Displacement and Mortality of Birds by High Voltage Transmission Lines in the Canadian Dry Mixed Prairie

by

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Abstract

Canadian grasslands are continuing to experience loss in habitat and degradation in quality due to agricultural expansion and fragmentation from roads, pipelines, and transmission lines. Today, only 43% of Canadian mixed grass prairie remains. This loss and fragmentation has led to a decline in grassland songbirds, with further reductions predicted as urban-industrial expansion continues. The construction of new high-voltage (>500 kV) transmission lines through the Mattheis Ranch in Southeastern Alberta in 2014-15 provided a unique opportunity to examine the effects of transmission line construction on grassland songbird occupancy and mortality. Baseline data collected at 168 sites across a 3,500 ha area from before transmission line construction in 2012–13 was compared to data collected after construction in 2016, as well as on control sites located >1500 m from transmission lines. The same 168 sites were sampled 3 times during the pre- and post-construction sampling periods, for a total of 6 sample periods, in the breeding seasons (May-June) of 2012-13 and 2016. Plots were run in transects and further blocked into treatments: transmission line only, highway only, highway and transmission lines on one side (one-sided), highway and transmission lines on both sides (split), and controls. Species richness did not differ between years, but a greater number of species was found in treatments with highways present. Corvids were more common near transmission lines after construction, while perching birds like the western meadowlark and Sprague’s pipit were more common further from transmission lines after construction. Six focal species – Baird’s sparrow, Brewer’s blackbird, Eastern kingbird, grasshopper sparrow, long-billed curlew, and marbled godwit – that represented a variety of functional groups, had different responses to powerline construction. The Brewer’s blackbird was negatively affected by transmission lines, while the

Baird's sparrow, Eastern kingbird, grasshopper sparrow, and long-billed curlew were positively affected. Marbled godwits showed no response.

Mortality due to collisions with transmission lines may also be contributing to declines in grassland birds, with estimates of between 2.5 to 25.6 million birds killed by transmission line collisions per year across 231,966 km of lines in Canada. There are over 3,800 km of transmission lines in the Canadian mixed-grass prairie. This study estimated avian mortality due to collisions with powerlines in a mixed-grass prairie. In the breeding season (May-June) of 2016 and the migration season (March-April) of 2017, two observers searched for bird carcasses along seven 500-m transects on the Mattheis Ranch with two transects beside highways, three under transmission lines, and two in controls where neither disturbance was present. Detectability and scavenging trials were conducted in 2016 to estimate bias in mortality estimates based on detectability (sightability and loss from scavengers). During the breeding season of 2016, 23 mortalities were recorded under transmission lines, 7 mortalities were found near roads, and no mortalities were found in controls. Subsequently, 24 mortalities were found under transmission lines in the spring migration season of 2017, 3 mortalities were found near roads, and no mortalities were found in controls. Scavenging rates were greater in this study (82% of carcasses were scavenged within 5 days) than reported in non-grassland habitats. Overall, linear disturbances within the immediate study area (Mattheis Ranch), including highways and high-voltage transmission lines, have the potential to contribute to the loss of 1,948 to 1,970 birds during one migration and breeding season (3,918 over a spring season). When considering all transmission lines in the Canadian mixed-grass prairie of Canada, I estimated a loss during the spring migration and breeding season of 192,316 birds. These findings point to the need for greater mitigation actions to prevent future losses of birds in areas where linear disturbances occur. Changes in vegetation, predator presence, and transmission lines functioning as ecological traps may be contributing to these changes.

Preface

This thesis is an original work by Caroline Martin. No part of this thesis has been previously published.

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List of Abbreviations

AC	Alternating current
AIC	Akaike Information Criterion
ANOVA	Analysis of Variance
AUM	Animal Unit Month
BACI	Before-After-Control-Impact
BASP	Baird's Sparrow
BRBL	Brewer's Blackbird
°C	Degrees Celsius
dbRDA	distance-based Redundancy Analysis
DC	Direct Current
EAKI	Eastern Kingbird
eps	Extinction (from Program PRESENCE)
gam	Colonization (from Program PRESENCE)
GLM	Generalized Linear Model
GLMM	Generalized Linear Mixed Model
GRSP	Grasshopper Sparrow
h	Hour
ha	Hectare
km	Kilometer
kV	Kilovolt
LBCU	Long-billed Curlew
m	Meter
mm	Millimeter
MAGO	Marbled Godwit
MG	Mixed Grass
p	Detection (from Program PRESENCE)
psi	Occupancy (from Program PRESENCE)
SE	Standard Error

Chapter One: General introduction

Temperate grasslands in North America have suffered severe reductions in area and condition since the 1700s, mainly due to conversion into agriculture and fire suppression (Samson and Knopf 1994; Herkert 1994). Other factors, such as urban-industrial sprawl and the associated construction of roads, have led to more fragmented landscapes, soil degradation, and species declines and extinctions (Richards 1984; Forman and Deblinger 2000). Combined, these factors have broad-reaching effects on grassland biota, including microbes, invertebrates, plants, mammals, and birds. For instance, soil compaction from road and high voltage transmission line construction can lead to changes in plant communities from native vegetation to disturbance-tolerant introduced plants (Hansen and Clevenger 2005). Fragmentation caused by the construction of roads and energy infrastructure can negatively affect mammals and birds. Overall, natural grasslands are considered the most altered and least protected terrestrial habitat in the world (Samson and Knopf 1994; Heidenreich 2009). Due to the loss of their requisite habitat, grassland birds in particular have undergone large recent declines (Summers et al. 2011; McCracken 2011). Disturbance to grassland habitats, such as that associated with road and transmission line establishment and subsequent operation (e.g., traffic effects, including noise), have lasting, negative effects on grassland bird abundance (Forman and Deblinger 2000).

Grassland songbirds are at the greatest risk of extinction, and have experienced the largest decline of any avi-fauna in Canada between 1970 and 2014 (World Wildlife Fund 2017). In fact, prairie birds are one of the most threatened wildlife groups in North America (Pruett et al. 2009). Early successional habitats, including within the mixed grass prairie, contain birds with the highest habitat specialization and therefore have the highest threat level, compared to late-successional habitats such as scrubland and forest (Reif et al. 2013). Since the early 1970s, grassland birds have been declining in both abundance and diversity (Schipper et al. 2016). This trend is predicted to continue in the future, and could result in the loss of some grassland bird species within the next 50 years.

In the mixed grass prairies of Canada, the ongoing conversion of native grasslands into crop agriculture, oil and gas expansion, road construction, and transmission line development, are all contributing to grassland losses and their fragmentation. Less than 43%

of native Canadian mixed grass prairie remains in Alberta, with an area less than 42,000 km^2 (PCAP 2005); past declines have contributed to losses of grassland bird species.

Oil and gas infrastructure, including pipelines and above-ground wells, can have varying effects on grassland birds. Some passerines, such as western meadowlarks (*Sturnella neglecta*), have been found to use fences and gas wells as perches, as they may function as being artificial shrubs with respect to perching behaviour (Rodgers and Koper 2017). However, in contrast to the use of these structures by some species, many other grassland birds avoid oil and gas infrastructure and instead experience lower nesting success near gas wells and transmission lines (Askins et al. 2012; Bernath-Plaisted and Koper 2016). Savannah sparrows and vesper sparrows were found to have lower nesting success and smaller clutches near oil and gas infrastructure, but vesper sparrow nest density increased with proximity to oil wells and compressor stations, suggesting that these disturbances may function as ecological traps (Bernath-Plaisted and Koper 2016; Yoo and Koper 2017). Oil and gas infrastructure development may also contribute to habitat fragmentation and facilitate brood parasitism of ground-nesting songbirds by brown-headed cowbirds (*Molothrus ater*) through the introduction of perches and anthropogenic edges, in turn lowering the nesting success of grassland songbirds (Bernath-Plaisted et al. 2017). Sensitive species, like the Sprague's pipit (*Anthus spragueii*), have also been found to avoid areas containing anthropogenic disturbance (oil and gas wells, and roads) (Koper et al 2009; Hamilton et al. 2011; Rodgers and Koper 2017).

Along with oil and gas development, the construction of roads further fragments landscapes affecting grassland species. Savannah sparrows were found to have lower nest success near gravel roads associated with oil and gas infrastructure (Yoo and Koper 2017), and the abundance of Baird's sparrows (*Ammodramus bairdii*) and marbled godwits (*Limosa fedoa*) increased with distance to gravel or paved roads, over a 1-km span from road edges (Sliwinski and Koper 2012). However, brown-headed cowbirds and vesper sparrows (*Pooecetes gramineus*) were more abundant near roadsides, while chestnut-collared longspurs (*Calcarius ornatus*), horned larks (*Eremophila alpestris*), long-billed curlews (*Numenius americanus*), savannah sparrows (*Passerculus sandwichensis*), Sprague's pipits (*A. spragueii*), western meadowlarks (*S. neglecta*), and willets (*Tringa semipalmata*) were not affected (Sliwinski and Koper 2012). Opportunistic or generalist species can also be attracted to roads due to increases in food sources (i.e. roadkill, insects), but these areas may also attract predators that grassland passerines avoid.

Large transportation routes have become increasingly busy as urban areas expand, with negative implications for breeding songbirds (Kociolek et al. 2011). Miller et al. (1998) found that recreational trails as narrow as 1 m influenced both nest locations and bird community composition during the breeding season, while others have found decreasing songbird abundance adjacent to busy highways (Clark and Karr 1979; Reijnen et al. 1996; Forman and Deblinger 2000). Others have found increasing bird abundance and species richness near roadsides when adjacent habitats are converted to unsuitable habitats (Camp and Best 1993). In Saskatchewan, Baird's sparrows (*Ammodramus bairdii*), chestnut-collared longspurs (*Calcarius omatus*), and Sprague's pipits (*Anthus spragueii*) showed apparent aversion to roadside habitats (Sutter et al. 2000). However, not all species react in the same way: in central Illinois, horned lark (*Eremophila alpestris*) densities decreased with decreased distances to roads, while red-winged blackbirds (*Agelaius phoeniceus*) exhibited the opposite response, likely due to differences in nesting site requirements (Clark and Karr 1979). Forman and Deblinger (2000) suggest a 600 m "road-effect zone" where within this zone birds experience negative effects from highways, such as traffic noise and physical disturbance, that lead to reductions in density. Forman and Deblinger (2000) found that the most sensitive grassland species experienced reduced densities out to 930 m away from a major road.

Transmission line construction also disturbs grassland habitats. Nesting success of some grassland birds, like the savannah sparrow and vesper sparrow, was lower at electric-grid sites relative to generator-powered sites, which suggests that power distribution lines may benefit some nest predators (Bernath-Plaisted and Koper 2016). Sharp-tailed grouse (*Tympanuchus phasianellus*) avoided areas within 100 m of transmission lines and highways, and perceived transmission lines as barriers to movement, but did not perceive roads as barriers (Pruett et al. 2009). The species-at-risk greater sage-grouse (*Centrocercus urophasianus*) avoided both roads and transmission lines during the breeding season (Baxter et al. 2017), while grasshopper sparrow (*Ammodramus savannarum*) occupancy was positively related to the amount of native grassland habitat (Irvin et al. 2013). For some species, such as ravens and raptors, artificial structures are used for nesting and as perches for hunting (Steenhof et al. 1993; Coates et al. 2014). Studies have shown that bird responses vary with increasing proximity to high-voltage (>500kV) transmission lines (Niemi and Hanowski 1984; Baker et al. 1998; Coates et al. 2014). For example, ravens and raptors take advantage of artificial structures for nesting (Steenhof et al. 1993; Coates et al. 2014) and early successional bird species, such as the chestnut-sided warbler (*Setophaga pensylvanica*), also increase in abundance due to the greater availability of successional habitat often found in right-of-ways from the clearing of vegetation (King and Byers 2002). However, overall bird abundances appear to decline with increasing proximity to transmission lines, likely due to clearing of vegetation, noise disturbance, and the presence of towers and cables (Niemi and Hanowski 1984; Baker et al. 1998).

There are also direct effects of roads and transmission lines on avian species. The greatest causes of human-related avian mortality in Canada are cat predation and collisions with windows, vehicles, and transmission lines (Calvert et al. 2013). Roads cause mainly negative effects on birds due to their vulnerability to road mortality and traffic noise causing displacement (Fahrig and Rytwinski 2009; Kociolek et al. 2011). For example, densities of songbirds decreased adjacent to roads in the Netherlands, with increased traffic loads leading to greater collision mortality and the negative effect of disturbance on birds extending further from roads (Reijnen et al. 1996). Over 1000 birds are estimated to be killed per 100 km per year by collisions with vehicles on 1- and 2-lane paved roads across Canada (Bishop and Brogan 2013), with industrial sources of mortality concentrated in Southern Ontario, Alberta, and Southwestern British Columbia (Calvert et al. 2013).

Transmission line collisions and electrocution have been estimated to kill over 1 billion birds annually worldwide, with over 10 million mortalities estimated to occur annually in Canada (Rioux et al. 2013; Loss et al. 2014). Many bird species are vulnerable to collisions, especially waterfowl with low maneuverability that do not react quickly to transmission lines (Scott et al. 1972; Savereno et al. 1996; Manville 2005; Shaw et al. 2010; Loss et al. 2014). Collision probability also increases in areas where transmission lines cross migratory routes, run through feeding and nesting sites, or occur adjacent to high use areas (Savereno 1996; Manville 2005). Collisions also are more likely during periods of low light at dawn and dusk (Liguori 2008), presumably due to reduced line visibility. Mitigation attempts include flagging, removing earth wires, and attaching flashing lights or noise makers (Scott et al. 1972; Savereno et al. 1996; Manville 2005; Loss et al. 2014).

Most studies examining the effects of transmission lines on breeding birds focus on birds that breed in mature forests (Olendorff et al. 1981; Olendorff et al. 1986; Kroodsma 1982; Niemi and Hanowski 1984; Baker et al. 1998; King and Byers 2002). However, with increasing demand for electricity due to urban development and sprawl, larger transmission lines are currently being constructed with their effect on birds largely unknown. Responses by breeding birds to transmission lines can vary among habitats, with relatively few studies done on the responses of grassland bird species (Kroodsma 1982; King and Byers 2002). As well, most studies have focused on bird responses to urban-industrial development using *in-situ* spatial assessments of proximity to development after the disturbance has occurred, but sampling designs that consider data collected before construction should be conducted, in a before-after-control-impact (BACI) framework (Eberhardt 1976), to control for both temporal and spatial factors.

Electrical transmission line development (hereafter 'transmission lines') has been increasing globally at a rate of 5% per year (Silva et al. 2010), and often includes an extensive network of infrastructure varying in size and stature, including the associated footprint of construction. Across Alberta, several major projects have been undertaken in recent years expanding the presence of high voltage (>500 kV) transmission lines across the province, in part to redistribute power among different areas of the province. In the prairies of southeast Alberta, the recent construction of several major high-voltage transmission lines between 2013 and 2014 provides a unique opportunity to compare avi-faunal communities, including bird composition, before and after construction, and to examine the cumulative effects of transmission lines and roads on breeding bird occupancy and mortality. In this thesis, I evaluate the effects of high voltage transmission line construction on grassland bird occupancy and community composition by employing a BACI framework (Chapter 2). Baseline data collected before transmission line development was compared to data collected following development to determine the direct impacts of construction. Chapter 3 focuses on mortality rates associated with collisions with transmission lines and provides the first Canadian dry-mixed prairie estimate of avian mortality for this region. Finally, I end with a synthesis (Chapter 4) of the thesis, including a discussion of management decisions for future transmission line development to mitigate negative direct and indirect effects.

Chapter Two: Breeding bird responses to high voltage transmission line development: focal species and community changes with a BACI framework

Abstract

Linear disturbances in grassland systems, including high voltage (>500 kV) transmission lines, roads, and pipelines, have led to fragmented landscapes, soil degradation, and declines in sensitive species. Grassland birds have undergone steep declines in populations due to the loss and degradation of mixed grass prairie habitat, of which only 43% remains in the province. The construction of a major high-voltage transmission line in Southeastern Alberta in 2014 provides a unique opportunity to determine the direct effects of powerline construction on songbird species by comparing pre-construction (2012–13) to post-construction (2016) bird survey data following transmission line development. Ten-minute point counts were conducted across a 300-m grid at Mattheis Ranch, located in Southeastern Alberta, during the breeding seasons of 2012, 2013, and 2016. A total of 372 point count sites were sampled in 2012 and 2013, and a subset of these point counts were re-sampled in 2016 to compare specific disturbance types with control areas lacking recent disturbances. Transects were blocked by treatment (road only, powerline only, road with powerlines on one side, road with powerlines on either side, and control). Species richness was greatest in treatments with roads present, but did not change within treatments between years. However, birds of prey and corvids were more common near transmission lines after development, while perching birds were found further away. Of six focal species examined in more detail (Baird's sparrow, Brewer's blackbird, Eastern kingbird, grasshopper sparrow, long-billed curlew, and marbled godwit), the Brewer's blackbird and Eastern kingbird were negatively affected by transmission lines, while the Baird's sparrow, grasshopper sparrow, and long-billed curlew were positively affected. Changes in vegetation, predator presence, and transmission lines functioning as ecological traps may be contributing to these changes. Future transmission line development should avoid areas containing sensitive species where possible, bury lines and towers to decrease fragmentation of landscapes, and promptly restore vegetation to pre-construction conditions.

2.1 Introduction

Urban-industrial sprawl has been increasing in Canada, and is associated with infrastructure development, including roads and electricity transmission lines. In particular, transmission line developments have been increasing globally at a rate of 5% per year (Silva et al. 2010), with potentially increased future demands as the population increases and the demand for energy infrastructure increases. Road expansion is also increasing with urbanization and increased economic activity, and the effect of both transmission lines and roads can be negative for many organisms, particularly for birds. Many grassland birds have experienced steep declines in abundance in recent years due to the loss of habitat, degradation of land due to overgrazing, and fragmentation from the construction of roads and transmission lines.

