Effects of Natural Gas Well Development on Songbird Reproductive Success in Mixed-grass Prairies of Southeastern Alberta

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ABSTRACT

Grassland songbird populations have experienced dramatic declines due to habitat loss and degradation. In Canada, energy development continues to fragment and disturb prairie habitat. Despite this impact to grassland bird breeding habitat, to date I know of no peer-reviewed published studies in North American mixed-grass prairies on the effects of oil and gas development on reproductive success of songbirds.

From 2010-2012, I monitored a total of 374 nests in mixed-grass prairie located in areas with differing proximities and histories of shallow gas well development, in southeastern Alberta. I estimated the probabilities of nesting success relative to gas well infrastructure and associated linear features (roads) to test for effects on nesting success, clutch size, and the number fledglings per nest. In 2012, I used motion-sensor cameras to identify potential nest predators and the occurrence of large-sized predators.

Predation was the primary reason for nest failure; however, there was very little effect of gas well pads on nesting success. Roads had a greater impact on nesting success, perhaps due to the great length of habitat edge associated with roads, which might host a greater diversity of predator species and act as travel corridors. Savannah sparrow and chestnut-collared longspur clutch sizes and fledgling numbers per nest were lower near gas well pads and cattle water sources, suggesting lower quality habitat in these areas. Large-sized predators occurred less in areas with older well pads but more frequently in areas with newer well pads. Concentrations of new well pads may have greater effects on chestnut-collared longspur reproductive success, particularly high (>10) concentrations. Minimizing habitat disturbance surrounding gas well pads, and reducing abundance of roads, should minimize impacts on reproductive success for most grassland songbirds. More studies are needed to understand mechanisms that drive predator presence in relation to these infrastructure types. Also, studies examining the interaction between cattle and gas well pads to understand productivity and post-fledging survival of grassland songbirds should be further explored.

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CHAPTER 1: INTRODUCTION

Background

Grassland songbird species have experienced severe population declines throughout North America's grassland habitats (Samson and Knopf 1994). The primary cause of this decline is the loss of native prairie habitat through land conversion (Owens and Myers 1973, Samson and Knopf 1994, Brennan and Kuvlesky 2005). Large tracts of prairie have been converted to row-crop agriculture and completely removed for human development, which has resulted in a 70% loss of prairies (Samson et al. 2004, Hoekstra et al. 2005). Prairie habitat is essential for grassland birds to breed and forage during the spring and summer months (Hill and Gould 1997, Robbins et al. 1999, Green et al. 2002, Ahlering et al. 2009). Population records starting from the 1960's indicate almost every (96%) grassland bird species has declined by at least 40% (NABCI 2009). Sprague's pipit and chestnut-collared longspur, which breed in Canada's mixed-grass prairies, have experienced over 68% population declines and both species are currently protected under the Species at Risk Act (SARA) (Hill and Gould 1997, Robbins et al. 1999, NABCI 2009, Government of Canada 2009).

Over the past century, oil and gas well development have also contributed to losses in prairie quality (intact and unfragmented with native vegetation) and both continue to alter and fragment much of Canada's remaining native mixed-grass prairie (Nasen et al. 2011). In Alberta, drilling of new gas wells has increased each year since the 1960s, reaching a maximum high of 14,000 wells drilled in 2005 (Alberta Canada 2013). Since then yearly drilling rates have decreased and approximately 1,500 wells drilled in 2012 (Alberta Canada

2013). A total of 167,118 gas wells have been drilled in Alberta (CAPP 2013). Although new gas well development has decreased, energy development (more oil than gas) still occurs and is prevalent across the prairie, with approximately 40,000 wells actively producing gas (Alberta Canada 2013).

New well development can create new access roads and active wells may prolong the use of existing roads (Nasen et al. 2011). Nasen et al. (2011) found over the course of 55 years, a 4350 ha area had undergone an increase of 18% - 45% in surface disturbance attributable to lease sites (96% oil, 4% gas) and roads. This habitat fragmentation may decrease habitat quality for many species. For example, greater sage-grouse (*Centrocercus urophasianus*) reproductive success has been found to decrease as a direct result of energy infrastructure (Holloran et al. 2010, Bui et al. 2010). Non-native vegetation (Lloyd and Martin 2005) as well as habitat edge caused by fragmentation (Gates and Gysel 1978) also have negative effects on grassland bird reproduction, but the extent of these types of effects caused by gas well development are unknown. Despite the decline in gas well development in recent years, and improved practices of native grass reclamation at well sites (Alberta Environment 2003), these types of lasting surface disturbance may be responsible for cumulative and long-term effects (Nasen et. al, 2011, Northrup and Wittemyer 2013).

Among grassland birds, predation is the primary cause of nest failure (Gates and Gysel 1978, Martin 1993, 1995, Pietz and Granfors 2000, Davis 2003, Kerns et al. 2010), and occur more frequently in edge habitat and fragmented landscapes (Gates and Gysel 1978, Angelstam 1986, Paton 1994), but this effect can vary depending on the habitat type (Ries et al. 2004, Renfrew et al. 2005). Therefore, habitat type, size and quality play a large and complex role in reproductive success (Bowman and Harris 1980, Herkert 1994, Dion et al. 2000, Renfrew and Rubic 2003, Davis 2004, 2005), as predator-prey interactions can be altered (Ries et al. 2004, Renfrew et al. 2005). However, patch size and abundance of edges may not make a difference if the predators in an area are highly successful at depredating nests (Renfrew et al. 2005). In addition, predator activity, distribution, and community composition can vary depending upon the region or local landscape (Renfrew and Ribic 2003).

A fragmented landscape can increase habitat edge effects (Laurance et al. 2007) and lower productivity due to brood parasitism by brown-headed cowbirds (*Molothrus ater*) (Gates and Gysel 1978). Edges can be degraded by non-native vegetation (Lloyd and Martin 2005, McDonald and Urban 2006), where reproductive success is negatively impacted and decreases nestling growth due to reduced food availability (Lloyd and Martin 2005). Insect abundance has been found to be lower in non-native habitat (Flanders et al. 2006, Hickman et al. 2006) and in habitats where vegetation structure and composition have been altered (Jepson -Innes and Bock 1989, Fielding et al. 1995, Debano 2006). Thus, many factors associated with gas well development and impacts on grassland bird reproductive success is unclear.

Problem Statement

In general, energy development can have variable effects on bird reproductive success in different habitat types (Naugle and Copeland 2011, Hebblewhite 2011, Copeland et al. 2011). For example, in sage steppe habitat, greater sage-grouse experienced greater nest failure near energy infrastructure and populations decreased directly due to energy development (Holloran et al. 2010). In contrast, lesser prairie chickens nesting success was not influenced by infrastructure associated with energy development (Pitman et al. 2005). These variable outcomes make it uncertain how energy development could impact songbird reproduction in grasslands.

Southern Alberta holds some of the greatest expanses of grassland habitat left (40%) in Canada (Gauthier and Wiken 2003, Koper et al. 2009), but also has high densities of oil and natural gas well infrastructure. Energy development in Alberta plays a large role in shaping what remains of the grassland landscape. As gas wells spread across the landscape, the cumulative environmental changes may influence grassland bird reproductive success (Davis 2004, 2006, Koper et al. 2009). In Alberta, gas well surface structures are subject to approval depending on other surface infrastructure, roads, and wells within a 200-m buffer (Alberta Regulation 2013). Infrastructure such as a shallow gas well (<5,000 ft. in depth) and its associated linear features (roads) create disturbance, produce edge effects, can alter predator-prey interactions, and spread non-native or exotic plant species (Berquist et al. 2007, Johnson and St.-Laurant 2011, Nasen et al. 2011). This suggests effects from shallow gas well development may influence grassland bird reproductive success, and may be particularly damaging for species at risk such as Sprague's pipit (*Anthus spragueii)* (Davis 2004, Davis et al. 2006, Koper et al. 2009) and chestnut-collared longspur *(Calcarius ornatus)* whose populations have dramatically declined (NABCI 2009). Sprague's pipits are habitat-sensitive and avoid edge habitat (Koper et al. 2009), and thus may be impacted by fragmentation associated with gas well development. Yet, no published studies have evaluated how current gas well densities and roads are impacting reproductive success in Alberta's mixed-grass prairie.

One published study, Hamilton et al. (2011), has looked at the effects of gas wells on grassland birds in Alberta; however, the study looked at abundance and not reproduction. The study found Sprague's pipit abundance declined, Savannah sparrow abundance increased, and there was no effect on chestnut-collared longspur abundance in response to gas well density (Hamilton et al. 2011). However, the study looked at a narrow range of well densities (low = 9 wells per site; high = 16 wells per site) situated in large survey areas (2.6 km^2) and therefore some effects may have not been detected for certain species. Therefore, an assessment of a wider range of gas well densities is needed on the potential impacts for species at risk such as chestnut-collared longspurs (Government of Canada 2009).

Rationale

Reproductive success is an important indicator for predicting avian population trends (Lack 1947, Lawton 1995). Therefore, it is important to understand whether shallow gas wells and associated linear features may be contributing to overall grassland bird population declines, particularly for developing future management strategies and mitigation methods.

Identifying predators responsible for nest failure, and effects of energy development on nest predation, can improve management for the conservation of grassland bird species. While there are many underlying mechanisms that influence nest fate and reproductive outcomes, predation has been shown to be the primary cause for nest failure for most avian species (Ricklefs 1969, Gates and Gysel 1978, Martin 1993, 1995), including nests of grassland songbirds (e.g. Pietz and Granfors 2000, Davis 2003, Renfrew and Ribic 2003, Renfrew et al. 2005, Kerns et al. 2010). Identifying causes of nest failure through observation of nest remains is highly unreliable, and the use of direct (nest cameras) evidence to identify nest predators is preferred (Angelstam 1986, Hernandez 1997, Pietz and Granfors 2000, Staller et al. 2005). In the northern mixed-grass prairie of Alberta, grassland bird predators have yet to be identified using nest cameras or documented during predation events (Pietz and Granfors 2000, Renfrew and Ribic 2003, Ellison and Ribic 2013).

My research helped to provide information on the reproductive success of grassland birds in response to gas well development and current gas well densities. By identifying potential and actual predators, my study will help managers better target efforts aimed at conserving grassland birds. My project also helped us to understand mechanisms contributing to certain grassland bird population trends (Koper and Schmiegelow 2006).

Objectives

The purpose of this study was to assess whether shallow natural gas wells and associated linear features impacted grassland bird reproductive success. Roads in the context of this study refer to high and low impact roads that indirectly or directly provide access to gas wells. High impact roads (indirect access) included well-traveled gravel or dirt roads. Low impact roads (direct access) included less-traveled trails where vegetation or small amounts of exposed bare ground was present in tire tracks.

To meet these objectives I:

1) Determined if grassland bird reproductive success varied with (a) gas well pad density (b) distance to well, road (high or low impact), and cattle water sources (i.e. stock ponds, dugouts).

2) Used motion sensor trail cameras to identify potential nest predators of mixed-grass prairie songbirds.

3) Determine whether potential nest predator activity or occurrence differed among sites with varying gas well pad densities and distances.

Hypotheses

1) If the presence of shallow gas well pads or associated roads and/or associated edge habitat alters predator-prey interactions, then nesting success will also differ with density and proximity to gas well infrastructure.
2) If gas well pads and roads create edges with altered vegetation composition and structure as well increased non-native vegetation, then reproductive output will be lower due to decreased food abundance and availability closer to gas well infrastructure.
3) Activity or occurrence of potential nest predators (mid-sized mammalian carnivores, ungulates, avian) will increase in areas of higher gas well pad densities due to an increase in travel corridors and/or perches.

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CHAPTER 2: LITERATURE REVIEW

2.1 Great Plains History and Habitat Loss

The arrival of Euro-American settlers on the Great Plains marked the beginning of grassland habitat conversion (Samson and Knopf 1994). The prairie is now one of the most anthropogenically altered and least protected biomes in the world (Hoekstra et al. 2005). The Homestead Act of 1862 and Canada Dominion Act of 1972 allowed for rapid conversion of the Great Plains prairie for agricultural purposes, resulting in the loss of 800,000 km^2 of natural prairie habitat (Samson and Knopf 1994). Native prairie habitat continues to be lost due to anthropogenic development, where losses range from 30% in Texas to 99% in Manitoba, most of which has become fragmented and degraded by non-native vegetation (Samson and Knopf 1994).

Southern Alberta is considered part of the northern Great Plains region. The landscape is comprised of flat to rolling hills, wetlands, and low precipitation (Askins et al. 2007). Alberta has approximately 40% remaining of its mixed-grass prairie habitat (Koper et al. 2009), and less than 0.01% is protected (Samson and Knopf 1994). Much of the mixed-grass prairie in this region is maintained through natural ecological drivers such as low precipitation, drought, and extreme weather (Samson et al. 1994, Askins et al. 2007). However, in other regions with mixed-grass prairie, historical bison grazing and fire likely suppressed woody vegetation (Askins et. al 2007). Periodic grazing among bison and other ungulates also contributed in shaping the landscape and additional shaping was done by the presence and grazing of small mammals such as ground squirrels and prairie dogs (Askins et al. 2007). Today, wild fires are suppressed or stopped before large areas can burn, allowing for some invasion of woody plants and shrubs as well as the reduction in grass species diversity (Askins et al. 2007). Cattle have replaced free-roaming bison and been confined to rangelands or pastures. Pastoral livestock grazing regimes cause the land to be grazed uniformly, which is ecologically different from the effects of free-roaming bison (Brennan and Kuvlesky 2005). In addition, prairie dogs no longer inhabit over 98% of their Great Plains historical range and, in Canada, wild populations persist only in southwestern Saskatchewan and one small, but viable, colony (escaped from captivity) north of Edmonton, Alberta (Trefry and Holroyd 2012). The loss of these important natural ecological disturbances in the prairie may be adversely influencing the prairie ecosystem.

