Structural Influence of Old Field on Breeding Summer Songbirds, and Overwintering Raptor Communities.

by

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Abstract

Old field is a unnatural habitat that usually occurs as a result of agricultural land abandonment and is the product of early-stage natural succession on a previously managed field. In an agricultural setting with monoculture crops, old fields provide more vegetative complexity through ground cover diversity and shrubs and hedgerows. In Delta, British Columbia, several old-field sites are managed for wildlife and provide nesting habitat for songbirds over the summer, as well as foraging habitat for overwintering raptors during fall and winter months. I surveyed two old-field sites near Boundary Bay, and two field sites at the Vancouver Landfill to compare the influence of old-field vegetation on different bird communities and improve understanding on species using the landfill. I conducted fixed-radius point counts for songbirds, and standing counts for raptors. Comparing replicate field types (n=2) I found that overall diversity of songbirds was higher in old field, and also associated with structural features like shrubs and trees, while abundances of Savannah Sparrows (*Passerculus sandwichensis*) decreased with proximity to shrubs and trees. My results support the conclusion that installing structural vegetation features at the landfill would maximize breeding songbird diversity. I also found the landfill to support higher diversity of wintering raptor species, but old field supported consistently higher abundances. This suggests that the landfill is currently functioning as lower quality wintering habitat, and that different management techniques should be considered.

Acknowledgements

Thanks to my supervisor Doug Ransome for continued support and encouragement through this project and for keeping me on track. To Nada Jagodic at the Vancouver Landfill for helping push this project forward and sharing her enthusiasm. To Markus Merkens from Metro Vancouver for helping get this project running. I also want to thank Samara Kolasko for helping me navigate this process along with my other peers who have supported me along the way. Thank you to all the BCIT and SFU faculty who have provided insight and support to me throughout this program, especially Eric Anderson who has repeatedly shared his bird expertise. And finally, thank you to my grandparents Paul and Amanda in California who gave me the first nudge into the world of birding, and were always available to “go feed the ducks”.

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Introduction

Across North America as urban development advances, natural areas are constantly more constrained (Stanton et al. 2018). The creation and management of old fields has emerged as a strategy to create high-quality field habitat in urban and rural areas (Baldwin et al. 1992). Old fields are typically an early-succession stage in abandoned agricultural fields but the condition and structure of an old field can be highly dependent on pre-existing vegetation and soil characteristics (Cramer et al. 2008). As an unnatural habitat, there is no singular natural reference condition to model the construction or restoration of old-field sites, but when managed with the goal of supporting bird communities old fields are valuable habitat in an otherwise modified landscape.

Delta, BC, is 180 km^2 and is part of the "Boundary Bay – Roberts Bank – Sturgeon Bank (Fraser River Estuary)" nationally designated Important Bird Area (IBA) in Metro Vancouver (IBA Canada, n.d.). Delta is also part of the Pacific Flyway making it an important stopover point for migratory bird species in the Americas (Wilson 2010). The locational importance of Delta to birds is amplified as a result of global declines in bird populations. Since 1970, migratory North American bird populations have declined by 29% and grassland birds in Canada have declined by 57% (Rosenberg et al. 2019, NABCI 2019). Habitat loss is an attributing factor. Naturally occurring habitat for grassland birds across North America is largely on the decline through increasing fragmentation, urban and agricultural expansion, and the decreasing quality of rangelands as habitat (Brennan & Kuvlesky 2012).

Old-field habitat has many functions pertaining to bird use. It can be used for summer-breeding, overwintering, year-round, or as a stop-over point in migration (Baldwin et al. 1992). Migratory and resident songbirds *(passerines)* also use old fields during winter and the summer breeding season. Baldwin et al. (1992) found increased species richness in old fields around Boundary Bay as a result of overwintering migratory songbirds. He also found hedgerows with trees have more songbird diversity compared to hedgerows lacking trees, indicating the importance of structural vegetation (Baldwin et al. 1992). Hedgerows are highly used by songbirds in old field, and factors like width, height, and composition all impact suitability for breeding songbirds (Hinsley & Bellamy 2000). However, less is known about how the field habitat itself (opposed to hedgerow margins) is used by songbirds.

There are many raptor species in the Lower Mainland that are specifically tied to old fields, both for breeding during summer months and for overwintering. Old field sites around Boundary Bay in Delta have been used by Bald Eagles (*Haliaeetus leucocephalus*), Red-tailed Hawks (*Buteo jamaicansis*), Rough-legged Hawks (*Buteo lagopus*), Northern Harriers (*Circus hudsonius*), Short-eared Owls (*Asio flammeus*), and Barn Owls (*Tyto alba*) (Baldwin et al. 1992). With the exception of the Bald Eagle, the other birds of prey all have a diet largely supported by small mammals (Luttich et al. 1970, Springer 1975, Baldwin et al. 1992, Serrention 1992, Wiebe 1992, Kross et al. 2016). Old fields are able to support high densities of small mammals like the Townsends vole (*Microtus townsendii*) that have been observed at densities of 145 individuals per hectare (Huang et al. 2010, unpub. data). Old field in the Lower Mainland is considered high-quality habitat for raptors to hunt in (Baldwin et al. 1992). A local threat to raptors that old field addresses is the frequent use of agricultural fields or grass set-asides along roads for hunting where prey is more accessible. Consequentially, hunting adjacent to roads exposes raptors to a higher risk of death or injury through collisions with vehicles. In addition, raptors can increase their secondary consumption of rodenticide through feeding on prey species that have consumed rodenticide in agricultural or urban areas (Hindmarch et al. 2015). Accessible old field acts as high-quality hunting habitat with fewer associated risks, and can also support breeding under the right circumstances (Baldwin et al. 1992).

The Vancouver Landfill in Delta, British Columbia is around 200 ha in size and is adjacent to the Burns Bog Conservation Area, which is suggested to be the largest undeveloped urban land mass in North America and also part of the same Fraser River Estuary IBA (Delta n.d. & IBA Canada n.d.). The landfill has been undergoing closure since 2009, and is anticipated to be entirely closed by 2037 (City of Vancouver 2019). While objectives pertaining to use of the landfill once closed are uncertain, the final product of closure is the fill (garbage) being covered with a specialized closure membrane and a metre of topsoil, seeded with grass and herbs for cover. One potential pathway for management of the landfill post-closure, would be to manage it as an ecologically important old-field site. While the landfill currently has only herb and grass cover from a manually applied seed mix, the management of vegetation could be shifted to more closely resemble old field if desired by Metro Vancouver.

As a result of declining bird populations, conservation and creation of old fields are highly important to aid in supporting future bird populations. When compared to an agricultural field, or a recently seeded field like the landfill, old-field vegetation can be more heterogeneous as the reduction in field management gives colonizing species more opportunities to establish (Bartha et al. 2003). In ecosystems, animal diversity is often associated with an increase in habitat heterogeneity and structural features (Tews et al. 2004). Old fields are suggested to support high diversity of herbs, grasses and shrubs; thus, in grassland ecosystems, this type of heterogeneity or patchiness can increase bird diversity (Fulendorf et al. 2006). The aim of this study was to characterize and compare summer-songbird and winter-raptor communities between old field and the landfill. By contrasting old field with the landfill, potential restoration techniques have been identified that could improve the ecosystem function and accelerate the development of old-field characteristics that have potential to enhance diversity of birds for the landfill sites.

Project Objectives and Hypotheses

Old fields are generally considered to be important bird habitats. This study aimed to investigate what components of vegetation influence bird use of a site and to determine if these vegetative structural attributes are positively associated with higher bird diversity among the study sites. In addition, bird species diversity was contrasted between the grassland habitats at the Vancouver Landfill with old-field sites. The following research questions and objectives were addressed in this study, and have been divided into sections focusing on songbirds and raptors.

Goal 1: Describe the influence of old-field vegetation structure on summer breeding bird communities.

Objective 1.1) Describe how vegetation cover/structure, and songbird species at the landfill vary from old-field sites.

Objective 1.2) Determine why differences exist between the landfill and old-field sites.

Objective 1.3) Create suggestions for management and manipulations to the landfill to encourage enhanced songbird use.

Goal 2: Describe the differences between over-wintering raptor use of the landfill and old-field sites.

Objective 2.1) Determine how the use of the landfill by raptors varied from that at the old-field sites.

Objective 2.2) Create suggestions for management and manipulations to the landfill to encourage hunting by over-wintering raptors.

Enhancing our understanding on how different species of birds will interact with varying aspects of the landscape can help guide management of novel old-field ecosystems. The Vancouver Landfill is currently being managed without a specific ecological goal, so if it is feasible to manage or manipulated the reclaimed sites to more closely function as old field it could be a beneficial addition to the Delta landscape. I hypothesized that the diversity of summer songbirds and overwintering raptors would be higher in old field than at the Vancouver Landfill as a result of more structural shrubs and trees, and taller and more diverse ground cover vegetation.

Site Overviews

Project Location

The Vancouver Landfill is in Delta, British Columbia, Canada, and is part of Metro Vancouver. The City of Delta is bordered by the Fraser River and Richmond from the north, the Georgia Strait from the west, Surrey from the east, and Boundary Bay from the south (Fig. 1). It is at the western extent of the Fraser River Valley, which makes up most of the Lower Mainland in British Columbia and is surrounded by the Coast Mountains to the north and Cascade Mountains to the south. Delta was formed by the deposition of sediment from the Fraser River that began during the melting of glaciers during the Holocene (Clague et al. 2011). Historic sediment deposition has resulted in Delta having fertile soils and primarily agricultural land use today. Delta is in the Coastal Western Hemlock Biogeoclimatic Zone that is characterized by cool summers and mild winters, rarely going below freezing (Meidinger & Pojar, 1991). Boundary Bay Regional Park (BBRP) is around 10 km south (Fig. 1) and on the edge of Boundary Bay with the landfill being around 6 km to the north.