Most studies examining the effects of transmission lines on breeding birds focus on birds that breed in mature forests (Olendorff et al. 1981; Olendorff et al. 1986; Kroodsma 1982; Niemi and Hanowski 1984; Baker et al. 1998; King and Byers 2002; Askins et al. 2012). However, the responses of birds in grasslands may also be substantial because large structures likely interfere with flight paths and landscape connectivity in open environments. Previous work in grasslands of western Canada has shown that bird diversity and abundance can be negatively affected by roads, and oil and gas infrastructure (Bernath-Plaisted and Koper 2016). Overall, there appears to be a decline in bird abundance with increasing proximity to transmission lines, likely due to clearing of vegetation, noise disturbance, and the presence of towers and cables (Niemi and Hanowski 1984; Baker et al. 1998). On the other hand, species richness and abundance may be greater near roads (Camp and Best 1993). Bird communities may also differ between disturbed and non-disturbed areas (Boren et al. 1999). For example, generalist species may be attracted to more urbanized landscapes, while specialist species may move away from fragmented areas (Boren et al. 1999). However, vegetation structure may be more important than other factors, including proximity to infrastructure (Bogard and Davis 2014).

Studies examining the effects of anthropogenic infrastructure (i.e. roads, wind turbines, oil/gas wells, and transmission lines) on birds within grasslands have found varying responses between species and proximity to structures (Baker et al. 1998). For some species, such as ravens and raptors, artificial structures are used for nesting and as perches for hunting

(Steenhof et al. 1993; Coates et al. 2014). Other opportunistic or generalist species can also be attracted to roads and transmission lines due to increases in food sources (i.e. roadkill, insects). Other passerines, such as western meadowlarks (*Sturnella neglecta*), have also been found to use fences and gas wells as perches (Rodgers and Koper 2017). In contrast to the use of structures by some species, other grassland birds avoid infrastructure with lower nesting success near gas wells and transmission lines (Askins et al. 2012; Bernath-Plaisted and Koper 2016; Yoo and Koper 2017). For instance, sharp-tailed grouse (*Tympanuchus phasianellus*) avoided areas within 100 m of transmission lines and highways, and perceived transmission lines as barriers to movement, but did not perceive roads as barriers (Pruett et al. 2009). The species-at-risk greater sage-grouse (*Centrocercus urophasianus*) avoided both roads and transmission lines during the breeding season (Baxter et al. 2017), while grasshopper sparrow (*Ammodramus savannarum*) occupancy was positively related to the amount of native grassland habitat (Irvin et al. 2013). For other species, such as the vesper sparrow (*Pooecetes gramineus*), nest density increased with proximity to oil wells and compressor stations, which may function as ecological traps (Bernath-Plaistad and Koper 2016). However, Sprague's pipits (*Anthus spragueii*) have also been found to avoid areas containing anthropogenic disturbance (oil and gas wells, and roads) (Koper et al 2009; Hamilton et al. 2011).

Little is known about how grassland bird species are affected by transmission line construction with most research examining wind farms, oil and gas development, and roads. There is also limited information on how bird community composition is affected by transmission line construction. In this study, I examine six focal grassland bird species, including the Baird's sparrow (*Ammodramus bairdii*, BASP), marbled godwit (*Limosa fedoa*, MAGO), long-billed curlew (*Numenius americanus*, LBCU), Brewer's blackbird (*Euphagus cyanocephalus*, BRBL), eastern kingbird (*Tyrannus tyrannus*, EAKI), and grasshopper sparrow (*A. savannarum*, GRSP), relative to the establishment and presence of transmission lines. These are common species that occupy 30-60% of point counts in the study area, and previous studies have shown variable responses of some of these species to anthropogenic disturbances (Koper and Schmiegelow 2006; Ludlow et al. 2015). However, for most species, the relationship with transmission lines is unknown or understudied.

Here I employ a before-after-control-impact (BACI) design (Eberhardt 1976) to compare the distribution of these birds before transmission line construction to data collected after transmission line construction. The objectives of this study were to determine the effect of transmission line construction on the breeding habitat of six focal bird species, in the mixed-grass prairie of southeastern Alberta. I hypothesize that grassland specialists (e.g., Baird's sparrow, long-billed curlew, eastern kingbird, and grasshopper sparrow) should avoid transmission lines, while generalist species (e.g. marbled godwit, Brewer's blackbird) will not be affected by transmission line construction because they can capitalize on multiple food sources and breeding habitats. I also predict that range health will decrease near transmission lines due to the direct impacts of recent construction activity on grassland vegetation, and that this decline will be less likely to support grassland-specific bird species.

2.2 Methods

2.2.1 Study area

The study took place at the University of Alberta Mattheis Research Ranch, located in southeastern Alberta (50.896736 N, -111.952711 W; Figure 2.1). The ranch encompasses 4,900 ha of mainly native grassland bounded in the north by the Red Deer River and in the south by Matzhiwin Creek. Most of the ranch is native (i.e. intact non-cultivated) grassland with several embedded wetlands constructed by Ducks Unlimited Canada to provide waterfowl habitat. The ranch is divided into east and west blocks by Highway 36, a high-use transportation route connecting the central and southern regions of eastern Alberta. A paved secondary highway (Highway 556) also runs east-west and divides the west block further into two unequal sections. Three transmission lines were constructed along Highway 36, including two high-voltage transmission lines constructed in 2013–15 (one 500 kV alternating current, one 500 kV direct current; see Figure 2.2) and one pre-existing low-voltage distribution line (240 kV) dating back several decades. The two high-voltage transmission lines were constructed in 2014–2015, and contribute to a total of 27.5 km of linear disturbances running through the study area. Transmission line towers were spaced between 300 to 400 m apart, and the three different lines were at least 50 m apart from each other, encompassing at minimum a 100-m-wide disturbance. The area under investigation here is also grazed by cattle at moderate stocking during the growing season using a once or twice over rotational grazing system (~0.6 AUM ha^{-1}), and has a widespread abundance of natural gas wells interconnected with a comprehensive network of pipelines. Well sites and pipelines were installed mostly in the 1970's and 80's, with the affected areas having since been re-vegetated.

This region of Alberta is comprised of dry mixed-grass vegetation, and is associated with a semi-arid climate, with a typical growing season from late April through the end of October. Average annual rainfall is 354 mm, the growing season is approximately 120 days (5°C), and the average temperatures is 13.6°C over the growing season. Dominant plant communities include needle-and-thread grass (*Hesperostipa comata*), blue grama (*Bouteloua gracilis*), western wheatgrass (*Pascopyrum smithii*), Junegrass (*Koeleria macrantha*) and sand grass (*Calamovilfa longifolia*). Common shrubs include thorny buffalo-berry (*Shepherdia argentea*), western snowberry (*Symphoricarpos occidentalis*), prairie rose (*Rosa arkansana*), and chokecherry (*Prunus virginiana*). *Shepherdia argentea* is an important shrub for the threatened Loggerhead shrike and is encroaching following the creation of artificial wetlands (Dahl 2014). Common forbs include pasture sage (*Artemisia frigida*), buffalobean (*Thermopsis rhombifolia*), and yellow sweet clover (*Melilotus officinalis*).

2.2.2 Experimental design

I implemented a BACI design to examine bird responses to urban-industrial development, particularly high-voltage transmission lines. Most previous studies have employed *in-situ* spatial assessments of proximity to development (e.g., Askins et al. 2012; Bernath-Plaisted and Koper 2016), but few compare data collected before and after a disturbance or development to determine the direct effects with both temporal and spatial controls. Here the same locations were sampled before and after transmission line construction in the study area, as well as within control sites located at least 1500 m from disturbance.

In 2012 and 2013, point counts were performed by two observers at the Mattheis Ranch using a 300-m grid on the eastern part (~3500 ha) of the ranch to sample 372 points, each with a 150-m radius (Figure 2.1). Point counts were conducted between the hours of 4:00 am and 11:00 am from May 8 to June 26 in 2012 and May 4 to June 25 in 2013, except on days with precipitation or wind exceeding 20 km h^{-1}. Pastures were selected systematically over time within the sample season to reduce seasonal/regional bias with groups of points done sequentially (i.e., hiking between observation points). Sampling in pastures that contained cows was avoided when possible. Each point count consisted of 10 minutes of observation (watching and listening) at the grid point and recording every species seen or heard. Observers marked the direction they were facing at the start of the survey and then spent time facing each direction within the 10-minute survey. All point counts in this open grassland had a 150-m assumed listening radius (Cyr et al. 1995).

Point counts were then completed by two observers after transmission line construction (which took place from fall 2013 to spring 2015) in the summer of 2016 during the breeding season from April 25 to June 25. A total of 168 locations were selected from the original 372 sites, by selecting sites arranged along 1200-m linear transects (i.e., blocks of 4 plots where topography permitted – 3 in road-only transects, 5 in powerline-only transects) that were perpendicular to the disturbance treatment (e.g., transmission lines). Transects were spaced evenly from one another to encompass a variety of landscape and vegetation features found across the study area and were grouped into treatments to also focus on specific disturbances found in the study area (Figure 2.1). The four treatment strata used for comparisons were roads (i.e. paved highways) only, high voltage transmission lines (>500 kV), roads with transmission lines on both sides (split), and roads with transmission lines on one side (one-sided). Road-only transects were at least 500 m from transmission lines and situated on a secondary highway (Sec. 556) that generally received less traffic (270 vehicles per day in summer of 2016) than the adjacent primary highway (AB #36; 1400 vehicles per day in summer of 2016), the latter of which has the transmission lines constructed along it. Transmission-line-only transects were at least 500 m away from paved roads. Additional control transects were established at least 1500 m from transmission lines and highways (Figure 2.1). In total, there were 9 control transects, 6 transmission line-only transects, 10 road-only transects, 13 one-sided transmission line transects, and 8 split transmission line transects (Figure 2.1).

During each point count, observers recorded the time of day, temperature, and minimum and maximum wind speed. Vegetation was also assessed at each site in June and July of 2016. The proportion of grassland, short shrubs, tall shrubs, open water, wetland, road, and bare ground were estimated within a 150-m radius of each point count. Detailed vegetation composition was also assessed at the center of each site, using five 0.5-m quadrats to estimate percent cover of plant species. One quadrat was surveyed in the middle of the plot, and the other four were surveyed 5 m away from the center of the site in each of the four cardinal directions (Figure 2.3). Visual obstruction readings (VORs) were also taken at each of the quadrat locations by measuring the vegetation height (cm) above the ground at which a Robel pole was concealed with an observer distance of 5 meters, along with maximum vegetation height where the tallest plant of the species that resulted in most of the obstruction was measured. I examined range health for native grasslands by assessing vegetation composition and structure, litter, site stability, hydrologic function, and noxious weed presence at each plot following the Government of Alberta Range Health Guides (Adams et al. 2016).

2.2.3 Statistical Analysis

<u>i. Data Preparation</u>

Distances of each point count site from transmission lines and paved roads were converted into distance decays (using the formula $d = e^{-ax}$, $a = 0.006$), so that the effect of the transmission line or road was negligible ($d = 0.050$) at 500 m. This distance was then subtracted from 1 to facilitate intuitive interpretation of distances (larger distance decays mean further away from roads and transmission lines). Plots from samples conducted before transmission line construction were given a distance decay value of 1 (maximum distance decay away from a road or transmission line). All covariates were standardized before analysis by converting to *z* scores.

Semivariograms were run to detect collinearity among sites. As well, Moran's I tests were used to examine the presence of spatial autocorrelation with single species (i.e., among plots), while Mantel tests were used to examine the presence of spatial correlation with communities (groups of species). Where significant (p <0.05), in the case of the grasshopper sparrow, plots were reduced based on the distance that autocorrelation was observed (from the constructed semivariogram, $x = 500$ m) and a simplified dataset used for analysis (n = 82).

ii. Species Richness and Diversity

Species richness was determined by combining the total number of unique species detected at each point count site over all sample periods. Mixed effects generalized linear models were used (R, v. 3.3.3) to determine the effects of distance to transmission line, as well as other habitat covariates (proportion of vegetation types, visual obstruction readings, and range health scores), on species richness. Linear and quadratic terms of each vegetation proportion covariate were tested to determine characteristics of vegetation that influenced species richness. Vegetation was assumed to be constant between years. Ecological models were constructed for both pre- and post-construction data. Then, distance to highway was added to the pre-construction model, and distance to transmission line was added to the post-construction model. Standardized beta-coefficients were compared to determine whether the magnitude of effect changed between years.

iii. Bird Community Analysis

Multivariate techniques, specifically distance-based redundancy analyses (dbRDA) in R (v. 3.3.3), were used to determine characteristics of the landscape that influenced bird communities. Fifteen species of waterfowl, geese, and herons were removed from all analyses due to their reliance on water, which was found only sporadically across the study area; thus, the results here emphasize responses in upland grassland bird communities.

First, birds were grouped into five major categories (shorebirds, songbirds, corvids, birds of prey, and gamebirds; Table A.5) to determine how landscape characteristics influence general functional groups of birds, because I predict that generalist and opportunistic species (such as corvids and blackbirds) are more likely to take advantage of perches and roadkill typically found near transmission lines and roads, while more specialist species (such as songbirds) would avoid areas of disturbance.

Second, entire bird communities were analyzed using a dbRDA in R (v. 3.3.3) to determine general patterns caused by the vegetation in the landscape and other covariates, such as distance to transmission line and range health.

iv. Focal Species and Transmission Lines

The six focal species chosen for analysis (Baird's sparrow, marbled godwit, long-billed curlew, brewer's blackbird, eastern kingbird, and grasshopper sparrow) occupied between 30-60% of sites in either the pre- or post-construction sampling periods, to ensure sufficient observations for modeling. They also represent a variety of types of birds (grassland specialists and generalists; ground nesters, tree nesters, and shrub nesters; perching birds and wading birds), as well as varying conservation risk status (Table 2.1). Multiseason analyses in Program PRESENCE (v. 12.7, Hines 2006) were used to estimate the effects of transmission line construction on the occupancy of the six selected focal species before and after transmission line construction.

The effects of roads and transmission lines were compared to an ecological null model for each focal species. The detection part of the model was developed first, and included visual obstruction readings, time of day, Julian day, presence of fences, days since grazing (recent cow manure may attract insects, a possible food source for birds, therefore increasing detectability), and maximum wind speed. Time was included instead of temperature because they were correlated ($r > 0.60$), and time is a better predictor of avian activity than temperature (Brown 1963). Variables for occupancy were then added. This included range health score, the proportion of cover (tall shrubs, short shrubs, open water, grassland, bare ground), presence of fences, presence of dirt roads, and presence of oil and gas infrastructure (e.g., well heads or risers). Linear and quadratic terms of each vegetation proportion covariate were tested to determine characteristics of vegetation that influenced species richness. After fitting the ecological null model for each species, the distance to transmission line, paved roads, and the interaction between these two factors were added as extinction and/or colonization factors to examine their effect on occupancy in the following year. Both distance to road and transmission line was added to examine the different transmission line and road patterns observed at the ranch (one-sided and split areas) and to determine combined effects of both disturbances. Fit of models was determined using AIC values.

2.3 Results

2.3.1 Species Richness and Diversity

A total of 72 species were detected before transmission line construction across the study plots, and 74 species were detected after construction. Fifteen of the species prior to and after construction were waterfowl, herons, geese, or gulls. The most common species was the western meadowlark, which was found at every site in both pre- and post-construction sampling periods. Of the remaining species, 7 species were found in over 50% of sites in either pre- or post-construction sampling periods (Table A.3). The occupancy rate of each of the six focal species varied between years, although the most abundant species were similar between years (Table A.3).

Average bird species richness differed between treatments, but not between years (Figure 2.4). The greatest number of species were found in the road-only transects (13.7 ±3.3, 13.8 ±2.7; before and after, respectively; Figure 2.4), while the least number of species were found in the control and transmission line-only transects (control: 9.4 ±2.3, 9.8 ±2.6; transmission line only: 10.4 ±3.0, 10.7 ±3.5; before and after, respectively; Figure 2.4). Transects with roads and transmission lines together contained a moderate number of species, but were not significantly different than the road-only transects (Figure 2.4). However, they still contained significantly more species than those in control and transmission line-only transects. Road-only transects were located on a lower-volume secondary highway, while transects with transmission lines and roads were located on a higher-volume primary highway. However, the before-after nature of this study will still determine the effects of transmission lines.

Pre-construction, species richness was greatest at an intermediate proportion of tall shrubs and decreased with distance from paved roads (Table 2.3; Figure A.2). Post-construction, species richness decreased with increasing proportions of grass (Table 2.3). Species richness also increased with distance from transmission lines, but was greater in areas with paved roads found away from transmission lines (Figure 2.5).

2.2.2 Community Effects

Bird groups shifted before and after transmission line construction (Figure 2.6). After construction, perching birds were more commonly found further away from transmission lines and in areas with more grass and better range health, while corvids were more commonly found close to transmission lines and in areas with lower range health. Shorebirds and grouse appeared to be unaffected by construction. Shorebirds were also found in areas with fewer short shrubs.

The overall avian community also shifted after transmission line construction, with some species (marbled godwit, brewer's blackbird, and grasshopper sparrow) more common before construction and others (long-billed curlew, Baird's sparrow, and eastern kingbird) more common after (Figure 2.7). Many opportunistic species, such as the black-billed magpie and American crow were more likely to be found near transmission lines, while marbled godwits and western meadowlarks were more likely to be found at greater distances from transmission lines.

2.3.3 Focal Species and Transmission Lines

Of the six focal species, Brewer's blackbird and Eastern kingbird were negatively affected by distance to transmission lines, while Baird's sparrow, grasshopper sparrow, and long-billed curlew were positively affected by distance to transmission lines, and one species – marbled godwit – was not affected (Table 2.4; Table A.4). Baird's sparrow, grasshopper sparrow, long-billed curlew, and marbled godwit were negatively affected by distance to paved roads, while Brewer's blackbird and Eastern kingbird were positively affected by distance to paved roads (Table 2.4; Table A.4).

The detection of Baird's sparrows increased further into the breeding season, decreased when fences were present, and increased when pastures had recently been grazed. However, no habitat factors examined influenced occupancy by this species. Colonization of Baird's sparrows after transmission line construction was greater further from paved roads, but closer to transmission lines (Table 2.4).

The detection and occupancy of Brewer's blackbirds was not influenced by any covariates or habitat features (Table 2.4). However, the extinction rate of Brewer's blackbirds after transmission line construction was extended further from paved roads, but closer to transmission lines (Table 2.4).

The detection of Eastern kingbirds was not affected by any covariates (Table 2.4). Occupancy increased with greater proportions of tall and short shrubs, as well as the presence of fences, but decreased with increasing range health scores. Colonization rates for this species after transmission line construction were inversely related to distances from transmission lines and paved roads (Table 2.4).

The detection of grasshopper sparrows was not affected by any covariates (Table 2.4). Occupancy was inversely related to range health scores and tall shrubs (Table 2.4). After transmission line construction, grasshopper sparrows preferred areas near transmission lines, but further from paved roads (Table 2.4).