Furthering habitat loss and degradation is the development of oil and gas infrastructure across the prairie (Nasen et al. 2011). The beginning of the oil industry coincided with agricultural development in the 1880's (Klassen 1999). By the mid 1900's, Imperial Oil, a main oil producer was producing 13 million barrels of oil a day (Klassen 1999). Since then, many oil companies have emerged and branched off to include natural gas extraction. Currently 200,154 gas wells (not including oil wells) have been placed across Canada's landscape with 162,848 wells in Alberta alone (Land, Exploration, Drilling 2011). Cenovus Energy owns and operates 25,000 of those wells in southern Alberta (Operations n.d.). Oil and gas development increasingly alters the landscape at local levels with cumulative effects on the landscape and ecosystems remaining much unknown (Copeland et al. 2011).

2.2 Energy Development, Birds, Nesting success

Infrastructure and energy development activities are having an effect on the landscape and wildlife (Naugle and Copeland 2011, Hebblewhite 2011, Copeland et al. 2011). Effects of energy development include disturbance and changes to landscape, habitat, natural ecosystem processes, wildlife populations, and species dynamics (Hebblewhite 2011). One direct effect is bird mortality from energy development (Johnson and Stephens 2011). Locations of wind turbines in a region, as well as species-specific behaviors, make certain species more susceptible to collision and mortality (Johnson and Stephens 2011). For example, raptors that perch on transmission lines or buildings located in wind turbine facilities experience higher mortality rates than songbird species that do not use infrastructure as perches (Johnson and Stephens 2011). In addition, ducks and other songbirds sometimes use tailings ponds created during oil sand extraction that are contaminated by toxic byproducts, resulting in an estimated 840,000 bird mortalities per year (Trail 2006).

Energy development has both positive and negative effects on bird abundance (Walker et al. 2007, Hamilton et al. 2011, Gilbert and Chalfoun 2011). Trends so far indicate gas well development has negative effects on habitat sensitive bird species, while less sensitive bird species experience no or positive effect (Walker et al. 2007, Hamilton et al. 2011, Holloran et al. 2010, Gilbert and Chalfoun 2011). Yet, the magnitude of these effects may be dependent on the amount of gas well development present within a landscape (Gilbert and Chalfoun 2011).

Similar trends were found in studies on forest birds. Bayne et al. (2008) found that habitat sensitive species such as the ovenbird occurred in lower numbers near seismic lines

(<50 m) created during energy development in forest habitat. However, many generalist forest species that prefer areas of early successional forest habitat were found near seismic lines (Fleming and Schmiegelow 2003). This suggests the effects of disturbance and implications associated with the width of the seismic lines vary among species (Fleming and Schmiegelow 2003).

Linear features such as roads and trails associated with energy development can also affect bird abundance. The presence of a linear feature may have some effect, but the level of vehicle activity is the main indicator of bird abundance (Kociolek et al. 2010). Similar to the aforementioned trends, other studies have shown that presence alone and vehicle activity as low as 7-10 vehicles per day associated with energy development had a negative effect on habitat sensitive bird species abundance while other generalist species showed no or positive effects (Lyon and Anderson 2003, Ingelfinger and Anderson 2004).

Some studies have shown positive and negative effects on bird nesting success in response to various types of energy development and activity. A study done in sage brush habitat found energy development was a direct cause of population declines of the habitat sensitive species greater sage-grouse when breeding and nesting within 900 m from infrastructure (Holloran et al. 2010). In another study, raven pairs occupying areas within 400 m of energy development were correlated with greater nest failure of greater sage-grouse nesting in near-by sagebrush habitat (Bui et al. 2010). In contrast, a study on lesser prairie chickens in sand-sagebrush habitat found that nesting success was not influenced near well heads (as close as 80 m) or buildings (1 km) associated with energy development (Pitman et al. 2005). Another study that took place in remote boreal forest found that reproductive success was not influenced by proximity to pipelines or seismic lines or edges created by those linear features (<600 m); however, results may have been biased due to the remoteness of the sites, which had little disturbance and edges that were not significantly different from the surrounding habitat (Ball et al. 2009). In other studies, forest bird abundance and nest density were higher further away (up to 700 m) from noisy oil and gas compressor stations (Bayne et al. 2008, Bayne and Dale 2011) and 14 out of the 19 species nested in sites absent of noisy compressor stations (Francis et al. 2009); however, nesting success was higher due to fewer occurrences of a primary predator (32% decrease) in areas of noisy compressor stations (Francis et al. 2009). This highlights how energy development and activities may be influencing nesting success and reproduction in a variety of ways, depending on the individual species, as well as changing the dynamics of bird and predator species interactions in an ecosystem.

2.3 Reproductive Success

Grassland habitat, habitat edge, and nest site selection

Due to habitat loss and fragmentation (Brennan and Kuvlesky 2005), grassland-nesting birds have experienced the highest population declines of all avian guilds in North America (Peterjohn and Sauer 1999). Lands converted to cropland, hay land, or rangeland differ in structure and composition from native prairie habitat (Brennan and Kuvlesky 2005). In addition, anthropogenic development has created a prairie that is no longer contiguous, but rather a mosaic of varying sizes of fragmented grassland (Samson et al. 2004), thereby reducing the amount of available habitat for nesting birds.

While habitat loss, fragmentation, and degradation have caused grassland songbird population declines, there may be additional effects that influence songbird reproductive success (Davis 2004). Grassland songbirds select nest sites that are known to differ in vegetation composition and structure from surrounding habitat (Davis 2005, Fisher and Davis 2010, Lusk and Koper 2013). Habitat selection can play an important role in reproduction (Martin 1993, 1995, Davis 2005). Often habitat edge is associated with reduced habitat quality (change in vegetation structure and composition), where edges are vulnerable to non-native plant species can become established and then outcompete native species (Lloyd and Martin 2005). Habitat altered by roads or other development may create edge effects that influence reproductive success (Davis 2004, Koper et al. 2009). For example, Lloyd and Martin (2005) found chestnut-collared longspurs experienced lower nesting success and nestling survival when nesting in exotic crested wheatgrass (introduced to North America as an early season grass for cattle and to help control erosion) as opposed to native mixed-grass prairie, but no preference was shown towards either habitat. This suggests edges created by gas well development and associated linear features, which are susceptible to exotic invasion such as crested wheatgrass (Koper et al. 2014), could cause birds to experience lower reproductive success (Lloyd and Martin 2005).

Habitat edge and predation

Nest predation is the primary factor in nest failure (Gates and Gysel 1978, Martin 1993, 1995, Pietz and Granfors 2000, Davis 2003, Kerns et al. 2010). Grassland predators include a variety of small to medium-sized mammals as well as avian and snake species (Renfrew and Rubic 2003). Predator activity, distribution, and community composition can vary depending upon the region or landscape (Renfrew and Rubic 2003). Within a specific region, predator community and composition will vary due to the type of habitat, topography, vegetation, roads, and infrastructure existing on the landscape (Heske et al. 2001). Habitat edges created by roads, infrastructure, and differing adjacent habitats may support a higher frequency of diverse predator species (Gates and Gysel 1978, Winter et al. 2000). Meso-predators such as foxes may alter their movement near edges (Crooks 2001, Renfrew and Ribic 2003) and linear features (Frey and Conover 2006). Larger predators such as coyotes which may be "fragment sensitive", meaning they prefer to inhabit larger areas of un-fragmented land to smaller patches of habitat (Crooks 2001); however, regional differences may exist for this species, where coyote presence has increased in urban landscapes in northern regions of the United States (Dodge et al. 2013).

Medium-sized mammals have been shown to depredate nests closer to habitat edge and at higher rates than smaller sized mammals (Winter et al. 2000). Also, songbird nest predation is generally higher near wooded edges (Gates and Gysel 1978). However, Grant (2006) found that a regional difference in predator distribution near woodland edges, which caused clay-colored sparrows (*Spizella pallida*) and vesper sparrows (*Pooecetes gramineus*) to have higher nesting success near edges than interior habitat. Also, the ratio of edge to habitat patch size may also influence predation. Davis et al. (2006) found Baird's Sparrow (*Ammodramus bairdii*), chestnut-collared longspur (*Calcarius ornatus*), and western meadowlark (*Sturnella neglecta*) to have greater nest survival rates in smaller patch sizes (pasture size range; 18 ha to 11,600 ha), while Savannah sparrows (*Passerculus sandwichensis)* had a positive relationship with patch size.

A study on small mammals and edge effects found that the relative abundance of mouse species did not differ between edge and habitat interior, except in cases where mouse abundance was higher along taller vegetated edges than sparser and shorter interior habitat

(Pasitschniak-Arts and Messier 1998). This may suggest that some small mammals are indifferent to habitat edge but select vegetation structure as a means for cover or protection against predators, which poses as a problem for songbird species nesting in tall, dense vegetation (Schmidt et al. 2001).

Brown-headed cowbirds are known to be abundant near edges with infrastructure such as fences, which may increase rates of brood parasitism of grassland songbirds nesting closer to edges (Gates and Gysel 1978). In addition, birds of prey or corvids may use infrastructure as perch sites to hunt for prey such as birds or small mammals (Lammers and Collopy 2007). Furthermore, as small mammals are prey themselves and serve as predators for some grassland birds (Ribic et al. 2009), it creates a complex dynamic between predator-prey communities, which is further complicated by habitat and regional differences.

Songbird responses to resources and predators

Food availability and abundance can be important factors in reproductive success (Zanette et al. 2013). Grassland bird diets consist of insects (arthropods) and seeds (Cody 1985, Kaspari and Joern 1993, Ehrlich et al. 1998). Native habitat was found to have higher arthropod abundance than non-native habitat (Flanders et al. 2006). Less food availability or abundance can result in lower clutch sizes, lower nestling mass, or fewer fledglings (Arcese and Smith 1988, Lloyd and Martin 2005, Zanette et al. 2013). Altered habitat structure and composition through grazing surrounding oil and gas development (Koper et al. 2014) could impact food availability or abundance for grassland songbirds.

Natural selection combined with nest predation pressure has shaped anti-predator behavior of avian species (Martin 1993), influencing habitat selection, parental nest behavior, and life history traits (Ricklefs 1969, Martin 1993, Fontaine and Martin 2006). A decrease in predator abundance may result in an increase in nest density (Finney et al. 2003), since birds in certain habitats may be able to detect predator density and respond by building nests in areas with lower predation risk (Forstmeier and Weiss 2004). For example, a study found a flycatcher species was able to distinguish between two potential predator species and strongly avoided nest building in areas of perceived high predator threat (Morosinotto et al. 2010). Also, birds exhibiting year-to-year site fidelity can be a result of successful reproductive attempts and low expended effort, as well as indirect evidence of predator avoidance (Gavin and Bollinger 1988, Haas 1998).

Evolutionary response in species may occur when there are high levels of predation over time (Conway and Martin 2000); however, extended time away from nests may cause a decrease in provisioning rates and nestling growth (Scheuerlein and Gwinner 2006). For example, blue tits *(Cyanistes caeruleus)* were found to detect predators near nests using the sense of smell, which resulted in increased periods away from nests as a means to reduce attracting predators (Amo 2008). Conversely, bird species may spend more time defending and guarding their young at nests when known predators are near or have already partially depredated nests (Marzluff 1985). In addition, some species that have evolved with high predation risk produce smaller clutch sizes and shorter nestling periods as a trade-off to increase broods per year (Martin 1995). Also, when predation risk is reduced, clutch sizes may be larger (Zanette et al. 2013). On the other hand, in a recent experimental study it was found that some birds forego seeking habitat with less predator risk as a trade-off to gain earlier nest initiation and produce larger clutch sizes (Monkkonen et al. 2009).

2.4 Mixed-Grass Prairie Songbirds

Baird's sparrow (Ammodramus bairdii)

The Baird's sparrow was listed by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC) as threatened until 1996 (COSEWIC 2011), when it was delisted due to high numbers found in Saskatchewan (Green et al. 2002). Federally, they are listed as "special concern" and endangered in Manitoba (COSEWIC 2012). The Baird's sparrow displays annual population shifts across the prairie, which likely indicates a remnant behavioral response to once common ecological changes such as fire and bison grazing (Green et al. 2002). This species was historically very common with estimated total population losses of 75% since 1966 in the prairie (Green et al. 2002, Sauer et al. 2013). They breed from May-August and migrate south to a few southern U.S. states and a small portion of northern Mexico for the winter (Green et al. 2002, Ahlering et al. 2009).

The Baird's sparrow optimal breeding habitat is native mixed-grass and fescue prairies, but it also tolerates cultivated pastures with sufficient native grass (Green et al. 2002). Historically, natural fire and bison grazing suppressed woody and exotic vegetation overgrowth, which created optimal habitat for this species (Green et al. 2002). Nest site characteristics include native grasses with high density of dead vegetation and low density of live grasses, areas of taller vegetation, and high litter depth (Green et al. 2002).

