Exploring the Relationship Between Plant Diversity and Bird Abundance at Tūhaitara Trust[1]

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GEOG309-25S2 – Research for Resilient Environments and Communities

17/10/25

[1] Cite as *Keay S, Mortimer P, Roberts C, Johnson E & Clamp J. 2025, Exploring the Relationship Between Plant Diversity and Bird Abundance at Tūhaitara Trust. A report produced as part of the GEOG309 Research for Resilient Communities and Environments course, University of Canterbury, 2025.*

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Executive Summary

- Tūhaitara Trust manages Tūhaitara Coastal Park and Katiritiri Ridge with the intention of restoring these areas back to their original state. A key part of this plan is the establishment of biota nodes, which are meant to support native bird populations. To assess whether the biota nodes were having the desired effect on native bird abundance, the following research question was posed:
- Is there a relationship between plant diversity and bird abundance in the land managed by Tūhaitara Trust, and if so, how can this inform future planting and management plans?
- Tūhaitara Trust were also struggling with low survivorship of immature native plants. Since dry soil was a main concern, soil moisture content was explored throughout the park.
- Ten sites were selected for sampling; at each site a soil moisture logger was placed in the centre and a soil sample was taken. Two 5-minute bird counts were performed at each site on each day of data collection and vegetation was assessed using a 10 x 10 m quadrat created around the soil moisture logger. Data analysis was completed using Excel, RStudio, and ArcGIS.
- Although plant diversity did not predict bird abundance, plant cover and site type did. Bird abundance was the highest at the wetland and lagoon sites and the lowest at the pine sites. Alternately, soil moisture was highest at the pine sites and lower at the other site types.
- Although this study had several limitations, recommendations can be made based on the results. Notably, Tūhaitara Trust should develop a network of biota nodes in pine plantations, apply mulch to biota nodes in dry zones, and prioritise planting high-tolerance native plants suited to low-moisture soils.
- Future research should explore utilising satellite imagery to up-scale monitoring, developing species recognition software to enable the use of audio recording units, sampling during different seasons, and exploring drivers of low immature native plant survivorship.

Introduction

Established as part of the settlement between Te Rūnanga o Ngāi Tahu and the Crown, Tūhaitara Coastal Park is a 700ha coastal park of rich cultural history and ecological significance. It is located just north of Christchurch, spanning from the Waimakariri River to Waikuku Beach (Figures 1 & 2). The park hosts a diverse range of ecosystems, including exotic pine forest, coastal dunes, wetlands, and 'biota nodes' of native plants. Through these aspects, the Tūhaitara Coastal Park provides opportunities to preserve Ngāi Tahu values, retain and enhance biodiversity, and provide recreational and educational opportunities for all. The park is managed by the Tūhaitara Coastal Park Trust, which is following a 200-year plan working towards restoring the wetland and surrounding environments, slowly transitioning pine plantations into native forests. The creation of 'biota nodes' is a large part of this plan and one of the Trust's keystone projects. Biota nodes are small areas with high native plant diversity meant to help support native bird populations by providing food and promoting connectivity. However, plant survivorship is currently low.

Tūhaitara Trust wanted to explore whether plant diversity in the biota nodes was having the desired effect on native bird abundance. Additionally, they hoped that an estimate of current bird abundance and distribution could be provided. This would allow them to compare future measures to a baseline and assess the effects of their restoration efforts. Tūhaitara Trust was also looking for ways to improve their planting plans to increase the survivorship of their immature native plants, with a main concern being the dryness of the soil. To address these interests and concerns, the main research question was: Is there a relationship between plant diversity and bird abundance in the land managed by Tūhaitara Trust, and if so, how can this inform future planting and management plans? To support the recommendations and help understand the factors affecting immature native plant survivorship, soil moisture content was also explored throughout the park.

This report consists of a review of relevant literature, followed by a description of the methods and results. The results are then interpreted and contextualised in the discussion, which also explores the research's limitations, future research opportunities, and recommendations for Tūhaitara Trust. Finally, the conclusion summarises the key findings and thanks are given to all those who contributed to this project in the acknowledgements.

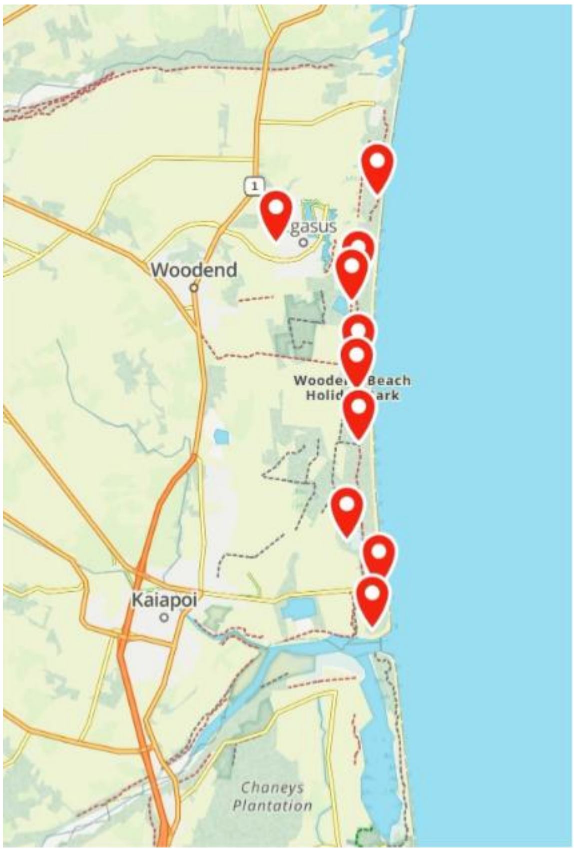

Figure 1) Map of Tūhaitara Coastal Park and the surrounding area, survey sites marked with red icons.