The detection of long-billed curlews was also not affected by any covariates (Table 2.4), while occupancy was inversely related to visual obstruction and the proportion of area containing grassland (Table 2.4). Extinction decreased with greater distances from paved roads, but increased with greater distances from transmission lines (Table 2.4).

The detection and occupancy of marbled godwits was not affected by any measured covariates, habitat features, or distance to transmission line (Table 2.4). However, extinction rate after transmission line construction decreased further away from paved roads (Table 2.4).

2.4 Discussion

Bird species richness differed between treatments, but was similar between years. Transects with paved roads had greater numbers of species compared to the control and transmission line-only sites. Roads may attract more species, such as corvids and birds of prey, due to food sources from roadkill (Forman and Alexander 1998), or insectivorous birds due to warmer temperatures and increased insect activity on roadsides (Forman et al. 2002). Other perching structures such as fences may also attract more species (Rodgers and Koper 2017). Other studies have found more species in roadsides compared to adjacent fields (Camp and Best 1993), and have observed birds perching on structures that may act as artificial shrubs, such as fences and gas wells (Rodgers and Koper 2017), and the same may have occurred here with transmission line tower structures.

Although there was no difference in species richness before and after transmission line construction, species composition changed with distance to transmission line. Birds of prey were more likely to be found near transmission lines, likely due to the presence of hunting perches. The presence of birds of prey may have caused prey species (perching birds such as the western meadowlark or sparrows) to move further from the transmission lines and away from predation risk. Ravens have also been documented to nest on anthropogenic features and are also more likely to nest near agriculture (Coates et al. 2014). Studies have shown that nesting success of some grassland bird species, such as the savannah sparrow and vesper sparrow, is lower at infrastructure sites, suggesting that transmission line infrastructure may benefit nest predators (Bernath-Plaisted et al. 2016).

Transmission line construction appears to have varying effects among different grassland bird species. For example, Brewer's blackbirds were negatively affected by transmission line construction and were less likely to occupy sites post-construction near transmission lines, while Baird's sparrows, Eastern kingbirds, grasshopper sparrows, and long-billed curlews were positively affected by transmission lines and were more likely to occupy sites post-construction near transmission lines. Marbled godwits were not affected by transmission line construction. Baird's sparrows, grasshopper sparrows, and long-billed curlews were all positively affected by transmission lines, but notably do not have the same breeding habitat requirements, suggesting each of these species was responding to transmission line presence rather than habitat conditions, perhaps due to transmission lines acting as ecological traps. In-depth nesting success and density estimates for specific species are needed.

Contrary to my hypothesis, the focal species considered sensitive in the study area were less susceptible to transmission line disturbance than other bird species. Unexpectedly, Baird's sparrows, grasshopper sparrows, Eastern kingbirds, and long-billed curlews were more likely to occur near transmission lines. This is contrary to a study done by Forman and Deblinger (2000), which concluded that sensitive species were negatively affected by roads to a further distance away than generalist species. Transmission line construction may therefore be less of a disturbance than road development (i.e., due to their lack of ongoing vehicle traffic once built). Vegetation changes and the construction of new perching structures may also provide alternative breeding habitat for some species. Bernath-Plaisted and Koper (2016) found that although nest density of vesper sparrows increased near oil wells and compressor stations, their nest success was lower, suggesting that oil and gas infrastructure acted as an ecological trap. Similarly, while the three species here were more likely to occupy sites near transmission lines after construction, they may have had lower nest success than their counterparts at further distances from the lines, and would require further study. Alternative breeding habitat may be important for long-billed curlews, who are ground nesting birds that require rocky and bare habitats for breeding, which may be more common in cleared areas underneath transmission lines and towers, unintentionally attracting this species to these locations. Marbled godwits require similar breeding habitat as long-billed curlews, yet were unaffected by transmission line development and only negatively affected by paved roads, possibly due to road effects being a large enough deterrent to overcome effects of transmission line development. Nest surveys and success rates need to be evaluated to determine the full extent of the effect of transmission line construction on individual bird species.

Among the focal species, both generalist and grassland specialist species showed varying relationships with distance to transmission line. Vegetation structure may be important for some bird species, regardless of distance to disturbance (Bogard and Davis 2014). Boren et al. (1999) found that changes in vegetation cover led to changes in bird communities, and found more generalists in high density, rural landscapes where native vegetation was lower, and fragmentation and road development were greater. In this study, plant communities were not overly different near or far from transmission lines (most of the differences were likely due to soil type, elevation, and grazing patterns), which may have ameliorated some effects of transmission line construction if the vegetation remained mostly undisturbed. However, because detailed vegetation data were not collected before transmission line construction, nor was it collected with fine detail (vegetation characteristics change at a much finer scale than birds), the differences in vegetation between years may be of greater importance than apparent in this study, and may be caused by differences in precipitation and temperature between years (Table A.6). Grazing patterns may also be a factor that influence species and can mitigate or exacerbate effects of transmission line construction. Cumulative effects may also be important, as evidenced by Smith and Dwyer (2016) who found that the combined effects of grazing and burning were greater than a single disturbance, though the benefits of grazing and burning could be negatively influenced by woody edges and roads (Coppedge et al. 2008). However, no interactions between transmission lines and paved roads were significant for any of the six focal species, and transmission lines and paved roads tended to have opposite effects.

Traffic volume has also been found to have varying effects on birds (Forman et al. 2002), where increased traffic increases the distance to which birds are affected, with some species avoiding roads to a distance of over 1 km (Forman and Deblinger 2000), or having no effect at all (Warner 1992). Forman and Deblinger (2000) also determined a 600 m wide "road effect zone", which is asymmetric and can depend on a variety of factors, such as traffic noise, wind and water flow patterns, and topography. Traffic volume contributes to the noise effect zone, which can be anywhere between 50 m to 2000 m from roads (Madadi et al. 2017). Temperate grasslands also have the greatest area affected by noise presumably due to the lack of tall vegetation to block noises, and roads therefore cause habitat loss and fragmentation through physical occupation and traffic noise, and can act as barriers to reduce movement of animals (Madadi et al. 2017). In this study, there were more species found in road-only transects, but which were located adjacent to a lower-traffic secondary highway, while fewer bird species were found on transmission lines that ran along both sides of a high-traffic primary highway, suggesting that higher-volume roads depress species richness, regardless of the presence of transmission lines (i.e., there was no difference in species richness before and after transmission line construction). Four of the six focal species here were negatively affected by paved roads (Baird's sparrow, grasshopper sparrow, long-billed curlew, and marbled godwit), but it is unclear whether this was due to road noise, deterrence caused by collisions with vehicles, or edge avoidance due to fragmentation.

This study took place in the breeding season directly following transmission line construction, and the effects of transmission line construction may be short-term with effects that may disappear or decline in the years following construction. However, there is evidence that the effects of paved roads are still present over fifty years after construction, a similar pattern that may be experienced with transmission lines. One other BACI design experiment in grasslands by Shaffer and Buhl (2016) looked at the effects of wind energy on breeding grassland bird distributions in North and South Dakota, but did not focus on the associated transmission line structures. Additional studies on the direct effects of transmission lines are needed in native grasslands, as well as long-term studies to determine whether these effects are concentrated within the first few years after construction or whether they lead to long-term legacy effects on bird populations and communities.

2.5 Conclusion

Avian species richness differed between treatments, but was similar between years, with the greatest number of species found in transects containing paved roads. Perching birds were more commonly found further from transmission lines, while corvids were more commonly found close to transmission lines, whereas shorebirds and grouse appeared to be unaffected by construction. Because of the contrasting nature and varying degree of responses among individual bird species, it is difficult to suggest management strategies for maintaining important grassland bird species. Five of the six focal species were affected by transmission line construction. Transmission lines may function as ecological traps for other species, such as the Baird’s sparrow, grasshopper sparrow, and long-billed curlew, which were found more often near transmission lines, but with unknown nesting success and subsequent survival that may result in ecological traps. Vegetation characteristics were important in the occurrence of many focal species, suggesting that managing for habitat may contribute to the mitigation of transmission line construction effects. Future transmission line construction should avoid areas containing sensitive species where possible, bury lines to decrease further fragmentation of landscapes, and restore vegetation to pre-construction conditions.

Table 2.1. Species information for the six focal species.

Species	Status in Alberta*	Nesting Behaviour	Grassland specific?
Baird's sparrow	Sensitive	Ground nester	Yes
Marbled godwit	Secure	Ground nester	No
Long-billed curlew	Sensitive	Ground nester	Yes
Brewer's blackbird	Secure	Shrub nester	No
Eastern kingbird	Sensitive	Tree nester	Yes
Grasshopper sparrow	Sensitive	Ground nester	Yes

*Alberta Wild Species General Status Listing (Alberta Environment and Parks 2017)

Table 2.2. Proportion of point count sites ($n = 168$) in which each focal bird species was detected pre- and post-transmission line construction. Proportion in control sites are in parentheses.

	Naïve Site Occupancy	
Focal Species	Pre-construction (2012-13)	Post-construction (2016)
Baird's sparrow	0.125 (0.013)	0.298 (0.054)
Marbled godwit	0.577 (0.114)	0.440 (0.057)
Long-billed curlew	0.363 (0.054)	0.440 (0.067)
Brewer's blackbird	0.333 (0.018)	0.298 (0.016)
Eastern kingbird	0.333 (0.037)	0.393 (0.036)
Grasshopper sparrow	0.387 (0.041)	0.351 (0.024)

Table 2.3. Results from generalized linear model for bird species richness analysis. Distance from road and transmission line are decay distances.

Pre-construction	species richness ~ tall shrubs + tall shrubs^2 + distance to road				
AIC = 727.71		estimate	SE	*z*-value	*p*-value
	intercept	2.595	0.054	48.277	<0.001
	proportion tall shrubs	0.873	0.202	1.471	0.344
	proportion tall shrubs^2	1.906	0.503	3.788	<0.001
	distance to road	-0.236	0.069	-3.400	<0.001
Post-construction	species richness ~ tall shrubs + tall shrubs^2 + grass + distance to road*distance to transmission line				
AIC = 740.85		estimate	SE	*z*-value	*p*-value
	intercept	3.143	0.198	15.840	<0.001
	proportion tall shrubs	0.990	0.573	1.452	0.285
	proportion tall shrubs^2	0.805	0.590	1.364	0.173
	proportion grass	-0.688	0.227	-3.034	0.002
	distance to road	0.028	0.154	0.183	0.855
	distance to transmission line	0.343	0.111	3.095	0.002
	distance to road*distance to transmission line	-0.410	0.192	-2.134	0.033

Null model AIC values for pre- and post-construction models are AIC_{pre} = 757.82 and AIC_{post} = 770.22.

Table 2.4. Beta coefficients describing ecological covariates to each focal bird species for the most supported model. Variables were standardized and all are significant ($p < 0.05$; SE<Estimate).

Species (response)	Covariate	Beta estimate	SE
Baird's sparrow			
Detection (p)	Julian day	2.633	0.400
	presence of fence	-2.088	0.479
	days since grazing	0.558	0.372
Colonization (gam)	distance to road	1.217	0.358
	distance to transmission line	-1.106	0.279
Marbled godwit	Covariate	Estimate	SE
Extinction (eps)	distance to road	-1.132	0.356
Long-billed curlew	Covariate	Estimate	SE
Occupancy (psi)	visual obstruction	-0.690	0.342
	proportion of grass	0.394	0.250
Extinction (eps)	distance to road	-1.821	0.703
	distance to transmission line	0.614	0.420
Brewer's blackbird	Covariate	Estimate	SE
Extinction (eps)	distance to road	2.508	1.286
	distance to transmission line	-2.145	1.121
Eastern kingbird	Covariate	Estimate	SE
Occupancy (psi)	proportion tall shrubs	3.159	0.744
	proportion short shrubs	1.663	0.513
	presence of fence	1.503	0.499
	range health score	-0.555	0.268
Colonization (gam)	distance to road	16.207	2.795
	distance to transmission line	-14.909	2.628
Grasshopper sparrow	Covariate	Estimate	SE
Occupancy (psi)	proportion tall shrubs	-1.423	0.771
	range health score	0.782	0.362
Extinction (eps)	distance to road	-3.008	1.351
	distance to transmission line	1.778	1.024

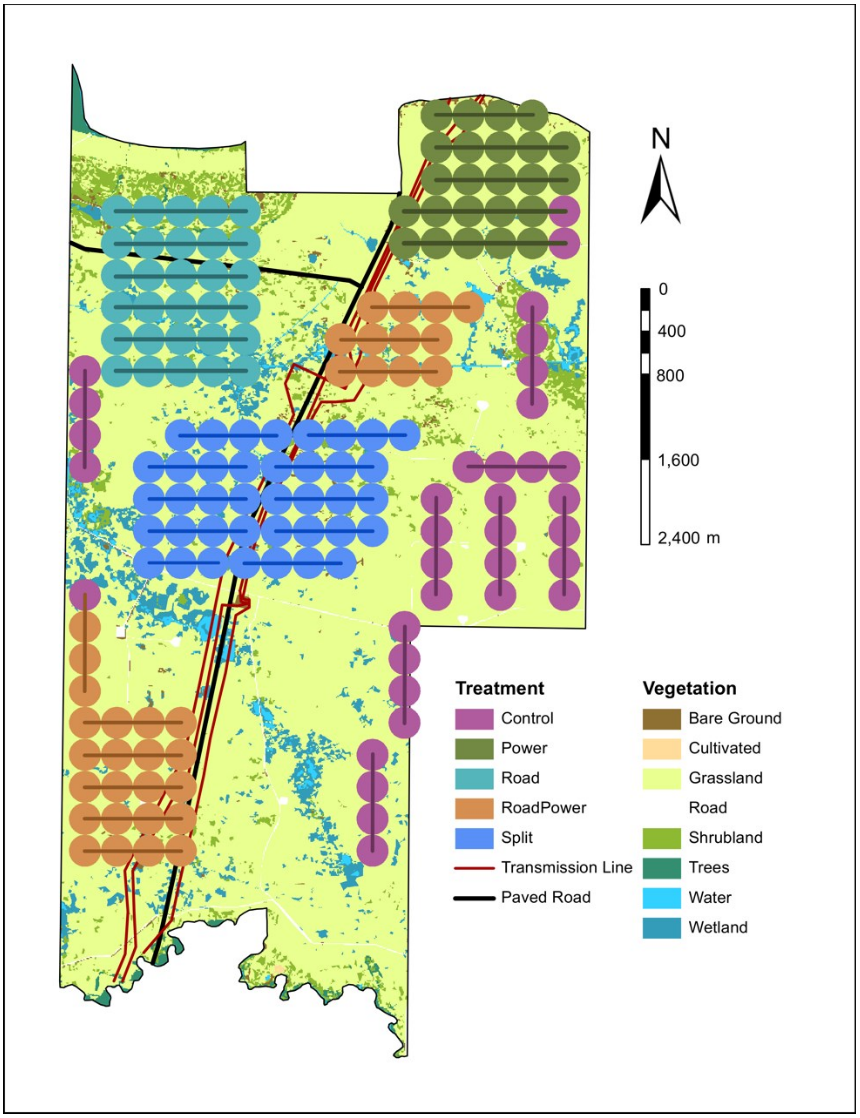

Figure 2.1. Map of the study area and sample locations pre- and post-transmission line construction. Each site (*n* = 168) was sampled 3 or 4 times during the breeding seasons of 2012/13 and 2016, before and after transmission line construction, encompassing a variety of habitat and disturbance types. Control sites were at least 1,200 m from transmission lines and highways (paved roads), Power sites were located near newly constructed transmission lines, Road sites were located along a secondary highway away from transmission lines, RoadPower sites were located where transmission lines ran along one side of the primary highway, and Split sites were located where transmission lines ran along both sides of the primary highway. Coloured lines connecting point count locatios represent sampling transects.

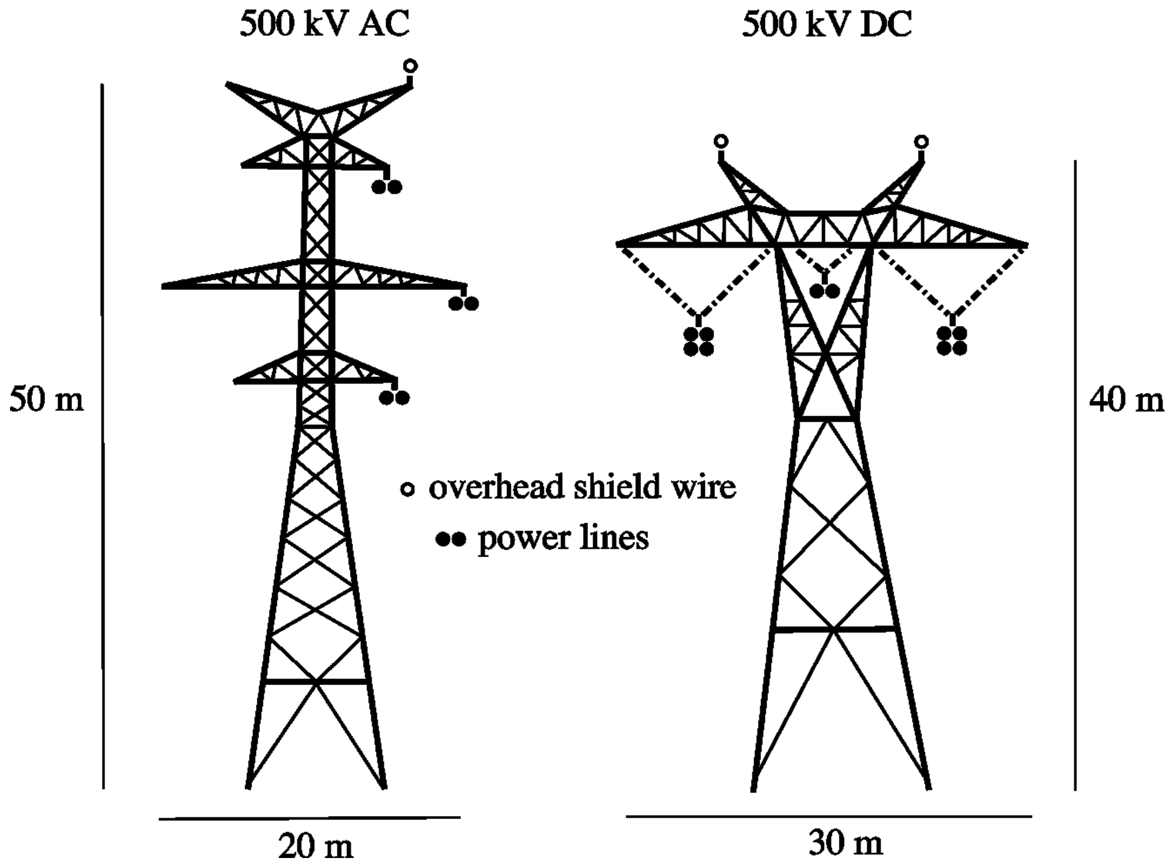

Figure 2.2. Depiction of two high voltage transmission line structures constructed in the study area: alternating current (AC) structure on left, direct current (DC) structure on right. Height and width measurements are approximate.

