The Effects of Conventional Oil Wells and Associated Infrastructure on the Abundances of Five Grassland Songbird Species in Alberta's Mixed-grass Prairie

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ABSTRACT

Although grassland bird populations have steadily declined, little research has examined the effect of oil infrastructure on abundances of grassland songbirds. Even less research has identified mechanisms that explain observed effects. To evaluate this, I sampled abundance of 5 songbird species at oil well sites with different pump mechanisms, power sources, and activity levels; I also evaluated the effects of perch and road density and exotic vegetation, all of which are associated with oil development. Both Baird's sparrows (*Ammodramus bairdii*) and Sprague's pipits (*Anthus spragueii*) had lower abundances at all sites that contained oil infrastructure. The other 3 species, chestnut-collared longspurs (*Calcarius ornatus*), western meadowlarks (*Sturnella neglecta*), and Savannah sparrows (*Passerculus sandwichensis*), were relatively unaffected by oil wells, linear features, or exotic vegetation. Given that oil well sites negatively affected two species of concern, more research is needed to determine mitigation strategies.

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This thesis is dedicated to Faith Reierson.

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1. INTRODUCTION

1.1 Background

Over the last 150 years, as much as 70% of the grasslands within the Great Plains of North America have disappeared (Samson et al. 2004). Agriculture was responsible for the majority of the prairies' disappearance (Wiggins 2006), though improper cattle grazing (Plumb and Dodd 1993, Fuhlendorf and Engle 2001) and wildfire control (Brennan and Kuvlesky 2005) have further degraded the remaining grassland of the Great Plains. Of the prairies that remain, the largest continuous tract of grassland lies in Alberta, Canada which retained 43% of its original prairie as of 2013 (Gauthier and Wiken 2003). While much of Alberta's prairie remains, most of it as at risk from economic development, as only 1.29% is federally protected (Government of Canada 2009).

Due to habitat loss and degradation throughout the Great Plains, grassland songbirds have experienced a larger and more geographically extensive decline than any other group of species in North America (Knopf 1992, Murphy 2003). Even though the northern mixed-grass prairie has fared better than other prairie regions, 22 of 25 obligate grassland species had declining population trends in this region (Sauer et al. 2015). The rate of decline varied from species to species, but overall grassland songbird abundance declined 1.1% per year between 1980 and 1999 (Murphy 2003). Comparatively, shrubland songbird species only declined an average of 0.26% per year (Murphey 2003).

Although historically agriculture was the dominant reason for grassland declines, other human disturbances may play a part in the continuing decline of this landscape and its species. One of those disturbances, conventional oil development, has only recently been studied. Models created during the peak of energy development in Alberta predicted that temperate grasslands would be greatly influenced by continuing energy development (McDonald et al. 2009); indeed, the Government of Alberta (2014) estimated that over 1,000,000 ha of Alberta land, encompassing parkland, boreal forest, and grassland ecosystems, has been affected by oil and natural gas extraction. This number has likely grown, as land in Alberta was at one point developed for energy at a rate of 120 ha/day (Government of Alberta 2014), though the rate of growth has slowed as a result of the decline in the price of oil and uncertainty about Alberta's energy production future. All of the oil infrastructure currently in place has the potential to negatively impact endemic grassland songbirds including at least 3 that are considered threatened or at-risk by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC 2016). Despite the rapid expansion and threat to species of concern, few studies have investigated how conventional oil infrastructure may affect abundances of obligate grassland songbirds (Askins et al. 2007). The studies that have occurred had contradictory results (Linnen 2008, Ludlow et al. 2015), leading to uncertainty regarding the effects of oil development, and the reasons for these effects.

1.2 Problem Statement

Studies have already demonstrated negative effects of oil development on forest songbirds (Fleming and Schmiegelow 2003, Bayne et al. 2008) and sage-steppe birds (Riley et al. 2012). Negative effects were seen not only around oil wells, but also in relation to power lines, roads and trails, and pipelines (Sutter et al. 2000, Skiffington and Pittaway 2010, Bayne and Dale 2011, Sliwinski and Koper 2012), all of which may be associated with oil development. Additionally, disturbances to the soil from construction of wells, roads, or pipelines have led to a change in vegetation in those areas (Bergquist et al. 2007, Riley et al. 2012). The linear features and change in vegetation create habitat edges, which may lead to edge effects, defined as the change in species composition or abundance at the edge of 2 vegetation types (Odum and Barrett 1971). To understand how oil development may affect grassland songbirds, I examined the effects of oil wells, associated linear features, and changes in vegetation structure on their abundance.

1.3 Research Questions

1. Does grassland songbird abundance differ at sites with oil infrastructure versus control sites?
2. Does grassland songbird abundance differ at different types of oil well pumps or at oil wells with different power sources?
3. Why does grassland songbird abundance differ at different types of oil wells?

1.4 Objectives

1. To determine effects of different types of oil wells on the relative abundance of grassland songbirds.
2. To determine the effects of oil infrastructure's linear features, such as power lines, fences, and roads, on the relative abundance of grassland songbirds.
3. To determine if the effects of oil infrastructure on abundance of grassland songbirds changes with distance to oil wells or linear features.
4. To determine if the effects of oil wells on grassland songbird abundance is caused by an effect of oil wells on vegetation structure, especially the abundance of exotic vegetation or the presence of perch sites, roads, or noise.

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2. LITERATURE REVIEW

2.1 Declines of grassland songbirds

Of all the birds in North America, grassland bird species have experienced the greatest declines (Herkert et al. 2003, Sauer et al. 2015). Between 1966 and 2013, 22 of 25 grassland bird species declined significantly, while only one species increased (Sauer et al. 2015). Most grassland bird species are declining throughout their range (Askins et al. 2007, Sauer et al. 2015).

Habitat loss is the primary force behind declining grassland bird populations. Hayfields and row-crop agriculture have replaced the majority of native prairie (Knopf 1994), due largely to the government driven settlement of the West (Askins 2007). Although most grassland conversion occurred before 1950, crops continue to displace the prairie (Brown et al. 2005, Doherty et al. 2013). Additionally, habitat is being lost to rural development, which was the fastest growing land use type in the United States (Hansen et al. 2005).

Habitat fragmentation, which is a byproduct of agriculture, associated infrastructure, and exotic species invasion, may further lower grassland songbird abundance (Johnson and Igl 2001, Davis 2004, Koper and Schmiegelow 2006). Fragmentation results in smaller patches of habitat with larger proportions of edge, which may lead to grassland songbirds avoiding these edges due to increased predation (Winter et al. 2000) or brood parasitism (Johnson and Temple 1990) and reduced food availability (Zannette et al. 2000). This may lead to a change in species' abundance or composition; collectively these differences along habitat edges are labeled edge effects.

2.2 The effects of oil infrastructure on greater sage-grouse and sage-steppe and forest songbirds

Though there are few studies on the effects of oil on grassland songbirds, other prairie species' responses to oil infrastructure are better understood. The greater sage-grouse (*Centrocercus urophasianus*) (hereafter, sage-grouse) has been the most frequently studied species in North American prairies in relation to oil and gas development, with nearly all reports finding a negative influence of infrastructure on sage-grouse populations (Riley et al. 2012). Sage-grouse avoided energy development and trails during winter (Carpenter et al. 2010) and the edges created by energy development during spring and summer, nesting away from anthropogenic influences (Aldridge and Boyce 2007). Since sage-grouse have avoided development, this can lead to a sizeable loss of functional habitat in high-density well areas (Carpenter et al. 2010). Other studies found that negative impacts on sage-grouse leks reached from 3.2 km (Walker et al. 2007) to 12 km (Tack 2009) away from oil and gas structures, suggesting that even low density well areas can drastically lower habitat quality. Energy development does not only affect sage-grouse abundance; near natural gas structures, yearling sage-grouse had a lower survival rate and adult grouse experienced lower fecundity (Holloran et al. 2010). Additionally, chick mortality occurred at higher rates near oil and gas infrastructure (Aldridge and Boyce 2007).

Oil infrastructure has also been documented to effect songbirds in forest habitats. Generalist species, which often prefer early successional forests, were frequently found near disturbances caused by energy development, while forest specialists were rarely detected in the same areas (Fleming and Schmiegelow 2003). Ovenbirds (*Seiurus aurocapilla*) were particularly sensitive to energy development and were never detected singing on power lines, pipelines, roads, or well pads (Bayne et al. 2008). Ovenbirds also reacted strongly to noise that is associated with energy development, and were 1.5 times denser in forest with no anthropogenic noise (Bayne et al 2008). Additionally, ovenbirds that set up territories at compressor sites, usually inexperienced males, had a significant decrease in their pairing success (Habib et al.

2006). Overall, 1/3 of the songbird species detected decreased in abundance within 300 m of the noise source (Bayne et al. 2008).

Energy development has also affected sagebrush-steppe passerines. As natural gas and oil well density increased in the Powder River Basin of Wyoming, there was a decline in Brewer's sparrows (*Spizella breweri*), sage sparrows (*Amphispiza belli*), and vesper sparrows (*Pooecetes gramineus*), though the decline in vesper sparrows was insignificant (Gilbert and Chalfoun 2011). Abundance of horned larks (*Eremophila alpestris*) increased as well density increased (Gilbert and Chalfoun 2011). Brewer's and sage sparrows also avoided low traffic roads associated with oil (Ingelfinger and Anderson 2004); both species declined 39-60 % within 100 m of roads. This is problematic, as roads are present at high densities in oil fields (Ingelfinger and Anderson 2004).

2.3 Effects of oil and natural gas on grassland passerine abundance

Results from the few studies that have examined the relationship between oil development and grassland passerines have been inconsistent. In one study, Baird's sparrows (*Ammodramus bairdii*), Sprague's pipits (*Anthus spragueii*), and chestnut-collared longspurs (*Calcarius ornatus*) avoided areas within 400 m, 300 m and 100 m, respectively, of conventional oil wells (Linnen 2008). Another showed that individual Sprague's pipit territories decreased in size during pipeline construction, and nest density declined within 100 m of construction areas (Skiffington and Pittaway 2010). More recently, a study looking at the effects of unconventional oil infrastructure found that Savannah sparrows, Sprague's pipits, Baird's sparrows, and chestnut-collared longspurs had lower densities within 228 m and 350 m of wells for the former 2 and 550 m for the latter 2 species (Thompson et al. 2015). However, another study concluded that it was not oil wells per se, but the presence of crested wheatgrass (*Agropyron cristatum*), an exotic species, that determined the Baird's sparrow's and Sprague's pipit's change in abundance around conventional oil wells (Ludlow et al. 2015). The researchers further indicated that western meadowlarks were not affected by oil wells or any variable associated with the wells, and that Savannah sparrow abundance was twice as high near wells.

The known effects of natural gas infrastructure on grassland songbirds are contradictory. In their wintering habitat, grassland songbirds responded negatively to active gas wells (Lawson et al. 2011). In their summer range, the number of Baird's sparrows increased with increasing distance from gas wells, while chestnut-collared longspurs abundance decreased with distance to wells in one study (Great Sand Hills Advisory Committee 2007), and showed no correlation to well density in 2 others (Hamilton et al. 2011, Kalyn Bogard and Davis 2014). Chestnut-collared longspurs, Baird's sparrows, and Sprague's pipits have avoided minimal disturbance gas wells (Linnen 2008). Baird's sparrows and Sprague's pipits have also avoided areas with a high density of gas infill drilling (Dale et al. 2009). However, a recent study found that Sprague's pipits were negatively associated with vegetation disturbed by natural gas extraction, rather than the wells themselves (Hamilton et al. 2011). Conversely, Savannah sparrows (*Passerculus sandwichensis*) were attracted to areas with gas wells (Dale et al. 2009, Hamilton et al. 2011).

2.4 The effects of linear features on grassland passerines

Perches, such as power distribution lines and fences, may be responsible for lowering abundance or deterring grassland songbirds from using nearby habitat. As height of structures increases, there is an increased chance of collision by birds and bats (Mabey and Paul 2007). While power lines and fences are not tall compared to other structures found in energy development, the cumulative impact of perches at a high density could be great (Riley et al. 2012). These structures' threat to birds is not limited to collisions. Brown-headed cowbirds (*Molothrus atar*), a brood parasite, were more abundant closer to perches, perhaps explaining why proximity to perches was a predictor for cowbirds parasitizing Savannah sparrow nests

(Hauber and Russo 2000). Some songbird species have developed mechanisms to allow them to recognize cowbird eggs and either eject the egg or abandon the nest (Klippenstine and Sealy 2008). However, in one study, Sprague's pipits, Baird's sparrows, vesper sparrows, Savannah sparrows, and western meadowlarks (*Sturnella neglecta*) accepted all or nearly all cowbird eggs (Klippenstine and Sealy 2008). Since cowbirds parasitized more nests closer to perches and grassland songbirds accepted cowbird eggs, more perches across the landscape could cause grassland bird populations to further decline. Additionally, anthropogenic perches may attract birds of prey such as the American kestrel (Smallwood and Bird 2008) and prairie falcon (Steenhof 2013) that will hunt grassland songbirds.

Gravel and dirt roads, which are heavily associated with oil development, could lead to further declines in abundance of grassland songbirds. Upland songbird richness and diversity increased further from roads (Koper and Schmiegelow 2006). Specifically, Baird's sparrows, Sprague's pipits, and chestnut-collared longspurs were 1.3-2.1 times more abundant on 2-tracks when compared to roads (Sutter et al. 2000). Low traffic dirt roads also affected sagebrush obligates, with densities of Brewer's sparrow and sage sparrow decreasing 39-60% within 100 m of the roads (Ingelfinger and Anderson 2004). Increased mortality along roads potentially drives this decrease in abundance (Trombulak and Frissell 2000). Hatch-year birds were killed often on roads, which was likely due to them foraging on grassy roadsides (Lloyd et al. 2009). Road kills, which were seen most often during the breeding season, were less frequent on low volume roads compared to large, paved highways (Clevenger et al. 2003). Along with causing mortalities, the noise and movement from traffic may discourage songbirds from using roadside habitat (Reijnen et al. 1996).