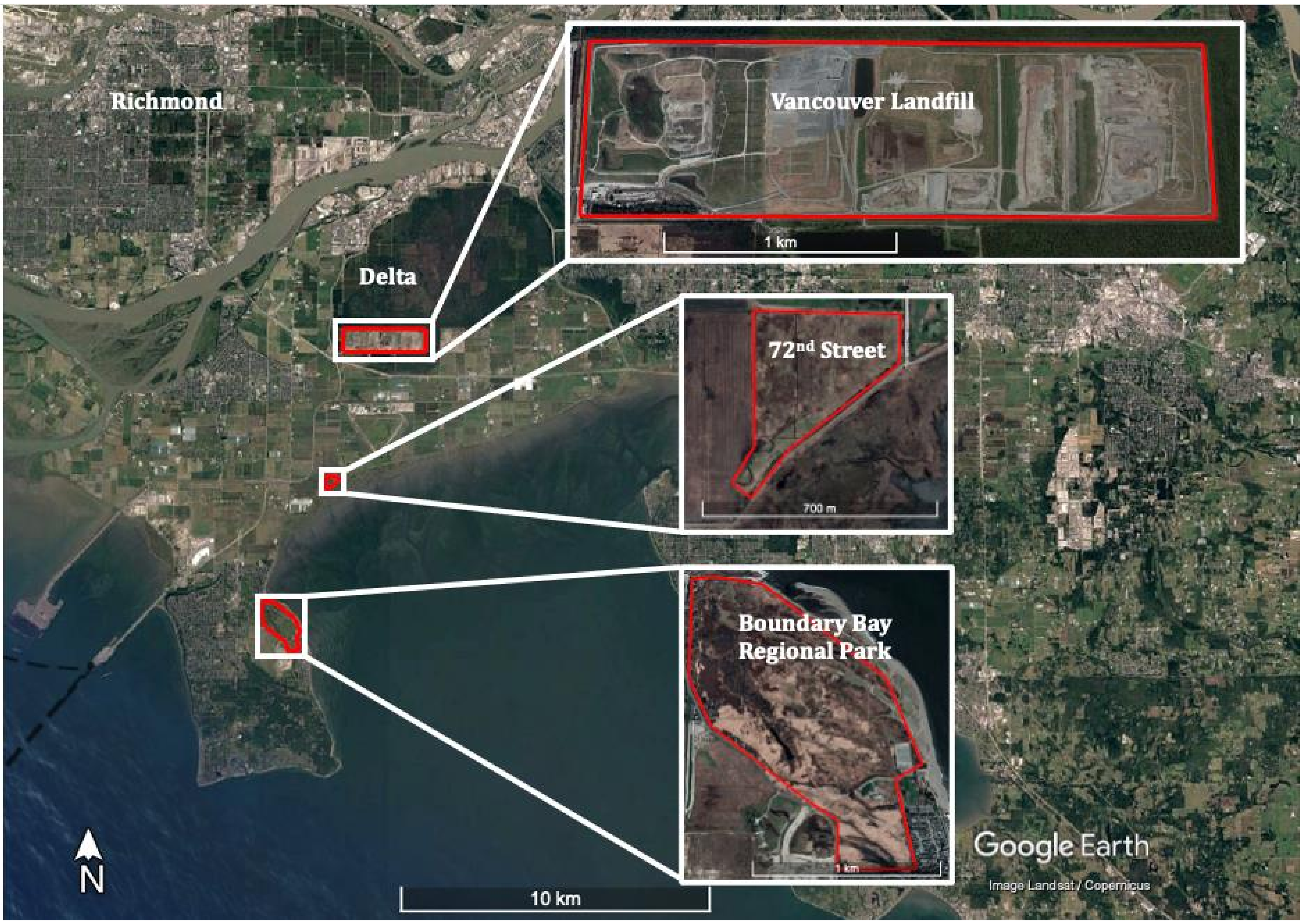

Figure 1. Delta, British Columbia, is part of Metro Vancouver and south of Richmond. The Vancouver Landfill and the two old-field sites (72nd Street and Boundary Bay Regional Park) are in Delta as indicated by satellite imagery taken in 2021.

This study uses two fields at the Vancouver Landfill, one old field at Boundary Bay Regional Park, and one old field by the Boundary Bay Dyke Trail at the end of 72nd street (Fig. 1). Fields at the landfill are considered simple fields as they undergo regular mowing and have been covered with a homogeneous seed mix, whereas the other two sites are both old-field and have the associated vegetative complexity.

Landfill Phase 2 (P2)

Phase 2 of the landfill is a 20-hectare section that was closed in 2013 (Fig. 2). It was seeded with an agricultural mix, and vegetation is predominantly orchard grass (*Dactylis glomerata*), red top (*Agrostis gigantea*), tall fescue (*Schedonorus* arundinaceus) and creeping red fescue (*Festuca rubra*).

The only structural features are gas wells which run along underground gas lines, and occur every 50 metres and a couple light posts. There is a constructed wetland in the south east corner of Phase 2 which was not actively surveyed. The west side of Phase 2 has an elevation of around 22 metres, and a gentle grade of 0.07 moving uphill towards the eastern limit at around 35 metres above sea level. A grid of gravel roads run across the site for access to wells for maintenance and the site has been regularly mowed to mitigate fire risk. There is a ditch filled with rocks running adjacent to the road. For this study, mowing was halted after the summer of 2020 so the site was less disturbed for a year prior to data collection.

Landfill Western-40 (W40)

The Western-40 hectares (Western-40) is at the western end of the landfill and is around 33 ha (Fig. 2). It was closed in 2020 so is seven years younger than Phase 2, and was seeded with a wetland mix. Current vegetation included a mix of grass and herb species including annual ryegrass (*Lolium multiflorum*), clover (*Trifolium* spp*.)* and white sweetclover (*Melilotus albus*). It has more varied localized topography with six constructed wetlands that were dry over summer but full during fall and winter. Gravel roads run through the site, but go around the constructed basins opposed to the Phase 2 section where they are more grid-like. Mowing was also halted after the summer of 2020 in this section.

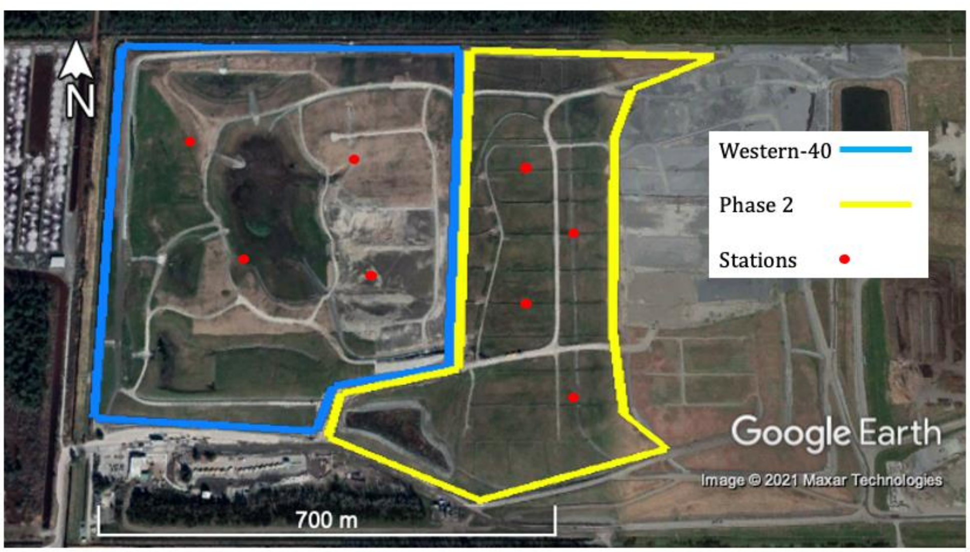

Figure 2. The Western-40 ha section and Phase 2 section of the Vancouver Landfill in Delta, BC. Taken from satellite imagery from 2021, the Western-40 section is on the west side and bordered with blue, the Phase 2 section is on the east side and bordered with yellow. Point-count station locations to monitor songbird diversity have been identified with red points.

72nd Street at Boundary Bay Dyke Trail (72S)

The 72nd street location is considered old-field in this study and is on the mainland side of the Boundary Bay Dyke that runs along the southern border of the site (Fig. 1). It is approximately 12 ha in size, with grasses and herbs being the predominant vegetative cover. The field is bordered by hedgerows, and there are several patches where Pacific Crab-apple (*Malus fusca*) trees grow. This site was previously used for agriculture (M. Merkens, pers. comm.), and remnants of this are still visible through the three ditches that run north to south through the site. Vegetation includes Douglas aster (*Symphyotrichum subspicatum*), willowherbs (*Epilobium* spp.), thistles (*Cirsium* spp.), velvet grass (*Holcus lanatus*) and dune bentgrass (*Agrostis pallens*) along with patches of the invasive Himalayan blackberry (*Rubus armeniacus*) and Cutleaf blackberry (*Rubus laciniatus*) (Fig. 3).