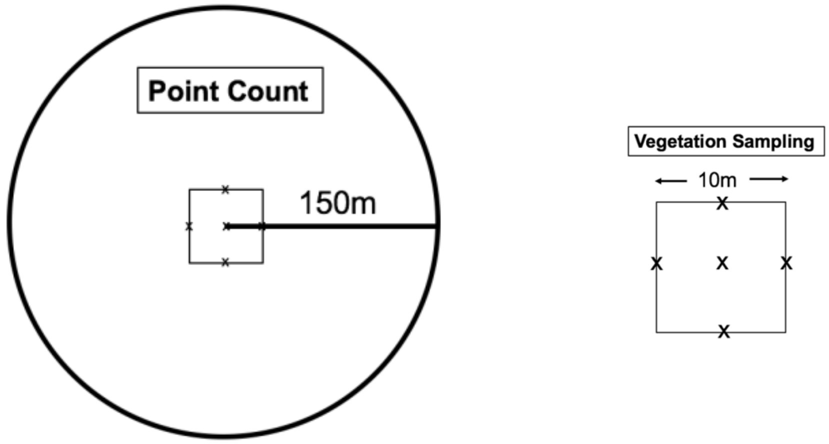

Figure 2.3. Layout of field sampling design, including the point count area and nested vegetation sampling plots within the middle of the point count. Five 0.5 m^2 quadrats were used to sample plant species cover at each point count.

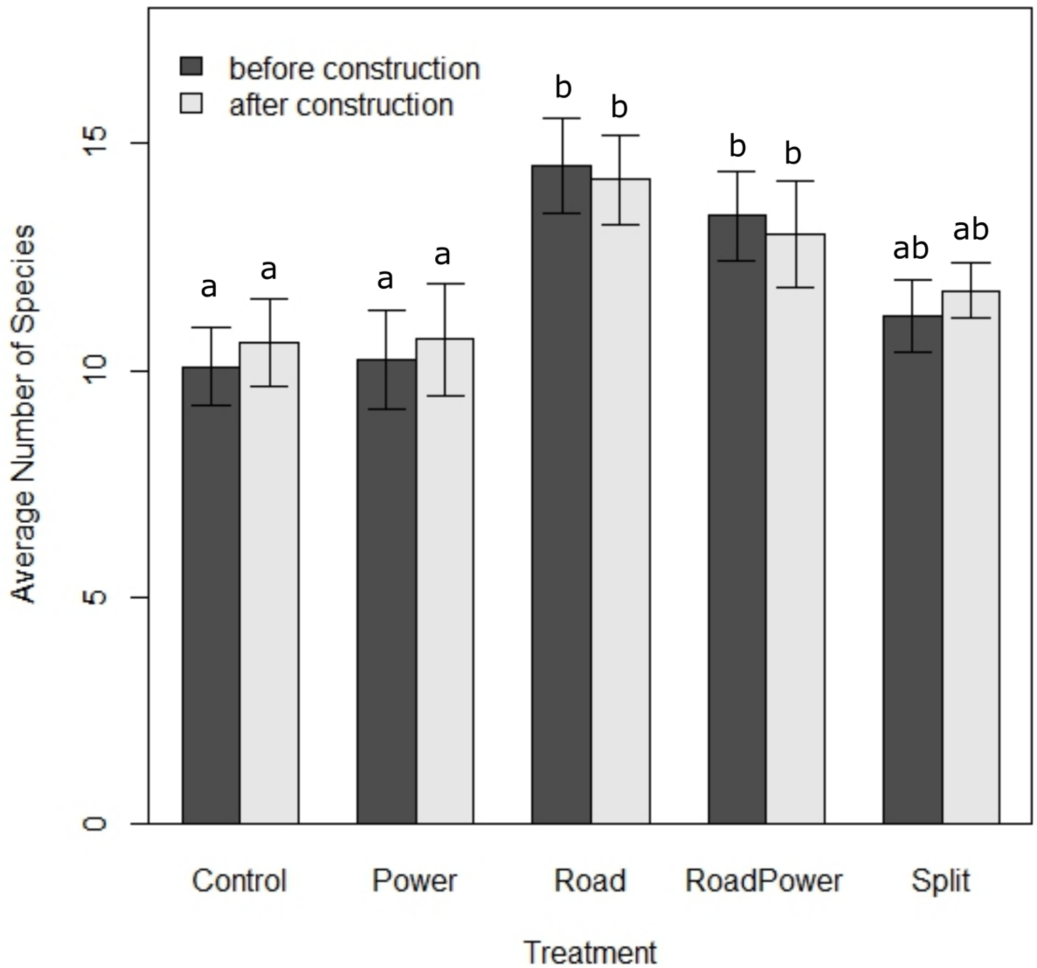

Figure 2.4. Summary of mean (± 95% CI) bird species richness (summed across all visits) between treatments before and after high voltage transmission line construction. There was no significant difference in species richness before and after transmission line construction. However, there were significantly more species in transects with highways present (Road and RoadPower) compared to other treatments (Control, Power). Control sites were at least 1,500 m from transmission lines, RoadPower sites occurred where transmission lines ran along one side of the highway, and Split sites occurred where transmission lines ran along both sides of the highway. Bars with similar letters are not significantly different.

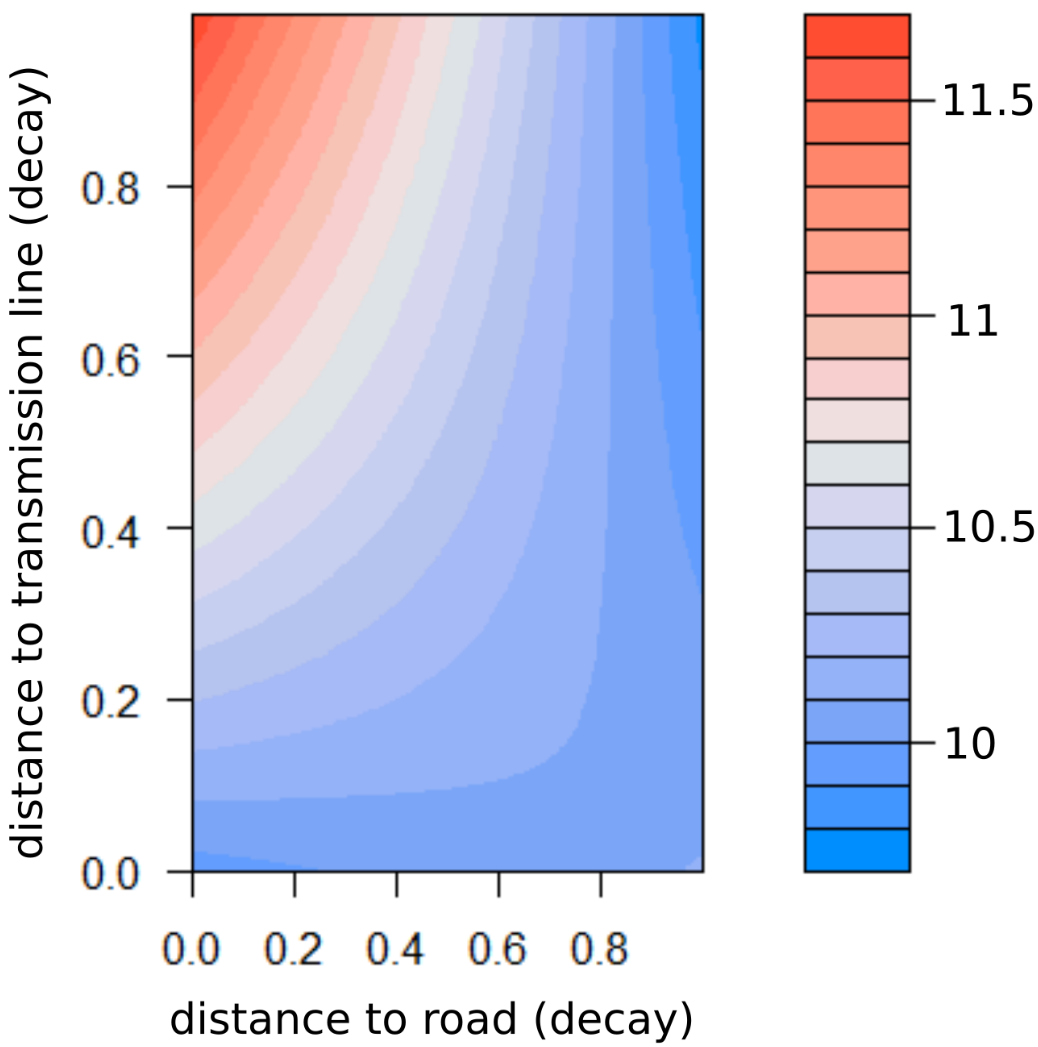

Figure 2.5. Predicted species richness from GLM for post-construction period (highway and powerline distance interaction, using decay distances). More species were found further from transmission lines, but close to highways.

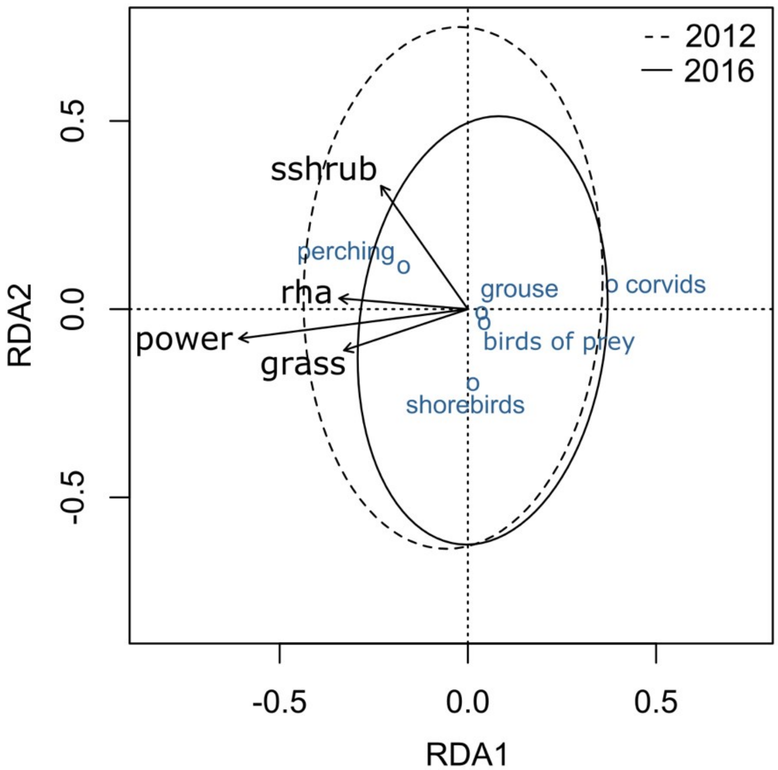

Figure 2.6. dbRDA for groups of species before (dashed line) and after (solid line) transmission line construction. “Power” refers to the decay distance to transmission line, “sshrub” is the proportion of short shrubs in point count area, “rha” is range health score, “grass” is the proportion of grass in point count area. Refer to Table A.5 for list of bird species within each group.

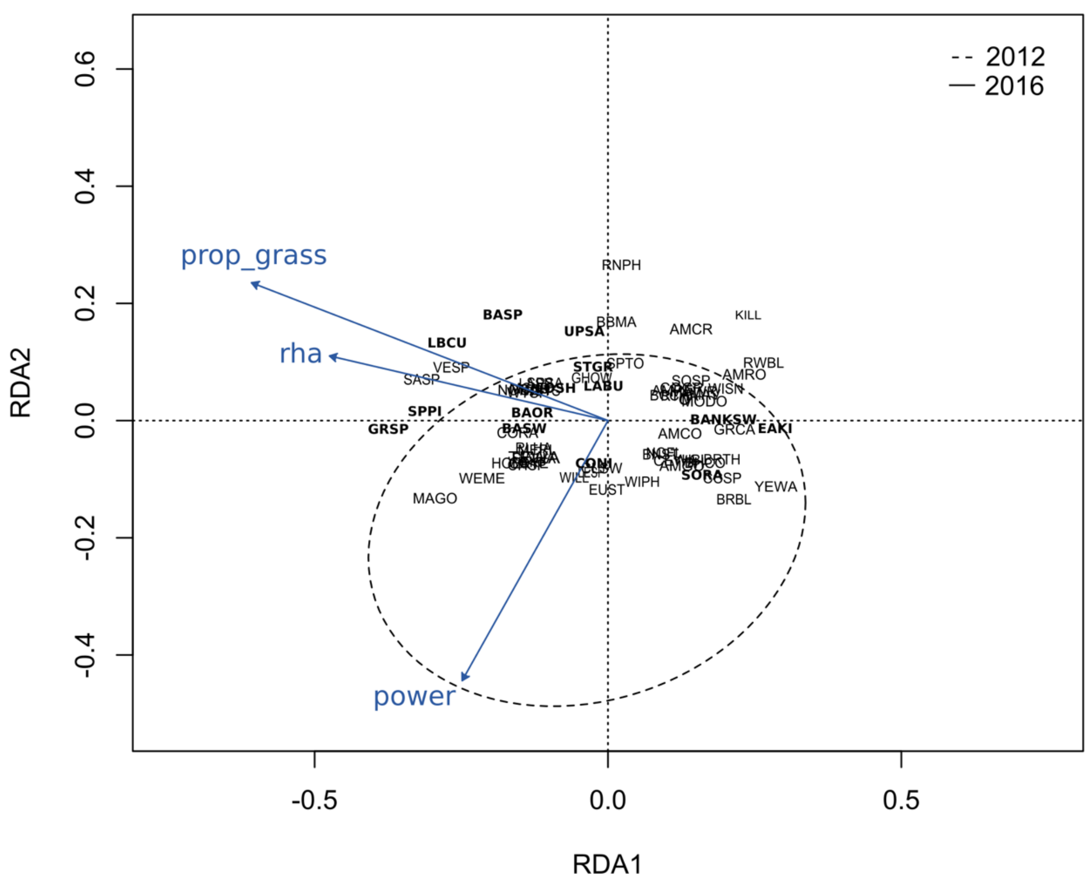

Figure 2.7. dbRDA on bird community data before (dashed line) and after (solid line) transmission line construction. “Power” refers to the decay distance to transmission line, “prop_grass” refers to the proportion of point count area containing grass, and “rha” is range health score. See Appendix A for species 4-letter codes. Bolded species are Sensitive in the province of Alberta (Alberta Environment and Parks 2017).

Chapter Three: Springtime mortality of birds from transmission line collisions in the mixed-grass prairie of Southeastern Alberta

Abstract

Transmission line development has been increasing at a rate of approximately 5% per year, which is increasing incidences of avian collisions with lines. Current Canadian estimates of transmission line collisions with birds range between 2.5 to 25.6 million bird mortalities per year. The most susceptible birds are those that are young, large-bodied, weak fliers, and those with low maneuverability, with an increased risk in open habitats or where transmission lines have recently been constructed. In this study, avian mortality was estimated for an area in the mixed-grass prairie of Southeastern Alberta following construction of two major transmission lines with mortality rates adjusted using detectability and scavenging trials. Specifically, seven 500-m transects were surveyed throughout the breeding and migration seasons (2 controls, 2 roadsides, and 3 under transmission lines). During the breeding season of 2016, 23 mortalities were recorded under transmission lines, 7 mortalities were found near roads, and no mortalities were found in controls. Subsequently, 24 mortalities were found under transmission lines in the spring migration season of 2017, 3 mortalities were found near roads, and no mortalities were found in controls. Scavenging rates were greater (82% of carcasses were scavenged within 5 days) when compared to studies in non-grassland habitats. Overall, linear disturbances within the study area, including highways and high-voltage transmission lines, are estimated to have contributed to 1,948 to 1,970 bird mortalities for one migration and breeding season. These findings point to the need for greater mitigation actions to prevent future losses of birds in areas where linear disturbances occur.

3.1 Introduction

An avian conservation issue receiving more attention is collisions and electrocutions of birds caused by transmission lines, a phenomenon first documented in 1876 (Coues 1876). With transmission line development predicted to increase globally at a rate of 5% per year, there is a subsequent increased risk of mortality to avian species (Loss et al. 2014; Silva et al. 2010). Currently, it is estimated that between 2.5 to 25.6 million birds are killed by transmission line collisions in Canada across 231,966 km of lines (from 2009, Rioux et al. 2013).

There are biological, environmental, and structural-related factors that contribute to the incidence of mortality at transmission lines (Bevanger 1998; Loss et al. 2014). Biological factors relating to collisions include the age, size, wing span, maneuverability, flocking behavior, and vision of the birds themselves (Ward and Anderson 1992; Loss et al. 2014). The most susceptible birds are those that are young, large-bodied, weak fliers, and those with low maneuverability (Bevanger 1998; Manville 2005; Loss et al. 2014). Adult birds are less likely to collide with transmission lines due to past learning. For example, juvenile sandhill cranes were found to collide twice as often as others in the population (Ward and Anderson 1992). Large birds with limited maneuverability, such as cranes and waterfowl, are the most likely to collide with transmission lines (Ward and Anderson 1992; Manville 2005; Shaw et al. 2010; Loss et al. 2015). Flock formations are also more likely to collide with transmission lines than solitary fliers (Scott et al. 1972; Liguori 2008; Loss et al. 2014).

Environmental factors that affect collision rates include topography, vegetation, and prey abundance (Loss et al. 2014; Liguori 2008). There is greater risk of collisions in areas where topography funnels birds through transmission line corridors, and where transmission lines cross migratory paths or breeding and feeding grounds (Savereno et al. 1996). Near wetlands, waterbirds and shorebirds are the most likely birds to collide with transmission lines, while raptors and passerines are more likely to collide in areas away from wetlands (Manville 2005). Shaw et al. (2010) found collision hotspots at transmission lines in South Africa, which were defined as areas prone to repeated collisions by a variety of species over a long period of time, and were related to line placement and design, as well as species-specific biology. Collisions are also more likely during periods of poor visibility, such as during dusk, dawn, and at night (Scott et al. 1972).