An overarching problem with oil infrastructure, such as power lines, fences, and roads, is the potential for edge effects. Sprague's pipits, Baird's sparrows, chestnut-collared longspurs, and grasshopper sparrows (*Ammodramus savannarum*) were all more likely to be found in larger pastures (Davis 2004, Ribic et al. 2009). However, an edge-to-area model was a better fit for explaining the results of one study rather than patch size alone, which suggested that species were avoiding areas with more edge (Davis 2004). Sprague's pipits were particularly area sensitive (Dale et al. 2009) and chestnut-collared longspurs and western meadowlarks had lower densities closer to edges (Koper and Schmiegelow 2006a). While specialist species generally reacted negatively to edge, generalists such as the brown-headed cowbird reacted positively (Davis 2004).

2.5 The effects of disturbance on the vegetation community

Energy development can potentially affect songbirds indirectly by changing vegetation composition and structure. Surface soil disturbances are associated with introducing invasive weeds into new areas, which may then outcompete native vegetation (Nasen et al. 2011, Riley et al. 2012). Closer to well pads and pipelines there can be an increase in nonnative species richness and a lower number and cover of native species (Berquist et al. 2007, Nasen et al. 2011, Koper et al. 2014). Nasen et al. (2011) noted that areas around oil and gas structures had lower occurrences of litter, biocrust, and forb cover, and a lower diversity of 'desirable' grassland plants compared to control sites. The combination of low biocrust, litter cover, and native diversity, and a higher density of invasive plant species led to areas close to structures scoring comparatively low for grassland health (Nasen et al. 2011). Low quality grasslands were seen near wells that ranged in age from wells that were constructed 50 years ago to wells constructed as recently as 2006, demonstrating that these impacts on vegetation are persistent (Nasen et al.

2011). However, another study (Koper et al. 2014) noted that while effects of well construction likely explain some changes in vegetation around well pads, cattle activity around wells, due to cattle's neophilia and attraction to rub posts, may further change vegetation structure.

Disturbances may also change properties of the soil. Disturbed soils have had significantly higher electrical activity and sulfate levels, while having decreased arysulfatase and dehydrogenase (Rowell and Florence 1993). Disturbed soils may also have a significant increase in soil salinity (Berquist et al. 2007). These factors lead to less nutrient availability and microbial activity, which creates poor growing conditions for plants (Rowell and Florence 1993).

Roads, which are heavily associated with oil development, are a primary source of exotic vegetation (Gelbard and Harrison 2003). Improved roads (usually gravel) had higher invasive vegetation within 50 m (Gelbard and Belnap 2003) and 100 m of the road (Tyser and Worley 1992, Berquist et al. 2007). Areas around secondary roads, which include 2-tracks and graded dirt roads, generally had higher native species richness than areas near paved roads (Gelbard and Belnap 2003), although graded roads also had an increase in invasive species up to 100 m from them (Tyser and Worley 1992). In general, areas without roads and major disturbances were less likely to contain exotics, as intact grasslands are more resistant to nonnative species (Gelbard and Harrison 2005).

2.6 The effects of changing vegetation structure on grassland passerines

When exotic species invade native grasslands, it often reduces habitat quality for grassland obligate passerines to the point where birds avoid areas with high exotic plant density (COSEWIC 2016). Species like Japanese brome (*Bromus japonicas*) can cause a decrease in above and below ground biomass, along with increased surface litter (Ogle et al. 2003). These types of structural changes in vegetation are a likely cause of habitat degradation. Baird's sparrows and Sprague's pipits were up to 5 times more abundant in native mixed-grass prairie compared with nonnative grassland (Belcher and Wilson 1989, Davis et al. 2013), and pipit territories rarely contained exotic vegetation (Dale et al. 2009). Savannah and grasshopper sparrows have also reacted negatively to exotic vegetation, as they have used sites with high leafy spurge (*Euphorbia esula*) density less than native grasslands (Scheiman et al. 2003). Chestnut-collared longspurs have used habitats dominated by crested wheatgrass for nesting, but nests in these areas were less likely to succeed and produced smaller chicks (Lloyd et al. 2009)

2.7 Natural history of focal species

Sprague's pipit

Sprague's pipit is a grassland specialist. Sprague's pipits only breed in the Northern prairies (COSEWIC 2010), and choose large, intact grasslands dominated by native cover (Robbins and Dale 1999, Davis et al. 2006, 2013). Sprague's pipits are most common where there is moderate litter depth and medium grass height and density (Robbins and Dale 1999). Due to this vegetation preference, Sprague's pipits avoided heavily grazed grasslands (Robbins and Dale 1999). Sprague's pipits also preferred low abundance of forbs (Davis 2004) and tall shrubs (Robbins and Dale 1999, Grant et al. 2004). For nesting, Sprague' pipits may avoid areas with bare ground, instead choosing areas with high density of dead vegetation close to the ground (Davis 2005).

Sprague's pipits are currently threatened in Canada (Government of Canada 2009). The pipit has declined over its entire range (Sauer et al. 2015) at a rate of 3.6% per year (Samson and Knopf 1994). Sprague's pipits were particularly sensitive to presence of exotic species (Davis et al. 2013), especially smooth brome (*Bromus inermis*) and crested wheat grass (Robbins and Dale 1999). Sprague's pipits are also thought to be edge sensitive, in part because their territories rarely cross 2-tracks roads (Dale et al. 2009), and minimal disturbance gas wells may reduce their ability to establish territories (Linnen 2006).

Baird's sparrow

The Baird's sparrow is dependent on intact native prairie (Belcher and Wilson 1989, Madden 1996, Davis et al. 2013). These sparrows prefer large tracts of mixed-grass and fescue prairie (Green et al. 2002). Baird's sparrows are known to avoid tree and tall shrub cover (Davis 2004, Grant et al. 2004) and heavily grazed areas (Green et al 2002). Although Baird's sparrows tend to choose grasslands with native species over those with exotic, they have been found in formerly cultivated lands that support exotic vegetation with similar structure to native prairie (Green et al. 2004). Nesting occurs only in Northern prairies (COSEWIC 2012), usually from late May to late July (Davis and Sealy 1998). Nesting sites generally had high litter cover and a high density of dead vegetation close to the ground (Davis 2005).

Over the last decade, Baird's sparrow abundance has declined 25% across its range in the United States and Canada (Sauer et al. 2015). While the Baird's sparrow is not currently listed by any federal agency, it is an endangered species in Manitoba (Government of Manitoba 2014), and is recognized as at-risk by some non-legally binding rankings such as the Audubon Society watch list (COSEWIC 2012). Alberta, Saskatchewan, and Manitoba currently support upwards of 60% of the remaining breeding population (Sauer et al. 2015). The main threats to Baird's sparrows are habitat destruction, degradation, and fragmentation; interruption of natural fire and grazing processes; and commercial pesticide use (COSEWIC 2012). Other threats include invasion of exotic plants, which contributes to habitat degradation, and brood parasitism by brown-headed cowbirds (Davis and Sealy 1998).

Chestnut-collared longspur

Chestnut-collared longspurs (hereafter, longspurs) are another native grassland specialist (Antsey et al. 1995). Similar to other grassland specialists, longspurs avoided areas with high tree and tall shrub cover (Grant et al. 2004). Longspurs are found in arid, short to mixed-grass prairie that has been recently disturbed, either by cattle or mowing (Hill and Gould 1997). Historically, the chestnut-collared longspur was found at sites that had either been recently burned or grazed by bison (Hill and Gould 1997). Nest sites are generally more exposed than those of other grassland specialists, as longspurs tend to choose sites of sparser vegetation (Davis 2005). Occasionally, longspurs will nest in areas dominated by crested wheatgrass, though always in lower numbers than nearby native grassland (Antsey et al. 1995). One study found that close to half of chestnut-collared longspur nests were adjacent to cow patties (Davis 2005).

The chestnut-collared longspur is classified as endangered in Manitoba (Government of Manitoba 2014) and threatened in Canada (Government of Canada 2009). Longspurs are found in Alberta, Saskatchewan and Manitoba (COSEWIC 2009), and have been declining over their entire range (Sauer et al. 2015). Disruption of natural disturbances, specifically fire and grazing, threaten habitat quality for longspurs (COSEWIC 2009). Road development that is associated with oil infrastructure threatens habitat quality by increasing habitat loss and fragmentation. This loss and fragmentation is especially concerning given that longspurs may be area sensitive (Davis et al. 2006).

Western meadowlark

The western meadowlark is not endemic to the northern grasslands and is more liberal in the vegetation types it uses (Davis and Lanyon 2008). Meadowlarks are most common in native grasslands and lands that have been converted from cropland (Davis and Lanyon 2008), although they can tolerate shrubs of up to a meter tall in some regions (Schwab et al. 2006). Western meadowlarks do not appear to be influenced by grazing or by the species of grazer (Davis and Lanyon 2008). Nesting habitat and territories usually consist of slightly taller and denser vegetation than other grassland songbirds (Madden et al. 2000, Davis 2005), but meadowlarks' density may fall where vegetation is too tall or dense (Davis and Lanyon 2008).

Western meadowlarks have not experienced as steep of a decline as the obligate grassland songbirds, although meadowlarks are still declining over their entire range (Sauer et al. 2015). Meadowlarks have larger territories than most other grassland songbirds, suggesting they may need large tracts of prairie (Davis and Lanyon 2008). Meadowlark density is likely influenced by a patch’s size and shape, which implies that edge effects could influence western meadowlark abundance (Davis et al. 2006).

Savannah sparrow

Savannah sparrows are a generalist species (Wheelwright and Rising 2008). They inhabit a variety of habitats, but prefer grassy meadows, cultivated fields (especially alfalfa), and lightly grazed pastures (Wiens 1969). In general, Savannah sparrows have benefitted from human activity (Wheelwright and Rising 2008), and do not seem to be affected by 2-tracks and exotic vegetation to the same degree as other songbirds (Dale et al. 2009). Nests usually occur in sites with dense ground vegetation, particularly grasses, with moist soils (Wiens 1969).

The Savannah sparrow is not listed by any government as a species of concern, although they have been steadily declining over their entire range (Sauer et al. 2015). Their breeding range includes most of North America, where they are generally associated with grassland habitats (Wheelwright and Rising 2008). Though Savannah sparrows are rather insensitive to exotic vegetation invasion, introduction of leafy spurge can negatively affect their density (Scheiman et al. 2003).

2.8 Literature Cited

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3. CONVENTIONAL OIL WELLS AND RELATED INFRASTRUCTURE HAVE VARIABLE EFFECTS ON 5 SPECIES OF GRASSLAND SONGBIRDS

3.1 Abstract

For many decades, grassland bird populations have steadily declined. This period coincided with significant increases in oil development, yet little research has been done to examine the effects of oil infrastructure on relative abundance of grassland songbirds. Even less research has been done on the reasons why oil infrastructure has an effect, which is important for understanding how we may minimize or mitigate those effects. To evaluate this, we sampled songbird abundance by conducting 800-m abundance transects at 41 sites twice per year in 2013 and 2014 in southern Alberta. In our analyses we compared the abundances of 5 songbird species at oil infrastructure sites with different pump mechanisms, power sources, and activity levels; we also evaluated the effects of perch and road density and exotic vegetation, all of which are positively associated with oil development. Using generalized linear mixed models, we found that abundance of birds varied with species and oil well type. Both Baird's sparrows (*Ammodramus bairdii*) and Sprague's pipits (*Anthus spragueii*) had significantly lower abundances at all sites that contained oil infrastructure. For Baird's sparrow, abundances were two-thirds lower at oil sites versus control sites, while Sprague's pipit abundances averaged one-half lower at oil sites. There was little evidence that noise, human activity, or traffic explained these effects. Because both species avoided most types of infrastructure, there are limited mitigation options. The other 3 species, chestnut-collared longspurs (*Calcarius ornatus*), western meadowlarks (*Sturnella neglecta*), and Savannah sparrows (*Passerculus sandwichensis*) were relatively unaffected by oil wells, linear features, or exotic vegetation. Given that 2 species of concern exhibited a consistently lower abundance at oil well sites, more research is needed to determine possible mitigation strategies.

3.2 Introduction

The prairies of North America were once widespread across 17 states and 5 provinces, but their extent has declined rapidly over the last 150 years, with as little as 30% of prairies remaining within the Great Plains (Samson et al. 2004). The northern mixed-grass prairie has fared the best, as Alberta still retains approximately 43% of its original prairie (Gauthier and Wiken 2003); however, only 1.29% of it is federally protected, leaving the rest at risk of disturbance or conversion (Government of Alberta 2009).

Due to habitat loss and degradation throughout the Great Plains, grassland songbirds have experienced a larger and more geographically extensive decline than birds of any other habitat in North America (Knopf 1992). In the northern mixed-grass prairie, 22 of 25 obligate grassland species have declining population trends (Sauer et al. 2015). The rate of decline varies from species to species, but overall grassland songbird abundance has been declining at a rate of 1.1% per year (Murphy 2003). Since bird guilds can act as indicators of ecological health, the decline in grassland birds is especially concerning (Bradford et al. 1998, O’Connell et al. 2000).

While conversion of native prairie to agriculture is the largest cause of habitat loss and degradation (Wiggins 2006), models have predicted that temperate grasslands will be greatly affected by continuing energy development (McDonald et al. 2009). Since 1900, over 300,000 conventional oil and natural gas wells have been drilled in Alberta (Government of Alberta 2014), many of which are located in the mixed-grass prairie region (Askins et al. 2007). The growing number of structures and associated linear features such as roads, fences, and power lines has the potential to introduce edge, introduce exotic vegetation, and change the landscape in ways that may deter grassland songbirds from using areas they once occupied (Davis 2004, Koper and Schmiegelow 2006, Dale et al. 2009, Ribic et al. 2009). Despite this disturbance, southern Alberta is still occupied by many endemic grassland species, including breeding populations of 3 songbird species that are federally or provincially protected: Sprague's pipit (*Anthus spragueii*), Baird's sparrow (*Ammodramus bairdii*), and chestnut-collared longspur (*Calcarius ornatus*) (SARA 2016).