Chestnut-collared longspur (Calcarius ornatus)

Chestnut-collared longspurs are native prairie specialists and endemic to the Canadian Prairie and Great Plains (Hill and Gould 1997). Chestnut-collared longspurs have been listed as threatened by COSEWIC since 2011, due to severe population declines (COSEWIC 2011).

COSEWIC recognizes that the current threats to this species include deterioration, fragmentation, and loss of native habitat caused by infrastructure and roads linked to energy development (COSEWIC 2011).

Chestnut-collared longspurs inhabit short to mixed-grass prairie, grazed or mowed tall grass prairie, and show some tolerance to non-native pastures and mowed airstrips (Hill and Gould 1997). Nest site characteristics include sparse and shorter native grasses with low litter accumulation (Hill and Gould 1997). This species arrives to the prairies in late April to early May and migrates to the southern U.S. and Mexico for the winter (Hill and Gould 1997).

Savannah sparrow (Passerculus sandwichensis)

Savannah sparrows inhabit open habitats with extensive breeding distributions ranging from northern United States (includes Alaska) and all of Canada (Wheelwright and Rising 1993). Being a more wide-spread generalist than endemic grassland birds (Knopf 1994), their range includes many open habitat types of native grassland, grazed pastures, roadsides, cultivated fields, coastal grasslands, salt marsh edges, and grassy meadows (Wheelwright and Rising 1993). Nest site characteristics include high litter depth, little to no bare ground, tall grass, and denser vegetation (Wheelwright and Rising 1993, Davis 2005). This species arrives in southern Canada during late April and early May for breeding and migrates to portions of the southern United States and all of Mexico for the winter (Wheelwright and Rising 1993).

Sprague's pipit (Anthus spragueii)

Sprague's pipits are specialists to native prairies and are considered sensitive to habitat patch size (Davis 2003, 2004), meaning this species is often found in larger fragments or parcels of native habitat. Sprague's pipits are endemic to the Canadian Prairies and Great

Plains (Robbins et al. 1999) and listed as threatened in 1999 (COSWEIC 2011). They arrive to breed in the prairies starting in late April – early May and migrate south to the mid-southern U.S. states and Mexico for the winter (Robbins et al. 1999). This secretive and elusive species inhabits large and open tracts of native grassland with low shrub density (Robbins et al. 1999). Sprague's pipit nest site characteristics include open grassland of dense and taller mixed-grass prairie, minimal forbs and bare ground (Robbins et al. 1999).

Vesper sparrow (Pooecetes gramineus)

Vesper sparrows are found in open grassland habitats with some shrubs, distributed across the southern half of Canada and northern half of the United States (Jones and Cornely 2002). This species arrives to the Canadian Prairie's and most of the upper U.S. to breed from May-August. For the winter, this species migrates to the southern U.S. and almost all of Mexico (Jones and Cornely 2002).

Vesper sparrows are considered to be habitat generalists occupying a range of grassland habitat types which include native prairie, pastures, old fields, desert shrublands, sagebrush steppe, woodland edges, while avoiding wetland areas of dense and tall vegetation (Jones and Cornely 2002). Nest site characteristics include open grassland habitat consisting of short sparse grasses with moderate bare ground and shrubs (Jones and Cornely 2002).

Western meadowlark (Sturnella neglecta)

Western meadowlark distributions encompass the western portion of North America in open habitats consisting of grasslands and cultivated lands (Lanyon 1994). This species is mostly resident throughout its range with varying movement from colder to warmer climates and small populations migrating great distances, e.g. Saskatchewan/Ontario to

Arkansas/Mississippi, (Lanyon 1994). This species moves to breeding grounds in May and migrates to wintering grounds starting in August (Lanyon 1994).

Western meadowlark breeding habitat includes native grasslands, pastures, crop fields, vegetated borders, along roads, and other open areas with local nest site characteristics of grass and litter cover (fairly dense vegetation) (Lanyon 1994). This species shows preference for singing perches such as fence posts, poles, power lines, and tall shrubs or forbs, but not trees (Lanyon 1994).

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CHAPTER 3: EFFECTS OF NATURAL GAS WELL DEVELOPMENT ON GRASSLAND SONGBIRD NESTING AND REPRODUCTIVE SUCCESS IN MIXED-GRASS PRAIRIES IN SOUTHEASTERN ALBERTA, CANADA

3.1 Introduction

Grasslands are one of the most altered habitats in the world (Hoekstra et al. 2005). Within North America, 70% of habitat loss has occurred within the Great Plains region (Samson et al. 2004) due to agricultural, urban and industrial development (Samson et al. 2004, Hoekstra et al. 2005). One direct consequence of habitat loss and conversion has been the severe reduction of grassland songbird populations, highest of any avian guild in North America (Peterjohn and Sauer 1999), and increasing threat of further decline due to limited habitat protection (Herkert 1994, 1995, Samson and Knopf 1994, Peterjohn and Sauer 1999, Herkert et al. 2003). In addition, anthropogenic development has created a prairie that is no longer contiguous, but is now a mosaic of varying sizes of fragmented grassland (Samson et al. 2004), thereby reducing the amount of available habitat for nesting birds, many of which are sensitive to habitat fragmentation (e.g. Davis 2004, Koper et al. 2009).

The development of oil and gas infrastructure across the prairie has exacerbated this habitat loss and alteration (Nasen et al. 2011). Currently, 167,118 of 205,590 (81%) gas wells that exist in Canada are situated in Alberta (CAPP 2013), overlapping with the regions of Canada's most extensive remaining grasslands (Gauthier and Wiken 2003). Studies have shown infrastructure and energy development activities can affect wildlife (Naugle and Copeland 2011, Hebblewhite 2011, Copeland et al. 2011). Effects of energy development include disturbance and changes to landscape, habitat, natural ecosystem processes, wildlife populations, and species dynamics (Hebblewhite 2011). One direct effect is bird mortality from energy development, but this risk varies by species and with location and type of energy infrastructure (Johnson and Stephens 2011). For example, raptors that perch on transmission lines or buildings located in wind turbine facilities experience higher mortality rates than songbird species that do not use infrastructure as perches (Johnson and Stephens 2011). In addition, ducks and other songbirds use tailings ponds created during oil sand extraction that are contaminated by toxic byproducts, which cause an estimated 840,000 bird mortalities per year (Trail 2006).

Linear features associated with energy development, such as roads, can also affect bird abundance, which is generally negatively correlated with levels of vehicle activity (Kociolek et al. 2010). However, road presence alone, and vehicle activity as low as 7-10 vehicles per day, had a negative effect on habitat-sensitive bird species abundance while generalist species often show no or positive responses to roads (Lyon and Anderson 2003, Ingelfinger and Anderson 2004).

Studies have shown both positive and negative effects of various types of energy development and activity on bird nesting success. Yet, the magnitude of these effects may be dependent on the amount of energy development within a landscape, and the avian species present (Gilbert and Chalfoun 2011). A study done in sage brush habitat found energy development was a direct cause of population decline of the habitat sensitive species Greater Sage-Grouse (Hollorn et al. 2010). Conversely, a study on lesser prairie chickens in sand-sagebrush habitat found that nesting success was not influenced by distance to energy development infrastructure and associated linear features (Pitman et al. 2005). Another study that took place in remote boreal forest found that reproductive success was not influenced by proximity to pipelines, seismic lines, or edges created by those linear features; however, these results may have been due to the remote sites having relatively little disturbance and edges that were not significantly different from the surrounding habitat (Ball et al. 2009). In other studies, forest bird abundance and nest density were higher further away from noisy oil and gas compressor stations (Bayne et al. 2008, Francis et al. 2009, Bayne and Dale 2011), whereas nesting success in shrubland ecosystems was higher near compressor stations because of predator avoidance of noise (Francis et al. 2009). This highlights how effects of energy development and activities are variable, and may change the dynamics of bird and predator species interactions in an ecosystem.

Infrastructure such as shallow gas wells and associated linear features can create disturbance, produce edge effects, alter predator-prey interactions, and spread non-native or exotic plant species (Johnson and St-Laurant 2011). These cumulative environmental changes may influence grassland bird nesting or reproductive success (Davis 2004, 2006, Koper et al. 2009); yet, no published studies have evaluated these effects on nesting and reproductive success in relation to gas well development and current gas well densities in Alberta's mixed-grass prairie. Nesting and reproductive success are important indicators for predicting avian population trends (Lack 1947, Lawton 1995). Studies on the rate and number of individuals coming into a population may help explain population changes. While there are many underlying mechanisms that influence nest fate and reproductive outcomes, predation has been shown to be the primary cause for nest failure for most avian species (Ricklefs 1969, Gates and Gysel 1978, Martin 1993, 1995) including nests of grassland songbirds (e.g. Pietz and Granfors 2000, Davis 2003, Renfrew and Ribic 2003, Renfrew et al. 2005, Kerns et al. 2010).

The purpose of this study was to assess whether shallow gas wells and linear features impacted grassland bird reproductive success. To meet these objectives I:

1) Determined if grassland bird nesting success and reproduction varied with (a) gas well pad density (b) distance to well pad, road (high impact, low impact), and cattle water source (i.e. stock ponds, dugouts).

2) Used motion sensor trail cameras to identify potential nest predators of mixed-grass prairie songbirds.

3) Determined whether potential nest predator activity or occurrence differed among sites with varying gas well pad densities and distances.

3.2 Methods

3.2.1 Study Site

My research was conducted in native mixed-grass prairies in southeastern Alberta, Canada, 2010-2012. Study sites were located in Newell, Vulcan, and Taber Counties surrounding Brooks, Alberta, Canada (approximately 50° 35'N, 111° 53'W, 760 m) (Figure 3.1). The study area was selected because it encompasses a wide range of densities of Cenovus Energy Incorporated gas wells in native mixed-grass habitat. Potential sites were initially selected using Satellite Imagery photos and suitability was confirmed with site visits. Selected sites were 258-ha (1 sq. mile; 2,580,000m^2) in area based on legal land descriptions, and were surrounded by buffers of native prairie to minimize edge effects caused by cropland. In 2010, 39 sites were surveyed (Figure 3.2; APPENDIX I). Four sites were dropped during the 2010 season due to differences in vegetation and topography criteria and not used in analyses. In 2011, these discarded sites were replaced, including two control sites. In 2012, 13 of the original 39 sites were surveyed and one new site was added, totaling 14 sites.

Sites were dominated by native mixed-grass prairie vegetation such as blue grama (*Bouteloua gracilis*), needle & thread (*Stipa comata*), Western wheatgrass (*Pascopyrum smithii)*, Northern wheatgrass (*Agropyron dasystachyum*), June grass (*Koeleria macrantha*), and Prairie sage (*Artemesia ludoviciana).* Site topography consisted of flat to gently rolling prairie with a range of shallow-gas development intensities from 0 – 16 gas well pads / section (2.56 km^2) and a max 32 well heads / section. Gas well pad densities were based on GIS records and maps provided by Cenovus Energy Inc. A single well was designated by one surface hole or well pad lease; in some cases, wells were commingled such that one well pad contained more than one well head. Gas well structural dimensions ranged from an average of 23.1 m^2 to a maximum of 42.3 m^2 (Figure 3.3a, 3.3b). Well ages ranged from 1 – 44 years.

Linear features in the context of this study refer to high and low impact roads that indirectly or directly provide access to gas well pads (Figure 3.4). High impact roads (indirect access) included well-traveled gravel or dirt roads, approximately an average of 7 meters in width. Low impact roads (direct access) included less traveled trails where vegetation or small amounts of exposed bare ground was present in tire tracks, approximately an average of 1.15 meters in width. For all sites, at least one edge of the 1X1 mile section was bordered by a high impact road, and multiple low impact roads either bordered or were found within the site (Figure 3.4). Roads that bordered sites often continued beyond (several miles) the length of the site. Google Earth imagery was used to determine road length. Cover of low impact roads may be underestimated due poor image quality and detectability. High impact roads covered approximately 0.5% - 1.5% of the site area and low impact roads covered approximately 0.08% - 0.6% (Table 3.1).

Cattle water sources (i.e. stock ponds, dugouts) (Figure 3.5) were included in the study because of their presence in or adjacent to nearly half the study site sections and their potential impact on nesting birds and bird food resources (White et al. 2001, Kruess and Tscharntke 2002, Tate et al. 2003, Fontaine et al. 2004, Bleho et al. 2014). Cattle water sources were anywhere from 250m^2 – 12,560m^2 in size, covering approximately 0.0% - 0.5% of each site area (Table. 3.1).

Although irrigation canals are prevalent in the study region, they were not incorporated in analyses because of the absence of canals in most of my study sites and not the focus of this study. Irrigation canals are often bordered by a road, which may influence distributions of some bird species or predators either due to the presence of the road.

This map has been removed due to copyright issues.

Image can be found at www.google.ca/maps

Figure 3.1. Study area located in southeastern Alberta.

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Image can be found at www.earth.google.ca

Figure 3.2. All study sites were located in the area surrounding the city of Brooks, Alberta.

Photo by J. Yoo, 2011

(b)

Photo by J. Yoo, 2012

Figure 3.3. Photo (a) - single gas well pad with above ground piping and cattle guard fence (typical), showing visible surface disturbance from well construction. Photo (b) – capped gas well no longer producing gas but above ground structures still present.

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Image can be found at www.earth.google.ca

Figure 3.4. Google Earth imagery of a study site (undisclosed) with five gas wells and roads.

Table 3.1. Total length (m) and area (m^2) of high and low impact roads found bordering or in each site and total area (m^2) of cattle water source located at sites.