Structural-related factors have also been found to affect avian collisions. Tall towers with guy lines kill 5-times more birds than medium-sized guyed towers, and 70-times more birds than medium-sized unguyed towers (Loss et al. 2015). Towers with wide spacing between lines increased mortality during nocturnal flights because birds avoiding one line would collide with another (Manville 2005). Newly constructed towers potentially have greater mortality risk due to the novelty of the obstacle.

Current Canadian estimates of avian mortality from transmission line collisions range widely between 2.5 to 25.6 million birds (Rioux et al. 2013). However, most of these data were compiled from very limited studies, the majority of which was gathered in forested areas and extrapolated across the country. It is unknown as to how many birds are killed by transmission line collisions in grassland environments and the factors that contribute to these collisions. Grassland birds may be at greater mortality risk due to the nature of transmission line towers being the only large obstacle in the landscape. In studies with transmission lines traversing topographically variable landscapes, avian mortalities were most common in flat areas, with the greatest number of mortalities in open grassland habitats and pastures (Demerdzhiev 2014). Migratory species may also be at greater risk, particularly in areas such as southeast Alberta because the grasslands found there are located within a migratory flyway (Central Flyway, Ducks Unlimited).

The grasslands of Canada are home to over 200 species of birds and many species at risk whose populations could further be jeopardized by collisions with transmission lines. Only 25% of native Canadian prairie remains today (Weiler 2010), with grassland avian species significantly declining due to the conversion of native prairie to agricultural fields (cultivation) and fragmentation due to the ongoing construction of roads and transmission lines (Weiler 2010). Transmission line collisions place more pressure on grassland birds remaining in sensitive environments.

The construction of two new major transmission lines in the mixed-grass prairie of Southeastern Alberta, Canada, in 2014 provided an opportunity to estimate mortality caused by collisions with transmission lines soon after construction. The objective of this work was to estimate mortalities caused by transmission line collisions, and then discuss the potential implications for estimating avian mortality across the 3,804 km of transmission line found in remaining mixed-grass Canadian prairie during the migration season.

3.2 Methods

3.2.1 Study Area

This study took place on the University of Alberta Mattheis Research Ranch in southeastern Alberta (50.896736 N, -111.952711 W; Figure 3.1). The ranch encompasses 4,900 ha of mainly native grassland bounded in the north by the Red Deer River and in the south by Matzhiwin Creek. Most of the ranch is native (i.e. intact non-cultivated) grassland with several embedded wetlands constructed by Ducks Unlimited Canada to provide waterfowl habitat. The ranch is divided into east and west blocks by Highway 36, a high-use transportation route connecting the central and southern regions of eastern Alberta. A paved secondary highway (Highway 556) also runs east-west and divides the west block further into two unequal sections. Three transmission lines were constructed in 2013–15 along Highway 36, including two high-voltage transmission lines (one 500 kV alternating current, one 500 kV direct current; see Figure 3.2) and one pre-existing low-voltage distribution line (240 kV) dating back several decades. The two high-voltage transmission lines were constructed in 2014–2015, and contribute to a total of 27.5 km of linear disturbances in the study area. Transmission line towers were spaced between 300 to 400 m apart, and the three different lines were at least 50 m apart from each other, encompassing at minimum a 100-m-wide disturbance. The area under investigation here is also grazed by cattle at moderate stocking during the growing season using a once or twice over rotational grazing system (~0.6 AUM ha^{-1}), and has a widespread abundance of natural gas wells interconnected with a comprehensive network of pipelines. Well sites and pipelines were primarily installed in the 1970's and 80's, with the affected areas having since been re-vegetated.

This region of Alberta is comprised of dry mixed-grass vegetation, and is associated with a semi-arid climate, with a typical growing season from late April through the end of October. Average annual rainfall is 354 mm, the growing season is approximately 120 days (5°C), and average temperatures of 13.6°C over the growing season (Table A.6). Dominant plant communities include needle-and-thread grass (*Hesperostipa comata*), blue grama (*Bouteloua gracilis*), western wheatgrass (*Pascopyrum smithii*), Junegrass (*Koeleria macrantha*) and sand grass (*Calamovilfa longifolia*). Common shrubs include thorny buffalo-berry (*Shepherdia argentea*), western snowberry (*Symphoricarpos occidentalis*), prairie rose

(*Rosa arkansana*), and chokecherry (*Prunus virginiana*). *Shepherdia argentea* is an important shrub for the threatened Loggerhead shrike and is encroaching following the creation of artificial wetlands (Dahl 2014). Common forbs include pasture sage (*Artemisia frigida*), buffalobean (*Thermopsis rhombifolia*), and yellow sweet clover (*Melilotus officinalis*).

3.2.2 Experimental Design

The study area was divided into 4 treatments and a control (Figure 3.1) with search areas for dead and injured birds situated in 30-m wide transects along primary paved roads (Highway 36), under and immediately adjacent to transmission lines, and control locations distant from linear disturbance, all surveyed during the breeding season (May through June) of 2016 and spring migration season (April) of 2017. Observers systematically walked in a zig-zag pattern from the center of the lines along eight 500-m-long transects on either side of the transmission line (or one side of Highway 36), every 3–4 days. Each transect was 30-m wide and was searched with 1.5 hr of search effort per person per 500 m distance (3 hr total). The location of all bird carcasses or partial remains were recorded and given a unique label, along with the date of discovery and the species identified. Other notes, such as the condition of (or type of damage to) the carcass, were also recorded. Carcasses were photographed and removed upon discovery to eliminate repeat counts, and where necessary, frozen for later identification. Carcasses were included in the count when there were at least 5 feathers with skin present, since feathers can individually fall out during molting or fights (Erickson et al. 2005). Incidental observations of bird mortalities outside of the transects were also recorded, but were not included in the analysis.

Transects were walked in the breeding season of 2016 (May 10 to June 24) and the spring migration season of 2017 (March 31 to May 5). Two road transects, two transmission line transects, two wetland transects under a transmission line, and two control transects were sampled. Transmission lines were at least 100 m from nearby roads, and wetland transects occurred when transmission lines were strung above a body of water at least 30 m in diameter and were sampled to further examine waterfowl mortalities. Seven transects were surveyed in the breeding season of 2016, with another transect added in the spring of 2017 to focus specifically on wetland habitats. This additional transect was removed from the analysis however, due to disturbance from nearby telephone pole installation during the sampling season. All transects were 500 m in length, except for the transmission line transect with a wetland underneath, which was only 400 m in length due to the size of the wetland.

Each transect was walked 10 times during the breeding season of 2016, with the exception of transect 7, which was walked 7 times because it was added later in the sampling season. In addition to general transect surveys, 28 carcasses were left for scavenging, and 2 detectability trials (described below) were done at each transect (one in the morning and one in the afternoon). During the migration season of 2017, each transect was walked 10 times and 23 carcasses were left out for scavenging detectability.

3.2.3 Detectability (Search-Bias) Experiment

Fourteen search-bias experiments (two per transect) were conducted to determine adjustment factors for detectability of carcasses. Trials evaluated the search ability of observers conducting ground surveys for carcasses of birds. Before each trial, several bird carcasses or remains with distinguishing factors (e.g., outer three wing primaries clipped, clumps of feathers placed in a bullseye pattern) were randomly placed within the search area by another person. These birds were obtained from hunters or were carcasses found during previous transect surveys, and represented a range of species and sizes, including ring-necked pheasant (*Phasianus colchicus*), rock dove (*Columba livia*), and sparrow species (i.e., *Pooecetes gramineus*, *Passerculus sandwichensis*, *Spizella pallida*). After placement, an independent observer promptly examined the search area using a similar sampling effort as during the main surveys, and recorded the number and location of carcasses found. The mean proportion of remains found at each site was used to adjust observer bias in undetected bird carcasses.

3.2.4 Scavenging Rate Experiment

To obtain scavenger removal rates, bird carcasses were placed near (within 300 m) the search areas of each treatment and control areas at known locations and monitored daily until all carcasses were removed by scavengers. Carcasses were either fresh or frozen birds, and were a variety of sizes and species (the majority were ring-necked pheasants, some of which were cut into smaller pieces to mimic smaller passerines, but also included crows, magpies, and blackbirds). Carcasses were thawed for at least 8 hr before being used. During the first three days of carcass placement, sites were checked twice daily during the first 3 days and once daily until scavenging occurred. During searches, the presence/absence of a carcass was recorded, as well as the stage of decomposition and scavenging activity. The surrounding areas (up to 50 m away) were also searched in case scavengers had moved the carcass. The average length of time before a carcass was removed, as well as the proportion of carcasses not removed, was calculated at the end of each season, and used to determine the scavenging rate. Cox proportional hazard analyses were used to determine whether the rate of scavenging varied across site, treatment, and time since placement.

3.2.5 Statistical Analysis of Mortalities

The number of bird mortalities associated with collisions with roads and transmission lines is based on the number of carcasses found, the detection rate of observers, and the carcass-removal rate from scavengers (Erickson et al. 2004). Bird mortalities caused by transmission lines were calculated using the equation from Erickson et al. (2004) of:

$$m_1 = \frac{\bar{c}}{\hat{\pi}}$$

where m_1 is the estimated mortality rate, $\bar{c}$ is the mean number of carcasses observed per kilometer of transmission line, and $\hat{\pi}$ is all bias (searcher efficiency and scavenging; Appendix C). Specifically, I provide a mortality estimate of birds over the 27.5 km of high voltage transmission lines in the study area, and discuss potential extrapolations for mortality of breeding birds over 3,804.5 km of transmission lines situated in the Canadian mixed-grass prairies based on data collected during the breeding season of 2016. Biases for habitat (Erickson et al. 2004) were not included because all areas were searchable due to short vegetation and safe terrain.

3.3 Results

During the 2016 breeding season, 23 dead birds were found underneath transmission lines, 6 were found next to or on roads, and none were found in the control (Figure 3.3, Table B.1). There were 9 confirmed species killed by transmission lines, with the Vesper sparrow the most common species mortality in 2016 (and incidentally, the second most common species breeding in the study area). The western meadowlark was the most common species found near roads (2 out of 6 mortalities; Table B.1).

During the 2017 spring migration season, 24 dead birds were found underneath transmission lines, 3 were found next to or on roads, and none were found in the control (Figure 3.3). Most remains were clumps of feathers and bone, although some remains were entire bodies, and one was a crippled western meadowlark. Although there were 9 confirmed species killed by transmission lines, western meadowlarks were the most abundant making up 45.8% of total mortalities (Table B.1). Western meadowlarks were also the most common species found in the study area during 2016 point counts (Table A.3) in an associated investigation (Chapter 2). During the 2017 spring migration season, 3 dead birds were found beside roads, each representing a different species (Table B.1).

Because there were no mortalities detected in control areas in either year, and transmission lines were at least 100 m from nearby roads, all carcasses found beneath transmission lines were presumed to have been caused by collisions with the overhead lines. In 2016, almost half of the carcasses found under transmission lines were found where lines were above water, whereas only a third of carcasses were found under transmission lines with water during migration in 2017 (Figure 3.3). There were no mortalities observed from gunshot (consistent with the fact that hunting is not permitted in the study area), with blunt force to the head, chest, or broken wings appearing to be the cause of death for full specimens. Other mortalities found under the transmission lines that included only feather or bone remains were assumed to have been caused by transmission lines and subsequently scavenged and were in similar condition to the experimental scavenging trials.

Detectability rates were similar between observers during the breeding season of 2016 (two-way *t*-test, $t_{141} = 0.590$, $p = 0.556$). Absolute detection rates of the two observers in 2016 were 0.655 and 0.629 (proportion of carcasses detected by observers), with no differences detected between treatment areas or transects (ANOVA; $p_{\text{treatment}} = 0.169$; $p_{\text{transect}} = 0.235$). An average detection rate of 0.642 was therefore used in the derivation of estimates of total mortality. In 2017, the individual detectability rate was assumed to be the same as the previous year, so the respective detectability rate value was used in the estimates for the 2017 migration season. Size of carcass had a marginally significant effect on detection, where large carcasses (wings or large birds) were detected more often than small carcasses (sparrows or feather clumps), with no effect of carcass colour (ANOVA, $p_{\text{small}} = 0.053$, p_{brown}

= 0.245, p_{grey} = 0.586; Table 3.2).

Scavenging rates were similar across treatments (ANOVA; p_{power} = 0.404, p_{road} = 0.953; Table 3.3). Cox proportional hazard models demonstrated that there was a constant loss of bird carcasses over time through scavenging regardless of site (Figure 3.4). An average scavenging rate was therefore used in the estimate of mortality, with 82.4% of carcasses scavenged within 5 days. Size and colour of carcasses did not affect scavenging rate (Table 3.2). One carcass under a transmission line was never scavenged during the duration of the trial (*n* = 43 days).

After including biases for detection and scavenging (using equations from Erickson et al. 2004; Table B.2, Table B.3, Appendix C), it is estimated that 1,368 birds died during the migration season and 1,390 birds died in the breeding season due to collisions with the 27.5 km of transmission lines in the study area. More specifically, this translates to mortality rates of 49.7 (migration season) and 50.6 (breeding season) birds per linear kilometer of transmission line. Roads also posed a mortality risk to birds, with estimated mortalities in the study area of 525 birds over two seasons (Table B.3), contributing to a combined total of 3,282 mortalities (1,631 in migration season and 1,653 in breeding season) caused by roads and transmission lines.

3.4 Discussion

Bird mortality rates associated with collisions with transmission lines were estimated at rates of 49.7 (migration) to 50.6 (breeding) birds per linear kilometer, while road mortality rates were approximately half that of transmission lines at 25.6 birds per kilometer, or 525 mortalities in the study area. Combined sources of mortality resulted in an estimated 3,282 birds killed over two seasons. It is important to note that these mortalities are only those associated with a single breeding and migratory period, and thus, do not represent an entire year of mortality for the study area.

The average number of dead birds found per kilometer of transmission line in this study was 49.7 to 50.6 mortalities per kilometer, which is within rates estimated in other studies (42.3 ± 17.1 birds per kilometer; Rioux et al. 2013). Previous Canadian studies are also based on data from shrublands or forests, but suggest that collision rates in open grasslands are similar. Anecdotal evidence suggests that collision rates are higher immediately after transmission line construction, as it is a new obstacle introduced into the environment, with collision rates decreasing after a few years. Studies suggest that between 5–30% of some grassland bird species demonstrate breeding site fidelity (Jones et al. 2007; Dornak 2010; Small et al. 2012) and may learn to avoid lines in the following breeding seasons. However, migrating birds may encounter these new obstacles each year, resulting in similar mortality rates every migration season. More work is needed to test this hypothesis.

The new transmission lines studied here may have attracted more raptors that hunt from towers, leading to increased predation and thus further increasing mortality (Steenhof et al. 1993; Coates et al. 2014). Each transect under the transmission lines included at least one tower and were searched for carcasses using a consistent procedure, with carcasses typically found along the total length of the transect, suggesting that predation was not the only cause of mortality. Scavenging rates were greater in this study (82% after 5 days) than previous investigations (39% after 7 days, Rioux et al. 2013), possibly because it is easier for scavengers to detect carcasses in open grasslands with favorable visibility.

Contrary to other studies, there was a greater proportion of passerine mortalities found here than large-bodied birds. This suggests that the detection of smaller species may be easier in grassland areas where vegetation does not obscure their detection (Longcore et al. 2012), or that passerines are more likely to strike the transmission structure in these regions. Passerines also make up the majority of birds in the grasslands, with few large-bodied birds found away from wetlands.

Detection rates were similar to other studies in open areas (for example, an average of 64.6% for small-medium, and up to 88.1% for large carcasses was found by Longcore et al. (2012), vs 64.2% from this study), but also differed greatly from others that averaged data across many habitats (80% efficiency from Rioux et al. 2013). Detectability trials from this study used a variety of sizes and colours of carcasses, while other studies focused on medium to large bird species. In this study, detection of smaller carcasses was lower than larger carcasses, which suggests these data may underestimate the number of passerine mortalities. Mitigation attempts of deterring passerines has not been examined elsewhere because they were not detected at levels considered to pose a significant risk. However, approximately 45% (21 deaths out of 47) of mortalities in this study were passerines, suggesting a greater need for research focusing on quantifying passerine mortality and testing mitigation strategies.

Attempts at mitigation, including line marking, managing surrounding lands, removing guy or overhead shield wires, changing line configuration, rerouting existing lines, and burying power lines, have had variable success depending on landscape differences. Studies have shown that increasing the visibility of lines results in significant reductions of collision risk. Alonso et al. (1994) found collisions were reduced by 60% when lines were marked with coloured bands. Yellow vibration dampers and yellow fiberglass swinging plates resulted in significant reductions of crane and waterfowl collision mortality in Colorado (Brown and Drewien 1995). Jenkins et al. (2010) recommended marking lines with devices that thicken the appearance of lines for at least 20 cm every 5 to 10 meters. Other attempts at marking lines in Spain have resulted in no significant declines in collision mortality (Janns and Ferrer 1999). Diverters installed on transmission lines in California resulted in reductions in collision mortality for many species of waterfowl, but not other bird groups (Ventana Wildlife Society 2009). Some studies suggest that one of the only solutions to effectively decrease avian collision risk is to bury lines, but at a relatively high expense and with greater effects on the surrounding vegetation (Janns and Ferrer 1999; Jenkins et al. 2010). In this study however, a greater proportion of passerine mortalities were detected than in other studies, suggesting that mortality risk for passerines is either under-studied or under-detected, and mitigation attempts should take this into consideration. Mitigation attempts focusing on waterfowl may also inadvertently reduce passerine mortality, but there are little data to support this.

The effect of mortality caused by collisions with transmission lines on local populations is unknown. Arnold and Zink (2011) suggested that mortalities caused by collisions with buildings and communication towers have no effect on population trends of birds in North America. A study by Zimmerling et al. (2013) also suggested that mortalities caused by collisions with wind turbines affect less than 2% by mortality or displacement and would likely not affect long-term populations, while Erickson et al. (2015) determined that local populations of grassland songbirds would have variable risks of extinction due to wind turbine collision mortality. However, studies on transmission lines have been limited to date, and the cumulative effects of mortality caused by collisions with buildings, communications towers, wind turbines, transmission lines, and cars may all contribute to greater local population loss due to cumulative direct and indirect effects (Smith and Dwyer 2016).