Energy development may contribute to the decline in abundance of grassland songbirds, though few studies have investigated this (Askins et al. 2007); studies that have been conducted produced contradictory results (Linnen 2008, Ludlow et al. 2015, Thompson et al. 2015). Energy extraction has been documented to negatively affect greater sage-grouse (*Centrocercus urophasianus*), waterfowl, and songbirds from non-grassland habitats (Riley et al. 2012), suggesting that grassland songbirds might also be sensitive. Negative effects on songbird abundances have been observed not only around oil wells, but also in relation to power lines, roads and trails, and pipelines (Sutter et al. 2000, Skiffington and Pittaway 2010, Bayne and Dale 2011, Sliwinski and Koper 2012). More studies on the effects of conventional oil wells and related infrastructure are necessary, given the known effects on other species and the lack of consensus about effects on grassland songbirds.

There are a number of reasons why oil infrastructure might be predicted to affect habitat suitability for grassland birds. Anthropogenic noise may disrupt or mask songbird communication (Habib et al. 2006, Schroeder et al. 2012), and masking may lead songbirds to avoid noisy energy infrastructure (Bayne et al. 2008). Increased human activity includes a rise in traffic, which can increases songbird mortality (Trombulak and Frissell 2000, Ingelfinger and Anderson 2004, Jack et al. 2015). Taller structures may lead to an increase in collision mortalities (Mabey and Paul 2007); in addition, since grassland songbirds generally avoid taller features on the prairie, such as shrubs and trees (Grant et al. 2004, Thompson et al. 2014), they may similarly avoid tall anthropogenic structures. Further, linear features associated with oil infrastructure, including roads, power lines, and fences, may act as perch sites or travel corridors for predators, increasing abundance and foraging efficiency of predators (Frey and Conover 2006, DeGregorio et al. 2014). Disturbances to the soil from construction of this associated development may lead to an increase in exotic vegetation around those areas, which can further hinder songbird populations (Bergquist et al. 2007, Riley et al. 2012). However, it is not known which of these mechanisms explain effects of oil wells on grassland songbirds. Inconsistent observations among previous studies might have resulted from the presence or absence of some of the above mechanisms; thus, understanding which factors are most influential will help us predict which types of energy infrastructure are likely to have the greatest impacts on grassland songbirds.

To investigate which mechanisms are driving changes in abundance at oil sites, we looked at several comparisons between oil structures. We compared between pumpjacks and screwpumps, which allowed us to look at the effects of visual disturbance, as pumpjacks are taller than screwpumps and have larger movements. We also compared grid-powered pumps, which have greater abundances of power-lines and thus perch sites for predators, to generator-powered pumps, which are noisier. Lastly, we analyzed wells by their activity; active wells are noisier, and have more traffic and human activity than inactive wells. Identifying which characteristics associated with oil infrastructure have the most influence on songbird abundance we will be better able to mitigate those effects.

We addressed 3 questions to better understand the effects of conventional oil development on grassland songbirds and how they may be minimized. First, does grassland songbird abundance differ at sites with oil infrastructure versus control sites? This question looked at the difference between abundance at control sites and sites with all types of oil wells.

Second, does grassland songbird abundance differ at different types of oil well pumps, or at oil wells with different power sources? This allowed us to look at effects of different types of infrastructure, to identify which oil extraction methods could minimize ecological effects of wells. Lastly, why does grassland songbird abundance differ between sites? Here, we determined how linear features such as perches and roads, exotic vegetation, and presence of noise, traffic, and human activity contributed to differences in songbird abundance to allow us to identify mechanisms that explain why wells influenced songbirds.

3.2 Methods

3.2.1 Study area

This study took place at 42, 800x800 m sites within 100 km of Brooks, Alberta (50°33’51” N 111°53’56” W). The area around Brooks is primarily comprised of native mixed-grass prairie (Bailey et al. 2010), agriculture lands, and a 66 km^2 manmade lake. This area receives an average of 34.8 cm precipitation annually (Environment Canada 2010). The common native grass species were needle and thread (*Hesperostipa comata*), western wheatgrass (*Pascopyrum smithii*), and Junegrass (*Koeleria macrantha*). Prairie silver sagebrush (*Artemisia cana cana*) and wild rose (*Rosa acicularis*) were the dominant shrub species in the area. To minimize confounding variables we chose sites without paved roads, wetlands, trees, or steep topography. Sites were located on private lands that were predominately native mixed-grass prairie, although exotic vegetation, such as goatsbeard (*Tragopogon dubius*) and crested wheatgrass (*Agropyron cristatum*), were present at sites at low abundances.

Sites

Each site consisted of a quarter section in the center of which we established a 100-m by 800-m area (transect) oriented North-South or East-West, with an oil structure or control point in the center of the transect. We further divided each transect into 8 1-ha blocks. All control sites were at least 800 m away from any oil structures, and the perimeter of sites, whether oil or control, were at least 300-m from other site perimeters. Crested wheatgrass, the most prevalent exotic species in our sites, was detected in 17.5% of our hectare blocks.

Fourteen sites were controls and 28 sites contained an oil structure. Habitat loss at each oil site was minimal; 2% was lost to the oil well pad, 0.5-1.5% was lost to high impact roads, and 0.08-0.6% was lost to low-impact roads (Yoo 2014). Sites were classed according to activity (active/inactive), well type (pumpjack/screw-pump) and power source (grid- or generator-powered). We chose to differentiate oil wells this way because of differences in sound, activity level, availability of perch sites, and/or size of each well class. Although pumpjacks and screwpumps produced noise at similar decibels (averaged 68-69 dB(C); Koper et al. 2016), pumpjacks were taller than screwpumps (7 m in height versus 2-3 m in height) (Figure 1); pumpjacks also moved vertically, with their pump mechanism swinging 2-3 m, while screwpumps have a much smaller mechanism that spins quickly and horizontally. Thus, visual stimuli differed between well types. Grid-powered pumps were in areas with more power lines and roads, and power distribution lines linked grid-powered wells to the provincial power grid; in contrast, distribution lines were absent at generator-powered wells. Conversely, wells with generators were noisier than grid-powered wells (73 dB(C) versus 62 dB(C) at pumpjacks; Rosa et al. 2015). Active wells produced noise and were visited at least once a day, sometimes more (S. Patey LeDrew, Cenovus, personal communication); in contrast, inactive wells were silent, still, produced no emissions, and were rarely visited by vehicles and personnel. All of the oil wells that we used were conventional wells owned and operated by Cenovus Energy Incorporated, and were typical of oil infrastructure in the region.

3.2.2 Field Methods

We gathered bird abundance data by conducting 2 rounds of 800-m by 100-m transect abundance surveys at each site for both 2013 and 2014. We conducted surveys from May 26 until July 1 and in conditions with no sustained winds more than 20 km/h, no precipitation, and little to no fog. We surveyed transects between dawn and 1000 hours. To follow provincial safety regulations and maintain the required minimum distance from infrastructure, observers had to stop an average of 23 m away from the center point of each transect. Two observers sampled each transect per round, one-half of the transect each, over 40 minutes; surveys were started either at the center or perimeter of the site. During transects, we recorded all birds heard or seen within 50 m of the center line (Pacifici et al. 2008, Leston et al. 2015). We recorded observer locations on the transect line, the bird's distance from observer, and the bird's bearing from the observer, to allow us to estimate the location of each bird observed. We then used the 5 most abundant grassland songbird species in our analyses.

At each site, beginning in July, we measured vegetation structure using 24 to 38 1-m^2 plots per site, evenly split between the 2 transects. On each transect, we sampled plots at 1, 5, 10, and 20 m away from the edge of the gravel pad at infrastructure sites, or from the center point at control points. In 2013, we also took vegetation measurements every 50 m, up to 400 m from the center point. In 2014, we sampled vegetation at the 1, 5, 10, and 20-m increments again, and then took measurements at 25-m increments. At all of our sites we measured 7 vegetation structure indices: density, litter depth, maximum vegetation height, and percent basal cover of bare ground, forbs (Fisher and Davis 2010), biocrust (mosses and lichens) (Pipher 2011), and exotic species (Belcher and Wilson 1989, Dale et al. 2009, Davis et al. 2013).

Using a GPS unit (Garmin eTrex 10), we mapped all aboveground anthropogenic features such as roads, power lines, natural gas wells, and fences that were within our sites or within 200 m of the outer boundary of a site. Hereafter, power lines, natural gas wells, and fences are referred to as perches. We defined roads as hard-packed dirt and gravel surfaces. The majority of roads mapped in the study were either county range and township roads or roads required to access oil infrastructure. We did not include grass 2-tracks or trails in this category, as there were relatively few of these at our sites and they were structurally smaller and less distinct compared with larger roads (Sutter et al. 2000). Perch density was calculated as the sum of linear meters of fences, power lines, and natural gas wells within 600 m of the center point of each site. Likewise, road density was the sum of linear meters of road within 600 m of the center point.

3.2.3 Analyses

Detectability

We used unadjusted relative abundance estimates as an index of abundance for our 5 focal species. This choice was made for several reasons: (1) we used an experimental deployment of song playbacks hidden in the grass to determine that noise from wells did not decrease detectability or accuracy in localization of bird songs in this study (Koper et al. 2016); (2) perceptibility of our focal species within 50 m of the observer in this study area was very high ($P > 0.98$; Leston et al. 2015); (3) Henderson and Davis (2014) also demonstrated that unadjusted counts are appropriate for estimating relative abundances of grassland songbirds in the northern mixed-grass prairie; and finally, (4) we did not meet assumptions of distance sampling and removal sampling (Leston et al. 2015), and not meeting these assumptions increases index bias (Marques 2004, Johnson 2008).

Models

We used Program R (R Core Team 2014) for all statistical analyses, and evaluated significance using an alpha value of 0.1 to minimize the risk of a Type II error (Taylor and Gerrodette 1993). We calculated upper and lower 90% confidence intervals for all estimates using the ez package (Lawerence 2013). We used generalized linear mixed models (GLMM) (Bolker et al. 2009) from the lme4 package (Bates et al. 2014) for all models. Except for comparing model fit, we used a frequentist, null hypothesis significance testing approach for all analyses (Mundry 2011).

We modeled the abundance of each of our 5 focal species separately. Prior to running models, we used diagnostic tests such as q-q plots, plots of residuals, and the degrees of freedom/residual deviance ratio to determine the distribution family that best fit our data. We used Poisson distribution for all models besides chestnut-collared longspur analyses, which we analyzed as presence/absence data due to low abundances, and site-scale Savannah sparrow analyses, for which we used a Guassian distribution. We ran models at 2 scales for each question: hectare (to evaluate local effects of distance to infrastructure on birds) and site (to evaluate effects of the presence of infrastructure at the scale of the quarter section, which is the scale at which many management decisions are made).

In preliminary analyses, we found that log (distance) was a better fit (delta AIC > 1.1) than an arithmetic scale for distance; therefore, subsequent models used log (distance to infrastructure). Similarly, log (perch density) and log (road density) fit data better than non-logged measures (delta AIC > 0.7). Preliminary modeling also revealed an outlier in site-scale exotic vegetation. There was no change in significance when we ran the models with and without the outlier, so for conciseness we only show models without this outlier. In preliminary analyses, we ran models both with and without vegetation variables, but there was no change in significance of the oil infrastructure variables, so we did not include the excess vegetation variables in our final models. If interaction terms were not significant, we removed them from the model and ran the model again, to reduce problems with collinearity (Quinn and Keough

2002). For site-scale models, we used the random variable site, and we used both site and hectare ID as the random variable for the hectare-scale models. We used random variables to account for repeated surveys in multiple years. We tested if including random variables resulted in a better fit by running models both with and without random variables and comparing their AIC scores.

Does bird abundance differ at sites with oil infrastructure?

To determine if the presence of oil well structures at the site scale influenced songbird abundance, we modeled abundance as a function of site type (oil well or control). To determine whether abundance of birds was different close to infrastructure, we modeled abundance as a function of site type, log (distance), and site type*log (distance).

Does bird abundance differ at sites with different types of oil infrastructure?

To determine if different types of wells affected songbird abundance differently, we ran 2 models at each scale. The first evaluated effects of power source on abundance, and included control sites and oil wells that were either a generator-powered screwpump or a grid-powered screwpump. Because we had only generator-powered pumpjacks, we did not include pumpjacks in this model. At the site scale, the model had one independent variable, power type, while power type, log (distance), and power type*log (distance) were included in the hectare-scale model.

The second model compared abundance at different well types, and included control sites and oil wells that were either generator-powered screwpumps or generator-powered pumpjacks. Because we did not sample at any grid-powered pumpjacks, grid-powered screwpumps were not included in this model, either. The model for the site scale had one independent variable, well type, while the model at the hectare scale included well type, log (distance), and well type*log (distance).

Why does infrastructure affect abundance?

To determine if the presence of noise or activity influenced songbird abundance at the site scale, we compared abundance at control sites, sites with active oil wells, and sites with inactive oil wells. At the local scale, we modeled songbird abundance with the independent variables activity (on, off, or control), log (distance), and activity*log (distance)

To determine whether the abundance of exotic vegetation, perch density, or road density influenced abundance of birds, we used exotic cover, log (perch density), and log (road density) as independent variables in site scale models. For the hectare scale, we used exotic cover within each 1-ha subsection of the transect, log (perch distance), and log (road distance) as independent variables.

3.4 Results

Does bird abundance differ at sites with oil infrastructure?

At the site scale, Sprague's pipit and Baird's sparrow abundances were nearly 2.5 and 3 times, respectively, greater at control sites compared with sites with oil infrastructure (Table 1; Figure 2i). Abundances of both species increased with distance to infrastructure. Sprague's pipit density was 31% higher 400 m from the center point at sites with oil infrastructure (Figure 2ii) and Baird' sparrow density was over 2 times greater 400 m from the center point at oil sites (Figure 2iii). The other 3 species' abundance did not show a response to the presence of oil wells.

Does bird abundance differ at sites with different types of oil infrastructure?