Figure 2) Map of Tūhaitara Coastal Park detailing walking trails and important information. Image sourced from https://www.tuhaitarapark.org.nz/recreation on 30/09/25.

Literature Review

Similar Restoration Attempts

Researching similar restoration attempts shows the need for thought-out and biodiverse revegetation. The Tūhaitara Trust has a 200-year plan to transition the park to native vegetation. However, there are numerous factors that they must consider, including carbon storage, climatic resilience, and pine productivity.

There is a range of recommendations across the literature on similar restoration attempts, but many overlap. Before starting restoration, addressing factors that will limit natural regeneration must be undertaken (Norton *et al*., 2018). These include understanding the challenges of the land's soil type, managing weeds, and sourcing ecologically appropriate plant species (Sullivan *et al.*, 2009).

The studies concluded that when transitioning from a pine plantation to native cover, the integration of mixed-species plantings is the most effective option (Forbes & Craig, 2013; Lambie *et al.*, 2021). This approach enhances biodiversity and climatic resilience (Jones *et al.*, 2023) while still allowing the plantation's continued productivity to earn revenue to fund native revegetation.

Habitat Fragmentation

Forest fragmentation refers to forests being divided into isolated patches due to factors such as land development or construction; the resulting loss of habitat and connectivity limits forests' ability to support bird populations. However, many bird species can traverse gaps between different vegetation clusters and habitat types, partially mitigating the effects of forest fragmentation. Although this ability varies between species, with some requiring large, unfragmented habitats due to their limited ability to traverse gaps (Innes *et al.*, 2022). Native birds appear to be disproportionately affected by forest fragmentation, with fragmented forests in the Banks Peninsula hosting a higher abundance of introduced species than intact forests, even though total bird abundance was similar (Gerard *et al.*, 2025). Forest fragmentation also increases the presence of edge effects, which have a significant effect on bird abundance (Barbaro *et al.*, 2012). Edge effects are where the conditions experienced near the edge of a habitat differ from those experienced in the center; for New Zealand's native forests, this often includes more introduced mammals, wind, and higher temperatures (Barbaro *et al.*, 2012).

Methods to Assess Bird Abundance & Distribution

Since robust methodology is important for producing reliable results that can be trusted to inform management decisions (MacLeod *et al.*, 2012; Klingbeil & Willig, 2015; Bombaci & Pejchar, 2018), several options for assessing bird abundance and distribution were explored. Initially, distance sampling (DS) was considered because it measures density and accounts for differences in viewshed, making it a reliable method for estimating bird abundance and distribution (MacLeod *et al.*, 2012). However, DS requires accurate judgement of distances, as inaccurate judgements lead to incorrect estimates of bird density, and therefore distribution

(MacLeod *et al.*, 2012). Alternatively, 5-minute bird counts (5MBC) provide less accurate estimates of bird abundance and distribution but require minimal resources and training since the observer's skills can be supplemented (MacLeod *et al.*, 2012; Klingbeil & Willig, 2015). 5MBC can be improved by performing a second one immediately following the first, where only new species are recorded, which increases the chance of capturing rare and cryptic species (MacLeod *et al.*, 2012). The use of automated recording units (ARUs) was also considered, since they record continuously and prevent bias caused by human presence (Klingbeil & Willig, 2015). However, ARUs require the development of species recognition software, and for short-term monitoring, their effectiveness has been found comparable to point counts (Klingbeil & Willig, 2015; Bombaci & Pejchar, 2018).

Soil Moisture

Successful native plant restoration depends heavily on understanding site-specific conditions, particularly soil moisture and drainage (Arnold *et al.*, 2014). Some native species are adapted to dry, nutrient-poor soils, making them ideal for restoration in harsh environments. However, not all species are this tolerant and instead require specific soil conditions to ensure their survival (Arnold *et al.*, 2014; Cieraad *et al.*, 2015; Meli *et al.*, 2014).

Exotic species, such as lupin or broom, can be used as shelter for native plants during early growth stages but need to be managed to ensure they do not outcompete natives. Similarly, gorse increases soil quality by fixing nitrogen and improving soil stability; its spines also discourage grazing, making it a good nursery species for native plants, although it must be closely managed to prevent it from dominating the environment (Galappaththi *et al.*, 2023). Alternatively, in recently disturbed areas, planting resilient natives can help reclaim areas that may be overrun by exotics (Burrows *et al.*, 2015; Pratt, 1999). Overall, restoration strategies need to be catered to the specific ecosystem, accounting for local soil conditions, species traits, and ongoing management needs to ensure success.

Disturbance Regimes

Disturbance refers to any system or action that disrupts an environment's natural state of being. This includes fire, floods, extreme weather events, and drought. Disturbance regimes describe how frequently disturbance occurs. Establishing how disturbance and disturbance regimes affect biodiversity is essential for effective management planning. Disturbance does not always negatively disrupt an ecosystem’s biodiversity (Hobbs & Huenneke, 1992). The intermediate disturbance hypothesis states that biodiversity is highest when an ecosystem experiences an intermediate disturbance regime because it balances the processes of colonisation and competition, enabling species with a wide range of life histories to establish (Moi *et al.*, 2020). However, in a high disturbance regime, only species with life histories enabling fast regeneration can establish, reducing biodiversity. Invasive species often possess these life histories, enabling them to outcompete native species, especially in environments where disturbance was historically uncommon (Gu *et al.*, 2023; Johnstone *et al*., 2016).

Methods

Site selection

Sites were chosen non-randomly because some had been pre-selected by the Tūhaitara Trust based on areas that they were interested in knowing more about. It was also important to ensure that the selected sites covered a wide range of ecosystem types. This allowed for comparisons in bird abundance between the different ecosystem types and to investigate any potential relationships between vegetation richness/cover and bird abundance/richness.

The selected sites were grouped into five categories based on ecosystem type. The number of sites within each category varied, with dunes (1), lagoon (1), mixed (3), pine (4) and wetland (1). Categorising the sites allowed for better comparisons between vegetation cover and bird abundance.