The current investigation indicates there is a substantial potential of bird loss due to collisions with transmission lines in Canada, with estimates arising from this study suggesting 192,316 springtime bird mortalities in the mixed-grass prairie, and 11,537,989 springtime deaths across Canada. As of yet, this is the first mixed-grass-prairie-specific estimate of bird mortality rate associated with transmission lines in Canada. The country-wide estimate is within estimates done by other studies, which suggest between 5.8 and 229.5 million birds die due to collisions with transmission lines nationally (Rioux et al. 2013).

3.5 Conclusion

This study is the first to report on bird mortality rates associated with high voltage transmission lines in the mixed-grass prairie of North America. Data specific to the spring breeding season and migratory period were used, together with detection and scavenging efficacy, to derive estimates of total mortality for the region. Findings indicate that the potential for mortalities of birds due to transmission line collisions in Canadian grasslands is substantial, and may represent more than 190,000 deaths in the mixed-grass prairie alone during this limited period of sampling (3 months). Among the species found to be most affected, passerines appeared to be particularly susceptible to mortality, and contrasts many previous studies focusing primarily on larger bodied birds. Mitigation and implementation of deterrents may reduce mortality and may be necessary to minimize their impacts given the growing population base and associated renewable energy needs of society in Canadian grasslands.

Table 3.1. Results from ANOVA evaluating the detectability of deceased birds based on the size and colour of carcass.

Factor		Estimate	Standard Error	*t*-value	*p*-value
	Intercept	0.869	0.167	5.210	<0.001
Treatment (Control as reference)	Power	-0.109	0.095	-1.138	0.257
	Road	-0.120	0.099	-1.207	0.230
Size (Large as reference)	Small	-0.259	0.133	-1.956	0.053
Colour (black as reference)	Brown	-0.130	0.112	-1.167	0.245
	Grey	0.089	0.163	0.547	0.586

Table 3.2. Results from the ANOVA evaluating the effect of scavenging time (days) based on tre atment, carcass size, and carcass colour.

Factor		Estimate	Standard Error	*t*-value	*p*-value
Treatment	Intercept	-9.687	32.087	-0.302	0.764
(control as reference)	Power	16.851	19.999	0.843	0.404
	Road	-1.242	20.840	-0.060	0.953
Size (large as reference)	Small	-6.583	32.436	-0.203	0.840
	Small-medium	10.875	34.364	0.316	0.753
	Medium	12.537	43.197	0.290	0.773
Colour (black as reference)	Black and white	72.101	40.977	1.760	0.086
	Brown	13.874	42.233	0.329	0.744
	Grey	-7.507	29.618	-0.253	0.801

Table 3.3. Proportion of mixed-grass prairie left in each Canadian prairie province and the total estimated transmission line length.

Province	Total Area of Province (km^2)	MG Prairie Area (km^2)	Percent remaining MG prairie (%)*	Area of MG prairie remaining (km^2)	Proportion of MG prairie area in province	Length of transmission line (km) in MG prairie
Alberta	661,848	97,000	43	41,710	0.063	
Saskatchewan	647,797	241,000	21	50,610	0.004	
Manitoba	651,900	14,700	18	2,646	0.078	
Total	1,961,545	352,700		94,966	0.048	3,804.47

* Nernberg and Ingstrup 2005

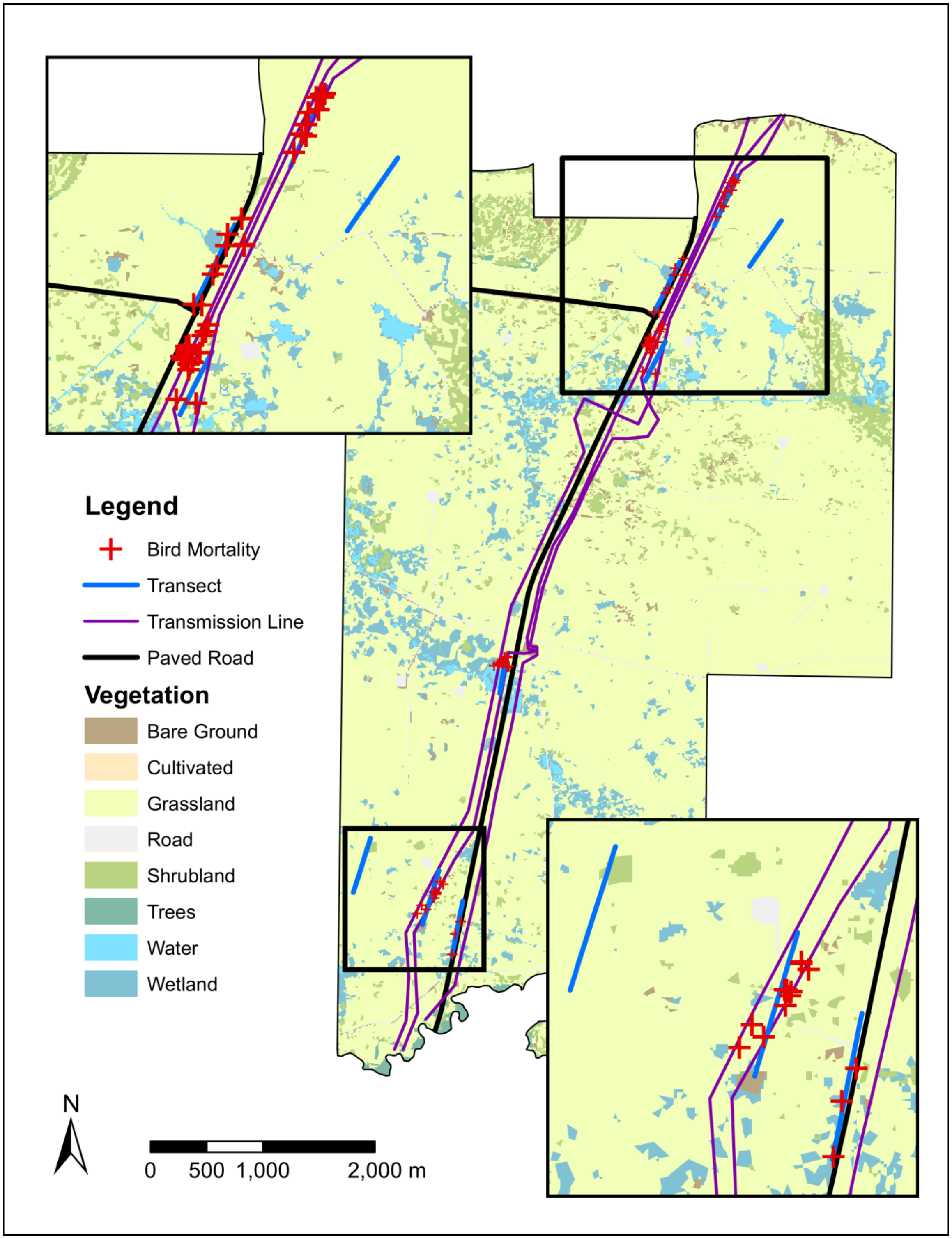

Figure 3.1. Map of study area, the Mattheis Research Ranch in Southeastern Alberta, with labelled transects where mortality surveys took place. Seven transects were sampled, excluding the central unlabeled wetland transect that was disturbed by telephone pole construction during sampling.

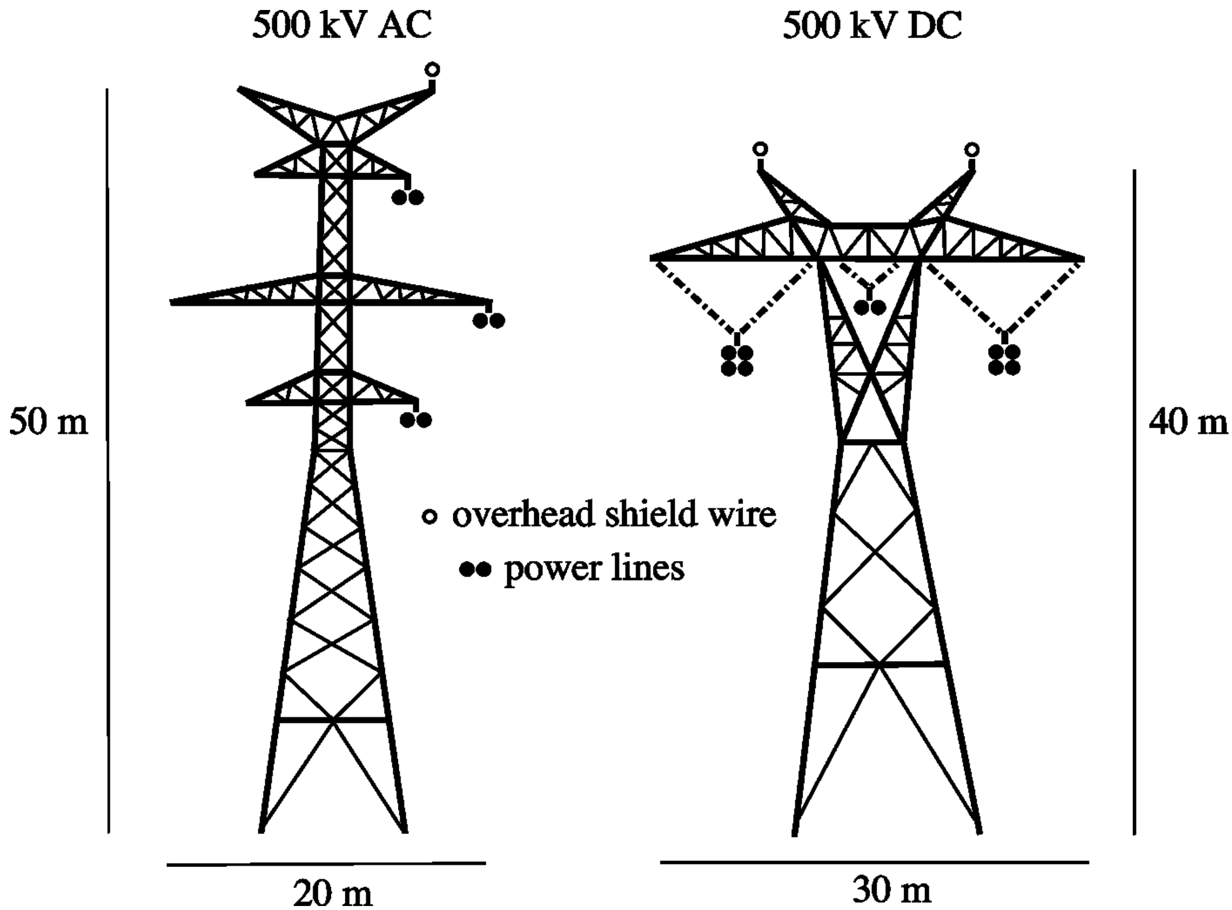

Figure 3.2. Depiction of two high voltage transmission line structures constructed in the study area: alternating current structure on left, direct current structure on right. Height and width measurements are approximate.

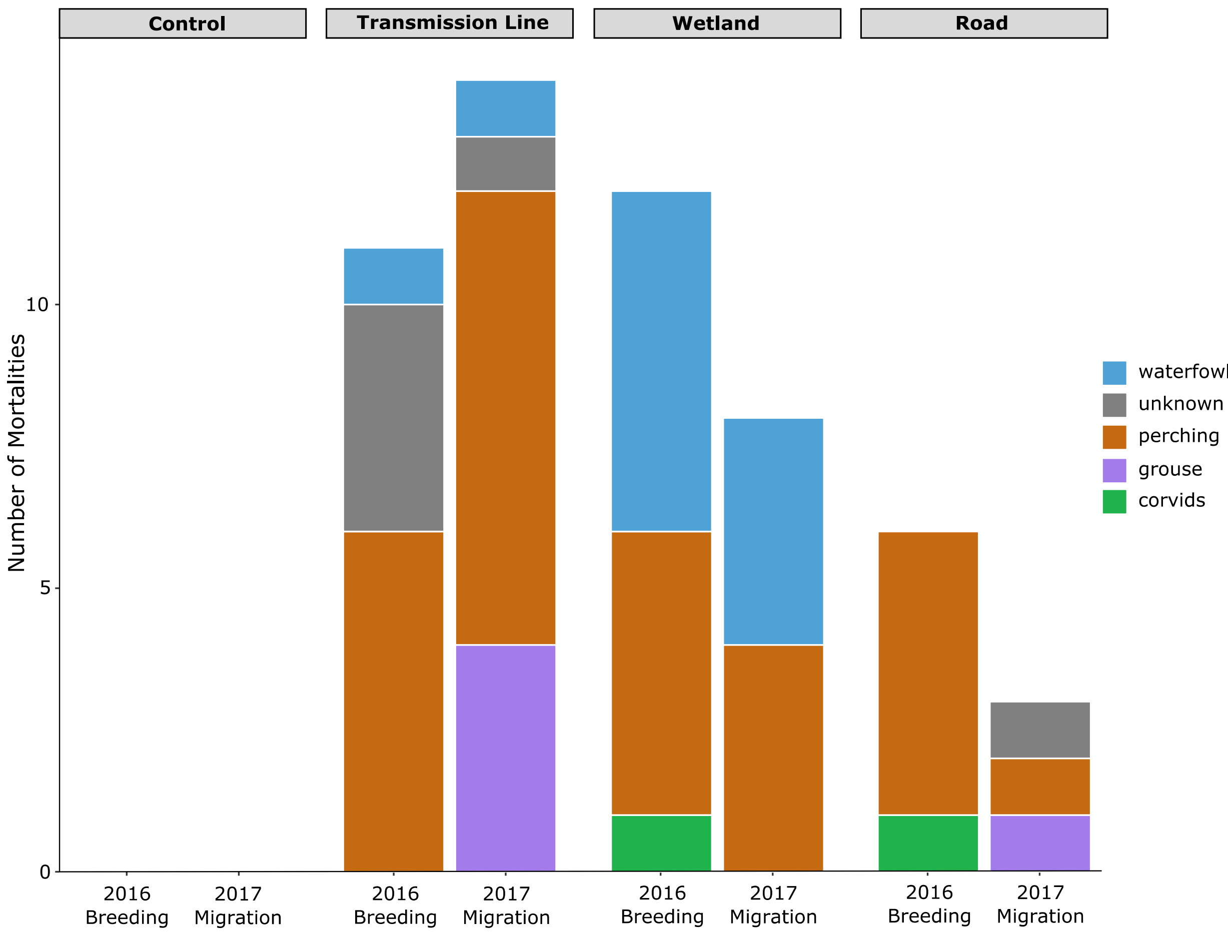

Figure 3.3. Number of mortalities by bird group (see Table B.1 for species) and season. More species were found in transects with transmission lines (with or without wetlands). The greatest number of waterfowl mortalities were found in transects with wetlands under transmission lines. Perching birds represented the majority of mortalities.

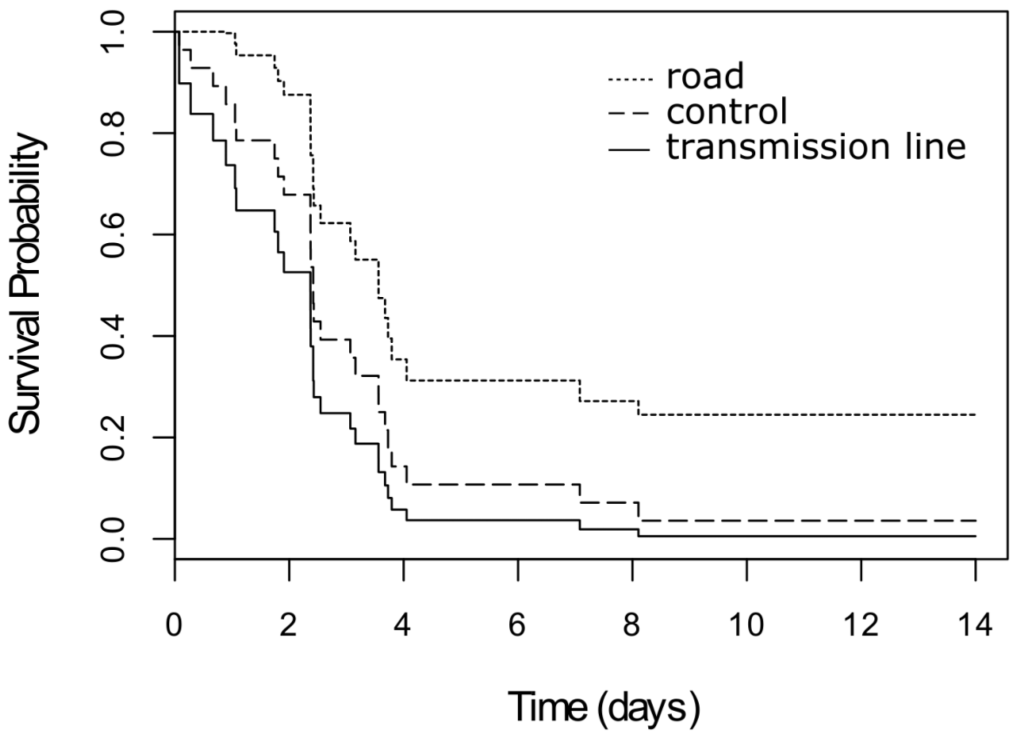

Figure 3.4. Cox hazard non-parametric test depicting the probability of carcass survival over time (days) ($W = 4.82$, $df = 2$, $p = 0.090$). Treatment did not affect carcass survival ($z_{transmission} = -0.539$, $p_{transmission} = 0.590$; $z_{road} = 1.534$, $p_{road} = 0.125$).

Chapter Four: Synthesis

Only 43% of the mixed grass prairie remains in Canada, largely due to conversion of land into agriculture and fragmentation from construction of roads, pipelines, and powerlines. High-voltage transmission lines pose a large risk to grassland birds, one of the most at-risk taxa in Canada, from both displacement and mortality due to collisions with the lines. Populations of many sensitive species in Alberta may decline further with increasing transmission line development.

Indirect effects of high-voltage transmission lines include displacement and increased predation risk. Species richness did not change before and after transmission line construction, but the composition of these species did change. Specifically, there were more species found near roads and these contained more opportunist species, like corvids, that may have been attracted to roadkill. After construction, there were more species found away from transmission lines, suggesting that species, mostly passerines, were avoiding this disturbance. However, individual species responses varied widely suggesting that altered habitat requirements due to construction may be contributing to these changes.

This study was the first to estimate mortality of grassland birds due to collisions with high-voltage transmission lines in the mixed-grass prairies of Canada. There is a large number of potential bird mortalities, especially passerines, which could contribute to further declines of species. I estimated that that 1,368 birds died during the migration season and 1,390 birds died in the breeding season due to collisions with the 27.5 km of transmission lines in the study area. Overall, linear disturbances within the study area, including highways and high-voltage transmission lines, are estimated to contribute to a combined total of 3,282 mortalities (1,631 in migration season and 1,653 in breeding season). There is a potential combined mortality of 333,605 bird mortalities in the mixed-grass prairie each spring.