Sprague's pipits and Baird's sparrows responded similarly to pumpjacks and screwpumps (Figure 3i, Table 1). However, western meadowlark abundance was over 40% greater at screwpump sites compared to pumpjacks and control sites. At the hectare scale, Sprague's pipit density increased by 51% 400 m away from pumpjacks, compared to abundances within 100m of pumpjacks (Figure 4i), while abundance remained low across all distances for screwpumps. Baird's sparrow density increased by 2.2 times 400 m away from pumpjacks and by 1.6 times 400 m away from screwpumps (Figure 4ii). In contrast, abundance of western meadowlark was higher close to screwpumps but not pumpjacks (Figure 4iii). The probability of chestnut-collared longspur presence increased by 2.6 times at pumpjack sites, although there was no effect of screwpumps (Figure 4iv). Savannah sparrows showed no change in abundance relative to either pumpjacks or screwpumps.

Control sites had greater than 2 and 4 times more Sprague's pipits and greater than 3 and 5 times more Baird's sparrows than at generator- and grid-powered well sites, respectively (Figure 3ii, Table 1). Sites with generator-powered wells had nearly 2 times more Sprague's pipits and nearly 3 times more Baird's sparrows than grid-powered wells. Western meadowlark abundance was 60% higher at generator-powered wells compared to grid-powered wells and control sites. Savannah sparrow abundance at grid-powered sites was 40% and 46% higher than at control sites and generator-powered wells. At the hectare scale, Baird's sparrow density increased by 56% over 400 m from generator-powered wells and by 2.8 times from grid-powered wells (Figure 4v). Western meadowlark density was significantly higher near generator-powered but not grid-powered wells (Figure 4vi). Chestnut-collared longspurs showed no change in abundance.

Why does infrastructure affect abundance?

There was no difference in abundance of Sprague's pipits and Baird's sparrows at sites with active compared with inactive wells, suggesting that noise is unlikely to explain the negative effects of wells we detected at the site scale (Figure 5i, Table 1). However, there was some evidence that within 200 m of wells, there was greater avoidance of active than inactive wells for Baird’s (Figure 5ii) and Savannah sparrows (Figure 5iii). Neither western meadowlark nor chestnut-collared longspur abundance nor occurrence changed in response to well activity.

Presence of perch sites and other linear disturbances may explain some negative effects of wells. Total linear meters of perch was negatively correlated with Sprague’s pipit and Baird’s sparrow abundance at the site scale (Figure 6i, Table 1), consistent with our observation that abundance of both species was lower at grid-powered than generator-powered sites (Figure 3ii). Baird’s sparrow and chestnut-collared longspur density were both positively correlated with distance to the nearest perch (Figure 6ii); western meadowlark density was negatively correlated. Similarly, distance to the nearest road was positively correlated with pipit and Baird’s sparrow density (Figure 6iii), while it was negatively correlated with chestnut-collared longspur density. Savannah sparrows were not correlated with availability of perches or roads; western meadowlarks were also not correlated with the latter.

Baird’s sparrow abundance was negatively correlated with percent cover of exotic vegetation within sites (Figure 6iv), whereas abundance of other species was independent of amount of exotic vegetation (Table 1). There was no effect of exotic vegetation on abundance or occurrence of birds at the hectare scale.

3.5 Discussion

Although no two species responded in the same way to different types of oil wells and their corresponding infrastructure, our results found a strong, negative correlation between the presence of oil wells, regardless of pumping mechanism or activity, and the abundances of Sprague’s pipit and Baird’s sparrow. The decline in both species is far more than what we would expect if the lower abundances were due to loss of habitat alone, suggesting that other factors are responsible. There were few differences between effects of pumpjacks and screwpumps, but grid-powered wells had greater impacts than generator-powered wells, despite the fact that grid-powered wells were quieter. Effects on other species were weaker, and included both positive and negative effects. The associated features of oil wells that we examined, including co-occurring roads, perches (power lines, natural gas wells, and fences), and exotic vegetation, had some influence on the abundances of some of our focal species, while noise, traffic, and human activity had little impact, particularly at the site scale. Overall, our results suggest that conventional oil infrastructure negatively impacts the abundances of two federally protected species, and that mitigation strategies should include restricting new oil production to developed areas.

While all types of oil wells negatively impacted Sprague's pipits and Baird's sparrows, occurrence of chestnut-collared longspur, another grassland obligate, was independent of the presence of or distance to wells. The studies by Thompson et al. (2015) and Linnen (2008) are consistent with our Sprague's pipit and Baird's sparrow findings; both noted that these two species avoided areas near wells. However, these studies also found negative effects of oil wells on chestnut-collared longspurs (Linnen 2008, Thompson et al. 2015) and Savannah sparrows (Thompson et al. 2015), whereas we detected no effect on either species. Unconventional oil wells (fracked wells), as studied by Thompson et al. (2015), might have a greater ecological impact than conventional oil wells because additional infrastructure, such as natural gas flares, is often present, and conventional oil wells have a larger footprint. Ludlow et al. (2015) also found a negative effect of oil wells on Sprague's pipits and Baird's sparrows, although they concluded that the lower abundances were due to the high presence of crested wheatgrass (*Agropyron cristatum*) around the oil wells in their study area, rather than the presence of oil wells per se. Because Ludlow et al. (2015) grouped oil and shallow natural gas wells together during analyses, this may have masked the greater effects of oil wells (Daniel 2016). This is because shallow natural gas wells are significantly smaller and quieter than oil wells in this region (Daniel 2016) and shallow gas wells have had mixed effects on grassland birds (Linnen 2006, Dale et al. 2009, Hamilton et al. 2011, Rodgers 2013).

At the site scale, pumpjacks and screwpumps had similarly negative effects; sites with either type of well had lower abundances of Baird's sparrows and Sprague's pipits. Baird's sparrow abundance also increased with increasing distance from both pump types; however, local effects close to wells differed with well type for Sprague's pipits. Abundance of Sprague's pipits increased as distance to pumpjacks increased, whereas their abundances remained low at all distance to screwpumps. This suggests that the negative effect of screwpumps on Sprague's pipit abundance was evident over a longer distance than the negative effect of pumpjacks, which was unexpected given that screwpumps are smaller and their movement seems to be less visually distracting than that of pumpjacks. Although we detected no effect of either type of well on abundance of Savannah sparrows, western meadowlarks and chestnut-collared longspurs responded differently to different pump mechanisms. Western meadowlark abundance was greater at sites with screwpumps than either control or pumpjack sites. Because screwpumps have less dynamic movement than pumpjacks, this may explain why meadowlarks were attracted to the screwpumps, but not pumpjacks. Western meadowlarks have also been more tolerant of human activity than other endemic grassland species, and they routinely use anthropogenic structures to perch (Davis and Lanyon 2008). As western meadowlarks were more abundant closer to perches, this suggests that perch availability may influence territory selection. Chestnut-collared longspurs showed no trend at the site scale, but they did exhibit avoidance of screwpumps at the hectare scale. The mechanism behind this is unclear; as this is the only time that we detected an effect of an oil well on chestnut-collared longspur abundance, it is possible that the result was spurious. Alternatively, there might simply be an avoidance of screwpumps in their immediate vicinity. Our results differ from previous studies, in which chestnut-collared longspurs avoided oil wells, whether conventional (Linnen 2008) or unconventional (Thompson et al. 2015), although a stronger effect was detected at unconventional oil wells. Unconventional wells include more infrastructure, which may account for the differences in that study and our own.

Surprisingly, Sprague's pipit and Baird's sparrow had lower abundances at grid-powered pumps when compared to generator-powered pumps. As grid-powered wells were quieter than wells with a generator, we expected to see lower abundances at the louder pumps, since noisy oil infrastructure has been negatively correlated with songbird abundance in forest habitats (Bayne et al. 2008). Our results instead suggest that noise may only be a minor component of why these species avoided oil wells. However, grid-powered pumps were associated with a higher abundance of power-distribution poles and lines, and both Baird's sparrow and Sprague's pipit had lower abundances at sites that contained larger amounts of anthropogenic perch. This is consistent with previous studies that have shown that these two species may be negatively affected by vertical structures, such as natural gas wells (Dale et al. 2009, Hamilton et al. 2011). Several studies have shown that grassland songbirds have lower abundances near woody vegetation (Robbins and Dale 1999, Davis 2004, Grant et al. 2004, Thompson et al. 2014), and our results suggest they may respond similarly to vertical anthropogenic structures, perhaps to avoid areas of increased predation risk (Grant et al. 2006, Klug et al. 2010) or nest parasitism (Clotfelter 1998, Saunders et al. 2003).

Western meadowlarks and Savannah sparrows responded to generator- and grid-powered wells at both scales. Western meadowlarks were attracted to generator-powered wells at the local scale; this led to higher abundances of western meadowlarks at generator-powered wells at the site scale. Savannah sparrows showed the same trends with grid-powered wells. It is not unexpected that western meadowlarks would have higher abundances at an oil site compared to controls, given their affinity for perching on shrubs (Schwab et al. 2006) and anthropogenic perches (Davis and Lanyon 2008). However, it is unclear why they were attracted to the noisier power type. One possible explanation is that meadowlarks may be avoiding sites with higher abundances of nest predators. Nesting success for grassland songbirds was lower at grid-powered sites used in our study, potentially because distribution lines were used as perch sites by avian predators (Bernath-Plaisted 2016). That Savannah sparrows were attracted to grid-powered wells is not especially surprising, as they are considered a generalist species, use perches when defending territories, and in general have benefitted from human activity (Wheelwright and Rising 2008); it is possible that they were also sensitive to the louder noises produced by generator-powered wells, as they showed some avoidance of active oil wells. Previous studies have also attributed a decrease in bird abundance with noise (Bayne et al. 2008, Blickley et al. 2012). However, because nesting success is lower near grid-powered wells (Bernath-Plaisted 2016), their attraction to those wells may result in ecological traps for Savannah sparrows (Battin 2004).

Surprisingly, noise and human activity do not seem to be major drivers of well avoidance by Sprague’s pipits and Baird’s sparrows. These results suggest that noise, and human activity and traffic around wells, are not primary reasons for these species avoiding oil wells, although they might have additive effects within 200m of wells. Western meadowlarks and chestnut-collared longspurs also showed no change in abundance nor occurrence between active and inactive wells. One study that looked at noisy and quiet energy infrastructure sites in boreal forests found that only 7 of the 23 species studies were negatively affected by noise (Bayne et al. 2008). It is plausible that had we included more species in our analyses, we would have detected species that avoided active well sites.

It is important to note that our results may have been affected by how we looked at noise. We considered a well active or inactive based on its activity when we conducted our transect, but it may have been more accurate to compare how many days over the breeding season a well was active/inactive or more specifically, whether the well was active or inactive when birds were selecting their territory. Unfortunately, this information was unavailable and may be a gap that future studies can examine.

Behavioral responses to linear features may contribute to responses to sites with oil wells. Chestnut-collared longspurs showed no change in occurrence in relation to amount of total linear feet of perch or road at the site scale, although their occurrence did decrease closer to perches. It is well known that chestnut-collared longspurs are intolerant of natural perches such as shrubs (Davis 2004, Henderson and Davis 2014) and unnatural perches such as shallow gas wells (Kalyn Bogard and Davis 2014). Additionally, chestnut-collared longspur occurrence increased closer to roads, which might be due their preference for shorter, sparser vegetation (Hill and Gould 1997, Davis 2005). Conversely, Sprague’s pipit and Baird’s sparrow abundances both decreased closer to roads; this is consistent with previous studies (Sutter et al. 2000, Koper and Schmiegelow 2006), although a more recent study did not detect a relationship between Sprague’s pipits and roads (Sliwinski and Koper 2012). Traffic along roads may discourage songbirds from using roadside habitat (Reijnen et al. 1996); increased mortality along roads may also explain this trend (Trombulak and Frissell 2000, Clevenger et al. 2003, Lloyd et al. 2009).

Baird's sparrow was the only species that had a response to exotic vegetation. At the site scale, there were lower abundances of Baird's sparrows at sites with a higher cover of exotic vegetation, similar to results of earlier studies (Davis and Sealy 1998, Ludlow et al. 2015). However, this trend was not seen at the hectare scale. This suggests that exotic vegetation may have a stronger effect on population distributions than individual territory location. Exotic vegetation, particularly crested wheatgrass, has a well-documented negative effect on Baird's sparrow abundances (Belcher and Wilson 1989, Davis et al. 2013, Ludlow et al. 2015). However, studies have also documented a negative effect of crested wheatgrass on Sprague's pipit (Belcher and Wilson 1989, Davis et al. 2013, Ludlow et al. 2015), and we did not find an effect of exotic vegetation on Sprague's pipits in our analyses. Our sites had relatively low levels of exotic vegetation; crested wheatgrass, the dominant exotic species, only occurred in 17.5% of our hectare blocks. It is possible that if our sites contained more exotic vegetation that we would have been able to detect an effect on other species.

Perhaps unsurprisingly, the mechanism behind why both Baird's sparrows and Sprague's pipits are consistently and negatively affected by oil wells is a combination of factors. Out of the three variables we tested, amount of perch seems to have had the largest and most consistent effect; both species had lower abundances at grid-powered wells compared to generator-powered wells and control sites, and grid-powered wells had more power distribution lines. Distribution lines, along with fences, may have acted as artificial shrubs in this area (Rodgers 2013). While it seems that distribution lines, roads, and exotic vegetation may cumulatively impact Baird's sparrow and Sprague's pipit abundance, additional mechanisms might also be important. Because we detected low abundances of both species even at well sites with low perch density, road density, or abundance of exotic vegetation, it seems likely that these species avoid sites with oil infrastructure due to the physical presence of oil wells, regardless of the presence of co-occurring anthropogenic features. Since two species of conservation concern, responded strongly and negatively to oil wells and their associated infrastructure, it is imperative that managers take action to mitigate these effects.