The area is fenced off from the public, and while people can walk along the adjacent Boundary Bay Dyke Trail, there is a large hedgerow along the path blocking the view of the study site. Directly surrounding the field are: a residential property to the north, agricultural fields to the west, a dirt road with parking, and adjacent golf course to the east. Overall the site is flat, with only 1-2 metres of elevation above sea level. Hedgerows along the margins of the field are composed of Himalayan blackberry, Pacific Crab-apple, Dog rose (*Rosa canina*), Saskatoon berry (*Amelanchier alnifolia*), and Black hawthorn (*Crataegus douglasii*).

Figure 3. Cutleaf blackberry (left) and Pacific Crabapple (right) photographed in July, 2021 at the 72nd Street old-field site near Boundary Bay, in Delta, BC.

Boundary Bay Regional Park (BBRP)

The old-field site at Boundary Bay Regional Park is 1.7 ha making it only 14% the size of the 72nd Street field (Fig. 1). Boundary Bay Regional Park is over 100 ha in size, and has a mix of old field and marsh areas throughout the park. Because of limits in accessibility, and the patchiness of marshes throughout the park, this was the only area that could be surveyed. The site is bordered by a row of trees and hedges on the east, a road on the north and west, and a managed field on the south. There is also evidence of agricultural-land use as there is a ditch that runs through the site. Vegetation includes reed canary grass (*Phalaris arundinacea*), Canada thistle (*Cirsium arvense*), ryegrass, and several patches of Himalayan blackberry.

Methods

Methods Overview

To compare old field to the landfill, I had two replicates of old-field sites and two replicates of landfill sites. To characterize sites for my summer surveys I delineated fixed-radius point-count stations within each site to sample songbirds and vegetation that were characteristic of the site. Figure 2 demonstrates the layout of point-count stations across both replicates at the landfill. Following my summer surveys, I began winter surveys for overwintering raptors in November. While I surveyed the same sites, I did not use the same point-count stations and was able to characterize raptor communities for the entire site from one standing-point location.

Vegetation Sampling

Within each point-count station five vegetation plots were surveyed using a 50- x 50-cm quadrat. Location of the quadrat placement was systematic as I walked ten steps on the north, south, east, and west axis and then threw the sampling frame, aiming straight ahead, but surveying wherever it landed. The fifth plot took place in the centre of the point-count station. Percent cover at five height classes (<25 cm, 25-50 cm, 50-75 cm, 75-100 cm, >100 cm) was measured to quantify vegetation coverage at ground level as well as vertical structure. Percent cover was also recorded for trees and shrubs when rooted in the plot and I measured the area of trees with a flexible measuring tape. By adding up the all the individual areas of trees and shrubs, the sum could then be divided by the total area of the point-count station (7854 m^2) to determine percent cover. There are no trees or shrubs at the landfill, so I only measured shrub and tree cover at the old-field sites.

Fixed-Radius Point Count Surveys

A total of 13 fixed-radius point-count stations were setup at the end of May 2021, with 4 stations each in the Phase 2, Western-40, and 72nd street, and 1 station at BBRP. Within each site, the location of the first station was selected randomly on a map in proximity to a convenient access point, and the following stations were placed at set 150-metre intervals. This interval also ensures independence among point-count stations by allowing at least 50 metres between the perimeters of individual stations, as is recommended by RISC (1991).

Each station was visited six times from May 28th to July 1st of 2021, with 4-5 days in between site visits. The landfill and old-field sites were always visited on different days; however, the order of stations surveyed was always reversed to minimize time bias. Point counts began at 5 am and were completed by 9 am, and they were never conducted during heavy rainfall or stormy conditions. Upon arrival at a point count station, there was a five minute acclimation period to allow birds to adjust to the disturbance of an observer, and then for the following 10 minutes all birds observed or heard were recorded.

Each point-count station had a fixed radius of 50 m and all visual and auditory detections of birds within the station were recorded. A rangefinder was used in each point-count survey to ensure that distances were being estimated accurately. Species information was taken along with distance from the observer, the substrate, and any additional behavioural observations. Particular emphasis was placed on behaviours that may indicate nesting; such as repeated instances of site fidelity through bringing food or nesting materials to the same location.

For each point-count station I calculated an average abundance value for each species observed over six survey sessions to provide the average detection per station. Then using the mean point-count station abundance values, I calculated an average abundance value that was representative of a given species for the entire site. I could then use these averaged abundances to calculate Shannon-Wiener's diversity indices that were representative of the sites. To determine species richness for a site, I compiled the number of species observed across an entire site over the full survey period.

Overwintering Raptor Surveys

November 2021 through January 2022 the same landfill and old-field sites were surveyed for overwintering raptors. These surveys functioned as a pilot study to provide a preliminary understanding of what raptor species are using the landfill during winter and how this use compares to that of the old-field sites. Each site (Western-40 ha and Phase 2 at the landfill, and the old field at 72nd Street and Boundary Bay Regional Park) was surveyed twice over two days, once a month for three months (n = 6 surveys/study site). One visit would occur either during the morning or afternoon on day one, and then this was reversed for the second day to ensure no time bias between 10:00-16:00 hours.

Each site was surveyed for 50 minutes and all observations of raptor activity were recorded, along with the maximum number of individuals of a species spotted at the same time. Based on my positioning and the use of landmarks as boundaries for observations, I was able to standardize each survey station to have an area of around 10 hectares, with the exception of BBRP which was 7 hectares. During surveys, an observation would begin when an individual raptor entered my sight and end once it had exited. Taking multiple observations of the same individual was important to contrast an individual that comes through a site once over the span of an hour compared to one which actively uses the site for a prolonged period of time.

To characterize the diversity of each site over the study period I first averaged the abundance of species over a survey session (two days), and then calculated mean abundance for each site by averaging abundances from all three survey sessions. Unfortunately because both of the landfill sites were adjacent to one another, the strength of conclusions from this portion of the study were weakened as a result of the landfill sites not being independent for raptor surveys. The old-field sites had around 5 km of separation between them, but the two sections of the landfill were directly adjacent to one another.

Statistical Analysis

To effectively summarize my point-count observations of songbirds where I visited each station six times, I calculated an average abundance of each species observed. If a bird species was consistently observed at every visit to a point-count station it would be reflected as an average of these observations, and if a bird species was only observed once, in the averaged point count it would be considered $1/6^{th}$ of an occurrence. I used these calculated mean abundances for each point-count station to calculate Shannon-Wiener's Diversity Index. The replicates in this study are the sites themselves, with multiple samples being averaged to represent the each site (except for BBRP, where only one point-count station was setup).

I used one-way ANOVA tests to determine if there were significant differences among population metrics like diversity and abundance, as well as comparing vegetation height. Results were deemed significantly different at $P < 0.05$, however I discuss other results of less significance where $P < 0.2$. To suggest linear correlations between variables, I have used scatterplots with r^2 values to suggest the strength of the linear relationship. To improve the power of my analyses in songbird diversity and vegetation height, I also conducted one-way ANOVA tests using individual point-count stations as replicates (n=8, n=5), in addition to using the sites (n=2) as replicates.

Results

Vegetation Characteristics

Point-count stations within the old-field sites had between 0-7% cover of rooted shrubs and trees with a total of 12 species identified (Table 1), whereas there were no shrubs or trees in any point-count stations at the landfill.

Table 1. Shrub and tree species identified in point-count stations at 72nd Street and BBRP old-field sites in Delta, BC, in July 2021. The Vancouver Landfill lacked shrub/tree cover entirely.

Species	Sites Observed	Invasive / Native
Himalayan Blackberry *Rubus armeniacus*	72nd Street, BBRP	Invasive
Cutleaf Blackberry *Rubus laciniatus*	72nd Street, BBRP	Invasive
Pacific Crabapple *Malus fusca*	72nd Street, BBRP	Native
Black Hawthorn *Crataegus douglasii*	72nd Street	Native
Saskatoon Berry *Amelanchier alnifolia*	72nd Street	Native
Red Elderberry *Sambucus cerulea*	BBRP	Native
Sitka Willow *Salix sitchensis*	BBRP	Native
Nootka Rose *Rosa nutkana*	72nd Street	Native
Multiflora Rose *Rosa multiflora*	72nd Street	Invasive
Dog Rose *Rosa canina*	72nd Street	Invasive
Ponderosa Pine *Pinus ponderosa*	BBRP	Native
Red Alder *Alnus rubra*	BBRP	Native

There were no significant differences in percent cover of grasses and herbs between old field and the landfill, (Fig. 4). While the landfill was subject to less variability, the mean proportions of grass to herb cover were similar. The landfill had a total species richness of 23, from 40 sampled vegetation plots, and old field had a total species richness of 28, from 25 sampled vegetation plots.