Site	# of Well pads	High impact roads (length, m)	High impact road (area; m^2)	Low impact roads (length; m)	Low impact road (area; m^2)	Cattle water source (area; m^2)
1	0	1852	12964	1852	2130	728
2	0	0	0	3704	4260	12560
3	0	0	0	1852	2130	1010
4	0	0	0	3704	4260	1261
5	0	1852	12964	1852	2130	-
6	0	0	0	3704	4260	-
7	1	3704	25928	1852	2130	1700
8	1	1852	12964	1852	2130	-
9	1	3704	25928	1852	2130	4995
10	3	3704	25928	2182	2509	-
11	3	1852	12964	6482	7454	-
12	3	0	0	4630	5325	-
13	4	1852	12964	8852	10180	-
14	4	1852	12964	4630	5325	352
15	4	0	0	7408	8519	705
16	4	1852	12964	3704	4260	-
17	4	1852	12964	5556	6390	-
18	5	1852	12964	5556	6390	544
19	5	0	0	2778	3195	1968
20	6	1852	12964	5093	5857	2000
21	6	3704	25928	14408	16569	-
22	7	0	0	4630	5325	-
23	7	1852	12964	3704	4260	3600
24	7	0	0	7408	8519	-
25	7	0	0	3704	4260	-
26	8	3704	25928	3704	4260	736
27	9	3704	25928	5556	6389	1500
28	9	0	0	5556	6389	-
29	9	1852	12964	5556	6389	-
30	9	3704	25928	7408	8519	-
31	9	1852	12964	4630	5325	-
32	10	5556	38892	5556	6389	-
33	10	1852	12964	3704	4260	250
34	10	1852	12964	1852	2130	1216
35	11	1852	12964	9260	10649	-
36	11	1852	12964	2778	3195	5757
37	11	0	0	1852	2130	-
38	15	0	0	5556	6390	850
39	16	3704	25928	4630	5325	918
Average		1706	11942	4629	5324	1727

This map has been removed due to copyright issues.

Image can be found at www.earth.google.ca

Figure 3.5. Google Earth imagery of a cattle water source (dugout) from a study site (undisclosed).

3.2.2 Data Collection

Research assistants and I conducted nest searches at each site to find and monitor songbird nests from mid-May – early August 2010, 2011, and 2012. Within each site, I randomly selected 100 X 1000 meter nest survey plots until I got two plots that did not overlap in orientation. Established nest plots at each site were surveyed twice per year. Nests were located by flushing incubating females from nests using the rope-drag method. The rope-drag method consists of two observers each holding one end of a 30-m stretched rope weighted by aluminum cans attached every 0.5-m, and dragging the rope along the grass to flush adults attending nests (Davis 2003). Nests found by rope dragging and incidentally were marked by a bamboo stake to the south and pin flag to the west, both 10-m from the nest, and were monitored every 2-4 days until fail or fledge (success). To calculate nesting success I assigned a "1" for successful nests and "0" for failed nests. Nests known or assumed to have at least fledged one offspring were considered successful, whereas any depredated, abandoned, or parasitized nests were determined to have failed. To determine nest fate, signs and cues at the nest as well as adult behavior were used. Signs and nest cues of successful nests were excrement in the nest cup with a crushed cup rim, auditory or visual confirmation of fledglings near the nest, or adults feeding or alarm calling near-by.

Precautions were taken to minimize research activity around nests to minimize human-induced predation rates. We approached and exited nest areas using different paths on each visit to reduce creating defined paths for predators to follow (Major 1999). We did not touch eggs, nestlings, nest vegetation or the immediate nest site area until after nests were complete.

3.2.3 Vegetation Surveys

We conducted vegetation surveys from May – August 2010-2012. Vegetation surveys consisted of measuring vegetation structure and density, height, and abundance of invasive species (crested wheatgrass, *Agropyron cristatum*). Research assistants and I took measurements of live grass, dead grass, forbs, bare ground, shrubs, lichen cover, moss, shrubs, height, litter depth, and crested wheatgrass.

To take vegetation measurements, a quadrat was created by placing two intersecting meter sticks on the ground (pointed in cardinal directions) (Wiens 1969). For vegetation structure at nests, the quadrat was placed so nests would be located in the center. Vegetation cover measurements were then taken in all four quadrants (NW, NE, SE, SW) of the quadrat (Wiens 1969). We placed the Wien's pole (6.3 mm dowel marked in 10-cm intervals) vertically in the middle of the quadrant and at the four cardinal points at the end of each meter stick (Wiens 1969). Height and litter depth were also measured using the Wien's pole (Wiens 1969). Density was measured by counting the number of live, dead, and invasive species stems that touched the Wien's pole (Wiens 1969). Surveys were also conducted at two random locations within 50 meters per nest (Wiens 1969).

3.2.4 Nest Cameras

From May – August 2012 we set up Bushnell Trophy Cam XLT series (size: 840 cm^3, 5 Megapixel image sensor, infrared light-emitting diodes (12m-15m flash range), focal length = 3.1, FOV= 50°, 0.2 trigger speed) motion sensor cameras in front of nest openings to document songbird predator species, predation, or any disturbances at nests. Cameras were set to trigger every 5 seconds and recorded 30-second video clips at 30 frames per second. Motion sensor cameras were secured to the ground approximately 25-36 cm from the nest rim (Renfrew and Ribic 2003, Hernandez et al. 1997, Pietz and Granfors 2000, Thompson et al. 1999). To avoid inducing abandonment, cameras were not placed at nests during egg-laying or early incubation stages or before 11 a.m. Mountain Standard Time. (Thompson et al. 1999, Pietz and Granfors 2000, Renfrew and Ribic 2003). We wore non-scented latex gloves and kept installment times within 10 minutes.

3.2.5 Predator Trail Cameras (motion sensor)

From May – Aug 2012 we set up motion-sensor predator trail cameras to document predator activity and occurrence at our sites. At any given time, we had three sites (3 cameras per site, 9 cameras total) collecting predator data simultaneously. Sampling periods lasted 3-4 days (Sargeant and Johnson 1997), allowing each site to be sampled at least two times during the nesting season. After failing to obtain predator data using a random approach to motion sensor camera placement, I decided to place cameras in non-random locations to increase the probability of predator observations. Cameras were then placed near road sides, cattle trails, dugouts, canal crossings, and fence lines. Cameras were attached to a 4 foot "U-Post" when not attached to fence lines. Camera height ranged from 0.6 m – 1.0 m from the ground and triggered by movement. Minimum distance between cameras was 300 meters. We used three types of motion sensor cameras (1) Bushnell Trophy XLT, *n*=10, (2) HC500 Reconyx Hyperfire, *n*=1, (size:74 in.^{3} or 1219 cm^3, 3.1 Megapixel, 0.2 sec. trigger speed, 15m flash range) and (3) Cuddeback Attack IR, *n*=1, (size: 316 in.^{3} or 5190 cm^3, 5 Megapixel, 35 LEDs, 18m flash range, 0.25 sec. trigger speed).

Potential predators included the American badger (*Taxidea taxus*), coyote (*Canis latrans*), white-tailed deer (*Odocoileus virginianus)*, mule deer (*Odocoileus hemionus*), pronghorn (*Antilocapra americana)*, elk (*Cervus canadensis)*, gulls (Family *Laridae*), common raven (*Corvus corax)*, American crow (*Corvus brachyrhynchos)*, western meadowlark (*Sturnella magna*), and brown-headed cowbird (*Molothrus ater)(*Pietz and Granfors 2000, Renfrew and Ribic 2003, Renfrew et al. 2005, Kerns et al. 2010). Although cattle are known to incidentally depredate eggs or nestlings (Nack and Ribic 2005), they were excluded from analyses because cattle occurred in all study sites. I could not detect rodents, reptiles, and other small mammals using this survey method due to camera height and field of view typically pointed towards the horizon. The American badger was the smallest mammalian nest predator detected using this method.

3.2.6 Statistical Analysis

I used SAS 9.3 (SAS Institute Inc. 2008) to conduct all analyses. Alpha value of 0.1 was used in all models. I chose to assess statistical relationships found to have an alpha probability of 0.1 or lower, as this can reduce the chances for Type II error, which is a significant problem in conservation biology (Taylor and Gerrodette 1993).

Preliminary Analyses

For nesting success analyses, I used a binomial distribution. To select all other model distributions, I used Proc Genmod to test distribution fit of residuals for each species. I determined whether residuals fit negative binomial, Poisson, or normal distribution by using the deviance/ degrees of freedom ratio, box plots or QQ plots.

Prior to using Generalized Estimating Equations (GEE) (Proc GENMOD) for analysis, I ran preliminary analyses to determine which repeated measure variable (site) and nuisance fixed effects variables (year, Julian day) to include in final models for each species based on lowest quasi-likelihood under the independence model information criterion (QIC). Similarly, prior to using logistic exposure (NLMIXED) or GLMMs (Proc GLIMMIX) for analysis, I ran preliminary analyses to determine which random (site, nest) and nuisance fixed effects variables (year, Julian day) to include in final models for each species based on lowest Akaike's Information Criteria (AICc) value (AIC, Akaike 1974).

Nest site selection and nesting success

Prior to nest site selection analysis, vegetation density and structure data collected from each quadrant per nest quadrat were averaged, to produce one value per vegetation plot. I used General Linear Mixed Models (GLMMs) (PROC GLIMMIX) to determine whether vegetation density or structure differed at nests compared to random locations. Response variables included vegetation density (live grass density, dead grass density, and crested wheatgrass density) and structure (live grass cover, dead grass cover, forb cover, bare ground cover, shrub cover, lichen cover, moss cover, shrub cover, height, litter depth, and crested wheatgrass). Response variables were chosen based on vegetation characteristics thought to influence nest site selection and success of grassland songbirds (Dieni and Jones 2003, Lloyd and Martin 2005, Fisher and Davis 2011, Lusk and Koper 2013).

Although our study sites had very low crested wheatgrass cover (average 0.38%; Rogers 2013) it was selected as a variable because it was once used as a restoration method after drilling (Alberta Environment 2003) and is known to reduce reproductive success for chestnut-collared longspurs (Lloyd and Martin 2005).

Random effects considered for these analyses included “site” and “nest”. On several occasions models failed to converge when both random variables were included. In these cases the random effect “nest” parameter was estimated to be zero, suggesting that it explained little to no variance in the data and thus was unnecessary, and it was, therefore, removed from subsequent models. Bare ground cover and crested wheatgrass were transformed to occurrence data (presence/absence) and analyzed using a binomial distribution, due to low abundances of both variables.

I used the logistic exposure method (Shaffer 2004) (NLMIXED) to determine whether vegetation influenced nesting success. All models included “site” as a random effect. Based on results of my preliminary analyses, models for Savannah sparrow included fixed effects of year and Julian day, while models for other species did not. For species with low sample sizes, lichen/moss and shrub cover were excluded from analyses due to low occurrence.

Effects of infrastructure on nesting success

I combined all three years of nesting data for each species to maximize sample sizes and because my objective was to evaluate general effects of infrastructure on nesting success regardless of year. Abandoned nests and those with unknown fate were excluded from analyses. All models included “site” as a random effect, based on lowest AICc value (AIC, Akaike 1974). Similarly, based on preliminary analyses described above, models for

Savannah sparrow included "year" and "Julian day" as fixed effects, while models for other species did not.

Using the logistic exposure method (Shaffer 2004), three separate models were developed for nesting success analysis to determine effects of gas well infrastructure on nest success. For each model I assessed how infrastructure variables influenced nesting success for combined nests of all species, and also species-specific analyses for Baird's sparrow, chestnut-collared longspur, Savannah sparrow, Sprague's pipit, vesper sparrow, and western meadowlark. The first model included five explanatory variables (gas well pad density, distance to wells, roads, low impact roads, and dugouts) to determine how infrastructure on the landscape influenced nest success. The second model included three explanatory variables (gas well pad density, age of well, and gas well pad density and age of well interaction) to determine whether the effects of gas well pad density varied with well age. The third model included three explanatory variables (distance to nearest gas well pad, age of well, and distance to nearest gas well pad and age of well interaction) to determine whether the effects of gas well distance varied with well age.

Effects of infrastructure on clutch size, number of fledglings per nest, and egg-laying

Exact fledgling numbers per nest were unknown, due to the absence of post-fledging data. Therefore, the number of fledglings per nest was estimated from successful nests that were known to have at least 8 day old nestlings prior to the final visit. I chose 8 day old nestlings because on average grassland species in this study can fledge on day 8 or up to 3-4 days later (Ehrlich et al. 1998). Nests containing brown-headed cowbird eggs or nestlings were excluded from analysis because parasitism may decrease productivity (Sandercock et al. 2008).

Generalized linear mixed models of effects of infrastructure on clutch sizes and numbers of fledglings per nest did not converge due to small sample sizes, so I used Generalized Estimating Equations (GEE) to determine effects of gas well infrastructure on clutch size. All models included "site" as the repeated measure, while fixed effects (year or Julian days) differed depending on species based on preliminary results.