Soil

On the first official day at the Trust (20th August), site locations were finalised, and soil moisture loggers were installed. The coordinates of each site were recorded in Gaia GPS, and the soil moisture loggers remained on site until they were removed on the final day (17th September). The same day, soil samples were collected from each site at the location of the site's soil moisture logger to maintain consistency. The soil samples collected were analysed in the lab by weighing each sample before and after drying it in an oven to calculate their gravimetric soil moisture content.

Bird Counts

Bird abundance at each site was measured using five-minute bird counts, which were repeated 4 times over three weeks. Bird counts were carried out from the soil moisture loggers at each site to keep the observation point consistent. When arriving at each site, a brief period was allowed for the birds to recover from any disturbance. After which a five-minute timer was set, during which all bird species seen and heard were recorded, as was the number of all birds seen. Species identification was aided by Merlin (a birdsong ID app) as well as binoculars and a camera. These allowed us to zoom in on individuals, allowing a clearer view for species identification. A second five-minute count was carried out following the first count in the same manner. However, this time, only species that were not detected in the previous count were recorded.

Vegetation Analysis

At each site, a 10 x 10 m quadrat was centred around the soil moisture logger. Once the quadrat was set out, all plant species within the plot were identified using prior knowledge in plant identification, plant guides, and iNaturalist. Each quadrat was divided into quarters, with one person assigned to each. Each person would estimate the percent cover of each species in their quarter, which was recorded by a final member. The percent cover estimates of each quarter were added to give the final vegetation cover of each plot.

Data Analysis

RStudio and Microsoft Excel were used to organise and analyse data, assessing patterns in vegetation cover, bird density, and soil moisture across sites. In RStudio, ANOVAs and linear models were produced to statistically assess potential relationships between variables and 'ggplot2' was used to produce scatterplots. QQ and residuals vs fitted plots were used to check that the data met the assumptions. If the assumptions were not met, the data was transformed using a log or square root transformation and the best result was chosen. During analysis, site 4 was classified as a 'pine' site when investigating canopy-level factors, like bird abundance and richness. This was decided as, although it was a biota node, pine forest dominated the surrounding area. However, when exploring soil moisture, site 4 was classified as a 'mixed' site. The reasoning behind this was that there was no organic matter on the ground, and it was primarily influenced by the immature native plants.

In ArcGIS, an interpolation map was created using the Inverse Distance Weighted method to show bird abundance across Tūhaitara Coastal Park. Another map was created to show the proportion of birds at each site by diet.

Results

Plant Cover and Bird Abundance

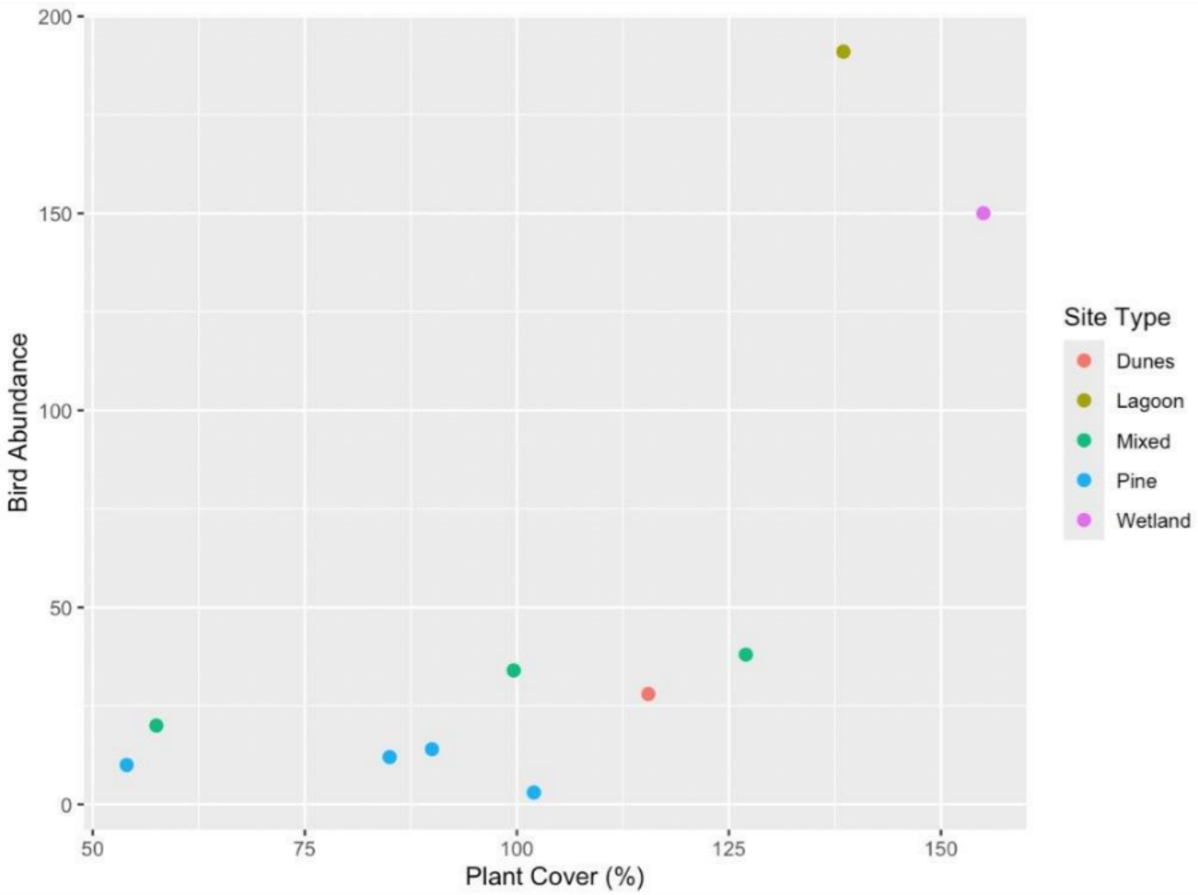

Figure 3) Scatter plot showing the relationship between plant cover (%) and bird abundance, colour coded by site type.