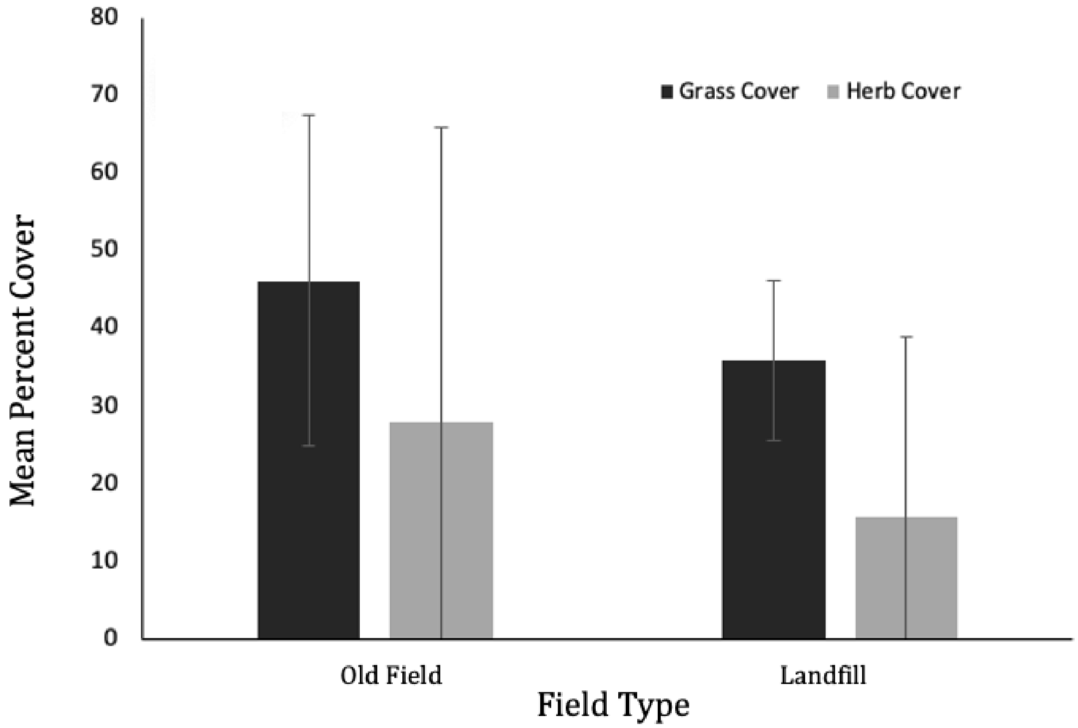

Figure 4. Comparison of mean (± 95% CI) percent cover of grass and herbs at old-field sites and the Vancouver Landfill. All sites were located in Delta, BC and vegetation data was collected July 2021. The figure demonstrates the high variability that exists in grass and herb cover at both sites.

There was a difference of moderate strength between old field and landfill sites for percent cover of grasses and herbs that exceeded 50 cm in height ($F_{1,2}$ = 9.38, P = 0.092) (Fig. 5). However, when point-count stations were treated as replicate units, an ANOVA test demonstrated a stronger significant difference ($F_{1,11}$ = 4.93, P = 0.048).

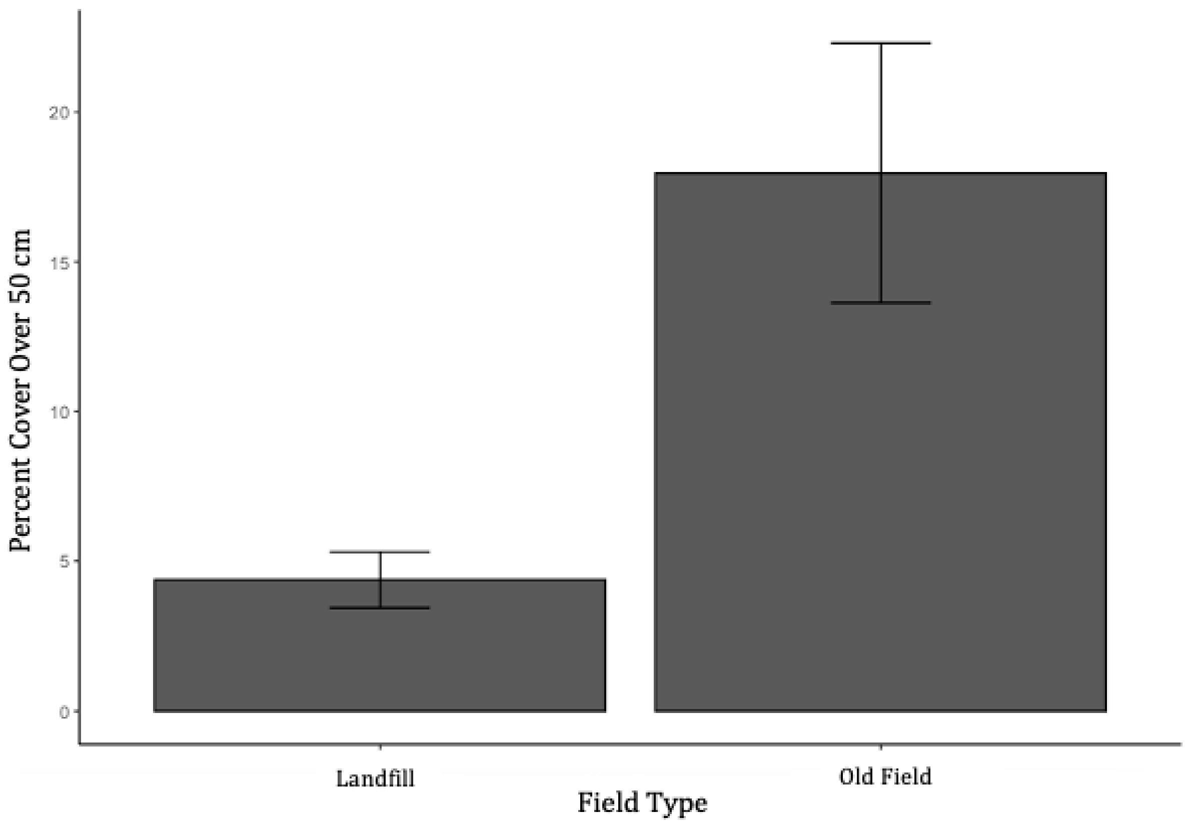

Figure 5. Comparison of means (± 95% CI) from herb and grass percent cover over 50 cm in height between the landfill and old field. Sites are located in Delta, BC and vegetation was surveyed in July 2021.

Summer Songbirds

A total of 502 bird observations made up of 22 species were recorded during summer point counts (Appendix A). A comparison of the four sites demonstrates how BBRP and 72S had higher diversity indices, whereas the landfill sites W40 and P2 had similarly low values (Fig. 6). 21 songbird species were observed at point-count stations in the old-field sites compared to only 4 species at the landfill.

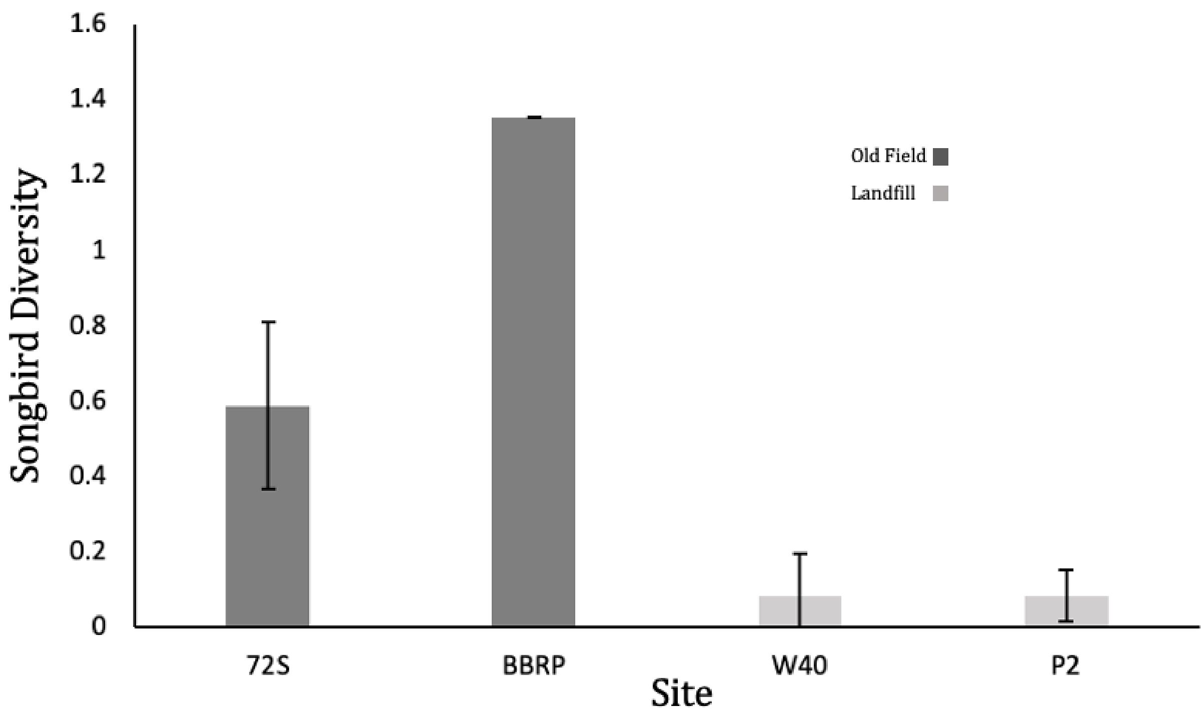

Figure 6. Mean (+/- SD) Shannon-Wiener's Diversity Index for bird species observed at point count stations at the 72nd Street and BBRP old-field sites, and Western 40 and Phase 2 sites at the Vancouver Landfill, in Delta BC over June 2021.

Beyond comparisons of the individual sites, the ANOVA test did not suggest significant difference ($F=_{1,2}=4.7$, $p=0.2$) in diversity between old field and the landfill (Fig. 7). However, there was a six-fold increase in diversity in old-field compared to the landfill. When point-count stations were treated as replicate units, an ANOVA test demonstrated a stronger significant difference ($F_{1,11}=14.2$, $P = 0.03$).