Three separate models were developed for clutch size analyses. The first model included five explanatory variables (gas well pad density, distance to wells, roads, low impact roads, and dugouts) to determine effects of infrastructure on clutch size. Because of low sample sizes for Sprague's pipit, vesper sparrow, and western meadowlark I was unable to assess effects of distance to high and low impact roads, and dugouts. The second model included three explanatory variables (gas well pad density, age of well, and gas well pad density and age of well interaction) to determine whether the effects of gas well pad density varied with well age. The third model included three explanatory variables (distance to nearest gas well pad, age of well, and distance to nearest gas well pad and age of well interaction) to determine whether the effects of gas pad distance varied with well age. Models that included gas well pad and interaction with well age as explanatory variables had centered Julian days to reduce collinearity caused by the interaction term in the model (Quinn and Keough 2002). The same models were conducted to evaluate effects of infrastructure on number of fledglings produced per nest; due to low sample size, the effects of gas well pad density and distance to well interaction with well age analysis for Sprague's pipit could not be evaluated.

I also used GEEs to determine whether egg-laying dates varied with distance to infrastructure (distance to well pads, roads, low impact roads, and cattle water source).

Predator Activity and Occurrence

Because I could not systematically identify potential predator individuals over time using data from motion-sensor cameras, I defined predator activity as the number of different predator species detected during a single survey period within each site. For example, within one survey period (ex. 72 hours), I detected three coyotes on three separate occasions, minutes apart, and an American badger; I assigned an activity value of 2 for the entire survey period as it represented the two species. If I observed two of the same species within one photo, then an activity level of two was assigned. This method may underestimate predator activity results, but reduces identification bias.

I described predator occurrence (binary) by assigning 1-presence and 0-absence; if one or more predators were detected during a single survey period it was assigned a 1 and if no predators were detected it was assigned a 0. "Site" was chosen as the repeated measure in all models as it had the lowest QIC value when compared to the null model.

I used Generalized Estimating Equations (GEE) to determine the effect of well pads on predator activity and occurrence, as GLMMs failed to converge due to small sample sizes. Three separate models were developed to assess effects of infrastructure on activity and occurrence. The first model included two explanatory variables (gas well pad density, distance to wells) to determine whether gas wells influenced predator activity or occurrence. The second model included three explanatory variables (gas well pad density, age of well, and gas well pad density and age of well interaction) to determine whether the effects of gas well pad density varied with well age. The third model also included three explanatory (gas well pad distance, age of well, and gas well pad distance and age of well interaction) to determine whether the effects of gas well pad distance varied with well age.

3.3 Results

3.3.1 General Results

From 2010-2012, 374 nests of 7 songbird species were found and monitored (Table 3.2). Six species were included in analyses: Baird's sparrow (BAIS) (*n* = 24), chestnut-collared longspur (CCLO) (*n* = 155), Savannah sparrow (SAVS) (*n* = 128), Sprague's pipit (SPPI) (*n* = 11), vesper sparrow (VESP) (*n* = 20), and western meadowlark (WEME) (n = 15). Species excluded from analyses were clay-collared sparrow (CCSP) (*n* = 5) and unknown species (*n* = 16).

Overall, 44% of the nests found were successful, 33% failed due to depredation, and 10% were abandoned (Table 3.2). Predation was the primary reason for nest failure. Chestnut-collared longspurs (5.9%) and Savannah sparrows (3.2%) had the highest abandonment rates compared to other species (Table 3.2). In 2012, abandonment among chestnut-collared longspur (7.4%) and Savannah sparrow (6.6%) nests seemed to be a direct result of placing motion sensor cameras in front of nests as part of the monitoring effort (Table 3.2). Occurrences of brood parasitism were low, accounting for only 0.5% of all nest outcomes (Table 3.2).

Average clutch size of all (successful and unsuccessful) nests included in analyses ranged from 3.8 to 4.9 eggs (Table 3.3) and average number of fledglings ranged from 3.2 to 3.8 per successful nest (Table 3.4). In general, each species had smaller clutch sizes later in the breeding seasons (Figure 3.5).

Western meadowlark had the earliest mean egg-laying initiation date (May 23) and vesper sparrow latest (June 20) (Table 3.5). Chestnut-collared longspurs and Savannah sparrows nest initiation peaked during May 15-30 and June 12-25; however, nest initiation peaks for other species were less discernable due to low sample sizes (Figure 3.7).

In 2012, we deployed 25 nest motion sensor cameras and recorded of two partial predation events. Two separate chestnut-collared longspur nests were partially predated by Plains Garter Snakes (*Thamnophis radix*) at the nestling stage (approx. 7-8 and 10-11 days). In both cases, a Plains Garter Snake forced-fledged one or more nestlings while consuming a nestling.

Also in 2012, we deployed motion sensor cameras to capture images of potential songbird predators. Of 65 observation periods, 33 (51%) captured at least one photo of a predator. Due to camera malfunctions, shortened battery life, or cameras being knocked out of place (mostly by cattle) throughout the season, total survey hours varied by site (Table 3.6, Appendix II). The most frequently observed potential songbird predator was the pronghorn (*n*= 13; 28.3%), followed by coyote and deer (*n*=11; 23.9% each), brown-headed cowbird (*n*=6; 13%), American badger (*n*=2; 4.4%) and least frequently observed were elk, corvids, and gulls (*n*=1; 2.21% for each) (Table 3.6). The greatest number of predators observed (*n*=9) was in a site with 4 gas well pads and none were observed were in two sites that contained 8 and 9 gas wells pads (Appendix II). In control sites, more predators (*n*=17) were detected and predator activity was highest (0.0137±0.0045), but this might be due to the variation in number of sampling sites (Table 3.6, Appendix II).

Daily and monthly precipitation data were obtained from the Government of Canada Climate weather station in Brooks, Alberta. May through August average daily precipitation was highest in 2012 and lowest in 2011 (Appendix III). Total rainfall in June 2012 was the second highest monthly record since 2000 (Appendix IV). Average monthly (May-Aug) rainfall in 2010, 2011, and 2012 were fairly similar and consistent with differences between years ranging from 10 mm – 20 mm. In comparison, years prior (2000-2009) were quite variable, during which average monthly rain fall varied anywhere from 10 mm – 80 mm year to year (Appendix IV).

Table 3.2. Grassland songbird nest abundance and fates in southeastern Alberta 2010-2012.

	Baird's Sparrow (*n*=24)			**Chestnut-collared Longspur (*n*=155)**			**Savannah Sparrow (*n*=128)**			**Sprague's Pipit (*n*=11)**			**Vesper Sparrow (*n*=20)**		
	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012	2010	2011	2012
Successful (%)	1(50)	3(33)	10(77)	25(38)	32(53)	11(38)	7(50)	29(63)	36(53)	0	1(100)	5(50)	3(60)	4(67)	4(44)
Depredated (%)	1(50)	4(44)	2(15)	23(35)	24(40)	7(24)	3(21)	14(30)	20(33)	0	0	5(50)	2(40)	1(17)	2(22)
Weather (%)	0	0	1(8)	1(2)	1(2)	0	1(17)	0	1(1.5)	0	0	0	0	0	0
Abandoned (%)	0	1(11)	0	11(17)	1(2)	10(35)	1(17)	2	9(13)	0	0	0	0	1(17)	0
Livestock (%)	0	0	0	1(2)	0	1(3)	1(17)	0	0	0	0	0	0	0	3(33)
Parasitized (%)	0	0	0	1(2)	0	0	0	0	0	0	0	0	0	0	0
Nonviable (%)	0	1(11)	0	4(6)	2(3)	0	1(17)	1	2(3)	0	0	0	0	0	0
Total nests found	2	9	13	66	60	29	14	46	68	0	1	10	5	6	9
Yearly %[1]	1.89	6.82	9.56	62.26	45.45	21.3	13.21	34.85	50	0	0.76	7.35	4.72	4.55	6.6

	Western Meadowlark (*n*=15)			**Clay-colored Sparrow (*n*=5)**			**Unknown Species (*n*=16)**			**Overall total (2010-2012)**	**% of all nests found (2010-2012)**
	2010	2011	2012	2010	2011	2012	2010	2011	2012		
Successful (%)	2(29)	2(67)	3(60)	0	2(67)	0	3(30)	0	1(50)	184	49
Depredated (%)	3(43)	1(33)	2(40)	2(100)	1(33)	0	3(30)	3(75)	0	123	33
Weather (%)	0	0	0	0	0	0	0	0	0	5	1
Abandoned (%)	1(14)	0	0	0	0	0	1(10)	0	1(50)	39	10
Livestock (%)	0	0	0	0	0	0	0	0	0	6	2
Parasitized (%)	1(14)	0	0	0	0	0	0	0	0	2	0.5
Nonviable (%)	0	0	0	0	0	0	3(30)	1(25)	0	15	4
Total nests found	7	3	5	2	3	0	10	4	2		
Yearly %[1]	6.6	2.27	3.68	1.89	2.27	0	9.43	3.03	1.47		

	2010	2011	2012	Total # of nests
Total nests	106	132	136	374
% of overall[2]	28.3	35.3	36.4	-

1 Percentage of nests found that year by species

2 Percentage of nests found out of the overall total

Table 3.3. Mean clutch size of all nests with standard deviation (SD) of six grassland songbirds in southeastern Alberta, 2010-2012. Clutch size per nest is indicated, as well as the percentage of nests found, indicated in parentheses.

	Clutch Size (%)						
	1	**2**	**3**	**4**	**5**	**6**	**Mean +/- SD**
Baird's sparrow (*n*=24)	0	0	1 (3.85)	12 (46.15)	13 (50.0)	0	4.400 ± 0.645
Chestnut-collared longspur (*n* = 176)	2 (1.14)	0	40 (22.73)	91 (51.7)	36 (20.45)	1 (0.57)	3.890 ± 0.820
Savannah sparrow (*n*=133)	1 (0.75)	3 (2.26)	14 (10.53)	46 (34.59)	66 (49.62)	3 (2.26)	4.326 ± 0.940
Sprague's pipit (*n*=11)	0	0	0	2 (18.18)	8 (72.73)	1 (9.09)	4.909 ± 0.540
Vesper sparrow (*n*=23)	0	0	6 (26.09)	14 (60.87)	2 (8.7)	0	3.783 ± 0.899
Western meadowlark (*n*=19)	0	2 (10.52)	1 (5.26)	6 (31.58)	7 (36.84)	3 (15.79)	4.556 ± 1.280

Table 3.4. The mean number of fledglings per successful nest with standard deviation (SD) of six grassland songbirds in southeastern Alberta, 2010-2012. Fledglings per nest is indicated, as well as the percentage, in parentheses.

	Number Fledged per Nest (%)					
	1	**2**	**3**	**4**	**5**	**Mean +/- SD**
Baird's sparrow (*n*=16)	1 (6.25)	1 (6.25)	3 (18.75)	8 (50.0)	3 (18.75)	3.688 ± 1.078
Chestnut-collared longspur (*n*=71)	7 (9.86)	6 (8.45)	26 (36.62)	28 (39.44)	4 (5.63)	3.225 ± 1.030
Savannah sparrow (*n*=74)	5 (6.76)	3 (4.05)	14 (18.92)	30 (40.54)	22 (29.73)	3.824 ± 1.110
Sprague's pipit (*n*=6)	1 (16.67)	0	1 (16.67)	3 (50.0)	1 (16.67)	3.500 ± 1.380
Vesper sparrow (*n*=13)	1 (7.69)	1 (7.69)	6 (46.15)	5 (38.46)	0	3.154 ± 0.899
Western meadowlark (*n*=8)	1 (12.5)	0	1 (12.5)	4 (50.0)	2 (25.0)	3.750 ± 1.280

Table 3.5. Early, late, median, and mean egg-laying initiation dates for each species in 2010, 2011, 2012, and all years.

				Mean Egg-laying Initiation Date						
	Earliest Date	Latest Date	Median Date	2010	*n*	2011	*n*	2012	*n*	All Years
Baird's sparrow (*n*=20)	10-May	28-Jun	21-May	25-May	3	31-May	4	30-May	13	28-May
Chestnut-collared longspur (*n*=106)	4-May	9-Jul	6-Jun	17-Jun	45	28-May	40	9-Jun	21	7-Jun
Savannah sparrow (*n*=92)	7-May	16-Jul	31-May	22-Jun	14	1-Jun	31	3-Jun	47	8-Jun
Sprague's pipit (*n*=9)	6-May	25-Jun	7-Jun	7-Jun	1	-----	0	1-Jun	10	4-Jun
Vesper sparrow (*n*=16)	17-May	8-Jul	16-Jun	8-Jul	5	14-Jun	3	10-Jun	8	20-Jun
Western meadowlark (*n*=12)	26-Apr	3-Jul	8-May	22-May	5	23-May	4	24-May	3	23-May

Figure 3.6. Percentage of nests of each clutch size across the breeding season by grassland bird species in southeastern Alberta, 2010-2012. Week 1 = April 24-30, Week 2 = May 1-7, Week 3 = May 8-14, Week 4 = May 15-21, Week 5 = May 22-28, Week 6 = May 29-June 4, Week 7 = June 5-11, Week 8 = June 12-18, Week 9 = June 19-25, Week 10 = June 26 – July 2, Week 11 = July 3-9, Week 12 = July 10-16. Clutch sizes indicated by colored lines.