3.6 Management suggestions

Our results suggest that the most effective way to minimize effects of oil extraction on Sprague's pipits and Baird's sparrows would be to minimize abundance of aboveground infrastructure, particularly anthropogenic perches. Mitigation can include burying power distribution lines, dismantling and reclaiming inoperative oil wells, and horizontally drilling new wells from existing well pads to avoid unnecessary aboveground infrastructure and roads. One study has already provided evidence that grassland songbirds do not react differently to single- and multi-bore well pads at unconventional oil sites (Thompson et al. 2015). However, the ecological benefits of minimizing the surface footprint of infrastructure must be balanced with the increased risk of spills associated with these drilling methods (Watson and Bachu 2009, Alberta Government 2012). Further, while other studies have suggested that noise has a negative impact on songbird abundance (Bayne et al. 2008), our study did not find an effect. Therefore, mitigation of noise by extending the power grid to generator-powered pumps or turning wells off during the breeding season is unlikely to increase abundance.

Future well construction should focus on reducing area and height of infrastructure, area of well pad, and employing on-site power sources. Accounting for the pattern of well sites on the landscape and concentrating well construction may prove invaluable in limiting the fragmentation of songbird habitat. Finally, taking measures to limit the introduction and spread of exotic vegetation species from well sites may also assist in reducing some of the impacts of oil wells on songbirds. Additional research into the specific mechanisms that drive the response of songbirds to oil well sites could provide further information and opportunities to reduce the impacts of oil wells and associated infrastructure.

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4. MANAGEMENT IMPLICATIONS

Energy development is widespread throughout the plains of central North America, where oil and gas infrastructure has already eliminated over 1.4 million hectares of prairie (Allred et al. 2015). This loss of habitat is placing additional stress on an ecosystem that has already lost over 70% of its area (Samson and Knopf 1994, Askins et al. 2007) and whose songbirds are declining at a rate faster than birds of any other habitat (Sauer et al. 2015). As energy development continues to expand, it is imperative that we identify how development affects wildlife.

I analyzed data from fixed-width transects using Generalized Linear Mixed Models (GLMM) to identify the effects of conventional oil wells and related infrastructure on the relative abundance of five species of grassland songbirds in southern Alberta. Savannah sparrows, western meadowlarks, and chestnut-collared longspurs had generally weaker responses to oil wells and associated infrastructure; these responses included negative and positive effects. However, all oil well types consistently had negative effects on abundances of Sprague's pipit and Baird's sparrow, both grassland specialists. Sprague's pipit and Baird's sparrow also responded negatively to linear features that are associated with oil development, including roads, power lines, and fences, and Baird's sparrow avoided exotic vegetation. It is likely that these variables all contribute to lower abundances at oil well sites.

The two species that were negatively impacted are of management concern. Baird's sparrow, though not federally listed, is a COSEWIC-listed species of special concern and considered sensitive in Alberta, while the Sprague's pipit is listed federally as threatened (COSEWIC 2016). From 1966 to 2013, Baird's sparrow and Sprague's pipit had declining annual population trends of -2.65% and -3.87%, respectively, across Canada (Sauer et al. 2015).

Although the lower abundances I observed at oil well sites do not necessarily mean that these species are not reproducing there, a study using the same sites I did found that while grassland songbirds still nested at oil sites, these nests were more likely to fail (Bernath-Plaisted 2016).

From a management and mitigation perspective, the most useful aspect of my study was that I compared between different oil well types. This not only allowed me to determine some of the mechanisms behind why certain songbirds had a negative response to oil wells, but also how government agencies and managers might be able to mitigate these effects by changing certain aspects of oil wells. Since neither Sprague's pipits nor Baird's sparrows showed a difference in abundance between pumpjacks and screwpumps, it would not be practical to replace pumpjacks, an older technology, with screwpumps, even though the latter is smaller and has less dynamic movement. Likewise, as grid-powered pumps had a stronger negative effect on Baird's sparrow and Sprague's pipit, extending the power grid to generator-powered pumps to make well sites quieter would likely further decrease abundances. Alternatively, it seems unlikely that turning grid-powered wells into generator-powered wells would increase abundances, as the higher amount of perch around grid-powered wells (power distribution lines) that may be driving this difference in abundance would still be present. Lastly, because the above species had lower abundances at wells regardless of their activity, trying to reduce the noise produced from oil wells, or simply turning wells off during the breeding season, would not benefit these species.

Given these songbirds' steady decline, concurrent with the rapid expansion of oil development throughout their range, managers must take action to mitigate the affects of oil infrastructure. As neither Sprague's pipit nor Baird's sparrow was less affected by a specific type of oil well pump or activity level compared to control sites, and generator-powered wells were only a minor improvement compared to grid-powered wells, the best option for continued oil development is to drill wells directionally or horizontally from previously existing well pads. Grouping wells this way will also limit the amount of added infrastructure required to service new wells, as few to no new roads or power lines would be necessary at a current oil well site. However, directional and horizontally drilled wells may be at greater risk of leaking (Watson and Bachu 2009). Another option to reduce future habitat loss is to prohibit further oil development. But, since oil development is viewed favorably in the county where my research took place, and the energy sector, along with being the largest employer in Newell County (Government of Canada 2011), also generates nearly double the wealth of the next largest employer (County of Newell 2015), banning oil development is not a realistic solution. Additionally, it is imperative that abandoned and inoperable wells are disassembled and reclaimed in a timely matter. Alberta's current legislation requires that capped, abandoned wells must have all surface equipment, cement, and debris removed within 12 months (Alberta Energy Regulator 2016). However, it seems that energy companies may circumvent this requirement by leaving wells open, and thus wells are not legally considered abandoned. Two of the sites used in our study may be examples of this; they were inoperable during both years of the study, and we never saw evidence that the wells were being maintained in some way (mowing on lease site, visited by Cenovus employees, etc.). Thus, government agencies such as Alberta Energy and the Environmental Protection Agency should re-evaluate and enforce policies that require clean-up of above-ground infrastructure.

The results of my study do not tell the whole story of the impacts of oil development. To accurately understand the effects of oil infrastructure on grassland songbirds' abundance, we need research from throughout the Great Plains, as songbirds' responses to habitat vary from region to region (Johnson and Igl 2001). Along with additional abundance studies, there were several aspects of oil wells that I was not able to include in my study for various reasons, including a lack of funding and resources. These include the effects of oil infrastructure on soil and air quality, insect populations, and predator populations, all of which may contribute to how grassland songbirds respond to oil infrastructure.

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Table 1. Responses of 5 species of grassland songbirds to different oil wells and related infrastructure in southern Alberta, Canada during 2013 and 2014. Beta value indicates how the second variable listed in the "Test" column relates to the first variable. SP = Screwpump PJ = Pumpjack D = distance to center point. *Denotes significance ($p < 0.1$).

	Sprague's Pipit			Baird's Sparrow			Western Meadowlark			Savannah Sparrow			Chestnut-collared Longspur		
Test	**Beta**	**Standard Error**	**P-value**	**Beta**	**Standard Error**	**P-value**	**Beta**	**Standard Error**	**P-value**	**Beta**	**Standard Error**	**P-value**	**Beta**	**Standard Error**	**P-value**
Site Scale															
Control vs. Oil Wells	-0.869	0.196	<0.001*	-1.041	0.227	<0.001*	0.187	0.189	0.321	1.216	1.593	0.45	0.218	1.244	0.861
Control vs. Gen.-powered PJ	-0.619	0.197	0.002*	-0.930	0.219	<0.001*	-0.039	0.215	0.855	-0.126	1.757	0.943	-0.703	2.129	0.741
Control vs. Gen.- powered SP	-0.790	0.268	0.003*	-0.589	0.280	<0.001*	0.507	0.259	0.05*	-0.514	2.294	0.824	3.310	3.121	0.289
Gen.-powered PJ vs. Gen.-powered SP	-0.167	0.256	0.515	0.348	0.319	0.276	0.561	0.288	0.052*	-0.436	2.229	0.847	3.387	2.697	0.209
Control vs. Grid-powered SP	-1.465	0.291	<0.001*	-1.629	0.315	<0.001*	0.297	0.217	0.171	4.803	2.167	0.036*	-0.055	1.503	0.971
Control vs. Generator-powered SP	-0.798	0.301	0.008*	-0.591	0.291	0.043*	0.501	0.234	0.033*	-0.524	2.419	0.830	2.184	1.854	0.239
Grid- vs. Generator-powered SP	0.677	0.386	0.079*	1.095	0.453	0.016*	0.209	0.274	0.445	-5.373	2.718	0.071*	1.632	1.173	0.164
Control vs. Active	-0.922	0.220	<0.001*	0.954	0.258	<0.001*	-0.032	0.214	0.882	-1.473	1.779	0.412	0.440	1.498	0.769
Control vs. Inactive	-0.803	0.194	<0.001*	-1.138	0.250	<0.001*	0.301	0.202	0.136	1.279	1.592	0.428	0.258	1.883	0.891
Active vs. Inactive	0.097	0.181	0.591	-0.165	0.237	0.487	0.275	0.183	0.132	-0.476	1.434	0.741	1.222	1.083	0.260
Total Perch	-0.131	0.058	0.025*	-0.108	0.058	0.059*	0.031	0.056	0.576	0.288	0.434	0.511	-0.272	0.396	0.492
Total Road	-0.174	0.217	0.423	-0.225	0.214	0.295	0.226	0.230	0.281	2.128	1.571	0.184	0.112	1.332	0.933
Exotic Vegetation	-0.018	0.016	0.261	-0.068	0.021	0.001*	-0.002	0.015	0.900	0.099	0.118	0.400	0.019	0.086	0.826
Hectare Scale															
Control*D vs. Oil Wells*D	0.439	0.164	0.007*	0.823	0.222	<0.001*	-0.247	0.298	0.407	0.101	0.152	0.506	0.062	0.515	0.904
Control*D vs. Gen.-powered PJ*D	0.540	0.192	0.005*	0.867	0.279	0.002*	-0.142	0.345	0.967	-0.024	0.109	0.826	1.368	0.691	0.048*
Control*D vs. Gen.-powered SP*D	0.400	0.283	0.164	0.659	0.342	0.054*	-1.082	0.403	0.007*	0.164	0.150	0.273	-0.451	0.657	0.492
Gen.-powered PJ*D vs. Gen.-powered SP*D	-0.145	0.306	0.635	-0.222	0.412	0.590	-1.066	0.392	0.007*	0.188	0.155	0.227	-1.890	0.799	0.018*
Control*D vs. Grid-powered SP*D	0.124	0.314	0.694	0.650	0.342	0.534*	-1.075	0.403	0.008*	0.157	0.141	0.268	-0.434	0.602	0.470
Control*D vs. Generator-powered*D	0.394	0.283	0.163	1.000	0.478	0.037*	0.193	0.387	0.619	0.163	0.110	0.140	-1.117	0.685	0.103
Gen-powered SP*D vs Grid-powered SP*D	-0.271	0.393	0.491	0.368	0.608	0.545	1.269	0.422	0.003*	0.006	0.147	0.965	-0.676	0.730	0.355
Control*D vs. Active*D	1.408	0.567	0.013*	1.343	0.316	<0.001*	0.014	0.356	0.969	0.224	0.104	0.032*	0.176	0.552	0.750
Control*D vs. Inactive*D	0.383	0.194	0.048*	0.414	0.266	0.120	-0.411	0.330	0.214	-0.053	0.101	0.598	-0.034	0.574	0.953
Inactive*D vs. Active*D	0.133	0.249	0.594	0.929	0.365	0.011*	0.420	0.327	0.199	0.279	0.102	0.006*	0.211	0.568	0.711
Distance to Perch	0.098	0.072	0.173	0.239	0.095	0.012*	-0.170	0.086	0.048*	-0.044	0.032	0.164	0.295	0.176	0.093*
Distance to Road	0.233	0.063	<0.001*	0.229	0.085	0.007*	-0.014	0.081	0.867	0.038	0.031	0.207	-0.433	0.182	0.017*
Exotic Vegetation	-0.005	0.005	0.322	-0.008	0.008	0.307	0.000	0.005	0.979	0.001	0.002	0.703	-0.012	0.013	0.373

Figure 1. A typical pumpjack (i) and screwpump (ii) from our conventional oil well sites in southern Alberta. Photos were taken in 2013.