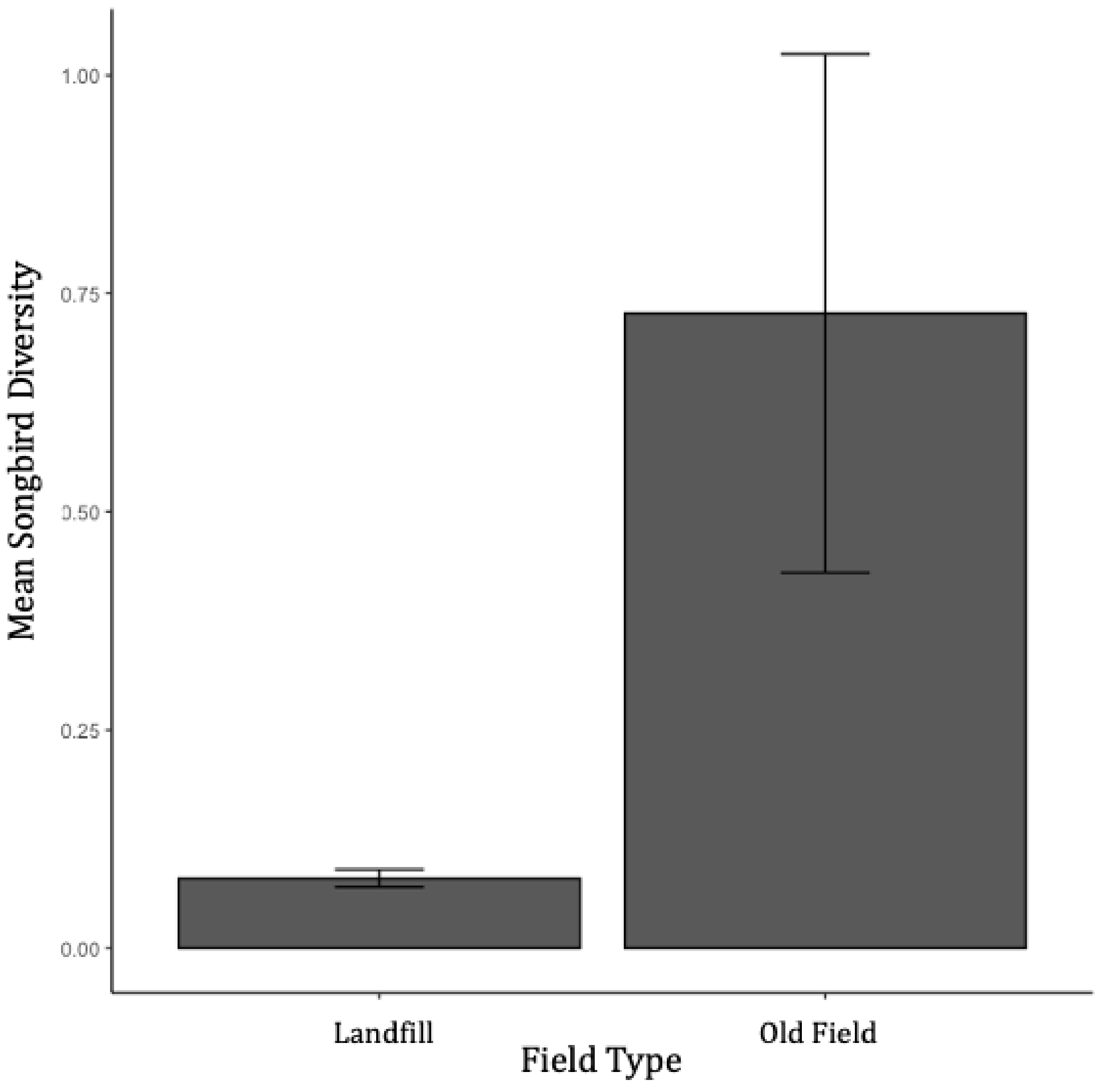

Figure 7. Comparison of mean Shannon-Wiener's Diversity Indices (± 95% CI) for songbird species observed through fixed-radius point count surveys at old field and the landfill in Delta, BC over June 2021.

There was a strong positive trend (R=0.95, r^2=0.9) between diversity and percent cover of shrubs and trees (Fig. 8). The point-count stations at the landfill sites had no quantifiable tree or shrub cover, and removing landfill data points increased the r^2 value to 0.94.

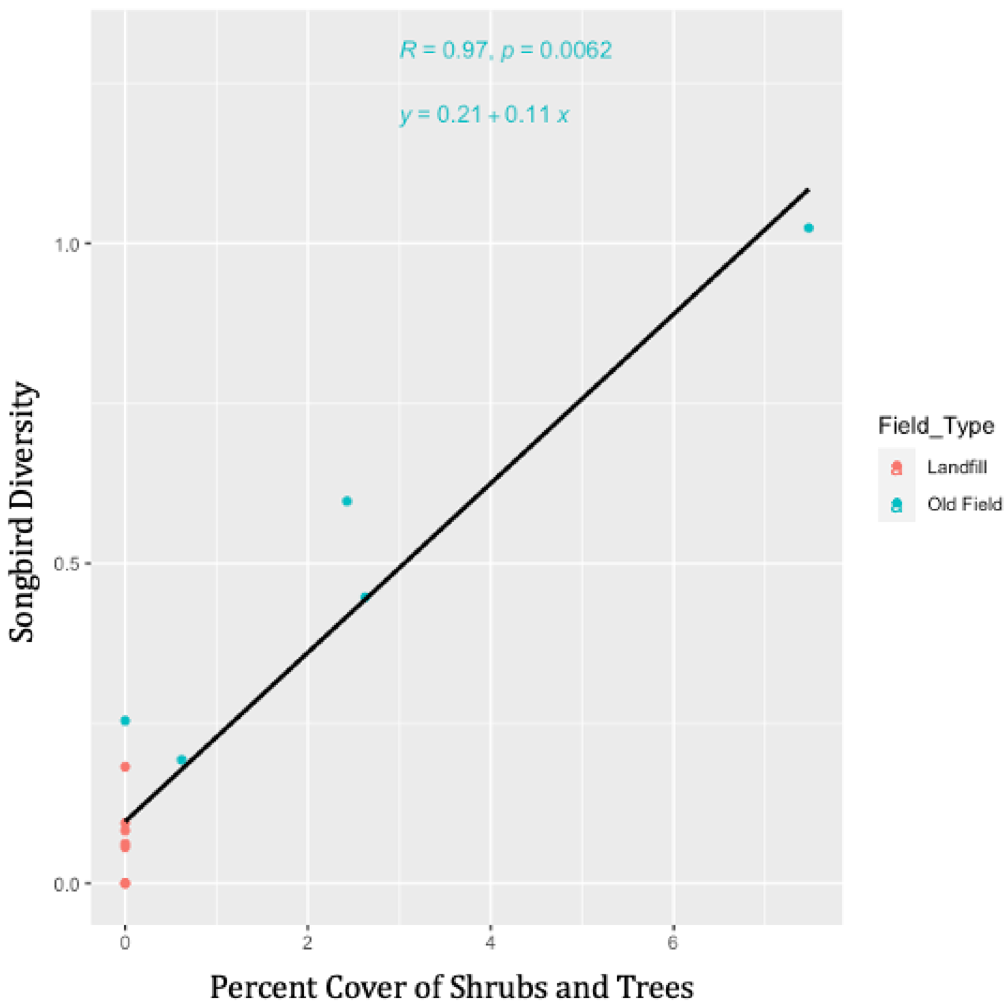

Figure 8. The relationship between Shannon Wiener's diversity index of bird species observed and percent cover of trees and shrubs in fixed-radius point-count stations at old-field sites (n=5) and the Vancouver Landfill (n=8) in Delta, BC over June 2021.

Savannah Sparrows (*Passerculus* sandwichensis) made up over 80% (413) of the observations and at the landfill were the only species observed for 41 of 48 point-count surveys conducted. They are the only species that I confirmed to be nesting at the landfill as there were multiple instances of

Savannah Sparrows displaying behaviours associated with nesting within point-count stations. Examining Savannah Sparrows (*Passerculus sandwichensis*) from within the old-field sites, a moderate negative correlation emerged (R^2=0.58) between percent cover of trees and shrubs and average number of Savannah Sparrows per point-count station (Fig. 9).