Plant cover was a predictor of bird abundance ($p = 0.014$), with bird abundance increasing with plant cover. When categorised by site type, it was revealed that the wetland and lagoon sites had both the highest plant cover and the highest bird abundance (Figure 3).

Alternatively, pine sites had the lowest bird abundance, which stayed relatively constant even as plant cover increased (Figure 3). Interestingly, mixed vegetation sites, which had immature native forests, open grasslands, and established pine forests, showed slight increases in bird abundance as plant cover increased (Figure 3).

However, native bird abundance was not predicted by native plant richness or cover ($p > 0.05$). Similarly, neither introduced plant richness nor cover predicted introduced bird abundance ($p > 0.05$).

Predicted Bird Abundance

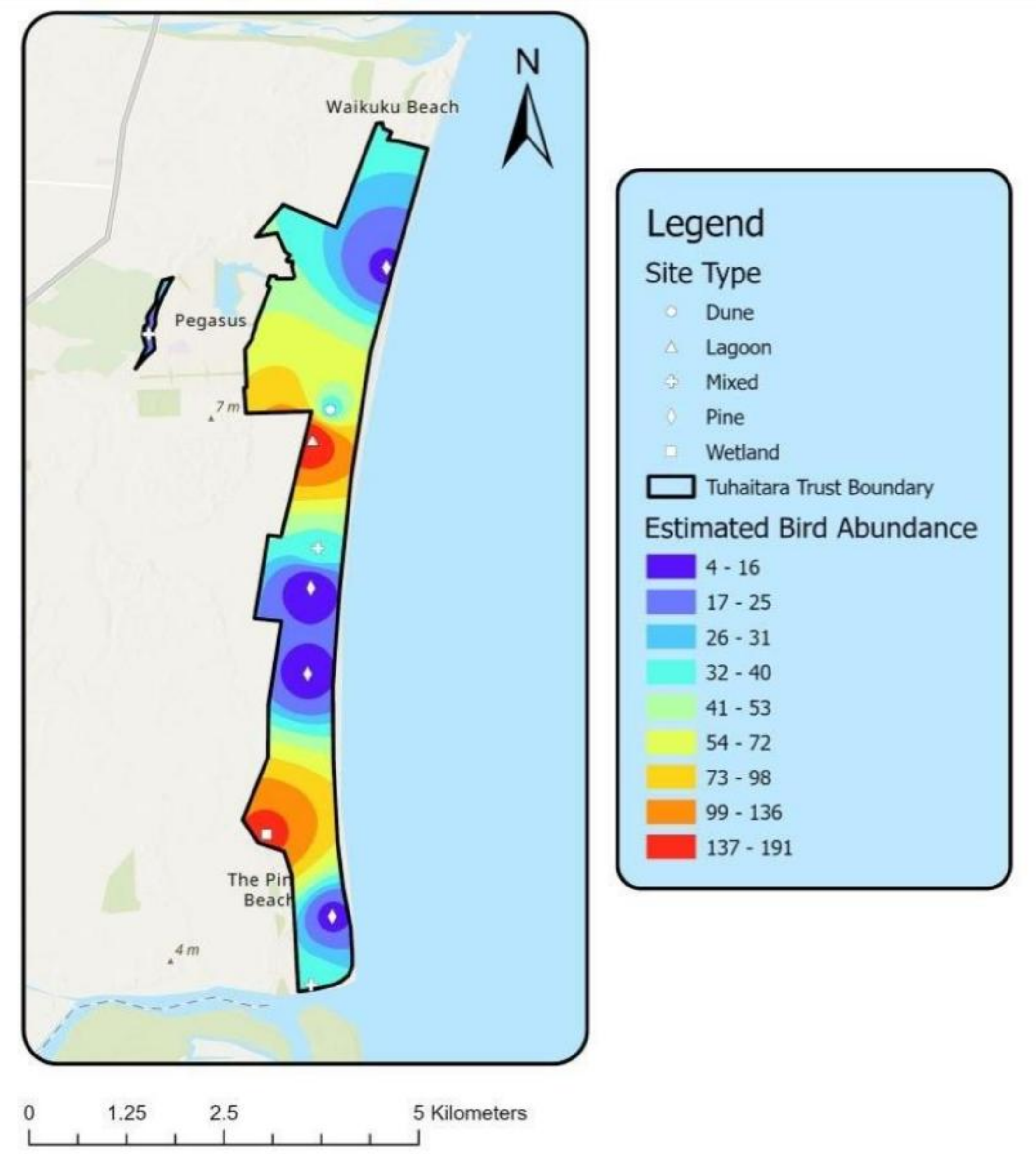

Figure 4) Interpolation map depicting predicted bird abundance throughout Tūhaitara Coastal Park and Katiritiri Ridge

The bird abundance observed at each site was used in an interpolation map predicting bird abundance throughout Tūhaitara Coastal Park. Expected bird abundance was highest at and around the wetland and lagoon sites, with predicted abundance between 73 and 191 (Figure 4). Sites 2, 4, 5, and 9, all of which were pine sites, had much lower expected abundance, with predictions for the surrounding areas ranging from 4 to 25 (Figure 4).