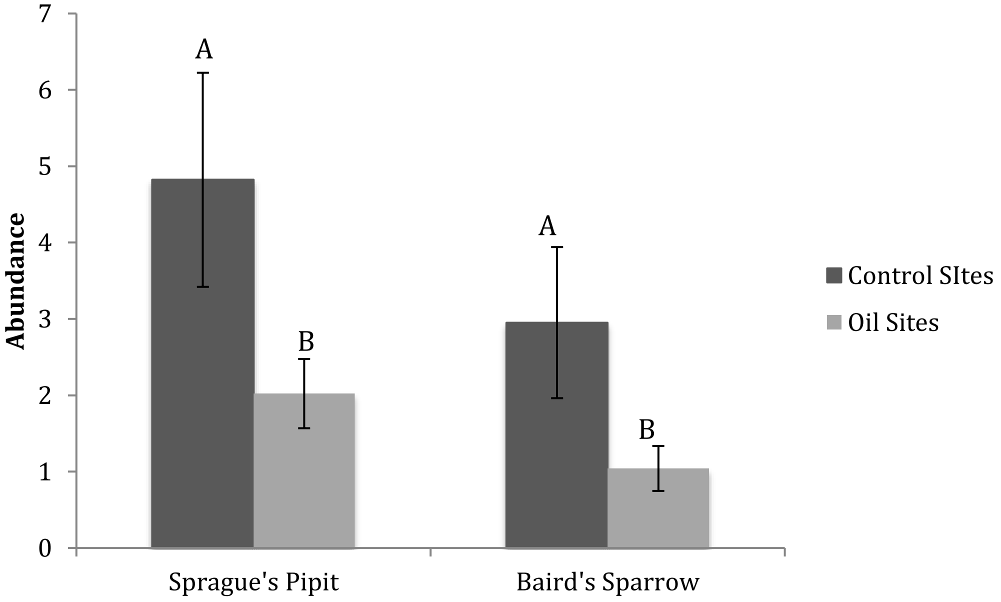
i) Pumpjack

ii) Screwpump

Photos by H. Nenninger

Figure 2. Effects of the presence of oil wells on Sprague's pipit and Baird's sparrow abundance at i) site scale and ii) - iii) hectare scale in southern Alberta from 2013-2014. Within a species, statistical significance is denoted by different letters (column A is significantly different than column B). There were no significant effects of oil wells or distance to oil wells on abundances of chestnut-collared longspurs, western meadowlarks, or Savannah sparrows. Error bars and dashed lines denote 90% confidence intervals.

i)



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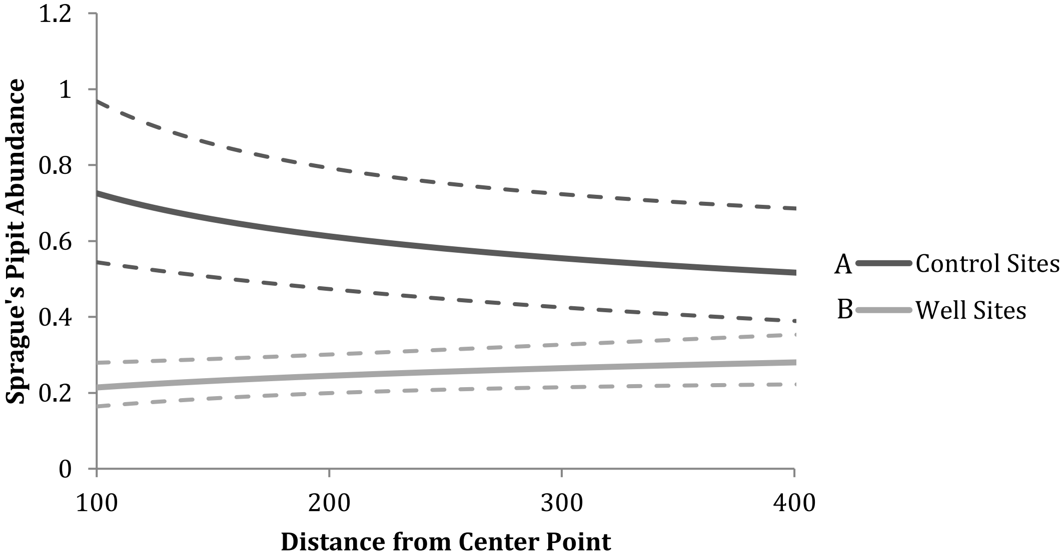

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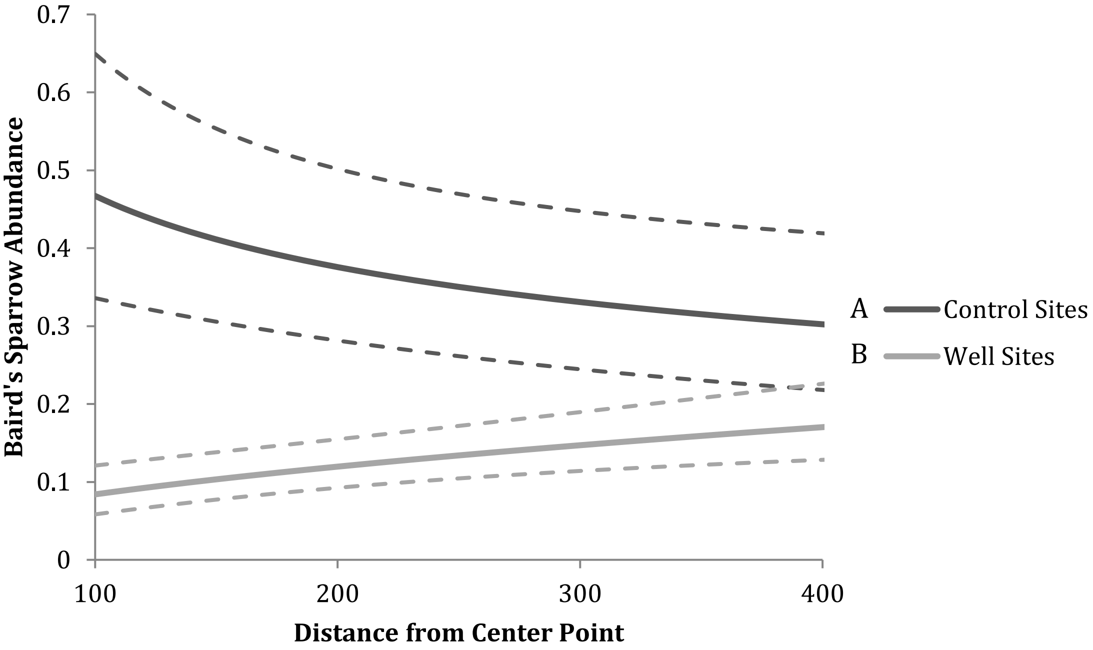
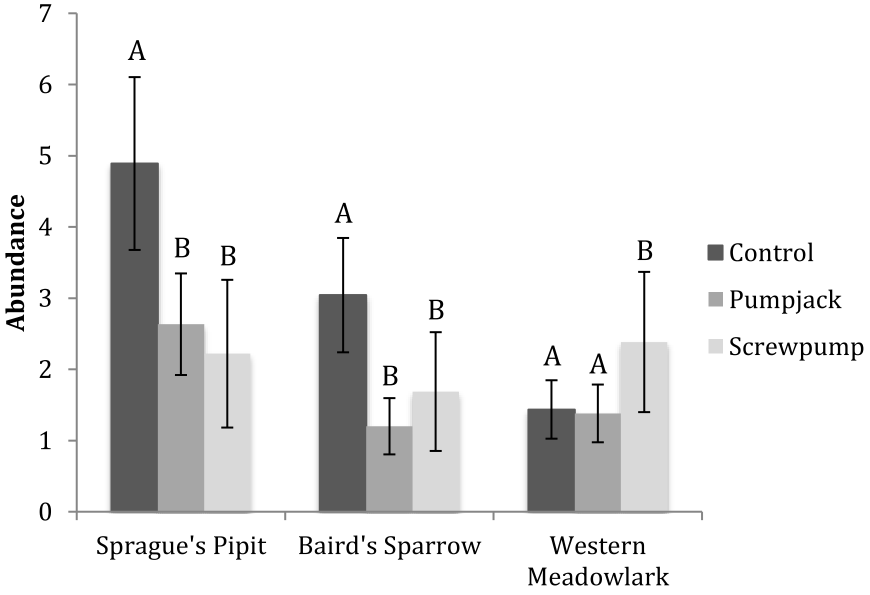

0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Baird's Sparrow Abundance
100
200
300
400
Distance from Center Point
A
Control Sites
B
Well Sites

Figure 3. Effects of different types of oil infrastructure on Sprague's pipit, Baird's sparrow, western meadowlark, and Savannah sparrow abundance in southern Alberta from 2013-2014. i) Effects of different oil pump types (pumpjacks or screwpumps) at the site scale. ii) Effects of different power sources (propane generator or electric grid) at oil wells at the site scale. Statistical significance is denoted by different letters. Error bars denote 90% confidence intervals. There were no significant effects of pumpjacks or screwpumps on chestnut-collared longspurs or Savannah sparrows, and no significant effects of grid- or generator-powered pumps on chestnut-collared longspurs.

i)



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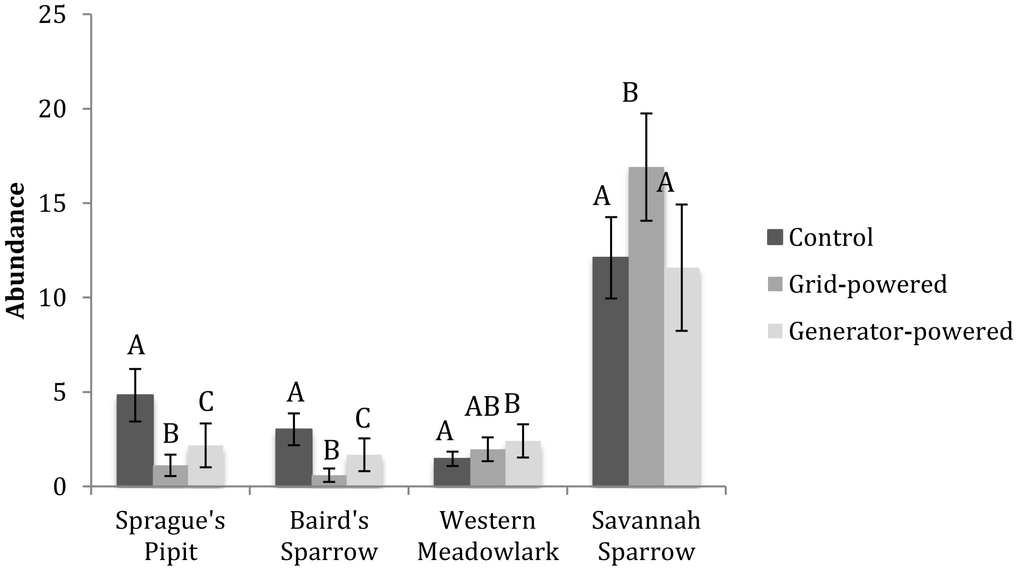
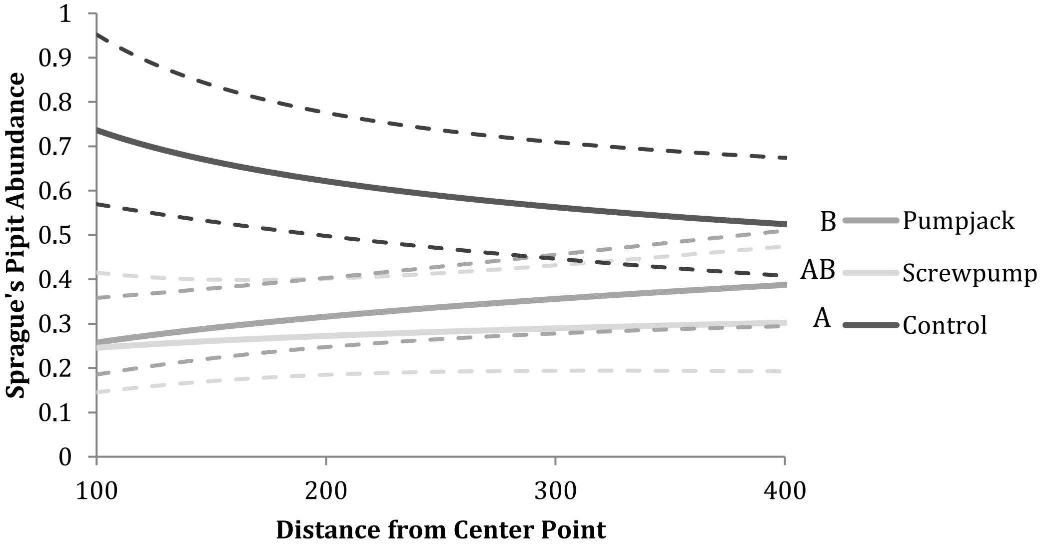


Figure 4. Effects of different types of oil infrastructure on Sprague's pipit, Baird's sparrow, western meadowlark, and chestnut-collared longspur distribution in southern Alberta from 2013-2014. i)-iv) Effects of distance to different oil pump types (pumpjack or screwpump). v)-vi) Effects of distance to different power sources (propane generator or electric grid) at oil wells. Statistical significance is denoted by different letters. Dashed lines represent 90% confidence intervals. There were no significant effects of distance to pumpjacks or screwpumps on Savannah sparrows, and no significant effects of distance to grid- or generator-powered pumps on Sprague's pipits, chestnut-collared longspurs, or western meadowlarks.

i)



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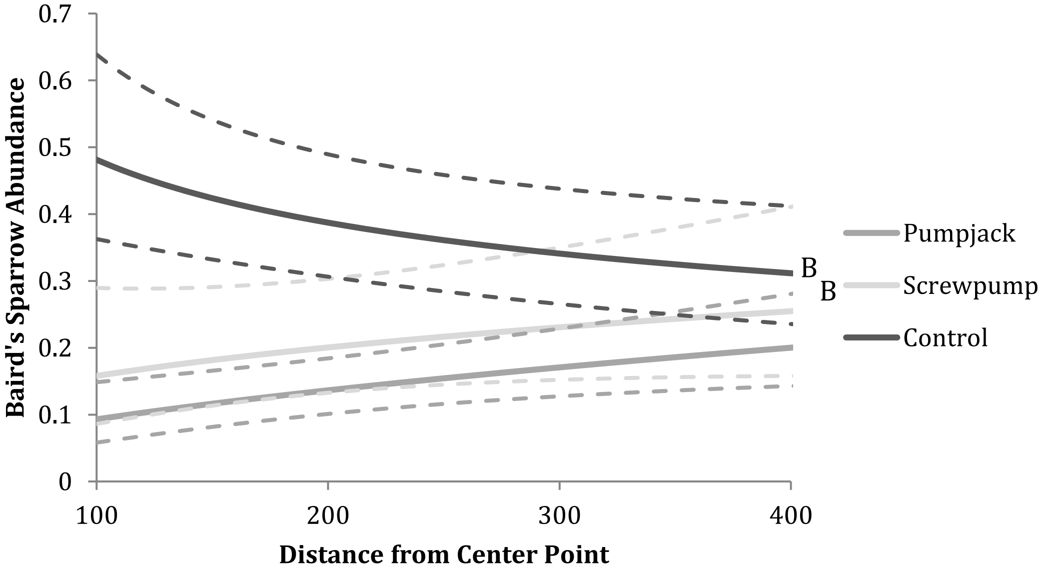

