **Corridors**

  Many of New Zealand's rarest forest species have been categorized as "gap limited" and therefore are limited in their ability to spread from the reserves they are currently located in, and behavioural records taken during fieldwork in this study indicated even on-farm species such as grey warbler and fantail rarely left the cover provided by trees and shrubs when traversing the site (Innes et al., 2022). Kānuka silvopasture provides the potential to connect up disparate landforms and isolated pockets of remnant native forest for birds to access, creating a much larger habitat range for some of our declining species. These corridors could be incorporated into long term plans (alongside pest control efforts) to restore rarer species to the mainland.

- **Policy fulfilment**

  There are a number of policies that look to the enhancement of biodiversity and native vegetation in New Zealand. The National Policy Statement for Indigenous Biodiversity emphasises the need to recognise "the interconnectedness of the whole environment" and sets targets for the rural and urban environment to have at least 10% indigenous vegetation cover (Ministry for the Environment & Department of Conservation, 2023). Additionally, kānuka could be used to fulfil New Zealand's obligations in combatting climate change. However, as it currently stands the ETS does not favour the use of native species (Case et al., 2022).

Poplar and willow silvopasture

Poplar have been the primary silvopasture tree in New Zealand since the 1960s and willow are frequently used alongside them (Charlton et al., 2007; Wilkinson, 1999). Both species are fast growing, easy to plant, and have large root networks that provide extensive soil stabilization (Charlton et al., 2007; Kemp et al., 2018; Wilkinson, 1999). They also provide additional forage and shelter for stock and can be used for carbon capture (Benavides et al., 2009; Mackay-Smith et al., 2024; Wilkinson, 1999). There has been very little study on the impact that poplar and willow have on farm biodiversity, particularly in regard to birds and the results of this study indicate poplar and willow have little positive impact on native birds. However, there is one possible conservation use for preexisting poplar/willow silvopastures the results of this study raise: Although native birds counts in Poplar/Willow were significantly lower than those in Open Pasture, native birds were still seen utilising poplar canopies, particularly when they bordered

kānuka groves or native forest remnants. Therefore, there might be untapped potential to improve the conservation value of preexisting poplar and willow silvopasture via the planting of native vegetation along its boundaries.

Open Pasture

As a general rule, Open Pasture has limited potential for conservation purposes, however it is important to note that it does provide vital habitat to introduced, but vulnerable, skylarks and to native pipits (Higgins et al., 2001). As my study's primary focus was on trees, it is unknown what smaller pasture species or undergrowth facilitated the presence of skylarks and pipits on site, however with the information currently available, it appears that these species do not benefit from any silvopasture.

4.6. Limitations

As this was an exploratory study trying to gain a general picture of how on farm birds interact with vegetation in the farm, it did not cover many realities of farm ecology in great detail. The study only took place on a single-hill country beef and sheep farm in the Wairarapa over the spring period. Therefore, it is not known how this information will extrapolate out to other seasons, land use types and regions. Additionally, the surrounding environment of the other farms and landforms were not covered in the survey. There may be impacts of the vegetation cover and connectivity in the broader and regional environment on the bird populations on specific farms. In my study for instance, the riparian vegetation of the river bordering one part of the farm was not taken into account.

The survey also did not include a thorough identification and analyses of the undergrowth present on each site that may have affected the bird communities present on site or look into the number of pest mammals on site that may cause a threat to local bird life (although several feral cats were noted to be present near survey points). Additionally, as the study primarily focused on the passerine species, landscape features such as large water bodies were avoided and therefore the farm species studied did not generally sample waterfowl and waders that might also be impacted by changes to vegetation on farm. Finally, each survey only took place within a

circular area 100 m in diameter, so there is potential to investigate how bird counts among silvopastoral sites change along a gradient.

4.7. What next?

This project has demonstrated that there is potential for silvopasture to double as a conservation tool, however further research will need to be conducted to understand the viability of this approach on a wider scale. Further studies on bird populations across a number of agricultural regions and management styles would be beneficial to gaining a more rounded understanding of bird responses to silvopasture or general agricultural planting. Comparisons between other silvopastural species beyond kānuka, poplar and willow are also needed. Additionally, it would be beneficial to look into the impact of low density kānuka on properties that neighbour national parks and nature reserves to gain a greater understanding of dispersal from large native forests into lower quality kānuka habitat. Further research may also need to be conducted on the age of kānuka plantings to understand at what point they become ecologically important to specific bird species.

4.8. Comment on methodology

This study was unique in its design as it was created with access to a detailed GIS dataset mapping of the locations and species of trees (Spiekermann et al., 2021). This dataset allowed for the generation of higher resolution statistical analyses of bird counts as they were able to be matched up with the exact measurement of tree density within the survey area. This dataset enabled a more detailed look into the bird responses to an increase in vegetation, however it is not available across every region. Modelling that utilised the four basic categories (Open Pasture, Poplar/Willow, Low Density Kānuka, and High Density Kānuka) nevertheless provided a significant level of detail during statistical analyses. Conducting similar studies across other regions should be possible with field investigations and carefully chosen survey sites, however the equivalent level of detail provided by the GIS tree mapping would be absent in those analyses.

4.9. Conclusion

Given the positive response of on-farm native bird populations to the presence of kānuka, its use as a silvopastoral plant has great potential to align conservation goals with the economic realities of agriculture; although there would need to be changes to the current ETS leGISlation and regional council programs that favour exotic forestry for this to fully be a reality. Poplar and willow plantings showed less potential as a conservation tool for native birds, however there is potential to utilise their established canopies as bird corridors if combined with additional native plantings.

Overall, this study does present on-farm bird populations as being more biodiverse than previously thought, with populations of native silvereye, grey warbler, pipit and fantail being particularly prominent onsite. Given the high presence of insectivorous species on site it is likely that invertebrate communities have a significant influence on what native birds can be present within the hill country farm environment. There is long-term potential to form bird corridors from silvopastoral erosion mitigation, however more work still needs to be done to fully understand the complexities of on-farm birdlife.

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Appendix A: Example of data collection sheet

Site Name:			**Date:**	
Weather 1)Fine 2) Partly cloudy 3)Overcast 4) Mist/fog 5)Rain	**Temperature** 1) Cold >5C 2) Cool 5-11 3) Mild 11-16 4) Warm 16-25 5) Hot 25-30 6) Very Hot 30<	**Precipitation** 1) None 2) Damp Foliage 3)Drizzle 4) Light 5)Moderate 6) Heavy	**Wind Direction: Strength** 1)Calm 2) Light Breeze 3) Moderate Breeze 4) Fresh wind 5) Strong Wind	**Other Vegetation Types:** 1)Pine 2) Totara 3)Willow 4) Kowhai Other:
Other Notes:				

Time	**Species**	**Number of Birds**	**Behaviour**	**Direction of Movement**	**Location**	**Notes**