Bird Abundance by Diet

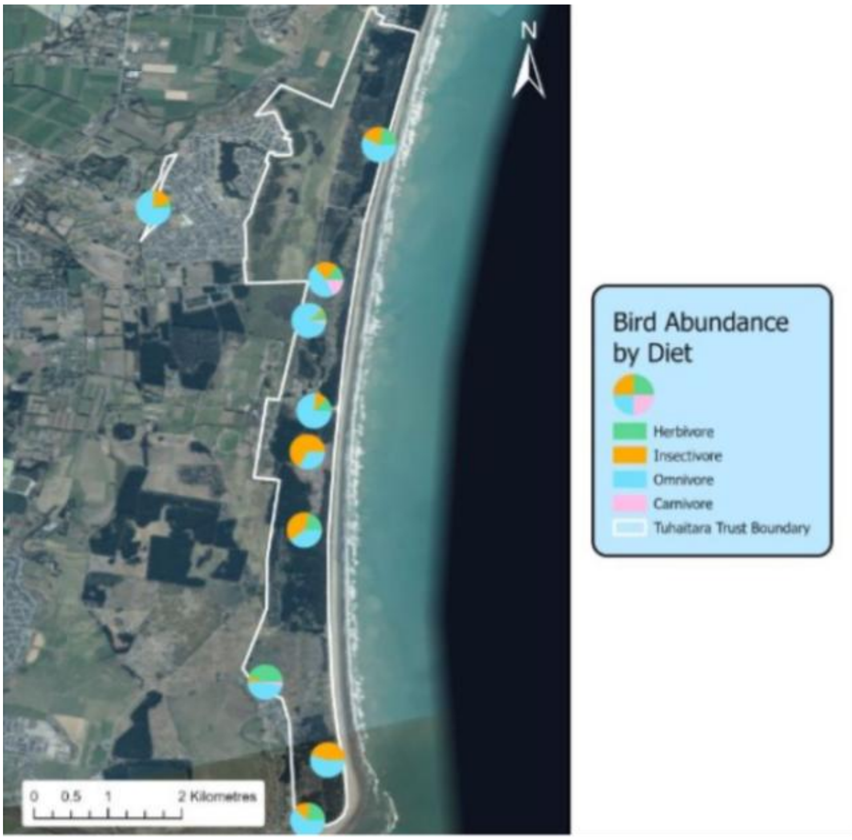

Figure 5) Map displaying the proportion of birds by diet present at each site, represented by pie charts.

To gain a better understanding of where different kinds of birds were throughout the park, species were divided into categories based on their diet. Omnivores dominated most sites but were found in the highest proportion at site 7, the lagoon site (Figure 5). Insectivores were found in the highest proportions at sites 2, 4, and 5, which were all pine sites. Herbivores were only the most abundant at site 3, the wetland site (Figure 5). Carnivores were the least widespread throughout the park. They were present in their highest proportion at site 8, which was located at the 13-year-old biota node in a grassy dune system (Figure 5).

Bird Species Richness

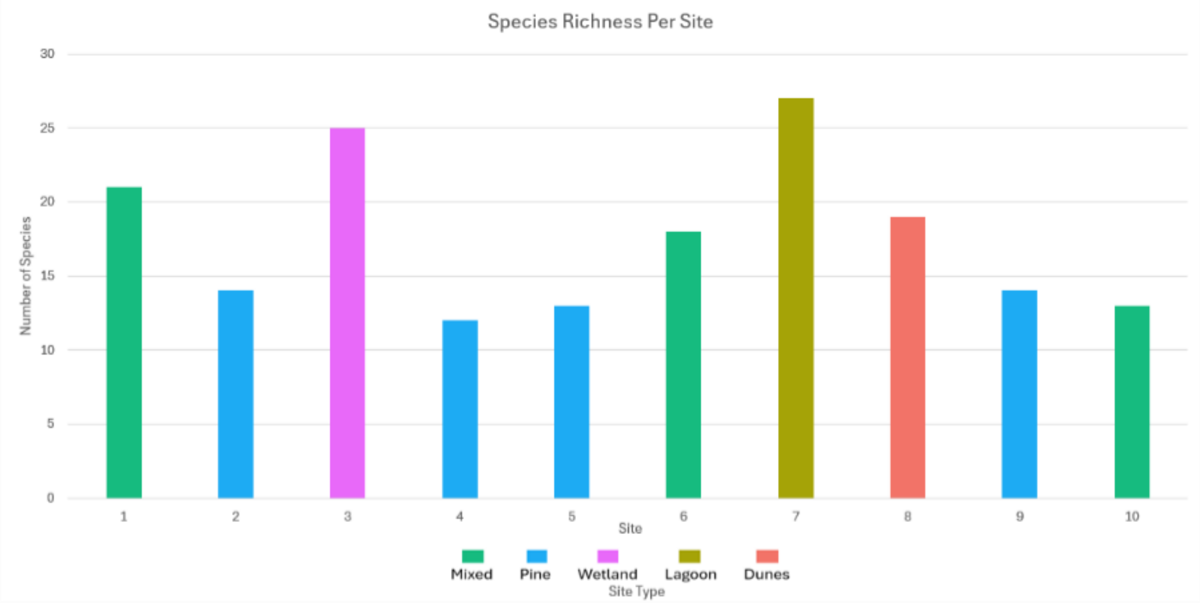

Figure 6) Histogram displaying the bird species richness (total number of different bird species) observed at each site.

The highest bird richness was observed at the wetland and lagoon sites, which had 25 and 27 species respectively (Figure 6). This differed greatly from pine sites 4 and 5, which only had 12 and 13 species respectively (Figure 6). Statistical analysis revealed bird richness increased with plant cover ($p = 0.039$) (Appendix A) and differed between site types ($p = 0.013$). However, further analysis suggested that the only notable differences in bird richness between site types were between pine-lagoon sites and pine-wetland sites (Appendix B). Neither native plant richness nor cover predicted native bird richness ($p > 0.05$). Although neither introduced plant richness nor cover predicted introduced bird richness ($p > 0.05$), the result for plant cover was approaching significance ($p = 0.051$). Introduced plant cover explained ~32% of the variation associated with introduced bird richness (Adjusted $R^2 = 0.3225$).