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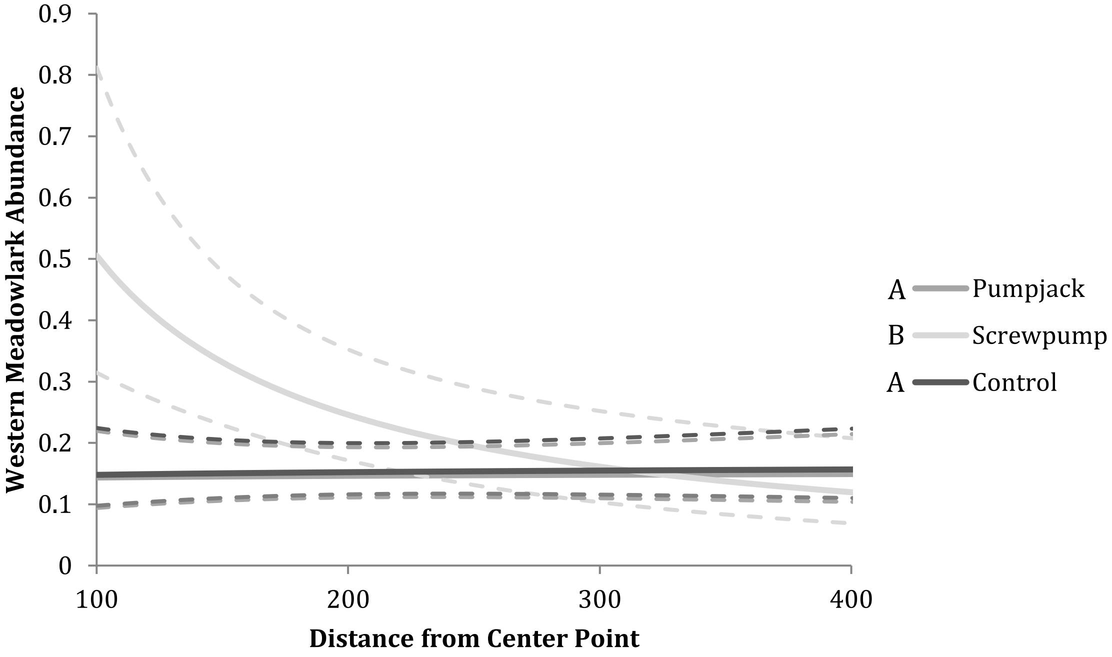
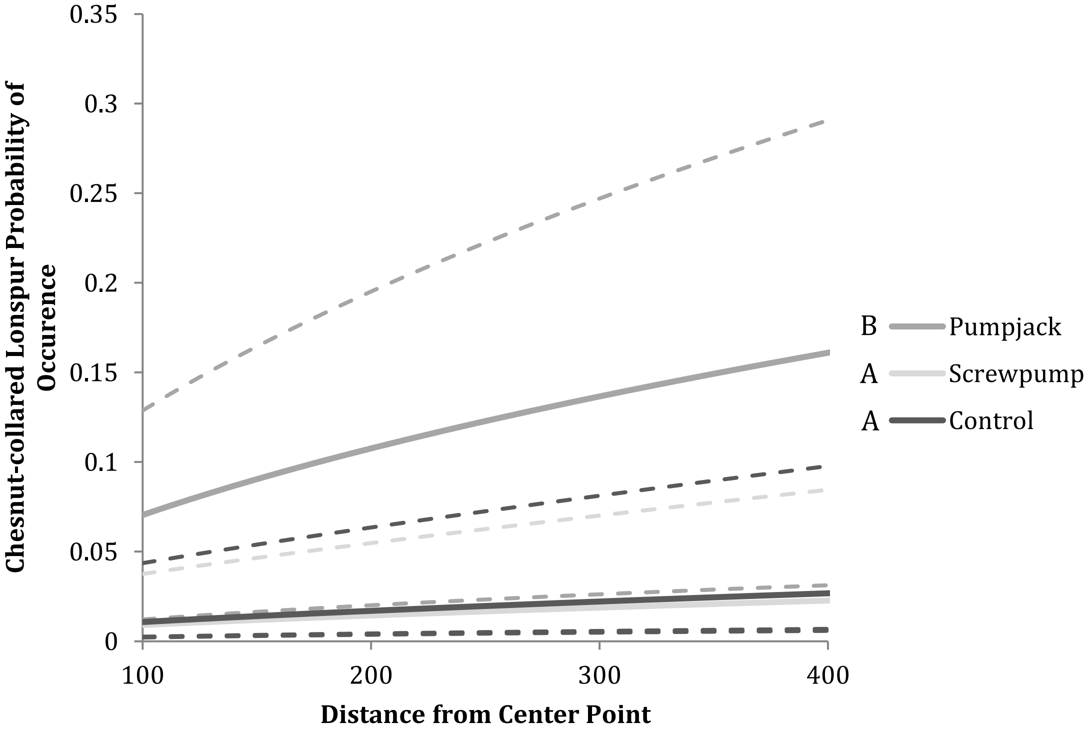
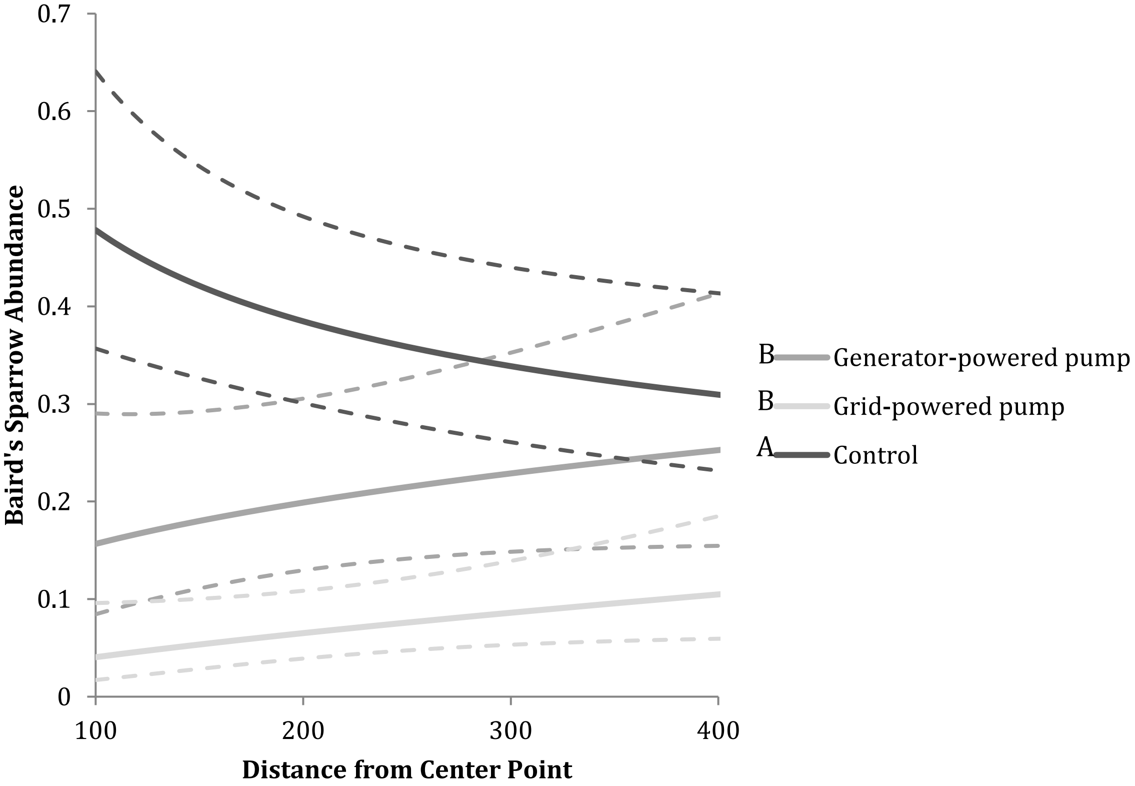

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Western Meadowlark Abundance
100
200
300
400
Distance from Center Point
A Pumpjack
B Screwpump
A Control

iv)


0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
Chesnut-collared Lonspur Probability of Occurence
100
200
300
400
Distance from Center Point
B Pumpjack
A Screwpump
A Control

v)


0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Baird's Sparrow Abundance
100
200
300
400
Distance from Center Point
B Generator-powered pump
B Grid-powered pump
A Control

vi)

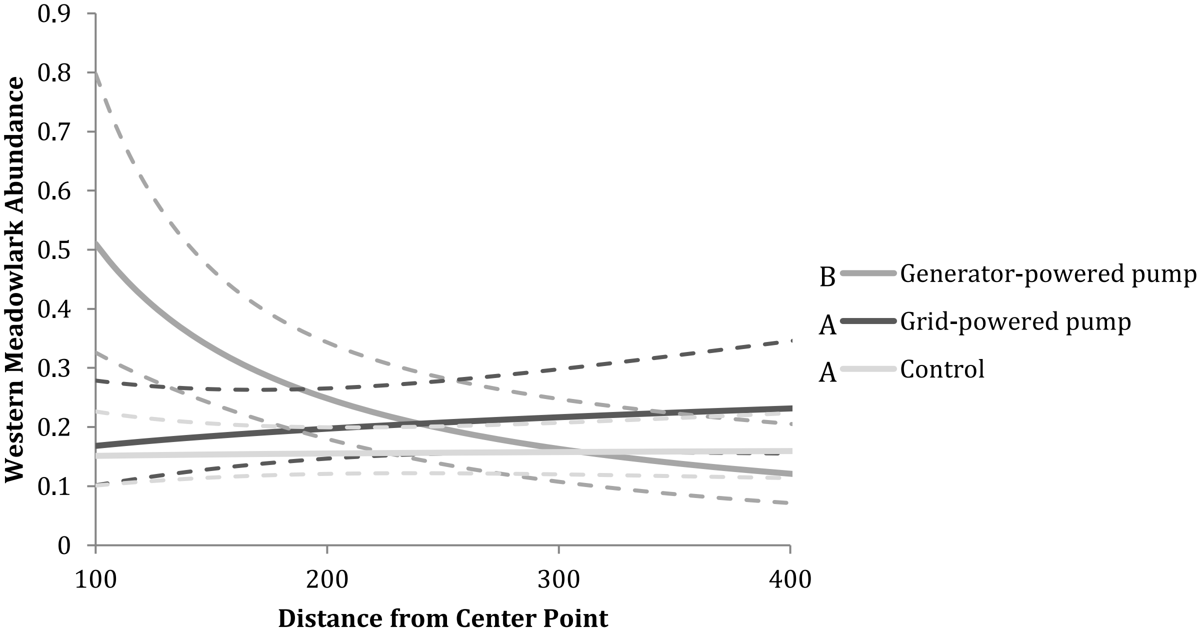
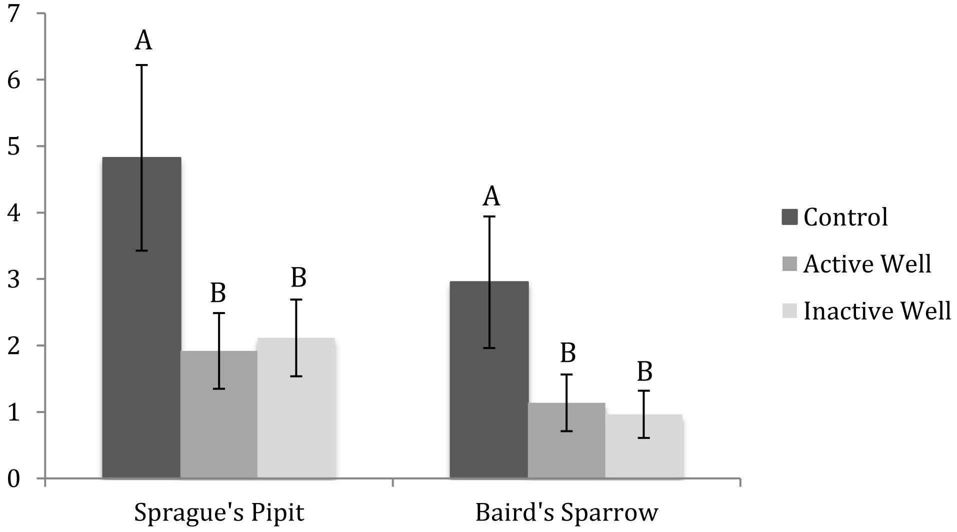
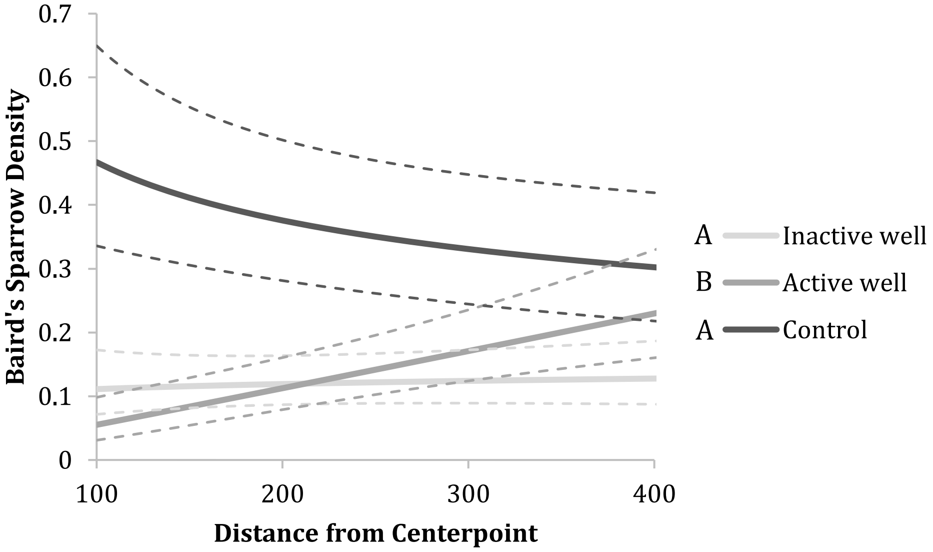

0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Western Meadowlark Abundance
100
200
300
400
Distance from Center Point
B Generator-powered pump
A Grid-powered pump
A Control