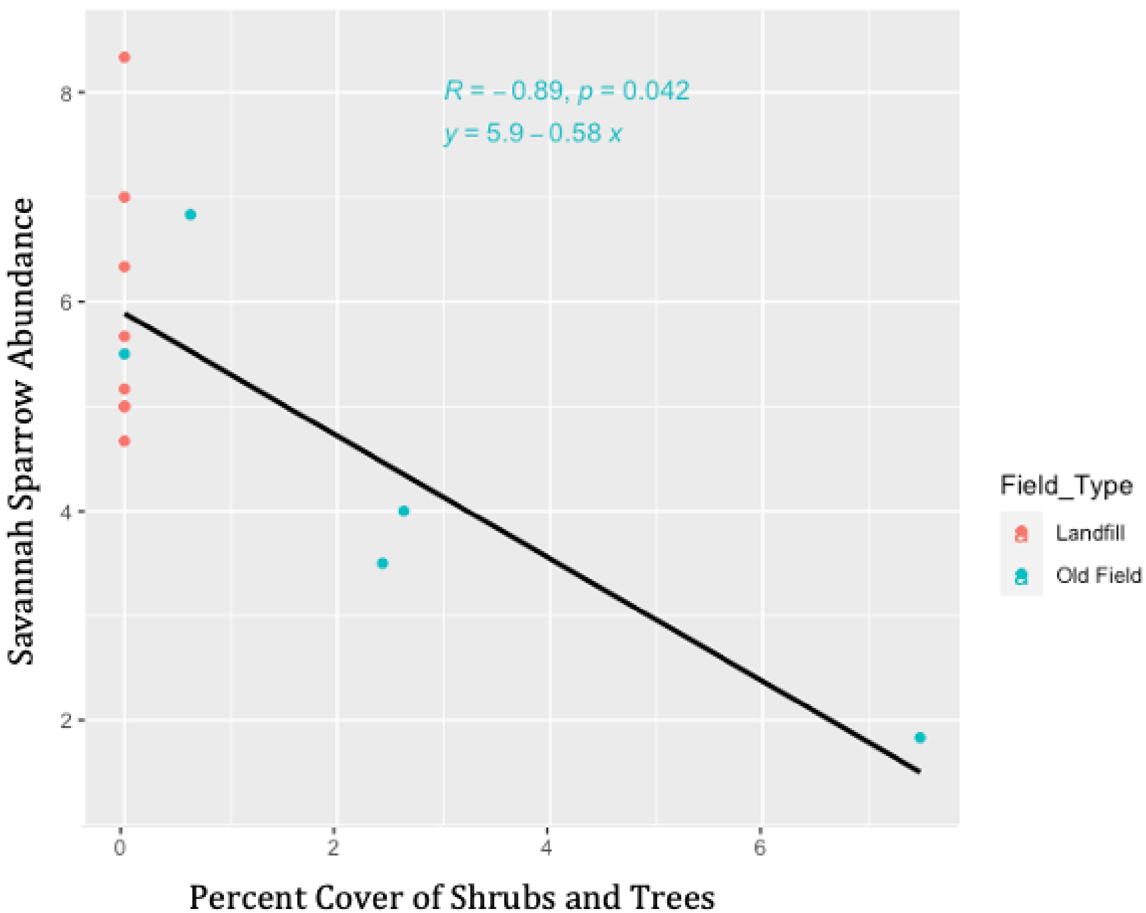

Figure 9. The relationship between mean abundance of Savannah Sparrows and percent cover of trees and shrubs in fixed-radius point count stations surveyed in June 2021 at the Vancouver Landfill (n=8) and old-field sites (n=5) in Delta, BC.

Overwintering Raptors

Bald eagles were the most frequently observed raptor at all study sites, however they were excluded from all measures of diversity as they are not a target species for this study. Other observed raptor species were the Red-tailed Hawk, Rough-legged Hawk, Northern Harrier, American Kestrel (*Falco sparverius*), and Merlin (*Falco columbarius*). I found the landfill to have significantly higher Shannon-Wiener diversity of raptors than the old-field sites (F=(1, 2)=30.54, p=0.03) (Fig. 10).

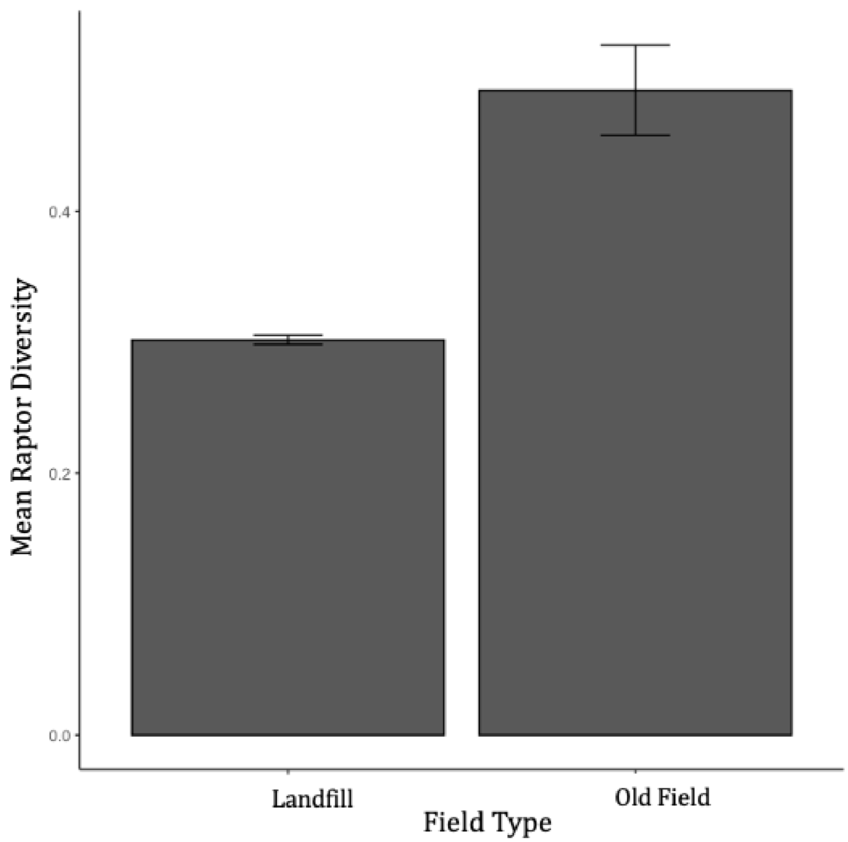

Figure 10. Comparison of mean (+/- 95% CI) Shannon-Wiener diversity of raptors observed using landfill (n=2) or old-field sites (n=2). Sites were located in Delta, BC and were surveyed three times between November 2021 – January 2022.

While the landfill appears to support more diversity for raptors, it did not appear to sustain raptor populations the same way as old field. Old field had a significantly higher average abundance of target raptor species F=(1, 2)=33.9, p=0.03) that was driven by consistent observations of Northern Harriers, Red-tailed Hawks, and Rough-legged Hawks (Fig. 11).

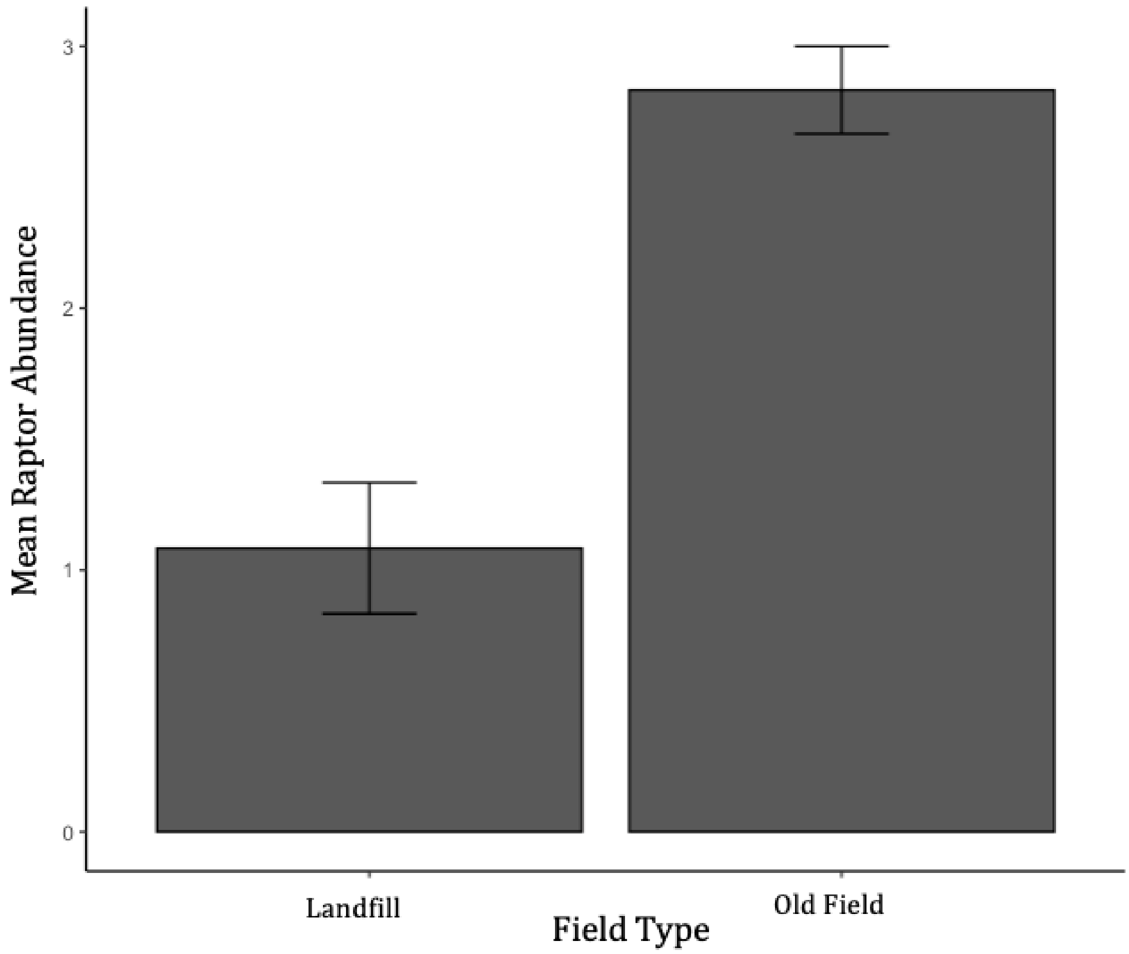

Figure 11. Comparison of mean (± 95% CI) raptor abundance (excluding Bald Eagles) at the Vancouver Landfill (n=2) and old-field sites (n=2). Sites were located in Delta, BC and were surveyed three times between November 2021 – January 2022.

Exclusively at the landfill, mean Bald Eagle abundances increased over eight-fold between the first and last survey session (Fig. 12). The Western-40 section stood out as it had over 40 individuals perched on gas wells and sitting on the ground during the final survey.