Soil Moisture

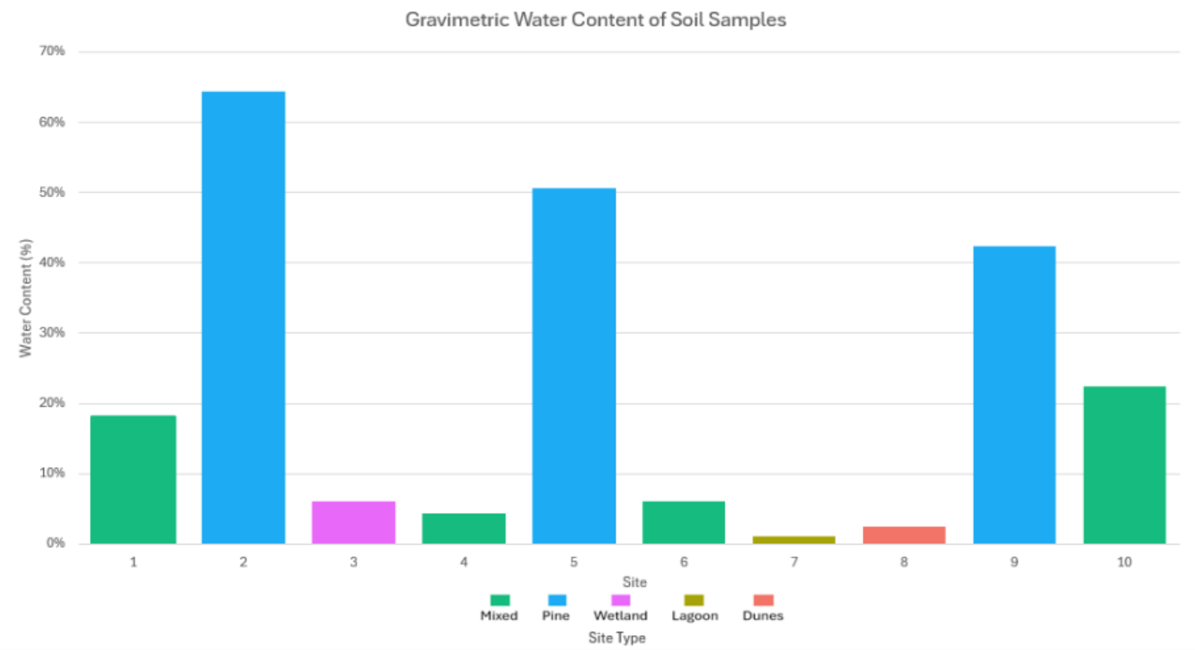

Figure 7) Histogram displaying the gravimetric water content (%) of the soil sample taken from each site.

The sample's gravimetric water content (GWC) was found to differ between site types ($p = 0.011$). Graphing the GWC for each site indicated pine sites consistently had higher GWC (Figure 7). To explore this, further statistical analysis was conducted. It revealed that the GWC of pine sites was significantly different from the GWC of all other site types ($p < 0.05$) (Appendix C). However, there were no significant differences between the GWCs of the other site types ($p > 0.05$) (Appendix C). This means the GWC of the wetland, dune, lagoon, and mixed sites were similar.

Discussion

Although no relationship was observed between plant diversity and bird abundance in the land managed by Tūhaitara Trust, the results still hold value for future planting and management plans. Notably, a positive relationship was found between plant cover and bird abundance; however, the relationship does appear to vary between site types (Figure 3). In mixed site types, bird abundance appears to gradually increase with plant cover (Figure 3). Since the surveyed biota nodes were classified as mixed site types, this result indicates that as the immature native plants grow, bird abundance in the vicinity of the biota nodes will increase. Alternately, bird abundance at pine sites remains similar across all levels of plant cover (Figures 3 & 4). While more analysis is required to determine whether these trends have statistical significance, these preliminary observations indicate that the biota nodes may eventually have the desired effect. However, the relationship between plant cover and bird abundance may be exaggerated by the lagoon and wetland sites. Despite these sites having high plant cover, the birds counted at these sites were overwhelmingly sighted in the water, where there was no above-water plant cover. The discrepancy between where the plant cover data was collected and where the birds were observed means that the positive relationship between plant cover and bird abundance may be misleading. Due to this, recommendations based on the relationship between plant cover and bird abundance have not been made.

The results suggested that the dominant diet at each site reflected the characteristics of the site's type. This was particularly obvious at pine sites where insectivores dominated, likely due to the lack of food available for herbivores (Seaton *et al.*, 2010). Although there was one outlier in this pattern; at site 9, a pine site, omnivores dominated, like at the mixed and dune sites (Figure 5). While the dominance of omnivores made sense in the more biodiverse mixed and dune sites, it was not on trend for a pine site. The reason for the omnivores' dominance at site 9 is unclear, but it may be attributed to site 9's location. This site was close to the Pegasus Township, and the omnivores counted were regular garden birds. This was supported by the fact that all bar one of the omnivores recorded at site 9 were also sighted at site 10 on Katiritiri Ridge, which is in a residential area. The singular omnivorous species that was not found at site 10 was the Red-billed Gull, which is expected at site 9 due to its proximity to the beach. Finally, it is worth noting that at the dune site, carnivores were at their highest proportion. This may be due to the open environment of the dunes, which is ideal for hunting. This result is useful in understanding at which site types birds are more reliant on Tūhaitara Trust's plantings, helping to guide where they should focus their revegetation efforts.

The lagoon and wetland sites had the highest species richness, likely due to their biodiverse nature and range of food sources (Figure 6). The dune site and then the mixed sites had the next highest species richness, with site 10 as an outlier likely due to its location in a residential suburb and not within the coastal park (Figure 6). Finally, the pine sites had the lowest species richness; this can likely be attributed to the lack of variation in food sources and the homogenous habitat (Figure 6). While this result isn't directly related to the main research question, it could be useful to indicate where Tūhaitara Trust should focus their revegetation efforts to maximise species richness.