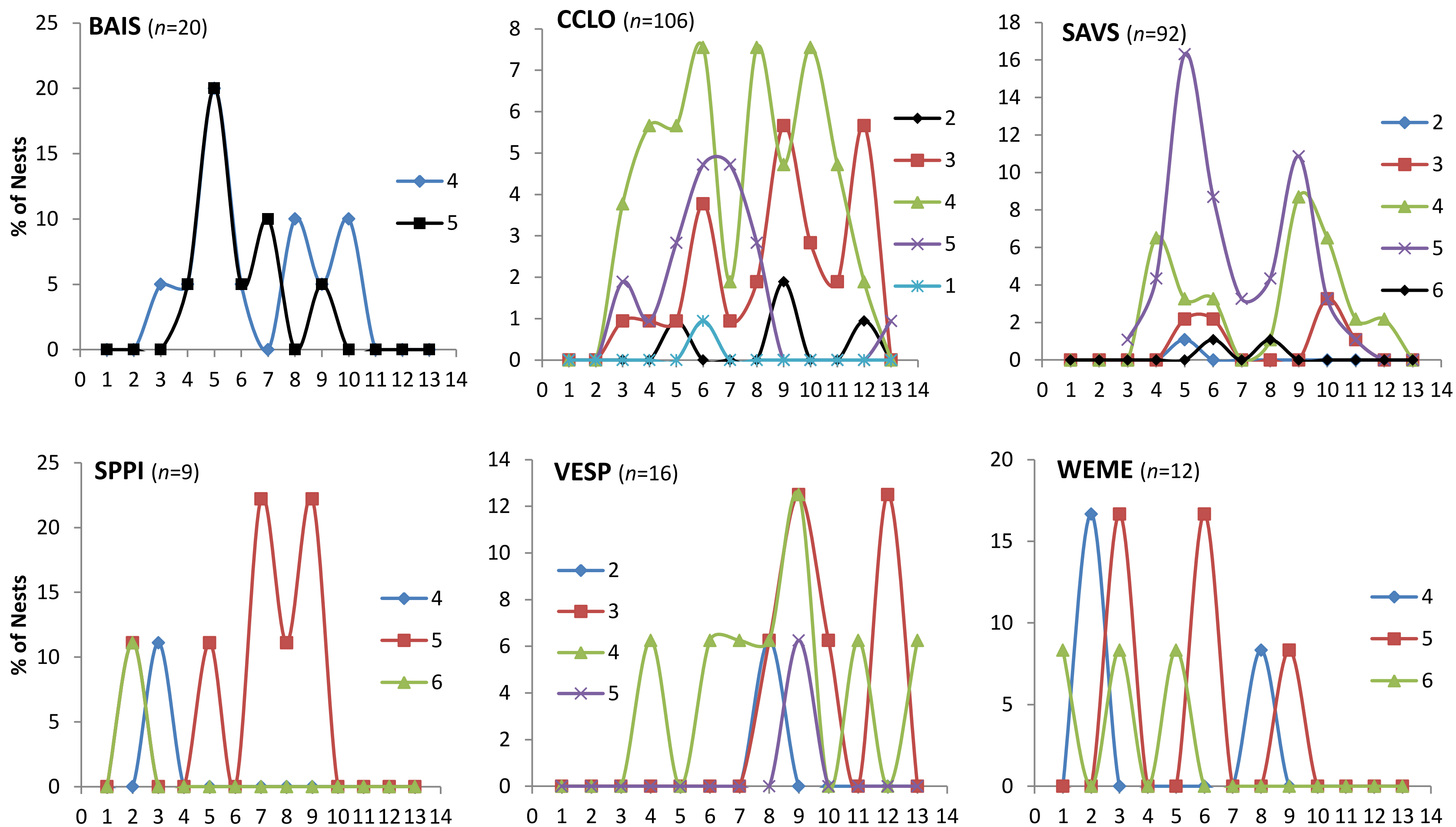


Figure 3.7. Percent nests initiated by grassland bird species in southeastern Alberta, 2010-2012. Week 1 = April 24-30, Week 2 = May 1-7, Week 3 = May 8-14, Week 4 = May 15-21, Week 5 = May 22-28, Week 6 = May 29-June 4, Week 7 = June 5-11, Week 8 = June 12-18, Week 9 = June 19-25, Week 10 = June 26 – July 2, Week 11 = July 3-9, Week 12 = July 10-16

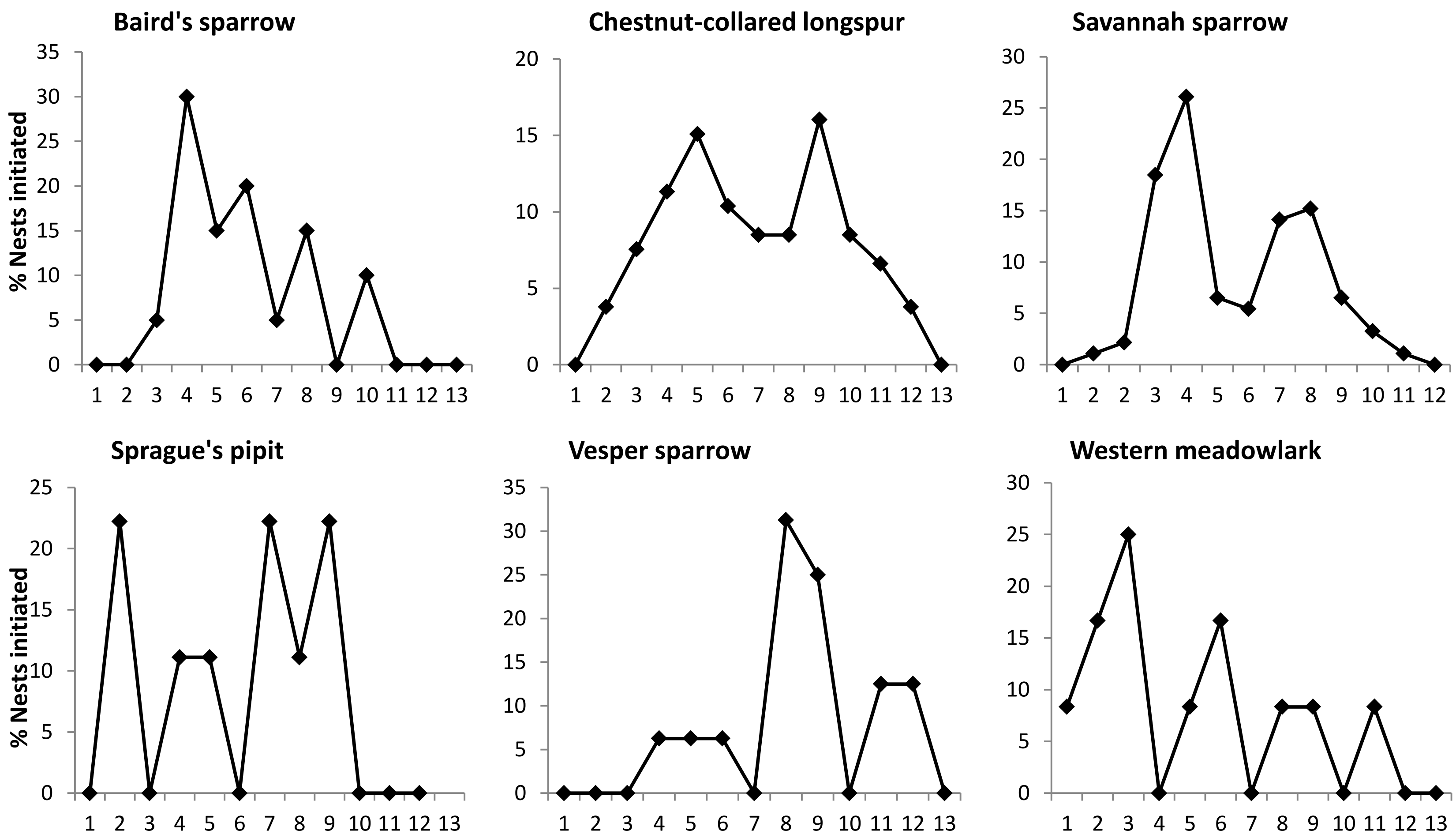


Table 3.6. Potential songbird predators and site activity in southeastern Alberta, 2012.

Well pads/ section (*n* = # of sites)	Predator Species										
	American badger (*Taxidea taxus*)	Brown-headed Cowbirds (*Molothrus ater*)	Common Raven *(Corvus corax)*	Gull *(Laridae)*	Coyote (*Canis latrans*)	Deer (*Odocoileus)*	Elk (*Cervus Canadensis)*	Pronghorn (*Antilocapra Americana)*	Total	Average activity/ total site survey hours	Total survey hours of all sites
0 (*n*=4)	0	1	0	1	5	4	0	6	17	0.014±0.005	1358
1 (*n*=1)	0	0	0	0	0	2	0	0	2	0.008±0.0	238
3 (*n*=1)	0	0	0	0	0	0	0	1	1	0.004±0.0	259
4 (*n*=2)	0	0	0	0	1	3	1	6	11	0.013±0.006	766
5 (*n*=2)	1	0	0	0	3	2	0	0	6	0.012±0.002	493
7 (*n*=1)	0	5	1	0	1	0	0	0	7	0.019±0.0	368
8 (*n*=1)	0	0	0	0	0	0	0	0	0	0.0±0.0	65
9 (*n*=1)	0	0	0	0	0	0	0	0	0	0.0±0.0	408
16 (*n*=1)	1	0	0	0	1	0	0	0	2	0.007±0.0	280
Total	2	6	1	1	11	11	1	13	46		

3.3.2 Nest site selection and nesting success

All species but vesper sparrow selected nest microhabitats that varied in structure or density of live grass, dead grass, grass height, bare ground, lichen and moss, or litter depth from the surrounding habitat (Table 3.7). Greater density and cover of both live and dead grass was found at nests of all five species (Table 3.7). Both Baird's (β: 5.75, SE: 2.071, *p-value*: 0.0149) and Savannah sparrow (β: 3.44, SE: 0.892, *p-value*: 0.0015) nests had taller grass than the surrounding area (Table 3.7). Both Baird's (β: -1.69, SE: 0.699, *p-value*: 0.0301) and Savannah sparrow (β: -0.83, SE: 0.305, *p-value*: 0.0098) nests were located in microhabitats with less bare ground than available; conversely, western meadowlark (β: 3.09, SE: 0.700, *p-value*: 0.0694) nests were surrounded by more bare ground than available (Table 3.7). Both chestnut-collared longspur (β: -4.51, SE: 1.712, *p-value*: 0.0134) and Savannah sparrow (β: -1.31, SE: 0.252, *p-value* < 0.0001) nests had less lichen or moss than the surrounding habitat (Table 3.7). Savannah sparrow (β: 0.21, SE: 0.081, *p-value*: 0.0142) nests had greater litter depth than the surrounding habitat (Table 3.7). The presence of crested wheatgrass, forb cover, or shrub cover did not vary at any species nest sites when compared to the surrounding habitat (Table 3.7)

Savannah sparrow nesting success increased where there was greater live grass cover and more bare ground (Figure 3.8a, 3.8b). Vesper sparrow nesting success decreased with greater bare ground (Figure 3.8c); however, the effect size was small. I found no influence of nest vegetation on nesting success for Baird's sparrow, chestnut-collared longspur, Sprague's pipit, or western meadowlark (Appendix III).

Table 3.7. Difference in nest vegetation microhabitat and random locations for six grassland bird species in southeastern Alberta, Canada, 2010-2012

		Density				% Cover						Presence/Absence	
Species		Height	Litter Depth	Dead Grass	Live Grass	Dead Grass	Live Grass	Bare Ground	Forb	Lichen or Moss	Shrub	Bare Ground	CWG
	β	5.7446	0.2896	1. 5347	0.2596	8.0676	7.5640	n/a	0.4070	n/a	n/a	-1.6885	-0.7647
BAIS	SE	2.0712	0.3179	0.5843	0.1650	3.5323	3.2913	n/a	2.4391	n/a	n/a	0.6999	1.4631
(*n*=20)	LCL	1.3022	-0.3922	0.2814	-0.0942	0.4917	0.5050	n/a	-4.8243	n/a	n/a	-3.1897	-3.9026
	UCL	10.1869	0.9715	2.7879	0.6134	15.6435	14.6231	n/a	5.6383	n/a	n/a	-0.1873	2.3733
	p-value	0.0149	0.3777	0.0199	0.1379	0.0385	0.0375	n/a	0.8699	n/a	n/a	0.0301	0.6094
	β	1.1199	0.0893	0.1683	0.1046	3.0861	1.9535	-0.8758	0.1372	-4.5069	-0.0118	n/a	0.1913
CCLO	SE	0.8921	0.0856	0.0575	0.0580	1.3731	1.3080	0.6336	0.0692	1.7119	0.1886	n/a	0.5375
(*n*=137)	LCL	-0.7046	-0.0857	0.0506	-0.0139	0.2778	-0.7217	-2.1715	-0.0044	-8.0081	-0.3976	n/a	-0.9079
	UCL	2.9444	0.2643	0.2859	0.2232	5.8945	4.6287	0.4200	0.2788	-1.0056	0.3739	n/a	1.2906
	p-value	0.2193	0.3051	0.0066	0.0814	0.0324	0.1461	0.1774	0.0570	0.0134	0.9504	n/a	0.7244
	β	3.4429	0.2092	0.2784	0.2633	2.9623	5.9178	-0.8303	-0.3962	-1.3126	-0.5774	n/a	-0.6184
SAVS	SE	0.9982	0.0812	0.0536	0.0502	1.4332	1.4401	0.3046	1.1668	0.2522	0.3697	n/a	0.5981
(*n*=120)	LCL	1.4184	0.0446	0.1697	0.1616	0.0556	2.9971	-1.4480	-2.7625	-1.8241	-1.3272	n/a	-1.8313
	UCL	5.4674	0.3738	0.3872	0.3650	5.8689	8.8386	-0.2126	1.9702	-0.8011	0.1725	n/a	0.5945
	p-value	0.0015	0.0142	<.0001	<.0001	0.0460	0.0002	0.0098	0.7362	<.0001	0.1271	n/a	0.3080
	β	0.8523	0.6931	0.3075	1.0083	n/a	0.0104	n/a	-4.5313	n/a	n/a	1.3348	n/a
SPPI	SE	1.3185	0.5345	0.1815	0.3559	n/a	3.9958	n/a	3.1149	n/a	n/a	1.1732	n/a
(*n*=11)	LCL	-2.3740	-0.6148	-0.1366	0.1375	n/a	-9.7669	n/a	-12.1530	n/a	n/a	-1.5358	n/a
	UCL	4.0785	2.0011	0.7516	1.8792	n/a	9.7877	n/a	3.0905	n/a	n/a	4.2054	n/a
	p-value	0.5419	0.2423	0.1412	0.0298	n/a	0.9980	n/a	0.1960	n/a	n/a	0.2986	n/a