There is need for better and more widespread mitigation for long-term avi-fauna conservation across existing and newly constructed transmission lines in the Canadian prairies. Most current strategies only focus on wetland species, such as waterfowl, but this study indicates many other bird species are being affected directly and indirectly. Current mitigation strategies may also prove unsuitable for non-waterfowl species, and passerines were found to be killed in greater proportions than previously known. Future transmission line development should consider burying lines to eliminate collision mortalities and reduce displacement due to fragmentation and predation risk. Revegetation of areas disturbed by construction is also important to further reduce displacement.

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Appendix A. Chapter 2.

Table A.1. Common and scientific name, 4-letter species codes, NatureServe rank, and Species at Risk Act (SARA) rank of all avian species found in study area.

Common Name	**Scientific Name**	**Spp. Code**	**NatureServe Rank**	**SARA Rank**
American Avocet	*Recurviostra americana*	AMAV	G5	Not Ranked
American Bittern	*Botaurus lentiginosus*	AMBI	G5	Not Ranked
American Coot	*Fulica americana*	AMCO	G5	Not Ranked
American Crow	*Corvus brachyrhynchos*	AMCR	G5	Not Ranked
American Goldfinch	*Spinus tristis*	AMGO	G5	Not Ranked
American Kestrel	*Falco sparverius*	AMKE	G5	Not Ranked
American Redstart	*Setophaga ruticilla*	AMRE	G5	Not Ranked
American Robin	*Turdus migratorius*	AMRO	G5	Not Ranked
American Wigeon	*Anas americana*	AMWI	G5	Not Ranked
American White Pelican	*Pelecanus erythrorhynchos*	AWPE	G4	Not Ranked
Bald Eagle	*Haliaeetus leucocephalus*	BAEA	G5	Not Ranked
Bank Swallow	*Riparia riparia*	BANKSW	G5	Not Ranked
Baltimore Oriole	*Icterus galbula*	BAOR	G5	Not Ranked
Baird's Sparrow	*Ammodramus bairdii*	BASP	G4	Not Ranked
Barn Swallow	*Hirundo rustica*	BASW	G5	Not Ranked
Black-billed Magpie	*Pica hudsonia*	BBMA	G5	Not Ranked
Black-capped Chickadee	*Poecile atricapillus*	BCCH	G5	Not Ranked
Belted Kingfisher	*Megaceryle alcyon*	BEKI	G5	Not Ranked
Brown-headed Cowbird	*Molothrus ater*	BHCO	G5	Not Ranked
Black Tern	*Chlidonias niger*	BLTE	G4G5	Not Ranked
Black-necked Stilt	*Himantopus mexicanus*	BNST	G5	Not Ranked
Brewer's Blackbird	*Euphagus cyanocephalus*	BRBL	G5	Not Ranked
Brewer's Sparrow	*Spizella breweri*	BRSP	G5	Not Ranked
Brown Thrasher	*Toxostoma rufum*	BRTH	G5	Not Ranked
Bufflehead	*Bucephala albeola*	BUFF	G5	Not Ranked
Blue-winged Teal	*Anas discors*	BWTE	G5	Not Ranked
Canada Goose	*Branta Canadensis*	CAGO	G5	Not Ranked
California Gull	*Larus californicus*	CAGU	G5	Not Ranked
Canvasback	*Aythya valisineria*	CANV	G5	Not Ranked
Clay-coloured Sparrow	*Spizella pallida*	CCSP	G5	Not Ranked
Cedar Waxwing	*Bombycilla cedrorum*	CEDW	G5	Not Ranked
Chipping Sparrow	*Spizella passerina*	CHSP	G5	Not Ranked
Cinnamon Teal	*Anas cyanoptera*	CITE	G5	Not Ranked
Cliff Swallow	*Petrochelidon*	CLSW	G5	Not Ranked

	pyrrhonota			
Common Goldeneye	*Bucephala clangula*	COGO	G5	Not Ranked
Common Grackle	*Quiscalus quiscula*	COGR	G5	Not Ranked
Common Nighthawk	*Chordeiles minor*	CONI	G5	Not Ranked
Common Raven	*Corvus corax*	CORA	G5	Not Ranked
Common Tern	*Sterna hirundo*	COTE	G5	Not Ranked
Common Yellowthroat	*Geothlypis trichas*	COYE	G5	Not Ranked
Eared Grebe	*Podiceps nigricollis*	EAGR	G5	Not Ranked
Eastern Kingbird	*Tyrannus tyrannus*	EAKI	G5	Not Ranked
Franklin's Gull	*Leucophaeus pipixcan*	FRGU	G5	Not Ranked
Gadwall	*Anas strepera*	GADW	G5	Not Ranked
Great Blue Heron	*Ardea herodias*	GBHE	G5	Not Ranked
Great Horned Owl	*Bubo virginianus*	GHOW	G5	Not Ranked
Gray Catbird	*Dumetella carolinensis*	GRCA	G5	Not Ranked
Gray Partridge	*Perdix perdix*	GRPA	G5	Not Ranked
Grasshopper Sparrow	*Ammodramus savannarum*	GRSP	G5	Not Ranked
Green-winged Teal	*Anas carolinensis*	GWTE	G5	Not Ranked
Horned Grebe	*Podiceps auritus*	HOGR	G5	Not Ranked
Horned Lark	*Eremophila alpestris*	HOLA	G5	Not Ranked
House Wren	*Troglodytes aedon*	HOWR	G5	Not Ranked
House Sparrow	*Passer domesticus*	HOSP	G5	Not Ranked
Killdeer	*Charadrius vociferous*	KILL	G5	Not Ranked
Lark Bunting	*Calamospiza melanocorys*	LARB	G5	Not Ranked
Lapland Longspur	*Calcarius lapponicus*	LALO	G5	Not Ranked
Lark Sparrow	*Chondestes grammacus*	LASP	G5	Not Ranked
Long-billed Curlew	*Numenius americanus*	LBCU	G5	Special Concern
Lesser Scaup	*Aythya affinis*	LESC	G5	Not Ranked
LeConte's Sparrow	*Ammodramus leconteii*	LCSP	G5	Not Ranked
Loggerhead Shrike	*Lanius ludovicianus*	LOSH	G4	Special Concern
Marbled Godwit	*Limosa fedoa*	MAGO	G5	Not Ranked
Mallard	*Anas platyrhynchos*	MALL	G5	Not Ranked
Marsh Wren	*Cistothorus palustris*	MAWR	G5	Not Ranked
McCown's Longspur	*Rhynchophanes mccownii*	MCLO	G4	Not Ranked
Merlin	*Falco columbarius*	MERL	G5	Not Ranked
Mourning Dove	*Zenaida macroura*	MODO	G5	Not Ranked
Northern Flicker	*Colaptes auratus*	NOFL	G5	Not Ranked
Northern Harrier	*Circus cyaneus*	NOHA	G5	Not Ranked
Northern Pintail	*Anas acuta*	NOPI	G5	Not Ranked
Northern Shoveler	*Anas clypeata*	NSHO	G5	Not Ranked

Northern Rough-winged Swallow	*Stelgidopteryx serripennis*	NRWS	G5	Not Ranked
Nelson's Sharp-tailed Sparrow	*Ammodramus nelson*	NSTS	G5	Not Ranked
Orange-crowned Warbler	*Vermivora celata*	OCWA	G5	Not Ranked
Pied-billed Grebe	*Podilymbus podiceps*	PBGR	G5	Not Ranked
Pileated Woodpecker	*Hylatomus pileatus*	PIWO	G5	Not Ranked
Ring-billed Gull	*Larus delawarensis*	RBGU	G5	Not Ranked
Red-breasted Nuthatch	*Sitta canadensis*	RBNU	G5	Not Ranked
Redhead	*Aythya Americana*	REDH	G5	Not Ranked
Red-eyed Vireo	*Vireo olivaceus*	REVI	G5	Not Ranked
Red-necked Grebe	*Podiceps grisegena*	RNGR	G5	Not Ranked
Ring-necked Pheasant	*Phasianus colchicus*	RNEP	G5	Not Ranked
Rock Dove	*Columba livia*	RODO	G5	Not Ranked
Rough-legged Hawk	*Buteo lagopus*	RLHA	G5	Not Ranked
Red-tailed Hawk	*Buteo jamaicensis*	RTHA	G5	Not Ranked
Ruddy Duck	*Oxyura jamicensis*	RUDU	G5	Not Ranked
Red-winged Blackbird	*Agelaius phoeniceus*	RWBL	G5	Not Ranked
Savannah Sparrow	*Passerculus sandwichensis*	SAVS	G5	Not Ranked
Say's Phoebe	*Sayornis saya*	SAPH	G5	Not Ranked
Sora	*Porzana Carolina*	SORA	G5	Not Ranked
Song Sparrow	*Melospiza melodia*	SOSP	G5	Not Ranked
Sprague's Pipit	*Anthus spragueii*	SPPI	G3G4	Special Concern
Spotted Sandpiper	*Actitis macularius*	SPSA	G5	Not Ranked
Spotted Towhee	*Pipilo maculatus*	SPTO	G5	Not Ranked
Sharp-tailed Grouse	*Tympanuchus phasianellus*	STGR	G5	Not Ranked
Swainson's Hawk	*Buteo swainsoni*	SWHA	G5	Not Ranked
Tennessee Warbler	*Leiothlypis peregrina*	TEWA	G5	Not Ranked
Tree Swallow	*Tachycineta bicolor*	TRES	G5	Not Ranked
Upland Sandpiper	*Bartramia longicauda*	UPSA	G5	Not Ranked
Vesper Sparrow	*Pooecetes gramineus*	VESP	G5	Not Ranked
Warbling Vireo	*Vireo gilvus*	WAVI	G5	Not Ranked
White-crowned Sparrow	*Zonotrichia leucophrys*	WCSP	G5	Not Ranked
White-throated Sparrow	*Zonotrichia albicollis*	WTSP	G5	Not Ranked
Western Kingbird	*Tyrannus verticalis*	WEKI	G5	Not Ranked
Western Meadowlark	*Sturnella neglecta*	WEME	G5	Not Ranked
Willet	*Tringa semipalmata*	WILL	G5	Not Ranked
Wilson's Phalarope	*Phalaropus tricolor*	WIPH	G5	Not Ranked
Wilson's Snipe	*Gallinago delicata*	WISN	G5	Not Ranked
Yellow-breasted Chat	*Icteria virens*	YBCH	G5	Not Ranked

Yellow Warbler	*Setophaga petechial*	YWAR	G5	Not Ranked
Yellow-headed Blackbird	*Xanthocephalus xanthocephalus*	YHBL	G5	Not Ranked

Table A.2. Plant species found in quadrats used for range health analysis and community data analysis, including scientific name, common name, NatureServe Rank, and whether the species is native or exotic in Alberta.

Scientific Name	Common Name	NatureServe Rank	Native or Exotic
Achillea millefolium	Common yarrow	G5	Native
Agoseris glauca	Pale agoseris, prairie agoseris	G5	Native
Agropyron cristatum	Crested wheatgrass	G5	Exotic
Agropyron dasystachyum	Northern wheatgrass	G5	Native
Agrostis scabra	Tickle hair grass	G5	Native
Androsace occidentalis	Pygmy flower	G5	Native
Antennaria parvifolia	Pussytoes	G5	Native
Arabis drummondii	Rock cress	G5	Native
Arnica fulgens	Foothill arnica	G5	Native
Artemisia cana	Silver sage	G5	Native
Artemisia frigida	Pasture sage	G5	Native
Artemisia ludoviciana	Prairie sage	G5	Native
Astragalus agrestis	Purple milk vetch	G5	Native
Astragalus cicer	Cicer milkvetch	G5	Exotic
Astragalus missouriensis	Missouri milk vetch	G5	Native
Atriplex argentea	Silver saltbush	G5	Native
Avenula hookeri	Hooker's oatgrass	G5	Native
Bouteloua gracilis	Blue gramma	G5	Native
Brassicaceae sp.	Mustard	GNR	Exotic
Bromus inermis	Smooth brome	G5	Exotic
Calamagrostis canadensis	Marsh reedgrass	G5	Native
Calamovilfa longifolia	Sandgrass	G5	Native
Campanula rotundifolia	Harebell	G5	Native
Carex filifolia	Threadleaf sedge	G5	Native
Carex pensylvanica	Pennsylvania sedge	G5	Native
Cerastium arvense	Chickweed	G5	Native
Chamaesyce serpyllifolia	Thyme-leaved spurge	G5	Native
Chamerhodos erecta	Pygmy rose	G5	Native
Chenopodium freemontii	Goosefoot	G5	Native
Chenopodium pratericola	Narrow-leaved goosefoot	G5	Native
Cirsium arvense	Canada thistle	G5	Exotic
Cirsium vulgare	Bull thistle	GNR	Exotic
Commandra umbellata	Bastard toadflax	G5	Native
Conyza canadensis	Horseweed	G5	Native
Crepis tectorum	Narrow-leaved hawksbeard	GNR	Exotic
Dalea candida	White dalea	G5	Native
Dalea purpurea	Purple dalea	G5	Native
Distichlis stricta	Saltgrass	G5	Native
Elaeagnus commutata	Wolf willow	G5	Native
Elymus canadensis	Rye grass	G5	Native

Elymus trachycaulus	Slender wheatgrass	G5	Native
Equisetum laevigatum	Horsetail	G5	Native
Erigeron caespitosus	Tufted fleabane	G5	Native
Erysimum cheiranthoides	Wormseed mustard	G5	Native
Erysimum inconspicuum	Small-flowered rocket	G5	Native
Escobaria vivipara	Pincushion cactus	G5	Native
Festuca idahoensis	Idaho fescue	G5	Native
Gaillardia aristata	Gaillardia	G5	Native
Galium boreale	Northern bedstraw	G5	Native
Gaura coccinea	Scarlet beeblossom	G5	Native
Geum triflorum	Three-flowered avens	G5	Native
Glycyrrhiza lepidota	Wild licorice	G5	Native
Grindelia squarrosa	Gumweed	G5	Native
Guttierezia sarothrae	Broomweed	G5	Native
Hedeoma hispida	Rough pennyroyal	G5	Native
Hedysarum alpinum	American hedysarum	G5	Native
Hesperostipa comata	Needle and thread	G5	Native
Heterotheca villosa	Hairy golden aster	G5	Native
Heuchera richardsonii	Alum-root	G5	Native
Hordeum jubatum	Foxtail barley	G5	Native
Juncus balticus	Baltic rush	G5	Native
Juniperus horizontalis	Creeping juniper	G5	Native
Koeleria macrantha	Junegrass	G5	Native
Krascheninnikovia lanata	Winterfat	G5	Native
Lactuca biennis	Tall blue lettuce	G5	Native
Lactuca serriola	Prickly lettuce	GNR	Exotic
Lepidium densiflorum	Common peppergrass	G5	Native
Liatris punctata	Blazing star	G5	Native
Linum lewisii	Blue flax	G5	Native
Lithospermum incisum	Narrow-leaved puccoon	G5	Native
Lygodesmia juncea	Skeleton-weed	G5	Native
Machaeranthera pinnatifida	Spiny iron plant	G5	Native
Maianthemum stellatum	Star-flowered solomon's seal	G5	Native
Medicago sativa	Alfalfa	GNR	Exotic
Melilotus albus	White sweet clover	GNR	Exotic
Melilotus officinalis	Yellow sweet clover	GNR	Exotic
Muhlenbergia richardsonis	Mat muhly	G5	Native
Oenothera nuttallii	Primrose	G5	Native
Opuntia polyacantha	Prickly pear cactus	G5	Native
Packera cana	Prairie groundsel	G5	Native
Pascopyrum smithii	Western wheatgrass	G5	Native
Penstemon albidus	White beard-tongue	G5	Native
Penstemon gracilis	Lilac-flowered beard-tongue	G5	Native
Phlox hoodii	Moss phlox	G5	Native
Plantago patagonica	Woolly plantain	G5	Native
Poa pratensis	Kentucky bluegrass	G5	Native

Poa secunda	Sandberg bluegrass	G5	Native
Populus tremuloides	Trembling aspen	G5	Native
Potentilla arguta	White cinquefoil	G5	Native
Potentilla pensylvanica	Prairie cinquefoil	G5	Native
Prunus virginiana	Choke cherry	G5	Native
Pseudoroegnia spicata	Bluebunch wheatgrass	G5	Native
Psoralidium lanceolatum	Scurf pea	G5	Native
Pulsatilla patens	Prairie crocus	G5	Native
Ranunculus cymbalaria	Seaside crowfoot	G5	Native
Ranunculus spp.	Buttercups	G5	Native
Ratibida columnifera	Prairie cone flower	G5	Native
Rosa arkansana	Prairie rose	G5	Native
Selaginella densa	Little club moss	G5	Native
Shepherdia argentea	Thorny buffaloberry	G5	Native
Solidago missouriensis	Low goldenrod	G5	Native
Sonchus arvensis	Perennial sow thistle	GNR	Exotic
Sphaeralcea coccinea	Scarlet mallow	G5	Native
Sporobolus cryptandrus	Sand dropseed	G5	Native
Stipa viridula	Green needle grass	G5	Native
Symphoricarpos occidentalis	Buckbrush	G5	Native
Symphyotrichum ciliatum	Rayless aster	G5	Native
Symphyotrichum ericoides	Tufted white prairie aster	G5	Native
Taraxacum officinale	Dandelion	G5	Exotic
Thermopsis rhombifolia	Golden bean, Buffalo bean	G5	Native
Tragopogon dubius	Goatsbeard	GNR	Exotic
Vicia americana	American vetch	G5	Native

Table A.3. Bird species list with naïve and corrected occupancy (Program PRESENCE, out of 168 sites) for pre- and post- transmission line construction. Bolded species indicate focal species used in species-specific analysis.