Figure 5. Effect of oil pumps' activity (on/off) on Sprague's pipit and Baird's sparrow abundance at the site scale (i) and (ii) hectare scale in southern Alberta from 2013-2014. iii) Effect of oil pumps' activity (on/off) on Savannah sparrow distribution at the hectare scale. Statistical significance is denoted by different letters. Error bars and dashed lines represent 90% confidence intervals. There were no significant effects of activity on chestnut-collared longspurs or western meadowlarks.

i)



ii)



iii)

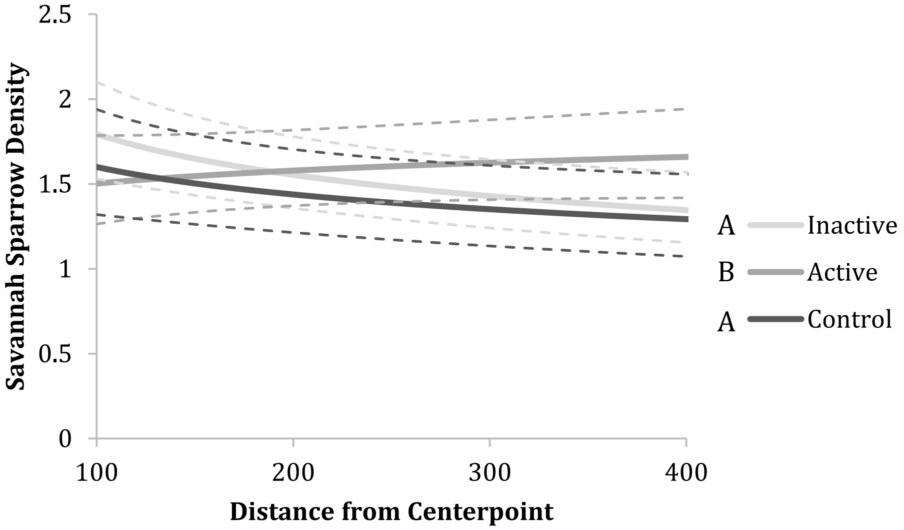
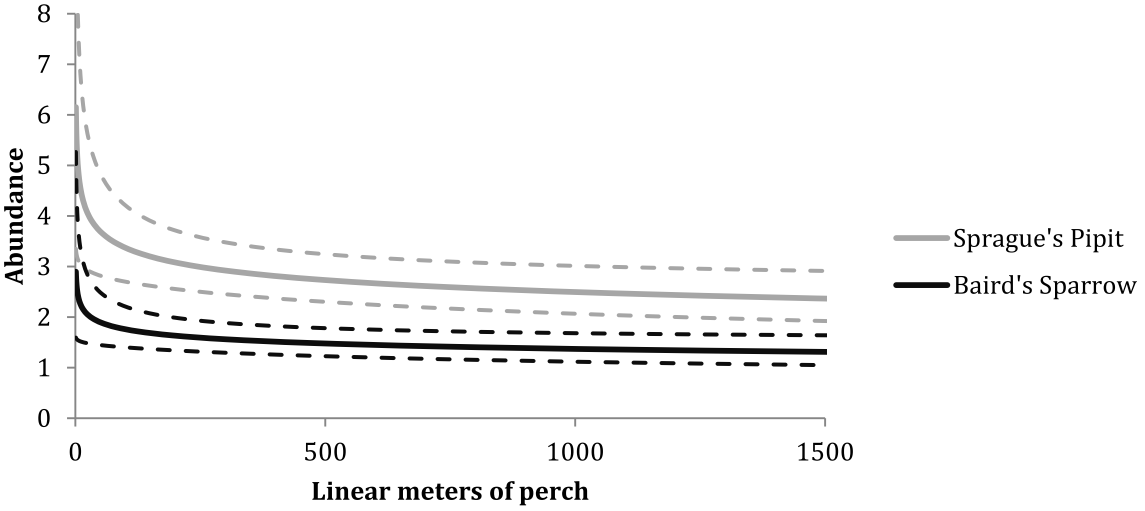
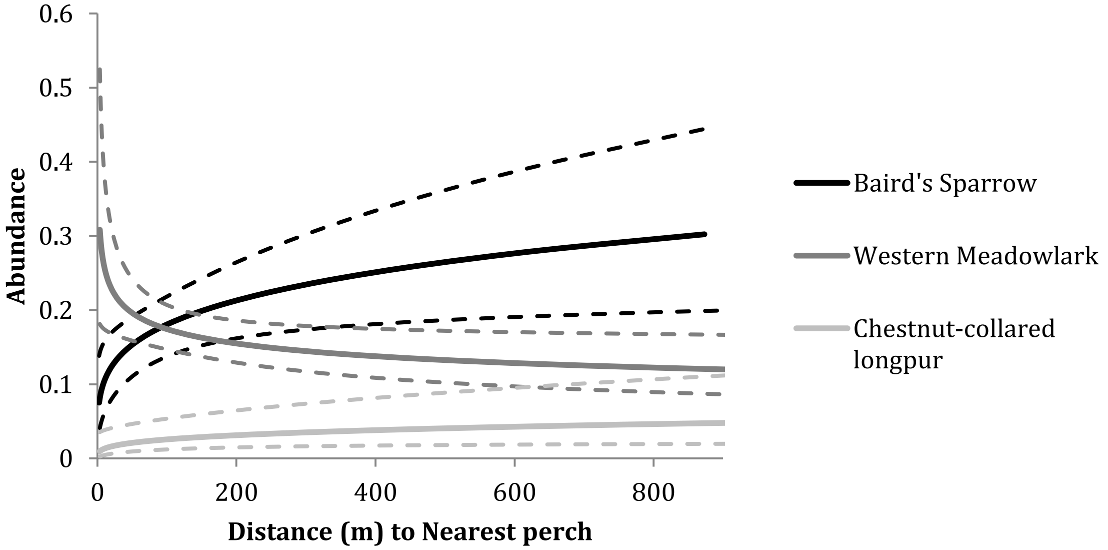

2.5
2
1.5
1
0.5
0
Savannah Sparrow Density
100
200
300
400
Distance from Centerpoint
A Inactive
B Active
A Control

Figure 6. i) Effect of total linear meters of perch on the abundance of Sprague's pipit and Baird's sparrow. ii) Effect of distance to perch on the distribution of Baird's sparrows, western meadowlarks, and chestnut-collared longspurs. iii) Effect of distance to road on the distribution of Sprague's pipit, Baird's sparrows and chestnut-collared longspurs. iv) Effect of exotic vegetation cover on Baird's sparrow abundance at the site scale. Dashed lines denote 90% confidence intervals. There were no significant effects of perch on Savannah sparrows, no significant effects of road on western meadowlarks or Savannah sparrows, and no significant effects of exotic vegetation on Sprague's pipits, chestnut-collared longspurs, western meadowlarks, or Savannah sparrows. All results are from southern Alberta from 2013-2014.

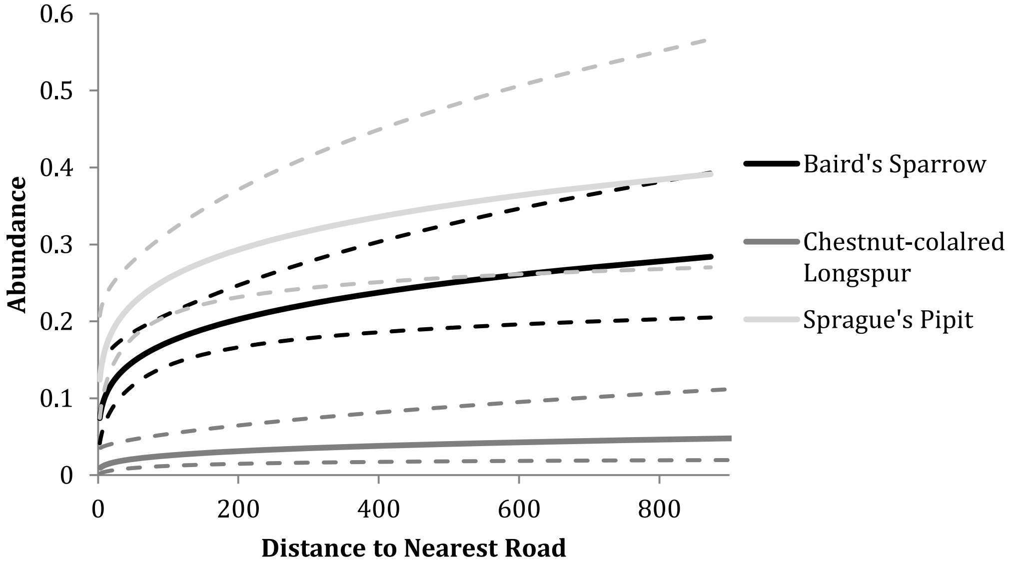
i)



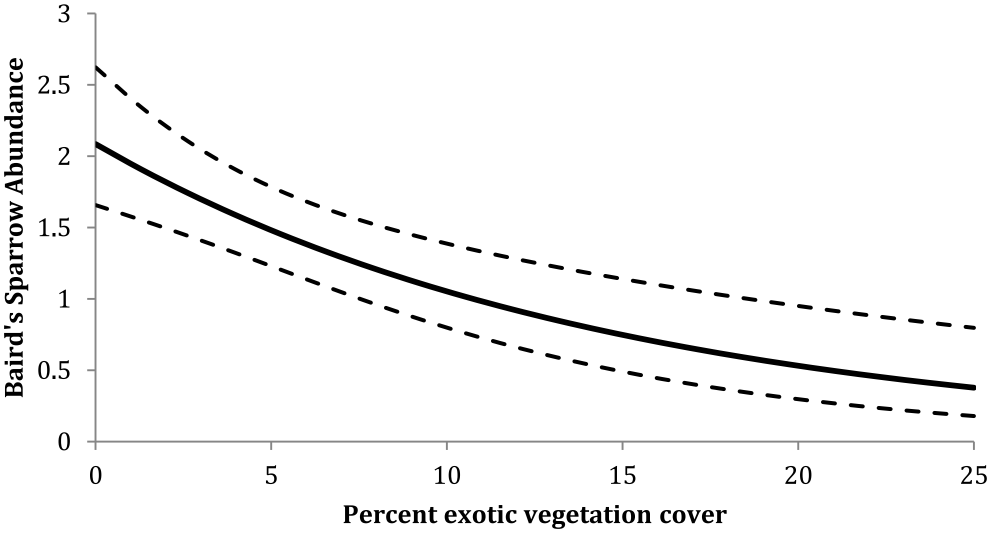
ii)



iii)


0.6
0.5
0.4
0.3
0.2
0.1
0
Abundance
0
200
400
600
800
Distance to Nearest Road
Baird's Sparrow
Chestnut-colalred Longspur
Sprague's Pipit

iv)


3
2.5
2
1.5
1
0.5
0
Baird's Sparrow Abundance
0
5
10
15
20
25
Percent exotic vegetation cover

APPENDIX I

Pump type, power source, and activity level for every site visited. Activity is split into the 4 round because wells could turn on or off from one site visit to the next

			Activity for Each Round			
Site Name	Infrastructure Type	Power Source	Round 1	Round 2	Round 3	Round 4
11	Pumpjack	Generator-powered	Active	Active	Active	Active
74	Screwpump	Generator-powered	Inactive	Active	N/A	N/A
75	Pumpjack	Generator-powered	Inactive	Inactive	Inactive	Inactive
76	Screwpump	Grid-powered	Inactive	Inactive	Inactive	Inactive
77	Screwpump	Grid-powered	Active	Active	Active	Active
79	Pumpjack	Generator-powered	Inactive	Inactive	Inactive	Inactive
80	Screwpump	Generator-powered	Active	Active	Active	Active
81	Pumpjack	Generator-powered	Active	N/A	Active	Inactive
83	Screwpump	Generator-powered	Inactive	Inactive	Inactive	Inactive
84	Screwpump	Generator-powered	Active	Active	Inactive	Inactive
87	Pumpjack	Generator-powered	Active	Inactive	Active	Active
94	Pumpjack	Generator-powered	Inactive	Inactive	Active	Active
129	Screwpump	Generator-powered	Inactive	Inactive	Inactive	Inactive
137	Pumpjack	Generator-powered	Active	Active	Active	Active
145	Pumpjack	Generator-powered	Inactive	Inactive	Inactive	Inactive
147	Screwpump	Grid-powered	Inactive	Inactive	Inactive	Inactive
154	Screwpump	Grid-powered	Inactive	Inactive	Inactive	Inactive
210	Pumpjack	Generator-powered	Active	Inactive	Active	Active
220	Pumpjack	Generator-powered	Active	Active	Active	Active
241	Screwpump	Grid-powered	Inactive	Active	Active	Active
245	Pumpjack	Generator-powered	Active	Active	Inactive	Inactive
247	Screwpump	Generator-powered	Inactive	Active	Inactive	Inactive
351	Pumpjack	Generator-powered	Inactive	Inactive	Inactive	Inactive
353	Screwpump	Grid-powered	Inactive	Active	Active	Active
363	Pumpjack	Generator-powered	Inactive	Inactive	Inactive	Inactive
401	Screwpump	Grid-powered	Active	Active	Active	Active
402	Pumpjack	Generator-powered	Inactive	Inactive	Inactive	Inactive
404	Screwpump	Grid-powered	Active	Active	Active	Active
C1	Control	N/A	N/A	N/A	N/A	N/A
C16	Control	N/A	N/A	N/A	N/A	N/A
C17	Control	N/A	N/A	N/A	N/A	N/A
C18	Control	N/A	N/A	N/A	N/A	N/A
C19	Control	N/A	N/A	N/A	N/A	N/A
C20	Control	N/A	N/A	N/A	N/A	N/A
C210	Control	N/A	N/A	N/A	N/A	N/A
C26	Control	N/A	N/A	N/A	N/A	N/A
C27	Control	N/A	N/A	N/A	N/A	N/A
C35	Control	N/A	N/A	N/A	N/A	N/A
C36	Control	N/A	N/A	N/A	N/A	N/A
C37	Control	N/A	N/A	N/A	N/A	N/A
C38	Control	N/A	N/A	N/A	N/A	N/A
JBPC	Control	N/A	N/A	N/A	N/A	N/A