	β	0.5819	0.2353	-0.1219	-0.1100	3.6667	-5.3929	n/a	0.3126	n/a	n/a	-0.2348	-0.4008
VESP	SE	2.8537	0.2295	0.1634	0.1835	3.6313	3.5998	n/a	0.1905	n/a	n/a	0.5954	1.1036
(*n*=21)	LCL	-5.6990	-0.2698	-0.4816	-0.5139	-4.3259	-13.3159	n/a	-0.1067	n/a	n/a	-1.5453	-2.8298
	UCL	6.8628	0.7404	0.2379	0.2939	11.6592	2.5302	n/a	0.7319	n/a	n/a	1.0756	2.0282
	p-value	0.8421	0.3272	0.4715	0.5610	0.3343	0.1622	n/a	0.1290	n/a	n/a	0.7008	0.7233
	β	2.3139	0.0480	0.5455	0.6224	3.6806	-2.0826	n/a	4.6021	n/a	n/a	3.0996	-0.3275
WEME	SE	2.3807	0.2183	0.1738	0.5080	4.3469	3.6709	n/a	2.8202	n/a	n/a	0.6999	0.9703
(*n*=15)	LCL	-3.0716	-0.4458	0.0683	-0.5266	-6.1529	-10.3868	n/a	-1.7776	n/a	n/a	0.3323	-2.5225
	UCL	7.6994	0.5418	1.0227	1.7715	13.5140	6.2216	n/a	10.9818	n/a	n/a	5.8669	1.8676
	p-value	0.3565	0.8308	0.0647	0.2515	0.4191	0.5844	n/a	0.1371	n/a	n/a	0.0694	0.7435

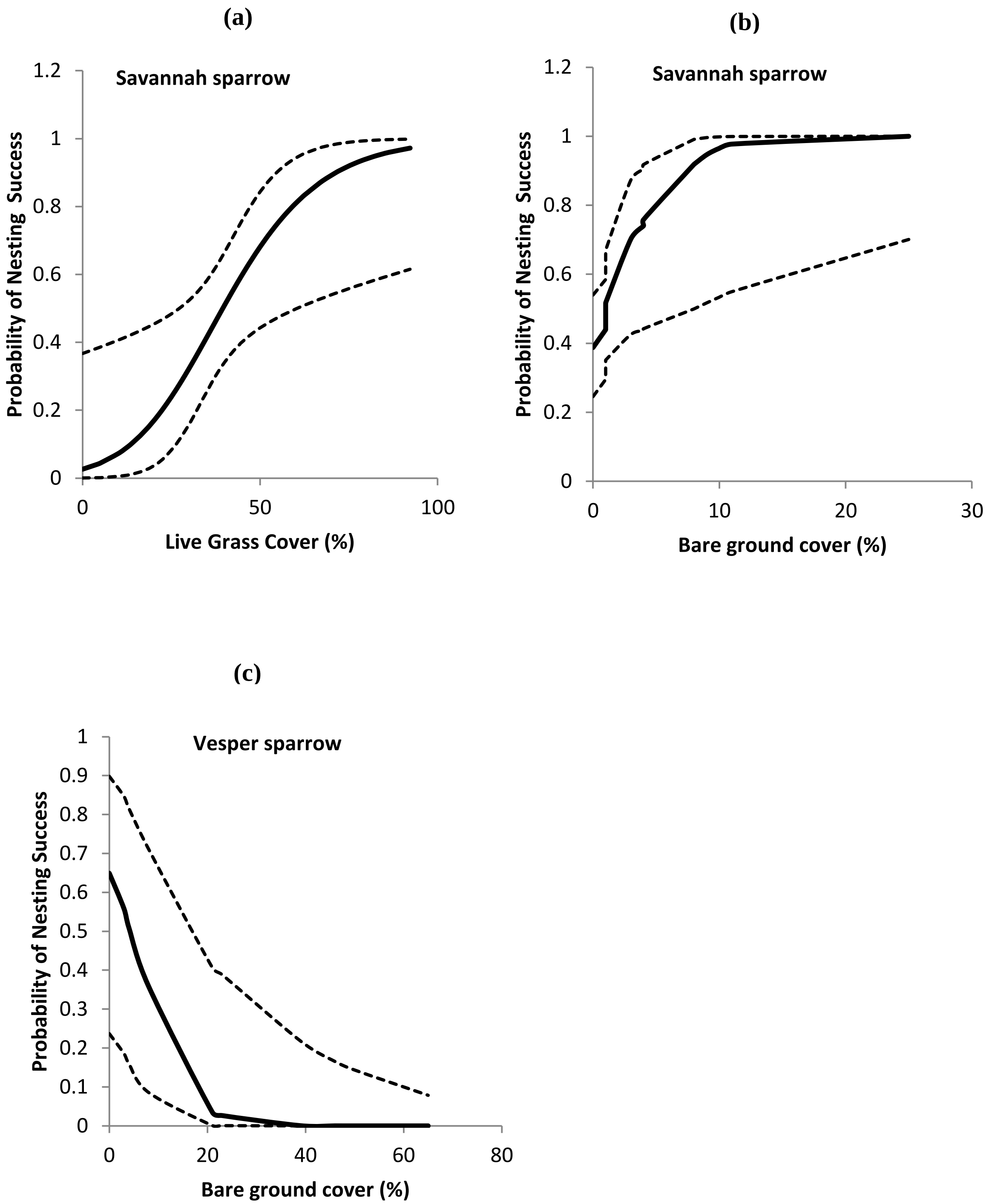


Figure 3.8. The effects of vegetation or lack thereof at nests on nesting success for: (a) live grass cover (%) on Savannah sparrow *(Passerculus sandwichensis)*, (b) bare ground cover (%) on Savannah sparrow *(Passerculus sandwichensis)* nesting success (c) bare ground cover (%) on Vesper sparrow *(Pooecetes gramineus)* nesting success in southeastern Alberta, 2010-2012.

3.3.3 Effects of gas well pads on nesting success

There was no effect of distance to gas well pads on nesting success for any species (Table 3.8) except western meadowlark (β: 0.33, SE: 0.175, *p-value*: 0.0811) (Table 3.9). Western meadowlark nesting success was low within 300 meters of newer well pads, but increased as distance to well pad increased; this effect declined as well age decreased (Figure 3.9).

Vesper sparrow was the only species that experienced greater nesting success as gas well pad density increased (β: 0.21, SE: 0.113, *p-value*: 0.0801 (Table 3.8, Figure 3.10). When well age interaction with gas well pad density were included as explanatory variables, no effects were detected for any species (APPENDIX IV), suggesting that older well pads had similar effects compared with younger wells.

Table 3.8. The effects of gas well pad infrastructure, associated wells, dugouts, Julian day, and year on nesting success of grassland songbirds in southeastern Alberta, 2010-2012.

		Parameter						
		Distances						
Species		Gas Well Pad	Road	Low Impact Road	Dugout	Gas Well Pad Density	Year	Julian Day
	β	0.1726	0.4688	0.6617	-0.0349	0.0324	n/a	n/a
All Species	SE	0.1950	0.2680	0.4546	0.1889	0.0319	n/a	n/a
($n_{interval}$=1026)	LCL	-0.0203	0.0261	-0.0892	0.2614	-0.0203	n/a	n/a
	UCL	0.0851	0.9114	1.4125	0.9114	0.0851	n/a	n/a
	p-value	0.3107	0.0816	0.1470	0.8536	0.3107	n/a	n/a
	β	0.2382	0.5632	0.6049	-0.0492	0.0071	n/a	n/a
CCLO	SE	0.3225	0.4364	0.7808	0.2798	0.05580	n/a	n/a
($n_{interval}$=375)	LCL	-0.2972	-0.1613	-0.6914	-0.5136	-0.0855	n/a	n/a
	UCL	0.7735	1.2877	1.9011	0.4152	0.0998	n/a	n/a
	p-value	0.4619	0.1998	0.4404	0.8608	0.8986	n/a	n/a
	β	-0.4898	-2.6981	-3.8786	1.3466	-0.1127	n/a	n/a
BAIS	SE	2.2518	1.9496	1.8831	1.4625	0.1614	n/a	n/a
($n_{interval}$=80)	LCL	-4.3835	-6.0692	-7.1346	-1.1822	-0.3917	n/a	n/a
	UCL	3.4039	0.6730	-0.6225	3.8754	0.1664	n/a	n/a
	p-value	0.8301	0.1824	0.0534	0.3687	0.4935	n/a	n/a
	β	-0.7206	1.0162	1.6729	0.2487	-0.0088	-0.6136	-0.0239
SAVS	SE	0.4833	0.5483	0.8639	0.3994	0.0613	0.3655	0.0127
($n_{interval}$=342)	LCL	-1.5245	0.1042	0.2358	-0.4157	-0.1107	-1.2216	-0.0450
	UCL	0.0833	1.9283	3.1100	0.0932	0.0932	-0.0056	-0.0028
	p-value	0.1398	0.0674	0.0562	0.5352	0.8864	0.0970	0.0637
	β	1.3648	0.4319	-2.0738	-1.3394	0.0622	n/a	n/a
SPPI	SE	2.7498	1.1348	2.5386	0.8491	0.0923	n/a	n/a
($n_{interval}$=88)	LCL	-3.4035	-1.5360	-6.4758	-2.8117	-0.0979	n/a	n/a
	UCL	6.1331	2.3998	2.3283	0.1330	0.2223	n/a	n/a
	p-value	0.6257	0.7080	0.4247	0.1321	0.5093	n/a	n/a

	β	-0.0598	-0.6153	1.6259	-0.6708	0.2058	n/a	n/a
VESP	SE	2.2529	1.1107	1.4820	0.5689	0.1133	n/a	n/a
($n_{interval}$=123)	LCL	-3.7726	-2.5048	-0.8953	-1.6386	-0.0130	n/a	n/a
	UCL	3.8922	1.2742	4.1470	0.2970	0.3985	n/a	n/a
	p-value	0.9790	0.5840	0.2820	0.2483	0.0801	n/a	n/a
	β	0.7018	-2.6271	1.8509	-1.4058	0.0513	n/a	n/a
WEME	SE	3.3284	1.4758	1.9634	1.0489	0.1016	n/a	n/a
($n_{interval}$=81)	LCL	-4.9926	-5.1520	-1.5082	-3.2004	-0.1226	n/a	n/a
	UCL	6.3962	-0.1023	5.2100	0.3888	0.2251	n/a	n/a
	p-value	0.8348	0.0877	0.3552	0.1927	0.6186	n/a	n/a

Table 3.9. The effects of gas well pad distance, age of well, well pad and age interaction, Julian day, and year on nesting success of grassland songbirds in southeastern Alberta, 2010-2012.