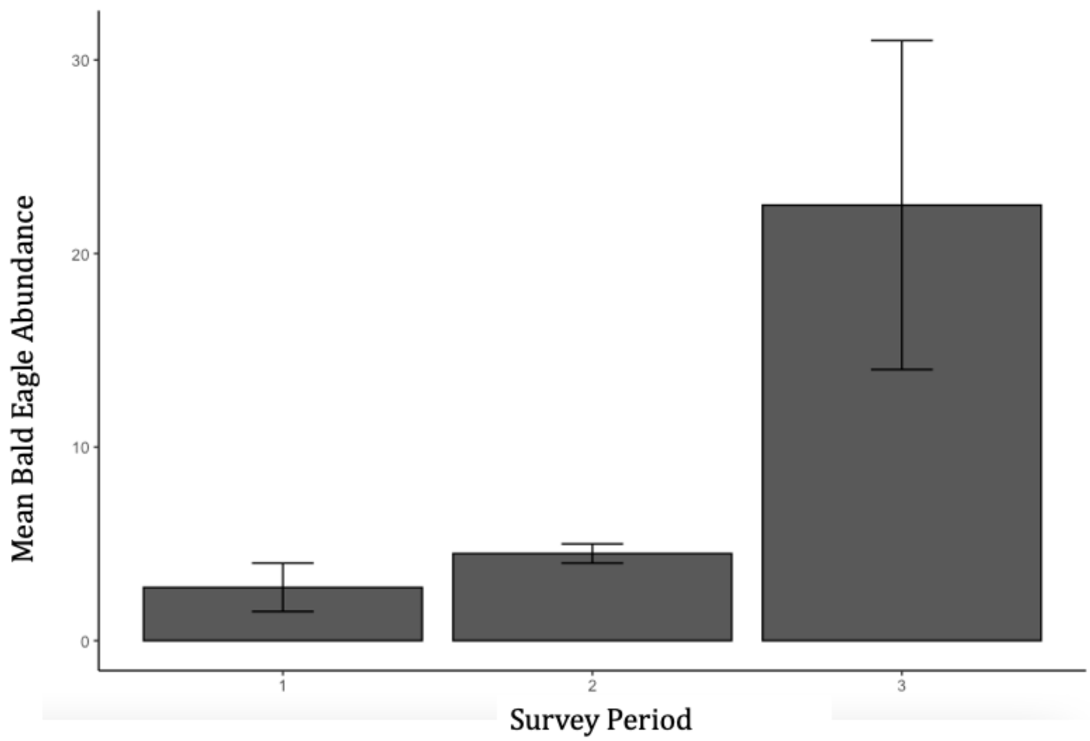

Figure 12. Mean (+/- 95% CI) abundance of overwintering Bald Eagles at the Vancouver Landfill in Delta BC, from three survey periods of two sections at the landfill. Three survey periods were conducted between November 2021 to January 2022.

Discussion

Old Field and Landfill Comparisons

The most obvious and striking difference between plant communities in old-field sites and at the landfill are the presence of shrubs and trees that provided old field sites with vertical structure. Point-count stations in old field showed higher vegetation height, higher vegetation richness, and variability between sites. An aspect of old field that my vegetation surveys did not effectively capture was the patchiness, and how the predominant cover type (often thistles, rushes, or aster) would shift.

I compared mean vegetation height between the landfill and old field (Fig. 4). Because the landfill has a history of mowing, even after a year of growth, the lack of variation in vegetation height generated much smaller confidence intervals compared to those of old-field sites. This comparison emphasizes how there is less consistency in old-field vegetation height that likely contributes to heterogeneity of the environment.

Throughout data analysis, a recurring effect of the low number of replicates in this study was a lack of power in statistical outcomes. If a similar study were to be carried out, it would be advantageous to have additional sites as replicates to generate stronger conclusions highlighting differences between old field and the landfill. Additionally, because old-field sites are subject to variation based on the history of land use and surrounding environment, more replicates could generate more certainty in what is normal for an old-field site in the Lower Mainland, versus what is perhaps an outlier.

Songbirds

I did not find differences in the songbird community that could be directly supported by ground cover vegetation. Fourteen songbird species were exclusively observed in association with shrub, tree, or hedgerow features; thus, percent cover of trees and shrubs is strongly correlated with bird diversity. There are two point-count stations in old field that had low (0% and 0.6%) values for percent cover of rooted trees and shrubs . These stations also had low bird diversity that was similar to the diversity found at the landfill. Overall, this supports the conclusion that shrubs and trees in old field are an important factor in supporting song bird diversity during summer.

Additionally, this points to the landfill functioning in a similar capacity for songbirds in areas of old field that lack shrubs and trees, however more monitoring would be required to confirm this.

Using the Cornell Lab of Ornithology's "All About Birds" online resource as criteria, I was able to differentiate observed species by habitat preference. Three grassland species were observed using the landfill in various capacities: Savannah Sparrows, Barn Swallows *(Hirundo rustica)*, and a Killdeer *(Charadrius vociferus*). Barn swallows are a blue-listed species in British Columbia designating them as a species of special concern. Barn swallows are not a ground nesting species, so their use of the landfill fields was as a foraging habitat for flying insects. Outside of point counts, I observed nesting swallows on a landfill building indicating that the landfill as a whole is currently functioning as nesting and rearing habitat for Barn Swallows. A Killdeer was observed once in Phase 2, and landfill management has confirmed that they have been observed to be nesting previously at the landfill. The Brown-headed Cowbird (*Molothrus ater*) is often considered a grassland bird and was also observed once during this study at the 72nd Street old field. However in North America, the Brown-headed Cowbird has proved highly adaptable and been identified in numerous field, woodland, agricultural, and urban environments; therefore, it presence is unlikely a strong indicator for determining field quality (Schaffer et al. 2003).

I found a negative correlation (Fig. 8) between percent cover of trees and shrubs and the relative abundance of Savannah Sparrows. This result aligns with the findings of Sample (1989) that Savannah Sparrow abundance decreases with proximity to shrubs and trees. This negative correlation differs from the positive correlation that shrubs and trees appear to generate with overall songbird diversity. This contrast highlights how old field is a novel environment and birds with different habitat preferences use different old-field features. While Savannah Sparrows used open old field, 17 species with woodland and scrub habitat preferences were observed using shrubs and trees. Relative to other grassland birds, Savannah Sparrows could be considered versatile in their habitat requirements as they occur across North America in different habitat types provided there is adequate open space and ground vegetation (Swanson 2002). As they are considered grassland generalists, their use of the landfill as nesting habitat is likely not a strong indicator of grassland quality.

O'Leary and Nyberg (2000) describe how features like tree-lines and hedgerows can fragment grassland landscapes and reduce abundances of grassland-nesting bird species that avoid habitat edges, the Savannah Sparrow included. Johnson and Temple (1990) found grassland nesting birds in tall grass prairies experienced more nest predation when nesting in proximity to wooded edges. With that in mind, it is important to differentiate between "grassland habitat" and natural grasslands. What we consider "grassland habitat" in the Fraser Valley is predominantly agricultural land that was historically part of an active river delta. True grasslands (like the prairies) in central North America are a feature on the landscape that has existed since long before the previous ice age (Axelrod 1985). Compared to other provinces in Canada and other regions of North America, British Columbia does not have an abundance of grasslands and they make up less than 1% of the province, largely located in the interior (Wikeem & Wikeem 2004). There are subspecies populations of the Horned Lark (*Eremophila alpestris*) and Vesper Sparrow (*Pooecetes gramineus*) that are in proximity to Delta, but otherwise all Red and Blue listed ground-nesting grassland specialists live towards the interior of the province (Cornell Lab of Ornithology 2019). While grassland migrants may sporadically appear in the Lower Mainland, the Vancouver landfill is not part of their regular range and therefore management as an old field site should emphasize habitat creation for scrub and woodland migrants.

Overwintering Raptors

Individual raptors demonstrated site fidelity in old field, which was shown through consistent observations of Red-tailed Hawks, Rough-legged Hawks, and Northern Harriers at 72nd Street and BBRP (Fig. 10). More so, multiple visits showed that individual birds like Red-tailed Hawks at BBRP, and a pair of Northern Harriers at 72nd Street were consistently present and even observed using the same habitat features. This was a stark contrast to the landfill, where there were five species collectively observed but at lower frequencies and usually without repetition, contributing to a higher diversity index but lower abundance of raptors.

One possible explanation for these differences could be variable perch availability. Wong (2018) found that overwintering raptors in California displayed a preference for perches in open areas. In my study, natural perches were available in old field for raptors through shrubs within the field area, and trees in the margins. The landfill lacked naturally occurring perches, and the adjacent Burns Bog is densely forested. Perches available in survey areas at the landfill were gas wells and a single lamp post. No raptors (aside from Bald Eagles) were observed to use gas wells as perches.

While target raptor species were observed in relatively low abundances at the landfill, Bald Eagles had an eight-fold increase in mean abundance at the landfill between the first and last survey periods and were the most abundant raptor species (Fig. 11). Bald Eagles have been shown to frequently kleptoparasitize smaller raptor species that hunt waterfowl during winter (Jorde & Lingle 1988, Dekker et al. 2012). I never observed fighting or aggressive behaviour between Bald Eagles and another species; however, I did observe multiple instances of eagles fighting with each other at the landfill. Temelles & Wellicome (1992) observed kleptoparasitism at Boundary Bay in Northern Harriers, Rough-legged Hawks, Short-eared Owls with 29% of aggressive interactions occurring between different species, and always via a larger species acting as the aggressor to a smaller species. As Bald Eagles evidently display kleptoparasitic behaviours, their high abundance at the landfill could be discouraging use of the fields by other smaller raptor species.