Most sites contained a similar gravimetric water content (<20%), while pine sites had a higher percentage (>40%) (Figure 7). This was likely due to the pine sites having a layer of organic matter which other site types lacked, this layer may promote moisture retention by preventing evapotranspiration (Liao *et al.*, 2021). There are few other explanatory differences between the sites and their soils, especially since all soils had sand components. This finding links to the research's secondary aim of investigating soil moisture as a potential driver of low plant survivorship in the biota nodes.

Limitations

Due to the project's short timeframe, data collection was restricted to late winter and early spring, meaning migratory birds present only in other seasons were not recorded. This bias likely influenced the abundance, richness, and distribution of birds recorded throughout Tūhaitara Coastal Park and Katiritiri Ridge. The lack of time also affected the number of sites surveyed. Ten was the maximum number of sites that could be reliably and repeatedly surveyed within the designated timeframe. However, this sample size was likely too small to detect effects if they were present. This problem was exacerbated by the fact that three site types were represented by only one site each. For more complex community analyses and more accurate estimates of bird abundance and distribution, a minimum of three sites per site type is recommended for future research. The lack of sites and adequate site type representation likely also contributed to the data not fitting some assumptions of linear models.

Another effect on data collection was the variation in viewshed. Some sites had unobstructed views for hundreds of meters, while other sites only had four or five meters of unobstructed views. This led to variation in how easily birds could be detected, with a greater impact on visual detection. However, aural detection was also impacted. During some surveys, wind was high (80 km/h), making the aural detection and identification of bird calls more difficult.

Future Research

There are multiple opportunities for conducting future research that builds on our results and mitigates our limitations, helping to further inform and refine Tūhaitara Trust's planting and management plans. Future research could utilise satellite imagery to up-scale monitoring at Tūhaitara Coastal Park and Katiritiri Ridge. This will enable park-wide assessments of plant cover and allow sites from different habitat types to be randomly selected for surveys (Greene & Pryde, 2012; MacLeod *et al.*, 2012; Bombaci & Pejchar, 2018). Additionally, if working with future GEOG309 groups, Tūhaitara Trust should consider requesting the development of species recognition software that would allow data from ARUs to be utilised. This would enable future research to involve long-term monitoring using ARUs, which would improve estimates of bird abundance and distribution throughout Tūhaitara Coastal Park and Katiritiri Ridge (Klingbeil & Willig, 2015).

Tūhaitara Coastal Park hosts several migratory species, so understanding how plant cover, bird abundance and distribution fluctuate with the seasons is important and could be explored using long-term monitoring. This will ensure that planting plans fulfil the resource requirements of different bird species present throughout the year. Tūhaitara Trust's planting plans could be further improved by conducting research exploring the survivorship of immature native plants and abiotic conditions present at each biota node. Although variation in soil moisture content throughout the park was investigated, its relationship to plant survivorship was not. Investigating potential drivers of low plant survivorship, including soil type, soil moisture, temperature, and light exposure, may reveal patterns or trends about how they influence plant survivorship. This information would be useful in informing future planting plans.

Recommendations

Since current biota nodes are seemingly not affecting bird abundance as desired, the Tūhaitara Trust should prioritise establishing a well-connected network within the pine plantations. Literature indicates native birds are disproportionately affected by forest fragmentation (Gerard *et al.*, 2025). Hence, creating a network of biota nodes in the exotic habitat may reduce the effects of forest fragmentation by increasing connectivity.

Alternatively, if creating the network is not possible due to forestry commitments, new biota nodes should instead be planned for areas where lupin and gorse are present. Although close management is required, using lupin and gorse as nursery species may be a cost-effective strategy for improving the survivorship of immature native plants (Galappaththi *et al.*, 2023).

To further improve survivorship, mulch should be applied to all current and future biota nodes while the immature native plants are establishing. As seen in pine sites, having a layer of organic matter (mulch) helps to trap moisture (Figure 7), creating better growing conditions for the plants. Additionally, planting native plants better suited to low soil moisture content is advisable. Specific plant recommendations can be found using Aotearoa-based tools like https://kiwiscience.com/TikaTipu/Kiwiscience.html and https://www.b4c3.com/rightplant-new-zealand. Further information can be inferred from Di Lucas' ecosystem maps of Christchurch. Although the maps do not cover the Tūhaitara Coastal Park area, they indicate that following planting recommendations for coastal plains would help to increase plant survivorship. The map's plant lists for the Akeake and Pingao ecosystem types will be particularly relevant. This will assist in achieving the Tūhaitara Trust's goal of restoring the park to its original state.

Conclusion

This study investigated the relationship between plant diversity and bird abundance at Tūhaitara Coastal Park to inform future planting plans and restoration strategies. Initially, we were focused on plant diversity, but our results showed that site type and vegetation cover were stronger predictors of bird abundance. Wetland and lagoon sites supported the highest bird numbers and species richness, while pine sites had consistently low abundance, likely due to limited food resources.

Dietary patterns were also aligned with habitat types. Omnivores were widespread, insectivores favoured pine sites, herbivores dominated wetlands, and carnivores were most common in open dune areas. Soil analysis revealed that pine sites had the highest moisture content, likely due to the layer of organic matter on top of the soil. This information is useful in guiding the trust towards meeting its restoration goals.

Limitations included seasonal timing, non-random site selection, varied viewsheds, and weather conditions that affected bird detection. Despite these constraints, there are still actions that can be implemented at the park. These include increasing sampling across seasons and ecosystems, focusing the locations of new biota nodes, applying mulch in dry zones to improve soil moisture, and prioritising high-tolerance native plants suited to low-moisture soils. Additionally, incorporating satellite imagery and ARU's could further enhance long-term monitoring of bird abundance across the park.