Species	Pre-Construction		Post-Construction	
	Naïve Occupancy	Corrected Occupancy	Naïve Occupancy	Corrected Occupancy
American avocet	0.030	0.148	0.048	0.233
American bittern	0.000	0.000	0.018	0.187
American crow	0.161	0.342	0.345	0.574
American goldfinch	0.054	0.275	0.024	0.216
American redstart	0.000	0.000	0.018	0.183
American robin	0.077	0.132	0.161	0.365
Baird's sparrow	**0.125**	**0.280**	**0.298**	**0.425**
Baltimore oriole	0.006	0.172	0.000	0.000
Bank swallow	0.000	0.000	0.018	0.234
Barn swallow	0.042	0.347	0.030	0.211
Black-billed magpie	0.179	0.407	0.357	0.465
Black-capped chickadee	0.000	0.000	0.006	0.179
Black-necked stilt	0.012	0.285	0.006	0.215
Brewer's blackbird	**0.333**	**0.982**	**0.298**	**0.636**
Brown thrasher	0.125	0.386	0.149	0.445
Brown-headed cowbird	0.726	0.974	0.774	0.986
Cedar waxwing	0.030	0.236	0.006	0.153
Chipping sparrow	0.030	0.084	0.000	0.000
Clay-colored sparrow	0.738	0.873	0.768	0.926
Cliff swallow	0.036	0.138	0.000	0.000
Common grackle	0.054	0.341	0.083	0.367
Common nighthawk	0.024	0.298	0.006	0.156
Common raven	0.077	0.264	0.060	0.233
Common yellowthroat	0.042	0.239	0.012	0.156
Eastern kingbird	**0.333**	**0.479**	**0.393**	**0.572**
European starling	0.071	0.248	0.006	0.183
Grasshopper sparrow	**0.387**	**0.534**	**0.351**	**0.405**
Gray catbird	0.095	0.384	0.119	0.485
Great-horned owl	0.012	0.331	0.036	0.201
Horned lark	0.077	0.226	0.042	0.082
Killdeer	0.238	0.493	0.482	0.610
Lark bunting	0.006	0.164	0.018	0.246
Lark sparrow	0.024	0.007	0.060	0.102

LeConte sparrow	0.042	0.385	0.006	0.276
Loggerhead shrike	0.077	0.288	0.089	0.326
Long-billed curlew	**0.363**	**0.755**	**0.440**	**0.551**
Marbled godwit	**0.577**	**0.740**	**0.440**	**0.868**
Marsh wren	0.000	0.000	0.024	0.323
McCown's longspur	0.000	0.000	0.006	0.221
Merlin	0.006	0.203	0.012	0.288
Mourning dove	0.048	0.283	0.054	0.350
Nelson's sharp-tailed sparrow	0.006	0.236	0.024	0.385
Northern flicker	0.012	0.327	0.012	0.374
Northern harrier	0.054	0.278	0.077	0.383
Northern rough-winged swallow	0.006	0.340	0.000	0.000
Red-tailed hawk	0.006	0.245	0.018	0.499
Red-winged blackbird	0.369	0.535	0.506	0.770
Ring-necked pheasant	0.524	0.721	0.827	0.966
Rough-legged hawk	0.000	0.000	0.006	0.137
Savannah sparrow	0.804	0.974	0.869	0.988
Sharp-tailed grouse	0.030	0.273	0.089	0.330
Song sparrow	0.012	0.184	0.065	0.122
Sora	0.071	0.254	0.036	0.201
Spotted sandpiper	0.006	0.194	0.006	0.176
Spotted towhee	0.042	0.322	0.125	0.539
Sprague's pipit	0.821	0.972	0.863	0.980
Swainson's hawk	0.024	0.264	0.012	0.166
Tennessee warbler	0.018	0.394	0.006	0.245
Upland sandpiper	0.304	0.694	0.435	0.723
Vesper sparrow	0.833	0.978	0.923	0.983
Warbling vireo	0.006	0.233	0.000	0.000
Western kingbird	0.030	0.284	0.000	0.000
Western meadowlark	1.000	1.000	1.000	1.000
White-crowned sparrow	0.006	0.183	0.000	0.000
White-throated sparrow	0.000	0.000	0.012	0.287
Willet	0.494	0.710	0.470	0.622
Wilson's phalarope	0.131	0.480	0.095	0.285
Wilson's snipe	0.304	0.632	0.369	0.788
Yellow warbler	0.208	0.543	0.196	0.316
Yellow-breasted chat	0.000	0.000	0.006	0.272
Yellow-headed blackbird	0.077	0.220	0.077	0.287

Table A.4. Summary table for various models linking ecological covariates to occupancy of each focal species. Null model, ecological model, disturbance (powerline/road) model with ΔAIC and loglikelihood (LL).

Species	Model	Model covariates	ΔAIC	LL
Baird's sparrow	Null	psi(.),gamma(.),eps(.),p(.)	154.79	643.11
	Ecological null	psi(),gamma(.),eps(.),p(Julian, fence, grazing)	18.37	502.69
	Disturbance	psi(),gamma(road, power),eps(.),p(ecological null)	0.00	482.32
Marbled godwit	Null	psi(.),gamma(.),eps(.)p(.)	18.45	1202.39
	Ecological null	psi(.),gamma(.),eps(.)p(.)	18.45	1202.39
	Disturbance	psi(),gamma(.),eps(road)p()	0.00	1183.94
Long-billed curlew	Null	psi(.),gamma(.),eps(.)p(.)	18.35	1046.12
	Ecological null	psi(vor, grass),gamma(.),eps(.)p(.)	11.65	1037.42
	Disturbance	psi(ecological null),gamma(.), eps(road,power),p(.)	0.00	1023.76
Brewer's blackbird	Null	psi(.),gamma(.),eps(.),p(.)	7.49	814.51
	Ecological null	psi(.),gamma(.),eps(.),p(.)	7.49	814.51
	Disturbance	psi(.),gamma(road,power),eps(.),p(.)	0.00	805.02
Eastern kingbird	Null	psi(.),gamma(.),eps(.),p(.)	62.28	924.28
	Ecological null	psi(tshrub, sshrub, fence, rha),gamma(.),eps(.),p(.)	7.67	863.67
	Disturbance	psi(ecological null),gamma(road, power),eps(.),p(.)	0.00	854.00
Grasshopper sparrow	Null	psi(.),gamma(.),eps(.),p(.)	21.04	486.63
	Ecological null	psi(tshrub, rha),gamma(.),eps(.),p(.)	11.12	474.71
	Disturbance	psi(ecological null),gamma(.),eps(road, power),p(.)	0.00	461.59

Table A.5. Avian species groups used for the RDA analysis. Note that waterbirds (waterfowl, herons, geese, and gulls) were removed from the analysis due to their dependence on water.

Grouse and Pheasants	Perching birds	Shorebirds	Corvids and Blackbirds	Birds of Prey
RNPH	AMGO	AMAV	AMCR	GHOW
STGR	AMRE	BNST	BBMA	MERL
	AMRO	KILL	BHCO	NOHA
	BANKSW	LBCU	BRBL	RLHA
	BAOR	MAGO	COGR	RTHA
	BASP	SORA	CORA	SWHA
	BASW	SPSA	EUST	
	BCCH	UPSA	RWBL	
	BRTH	WILL	YHBL	
	CCSP	WIPH		
	CEWA	WISN		
	CHSP			
	CLSW			
	CONI			
	COYE			
	EAKI			
	GRCA			
	GRSP			
	HOLA			
	LABU			
	LASP			
	LESP			
	LOSH			
	MAWR			
	MCLO			
	MODO			
	NOFL			
	NRSW			
	NSTS			
	SASP			
	SOSP			
	SPPI			
	SPTO			

TEWA
VESP
WAVI
WEKI
WEME
WTSP
YBCH
YEWA

Table A.6. Average precipitation and maximum temperature of the study area during the three years of surveys.

	Year	Average Precipitation (mm)	Average Maximum Temperature (°C)
September	2012	4.64	23.59
	2013	18.51	23.74
	2016	19.26	19.49
October	2012	34.39	8.69
	2013	10.93	12.95
	2016	19.26	9.46
November	2012	17.62	-1.44
	2013	21.10	-1.55
	2016	4.70	9.51
December	2012	15.07	-8.12
	2013	17.11	-8.61
	2016	-2.88	-6.58
January	2012	2.77	0.08
	2013	6.27	-3.90
	2016	15.32	-3.71
February	2012	8.89	1.96
	2013	1.49	0.43
	2016	9.83	4.56
March	2012	11.18	8.51
	2013	10.91	-0.65
	2016	4.05	9.80
April	2012	40.34	13.24
	2013	23.22	8.63
	2016	21.62	16.57
May	2012	52.97	17.98
	2013	51.23	20.70
	2016	68.96	18.86
June	2012	138.10	22.34
	2013	49.74	21.61
	2016	28.19	24.65
July	2012	26.33	27.30
	2013	49.74	24.77
	2016	120.53	25.02

	2012	39.41	27.00
August	2013	12.02	27.27
	2016	35.72	24.24

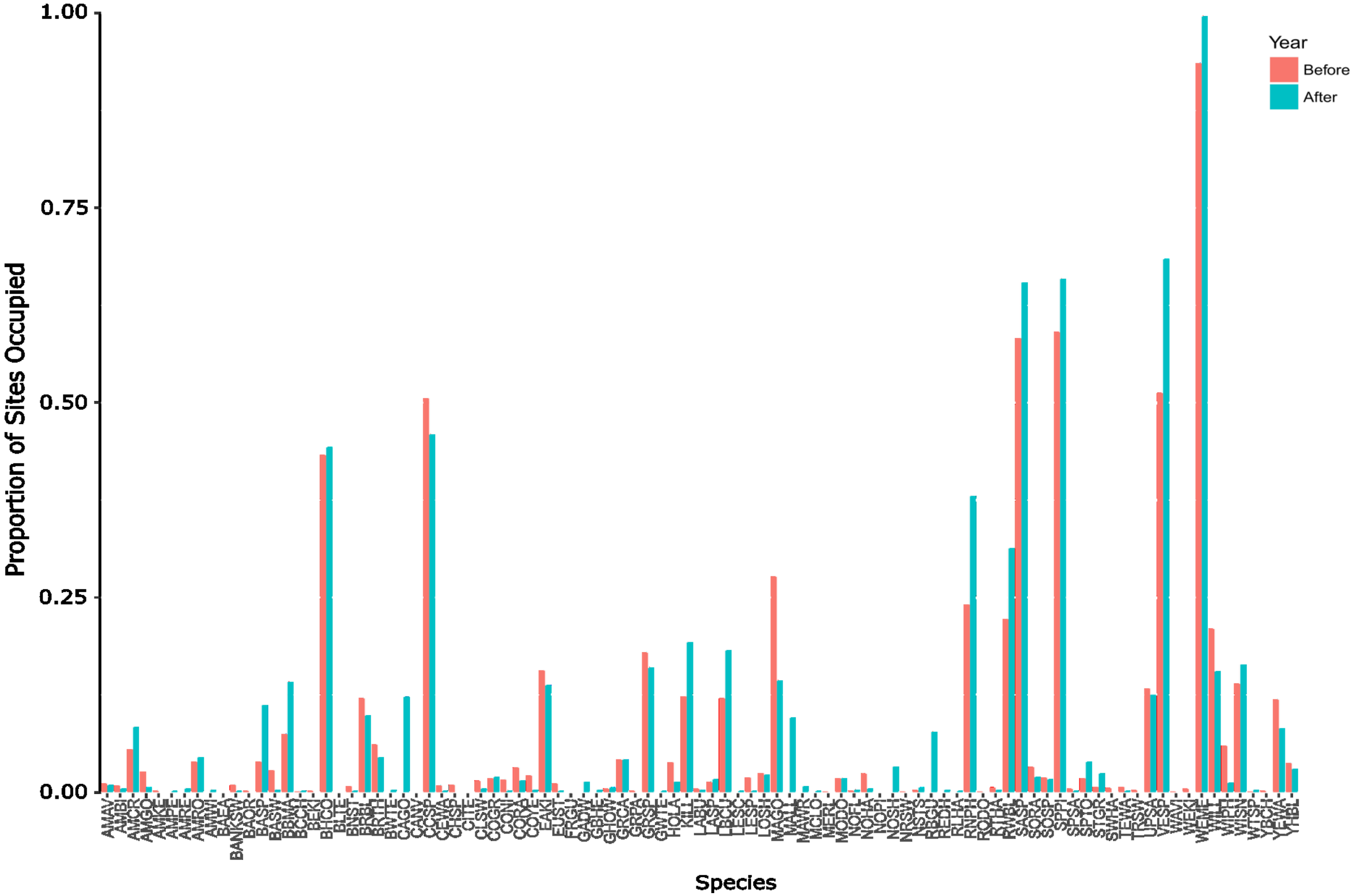

Figure A.1. Proportion of sites each bird species was detected in the study area before and after transmission line construction.

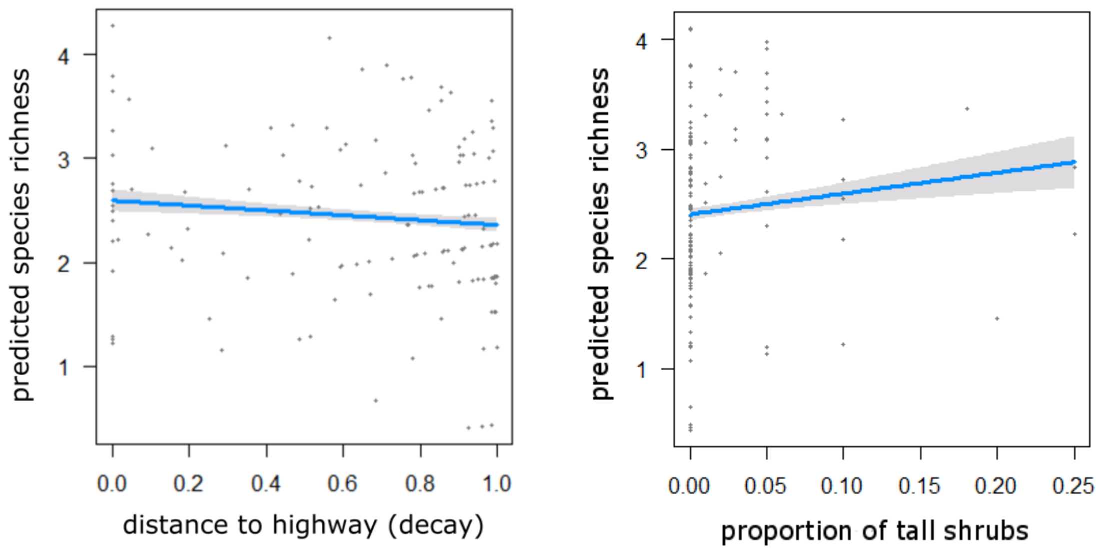

Figure A.2. Species richness prediction curves for GLMM of pre-construction data. There was a greater number of species near highways and with more shrubs.

Appendix B. Chapter 3.

Table B.1. Number of bird mortalities found by transect and species during the 2016 breeding season (May 10 to June 24) and 2017 migration season (March 31 to May 5). Counts in brackets represent the number of mortalities found in transmission line (powerline) transects with a wetland directly underneath the lines.

Transect	Species	Bird Group	2016 Count	2017 Count
Powerline	American coot	waterfowl	0	1
	American robin	perching	0	2
	Brown thrasher	perching	1	0
	Clay-colored sparrow	perching	(1)	0
	Lapland longspur	perching	0	1
	Mallard	waterfowl	(3)	(1)
	Northern shoveler	waterfowl	(3)	(3)
	Orange-crowned warbler	perching	1	0
	Ring-billed gull	waterfowl	1	0
	Red-winged blackbird	corvids	(1)	0
	Savannah sparrow	perching	0	(1)
	Unidentified sparrow	perching	(2)	(1)
	Sharp-tailed grouse	grouse	0	4
	Vesper sparrow	perching	3	0
	Western meadowlark	perching	3(2)	7(2)
	Unknown	unknown	4	1
Powerline Total			23(12)	22(8)
Road	American robin	perching	0	1
	Black-billed magpie	corvids	1	0
	Clay-colored sparrow	perching	1	0
	Eastern kingbird	perching	1	0
	Sharp-tailed grouse	grouse	0	1
	Western meadowlark	perching	3	0
	Unknown	unknown	0	1
Road Total			6	3
Control			0	0
Combined Total			29	25

Table B.2. Overview of values used in equation to estimate mortality caused by transmission lines during the breeding season and spring migration season.

	2016 Breeding	2017 Spring Migration
Length of transmission line in study area (km)	27.5	27.5
Annual mortality rate (deaths/km)	16.43	17.14
Average length of time for carcass scavenging (days)	2.67	2.21
Observer detection (proportion of carcasses detected)	0.64	0.66
Average interval between searches (days)	4.63	3.63
Adjusted annual mortality rate (deaths/km)	50.55	49.74
Annual mortality rate in study area (# deaths/year)	1,390	1,368

Table B.3. Overview of values used in equation to estimate mortality caused by collisions with cars on primary highways in the breeding and spring migration seasons in the study area.

	2016 and 2017 Average
Length of primary highway in study area (km)	10.24
Annual mortality rate (deaths/km)	10.00
Average length of time for carcass scavenging (days)	2.40
Observer detection (proportion of carcasses detected)	0.64
Average interval between searches (days)	3.22
Adjusted annual mortality rate (deaths/km)	25.64
Annual mortality rate in study area (# deaths/year)	525.11

* road length: Canada's National Highway System Annual Report 2015

Appendix C. Chapter 3.

Mortality estimate equations from Erickson et al. (2004)

Observed Number of Carcasses

$\bar{c}$ mean number of carcasses observed per kilometer of transmission line (17.04/km in 2016, 17.78/km in 2017)

Search-Bias Rate

p proportion of trial carcasses detected by observers (0.642 in 2016, 0.655 in 2017)

Estimate of Carcass Removal Rates by Scavengers

$\bar{t}$ is the average length of time a carcass remains at the site before it is removed (2.66 in 2016, 2.21 in 2017)

$\bar{t} = \frac{\sum_{i=1}^{s} t_i}{s - s_c}$, where t_i is removal time of the ith carcass, *s* is number of carcasses used in trial, and s_c is number of carcasses remaining at day 40 of trial (1 carcass remaining after 40 days in 2016, 2 carcasses remaining after 40 days in 2017)

Average Interval Between Searches

I = average interval between searches in days (4.63 in 2016, 3.63 in 2017)

All Bias

$$\hat{\pi} = \frac{\bar{t} \cdot p}{I}\left[\frac{\exp\left(\frac{I}{\bar{t}}\right) - 1}{\exp\left(\frac{I}{\bar{t}}\right) - 1 + p}\right]$$

where *p* is estimated search-bias rate, $\bar{t}$ is the estimated carcass removal time, and *I* is the average interval between searches (approximately 4.63 days in 2016, 3.63 in 2017).

Estimated Mortality Rate

$$m_1 = \frac{\bar{c}}{\hat{\pi}}$$