Because characterizing raptor diversity on sites required three rounds of surveys, I cannot demonstrate a significant relationship between increasing Bald Eagle abundance and decreasing raptor diversity; however, it was the final survey period at the landfill had the highest abundance of Bald Eagles and the fewest observations of other raptors.

Management Recommendations

Structural Vegetation

In agricultural environments, hedgerows make the landscape more suitable as a novel habitat for scrub and woodland birds. Generally, wider and longer hedgerows that contain vertical structure will be associated with high bird diversity, however species will have different preferences based on their natural habitat (Hinsley & Bellamy 2000). At the landfill the addition of hedgerows would likely increase habitat suitability for scrub and woodland birds as well as other non-avian fauna. These features may provide increased connectivity and habitat for foraging and nesting birds (Hinsley & Bellamy 2000).

Allowing trees to grow at the landfill is not possible as a result of the closure membrane, however shrubs with a shallower root depth may be a viable option. Native berry producing shrubs like Black Hawthorn, Saskatoon Berry and Red Elderberry can support frugivorous birds like Cedar Waxwings that feed on them. At the 72nd Street location I frequently observed Cedar Waxwings that had nested in a Black Hawthorn shrub feeding on fruit. Additionally, berry-producing shrubs benefit wintering-songbird populations that feed on remaining berries through winter (Baird 1980). While Himalayan Blackberry is already an abundant shrub species at both old-field sites, it can often reduce songbird diversity when present in hedgerows or other woodland-type habitats (Astley 2010, Edmonds 2017) and should be actively prevented from establishing at the landfill.

The practicality of hedgerows is often discussed as a method of enhancing a modified agricultural landscape, where fields between hedgerows are managed for crop production. The landfill is different in this respect, as fields are not being used for agriculture. Although hedgerows appeared to be responsible for the greatest proportion of songbird diversity, individual trees and shrubs that scattered the old-field sites also provided vertical structure often used by woodland and scrub songbird species. If the landfill could accommodate hedgerows as well as scattered patches of shrubs, management could proceed with the objective of having it function as a novel old-field scrubland environment. The non-native Rose Dog and Multiflora Rose species specifically appeared to support nesting Common Yellowthroats, as males would call from on top or within small clusters and 91% of observations had shrubs or hedgerows as a substrate. Planting native shrubs like Nootka Rose or Red Elderberry in small patches along the periphery of the landfill could potentially add to edge habitat and add novel scrubland environment to enhance the landfill landscape.

The addition of features like hedgerows would have secondary benefits for landfill ecology. The Vancouver Landfill juts out from the farmland of Delta that generally has an elevation of only 1-2 m above sea level. I frequently observed high winds at the landfill, which may be compounded by the increased elevation of the landfill relative to the surrounding landscape. Hedgerows can decrease wind on a landscape (Kanzler et al 2018), and this can have several associated benefits for songbirds and old-field ecology. Flying insects are more active in lower wind conditions, and increases in wind speed have been correlated to lower brood success in Barn Swallows (Møller 2013). Additionally, wind exposure on soil increases evapotranspiration, so adding windbreaks to a landscape can result in increased soil-moisture retention (Veste et al. 2020). When I conducted vegetation surveys in July, it was apparent that much of the herbaceous vegetation had dried out, likely amplified by the 2021 summer heat wave. Some climate projections for the Pacific Northwest predict drier summers as a result of climate change (Mote & Salathé 2010) so modifications that can also enhance moisture retention may prove valuable.

As the Western-40 section of the landfill has a low elevation with a large shared edge between the landfill and the Burns Bog forest, I would recommend it as a priority for shrub and hedgerow construction. The Western-40 section also has more similar topography to the old-field sites, compared to Phase 2 which sits on a hilltop. Planting small shrubs in clusters, or in hedgerows could extend the edge habitat between Burns Bog and the landfill, and promote songbird communities that are similar to those found in old field.

One potential drawback of shrubs and hedgerows are that their presence can deter ground nesting grassland birds. While my study did not identify any ground-nesting grassland birds except for Savannah Sparrows and Killdeer, the implementation of structural features could deter grassland specialists in the future (Besnard et al. 2016). Additionally, the Short-eared Owl, which is a blue-listed species in BC that has been observed recently at the landfill, has had hedgerow removal suggested as a habitat enhancement technique to encourage nesting (NYS DEC n.d.). The addition of structural vegetation could be tested in the northwest corner of W40 where it is flat, but also in proximity to the edge of the landfill to mitigate the amount of open grassland areas that are encroached on. Monitoring of a pilot restoration site could help determine whether the addition of structural vegetation is increasing bird diversity at the landfill, and also weighed against the possible loss of grassland area.

Ground Vegetation

As a pilot study on the effect of shrubs and hedgerows at the landfill would take several years to carry out, fields at the landfill can still be managed to best support grassland songbird nesting. Grassland heterogeneity is important for nesting grassland birds, and species often have different preferences of vegetation height and density that can have implications for nest success and survival (Davis 2005). To best support a mosaic of micro-habitats within a grassland environment, selective mowing over a multi-year schedule would better ensure diversity in vegetation, and diversity in vegetation height (Vickery et al. 2000). In this case, sub-sections of each section at the landfill could be mowed annually on a multi-year rotation to create more habitat diversity . Alternatively to mowing, non-intensive grazing by livestock has also shown to often benefit nesting songbirds, however this can be dependent on the type of livestock and how intensively they graze the field (Ahlering & Merkord 2016).

Bald Eagle Exclusion

The influence that highly abundant wintering Bald Eagles at the landfill may have on other raptor species is unknown; investigating the effect of reducing site suitability for them could have useful implications for landfill management. Bald Eagles have shown preference for perching in trees that are higher, larger, and with few obstructions (Buehler et al. 1992). A study out of northwest Washington showed that wintering Bald Eagles also showed a preference for dead trees and a preference for perching at the highest point in a tree (Stalmaster & Newman 1979). Zylo (2012) found wintering Bald Eagles in Arizona to select perch sites in forest types with lower vegetation, resulting in increased accessibility. Given that the landfill had no visual obstructions aside from the physical topography of the site, the addition of visual obstructions like shrubs and hedgerows could be investigated as a method of reducing the density of Bald Eagles on site.

Raptors often use perches as a vantage point for hunting, and construction of perches has been shown to increase field use by raptor species that predate small mammals (Zagorski & Swihart 2020). At the landfill, the only available perches are gas wells, but at the time of my last site visit they were entirely occupied by Bald Eagles. Bald Eagles are suggested to be between 3000-6300 grams, whereas all other target raptors are suggested to be below 1400 grams (Cornell Lab of Ornithology, 2019). As a result of this significant difference in weight, I hypothesize that in old-field environments shrubs might act favourably on smaller raptors as they prevent heavier Bald Eagles from perching on them and occupying old-field habitat. Using perch deterrents on gas wells, and providing shrubs that favour smaller raptors while decreasing visibility could be worth investigating as a management strategy for reducing Bald Eagle use of the landfill and increasing opportunities for use by target raptor species.

Conclusion

The Vancouver Landfill has enormous potential to positively contribute to existing bird habitat in Delta. This study suggests that old field is a higher quality habitat for summer songbirds and wintering raptors compared to the landfill, so modifications to the landfill to further replicate old-field environments would certainly have the potential to increase use of the site. That being said, certain aspects of habitat that are important to grassland birds may be lost with conversion to an old-field environment, so management objectives should be clear prior to further modifying the landscape.

As a result of the size of the landfill and the opportunity to further define post-closure management goals, pilot studies to test the potential effectiveness of restoration projects could be highly beneficial. My study focused on two seasonal components of old-field use, and expanding monitoring to other parts of the year would help inform future management goals.

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Appendices

APPENDIX A: Songbird Survey Species List

Species	Total number of observations	Locations	Species Code
Killdeer *Charadrius vociferus*	1	P2	KILL
Crow spp. *Corvus* spp.	2	BB	CROW
Rufous Hummingbird *Selasphorus rufous*	3	72S, BB	RUHU
Barn Swallow *Hirundo rustica*	7	BB, P2, W40	BASW
Black-capped Chickadee *Poecile atricapillus*	2	72S	BCCH
Bewick's Wren *Thryomanes bewickii*	1	BB	BEWR
American Robin *Turdus migratorius*	2	72S, BB	AMRO
European Starling *Sturnus vulgaris*	3	72S, BB	EUST
Cedar Waxwing *Bombycilla cedrorum*	6	72S	CEWA
Orange-crowned Warbler *Vermivora celata*	1	BB	OCWA
Common Yellowthroat *Geothylpis trichas*	32	72S, BB	COYE
Spotted Towhee *Pipilo maculatus*	5	BB	SPTO
Savannah Sparrow *Passerculus sandwichensis*	413	72S, BB, P2, W40	SASP
Song Sparrow *Melospiza meoldia*	3	72S, BB	SOSP

Species	Total number of observations	Locations	Species Code
Brown-headed Cowbird *Molothrus ater*	1	72S	BHCO
Red-winged Blackbird *Agelaius phoeniceus*	2	72S, BB	RWBL
Brewer's Blackbird *Euphagus cyanocephalus*	2	P2, W40	BRBL
Purple Finch *Carpodacus purpureus*	2	BB	PUFI
House Finch *Carpodacus mexicanus*	1	BB	HOFI
Red Crossbill *Loxia curvirostra*	6	BB	RECR
American Goldfinch *Carduelis tristis*	3	BB, W40	AMGO