Acknowledgements

We would like to extend thanks to our supervisor, Marwan Katurji, for his guidance; to UC'S lab technician, Justin Harrison, for his oversight; to our community partners from the Tūhaitara Trust, Kelli Patterson and Chris Dawson, for making this project run smoothly; and to Sara Kross for her expert advice. Finally, thank you to the GEOG309 professors for giving us the opportunity to work on this project.

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Appendix A

Bird abundance and plant cover

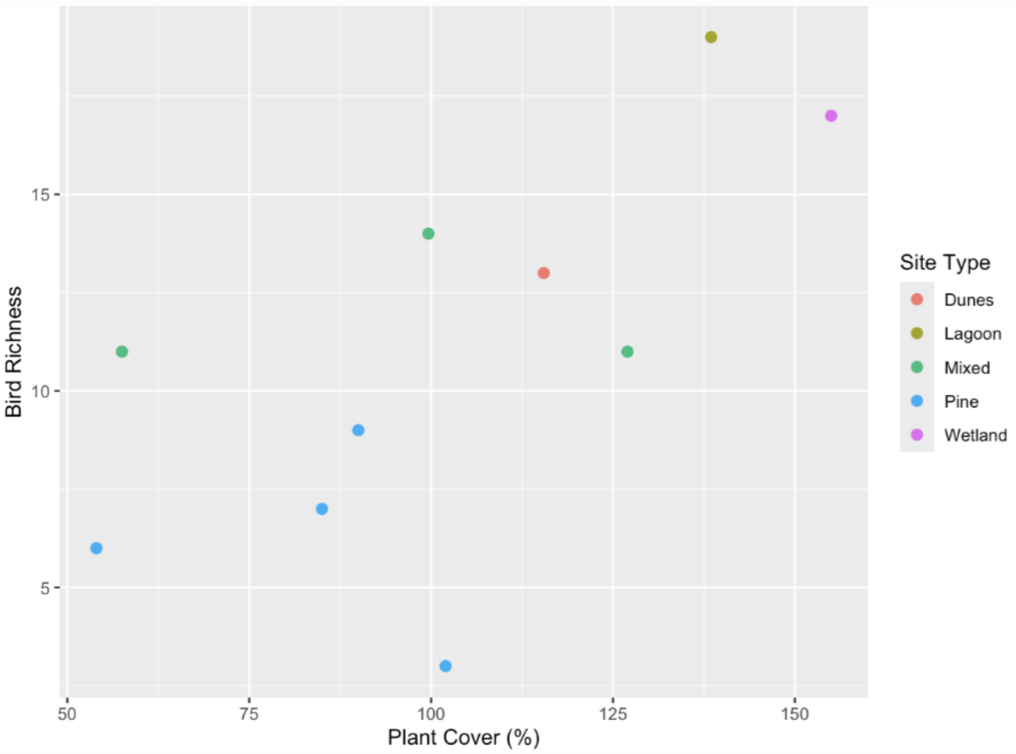

Figure A1) Scatter plot showing the relationship between plant cover (%) and bird richness, colour coded by site type.

Appendix B

TukeyHSD analysis of different site type's bird richness.

The richness of bird species only differed significantly between the pine sites and the lagoon, ($p = 0.02$), mixed ($p = 0.09$), and wetland ($p = 0.04$) site types (Table B1). However, there were no significant differences between the gravimetric water contents of the other site types ($p > 0.05$) (Table B1).

Table B1) Output of TukeyHSD analysis of different site type's bird species richness. 'diff' is the difference in means between the two compared groups; 'lwr' is the lower confidence interval, 'upr' is the upper confidence interval, and 'p adj' is the adjusted p value.

	diff	lwr	upr	p adj
Lagoon-Dunes	6.00	-6.6219053	18.621905	0.4163954
Mixed-Dunes	-1.00	-11.3057425	9.305743	0.9935678
Pine-Dunes	-6.75	-16.7284923	3.228492	0.1822538
Wetland-Dunes	4.00	-8.6219053	16.621905	0.717998

Mixed-Lagoon	-7.00	-17.3057425	3.305743	0.1801504
Pine-Lagoon	-12.75	-22.7284923	-2.771508	0.0189364
Wetland-Lagoon	-2.00	-14.6219053	10.621905	0.9623095
Pine-Mixed	-5.75	-12.5666079	1.066608	0.0917383
Wetland-Mixed	5.00	-5.3057425	15.305743	0.4007061
Wetland-Pine	10.75	0.7715077	20.728492	0.0376361

Appendix C

TukeyHSD analysis of different soil site type's gravimetric water content.

The gravimetric water content of pine sites differed significantly from the gravimetric water content of the dune ($p = 0.034$), lagoon, ($p = 0.31$), mixed ($p = 0.16$), and wetland ($p = 0.46$) soil site types (Table C1). However, there were no significant differences between the gravimetric water contents of the other site types ($p > 0.05$) (Table C1).

Table C1) Output of TukeyHSD analysis of different soil site type's gravimetric water content. 'diff' is the difference in means between the two compared groups; 'lwr' is the lower confidence interval, 'upr' is the upper confidence interval, and 'p adj' is the adjusted p value.

	diff	lwr	upr	p adj
Lagoon-Dunes	-1.00000	-56.565738	54.5657378	0.9999914
Mixed-Dunes	10.50000	-33.428573	54.4285728	0.862848
Pine-Dunes	50.33333	4.964098	95.7025682	0.0335553
Wetland-Dunes	4.00000	-51.565738	59.5657378	0.9979414
Mixed-Lagoon	11.50000	-32.428573	55.4285728	0.8239329
Pine-Lagoon	51.33333	5.964098	96.7025682	0.0310455
Wetland-Lagoon	5.00000	-50.565738	60.5657378	0.9951616
Pine-Mixed	39.83333	9.824405	69.8422615	0.0161449
Wetland-Mixed	-6.50000	-50.428573	37.4285728	0.9702181
Wetland-Pine	-46.33333	-91.702568	-0.9640984	0.0461954