		Parameter				
Species		Gas Well Pad	Age of Gas Well	Interaction	Year	Julian Day
	β	0. 9704	0.0306	-0.0760	n/a	n/a
All Species	SE	0.5333	0.0186	0.0470	n/a	n/a
($n_{interval}$=1082)	LCL	0.0900	-0.0001	-0.1536	n/a	n/a
	UCL	1.8508	0.0613	0.0001	n/a	n/a
	p-value	0.0700	0.1012	0.1071	n/a	n/a
	β	0.4692	-0.0103	0.02310	n/a	n/a
CCLO	SE	0.7745	0.0275	0.07241	n/a	n/a
($n_{interval}$=415)	LCL	-0.8150	-0.0559	-0.1432	n/a	n/a
	UCL	1.7534	0.0353	0.0970	n/a	n/a
	p-value	0.5458	0.7091	0.7503	n/a	n/a
	β	4.5101	0.1138	-0.3455	n/a	n/a
BAIS	SE	4.3923	0.1189	0.3717	n/a	n/a
($n_{interval}$=86)	LCL	-3.0480	-0.0907	-0.9851	n/a	n/a
	UCL	12.0682	0.3183	0.2941	n/a	n/a
	p-value	0.3162	0.3491	0.3631	n/a	n/a
	β	1.2868	0.0535	-0.1217	-0.2354	-0.0157
SAVS	SE	0.9932	0.0352	0.08042	0.2923	0.0113
($n_{interval}$=373)	LCL	-0.3625	-0.0050	-0.2552	-0.7207	-0.0344
	UCL	2.9361	0.1120	0.0119	0.2500	0.0031
	p-value	0.1982	0.1318	0.1335	0.4226	0.1679
	β	3.8316	0.0785	0.1598	n/a	n/a
SPPI	SE	19.9977	0.6216	2.3349	n/a	n/a
($n_{interval}$=56)	LCL	-32.8265	-1.0609	-4.1203	n/a	n/a
	UCL	40.4897	1.2180	4.4399	n/a	n/a
	p-value	0.8523	0.9022	0.9469	n/a	n/a
	β	-0.4377	0.0417	0.0135	n/a	n/a
VESP	SE	3.6545	0.0940	0.2889	n/a	n/a
($n_{interval}$=88)	LCL	-6.7952	-0.1217	-0.4892	n/a	n/a
	UCL	5.9197	0.2051	0.5161	n/a	n/a
	p-value	0.9061	0.6628	0.9634	n/a	n/a
	β	10.6304	0.3280	-0.0673	n/a	n/a
WEME	SE	8.3147	0.1745	0.3548	n/a	n/a
($n_{interval}$=52)	LCL	-4.0144	0.0206	-1.2983	n/a	n/a
	UCL	25.2751	0.6353	-0.0483	n/a	n/a
	p-value	0.2219	0.0811	0.0811	n/a	n/a

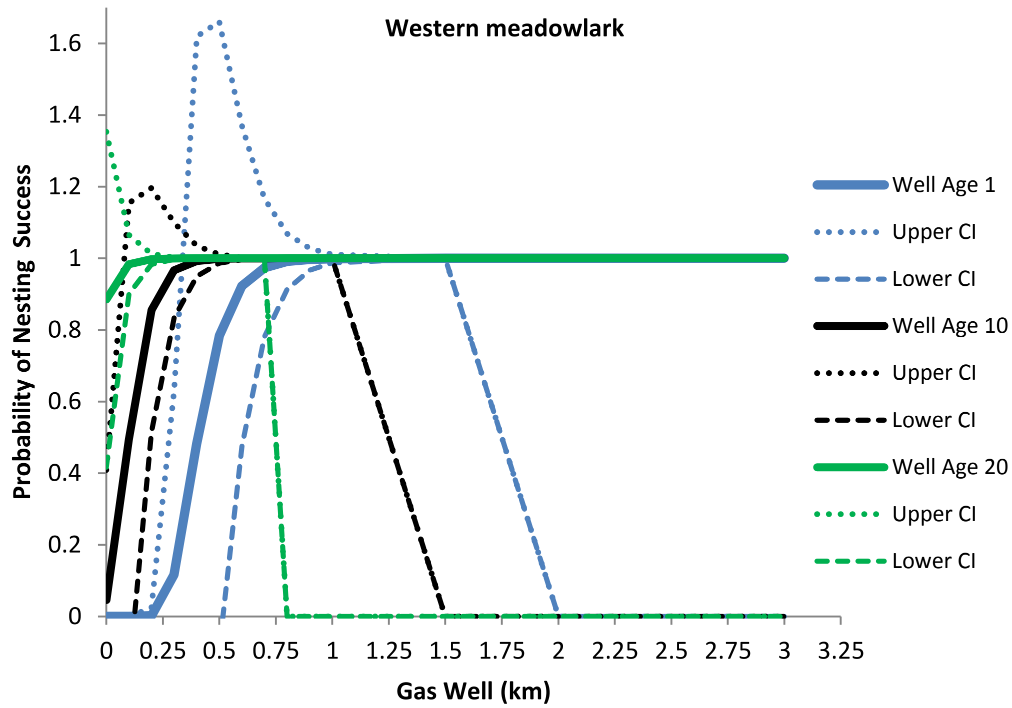


Figure 3.9. The effects of gas well pad distance and well age on Western meadowlark *(Sturnella neglecta)* nesting success in southeastern Alberta, 2010 – 2012.

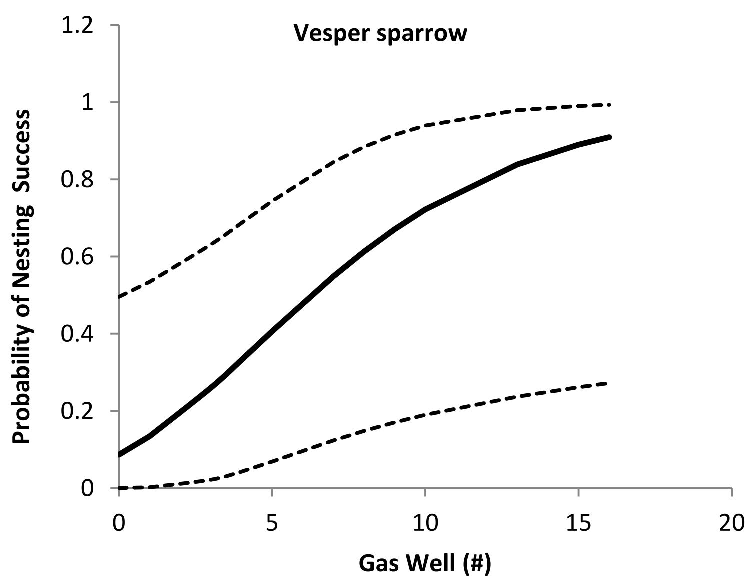


Figure 3.10. The effect of gas well pad density (wells per 2.56 km^2) on Vesper sparrow *(Pooecetes gramineus)* nesting success in southeastern Alberta, 2010-2012.

3.3.4 Effects of gas well pads on clutch size and number of fledglings per nest

Due to low sample size, relationships found for all species other than Savannah sparrow and chestnut-collared longspur reproductive success results may be spurious.

I found effects of distance to nearest gas well pad consistently and similarly impacted clutch size of all species but western meadowlark (Table 3.10). Clutch size increased further from well pads when all nests were pooled (β: 0.56, SE: 0.132, $P < 0.0001$) (Figure 3.11a), Baird's Sparrow (β: 0.64, SE: 0.214, *p-value*: 0.0027), chestnut-collared longspur (β: 0.29, SE: 0.129, *p-value*: 0.0266) (Figure 3.11b), Savannah sparrow (β: 0.10, SE: 0.042, *p-value*: 0.0173) (Figure 3.11c), Sprague's pipit (β: 0.31, SE: 0.107, *p-value*: 0.0036), and vesper sparrow (β: 0.85, SE: 0.496, *p-value*: 0.0850) (Table 3.10). However, the effect of distance of well pad and well age varied for two species. Vesper sparrow clutch size increased (β: 0.13, SE: 0.022, $P < 0.0001$) further from older (30+) well pads (Table 3.11, Figure 3.12a); conversely, Savannah sparrow clutch size decreased (β: -0.05, SE: 0.021, *p-value*: 0.0217) further from older (30+) well pads (Table 3.11, Figure 3.12b).

Effects of distance to gas well pads on the number of fledglings per nest varied among several species (Table 3.12). Baird's (β: 0.10, SE: 0.042, $P < 0.0001$) and vesper sparrow (β: 0.10, SE: 0.042, $P < 0.0001$) had greater numbers of fledglings per nest further from well pads (Table 3.12); however, Sprague's pipits experienced the opposite, where fledgling numbers per nest was higher closer to well pads (Table 3.12). The effect of distance to well pads did not vary with well age for any of the focal species (Appendix VII).

For Baird's Sparrow (β: 0.03, SE: 0.011, *p-value*: 0.0026) and Sprague's pipit (β: 0.02, SE: 0.008, *p-value*: 0.0177) clutch size increased as gas well pad density increased (Table

3.12). In addition, clutch size tended to be lower in sites with newer well pads, but higher in sites with older well padss for combined nests of the 6 focal species (β: 0.002, SE: 0.001, *p-value*: 0.0638), Baird's sparrow (β: 0.003, SE: 0.001, *p-value*: 0.0123), chestnut-collared longspur (β: 0.005, SE: 0.002, *p-value*: 0.0006), and western meadowlark (β: 0.010, SE: 0.005, *p-value*: 0.0549) (Figures 3.13a; 3.13b; 3.13c; 3.13d).

Baird's sparrow (β: -0.04, SE: 0.017, *p-value*: 0.0297), Sprague's pipit (β: -0.19, SE: 0.010, $P < 0.0001$), and Savannah sparrow (β: -0.02, SE: 0.011, *p-value*: 0.0443) (Table 3.12, Figure 3.14) nests had fewer fledglings per nest as gas well pad density increased (Table 3.12). In contrast, the number of vesper sparrow fledglings per nest increased as gas well pad density increased (Table 3.12). The effect of gas well pad density did not vary with well age for any of the focal species (Appendix VIII).

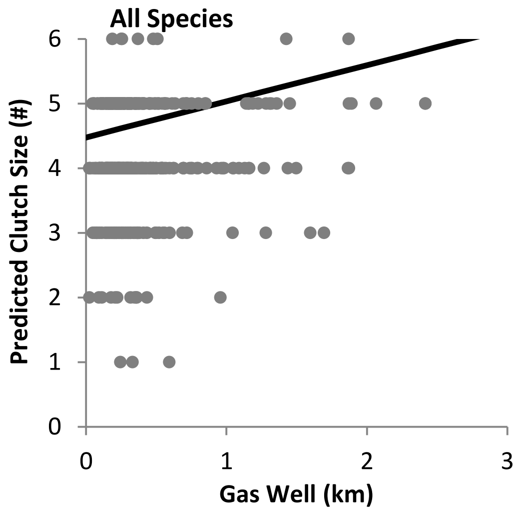
Table 3.10. The effects of gas well pad infrastructure, associated linear features, dugout, and Julian Day on predicted clutch size of grassland songbirds in southeastern Alberta, 2010-2012.

		Parameter					
		Distances				Density	Temporal
Species		Gas Well Pad	Road	Low Impact Road	Dugout	Gas Well	Julian Days
All Species (*n*=356)	β	0.5589	0.0264	0.0210	0.3008	0.0309	-0.0056
	SE	0.1322	0.1246	0.2102	0.0695	0.0197	0.0024
	LCL	0.3414	-0.1785	-0.3248	0.1865	-0.0015	-0.0096
	UCL	0.7764	0.2313	0.3668	0.4151	0.0632	-0.0016
	p-value	<0.0001	0.8323	0.9204	<0.0001	0.1163	0.0206
BAIS (*n*=24)	β	0.6417	-	-	-	0.0330	-
	SE	0.2136	-	-	-	0.0110	-
	LCL	0.2903	-	-	-	0.0150	-
	UCL	0.9930	-	-	-	0.0510	-
	p-value	0.0027	-	-	-	0.0026	-
CCLO (*n*=152)	β	0.2856	-0.2500	0.1160	0.1906	0.0268	-0.0047
	SE	0.1288	0.1776	0.2814	0.1114	0.0195	0.0028
	LCL	0.0737	-0.5421	-0.3469	0.0074	-0.0052	-0.0092
	UCL	0.4974	0.0421	0.5789	0.3738	-0.0588	-0.0002
	p-value	0.0266	0.1592	0.6802	0.0870	0.1691	0.0882
SAVS (*n*=114)	β	0.1003	-0.0183	-0.0563	0.0460	0.0110	-
	SE	0.0422	0.0274	0.0403	0.0237	0.0085	-
	LCL	0.0310	-0.0634	-0.1225	0.0070	-0.0029	-
	UCL	0.1697	0.0268	0.0099	0.0851	0.0249	-
	p-value	0.0173	0.5045	0.1620	0.0524	0.1932	-
SPPI (*n*=11)	β	0.3113	-	-	-	0.0200	-
	SE	0.1069	-	-	-	0.0084	-
	LCL	0.1354	-	-	-	0.0061	-
	UCL	0.4872	-	-	-	0.0338	-
	p-value	0.0036	-	-	-	0.0177	-
VESP (*n*=23)	β	0.8548	-	-	-	0.0304	-
	SE	0.4963	-	-	-	0.0362	-
	LCL	1.6712	-	-	-	-0.0292	-
	UCL	1.72	-	-	-	0.0901	-
	p-value	0.0850	-	-	-	0.4011	-
WEME (n=15)	β	0.6836	-	-	-	-0.0326	-
	SE	0.5394	-	-	-	0.0483	-
	LCL	-0.2036	-	-	-	-0.1121	-
	UCL	1.5709	-	-	-	0.0468	-
	p-value	0.2050	-	-	-	0.4992	-

Table 3.11. The effects of gas well pad distance, well age interaction, Julian day, and year on predicted clutch size of grassland songbirds in southeastern Alberta, 2010-2012.

		Gas Well Pad Distance and Age Interaction				
		Distance	Age	Distance and Age interaction	Julian Days	Year
All Species	β	0.5003	0.0117	-0.0149	-0.0060	-
(*n*=374)	SE	0.1570	0.0068	0.0164	0.0023	-
	LCL	0.2421	0.0005	-0.0419	-0.0098	-
	UCL	0.7585	0.0229	0.0120	-0.0022	-
	p-value	0.0014	0.0845	0.3628	0.0102	-
BAIS	β	0.7273	0.0196	-0.0556	-	-
(*n*=24)	SE	0.4614	0.0074	0.0353	-	-
	LCL	-0.0316	0.0075	-0.1136	-	-
	UCL	1.4862	0.0318	0.0025	-	-
	p-value	0.1149	0.0078	0.1155	-	-
CCLO	β	0.5913	0.0165	-0.0083	-	-
(*n*=155)	SE	0.2868	0.0079	0.0324	-	-
	LCL	0.1195	0.0036	-0.0617	-	-
	UCL	1.0631	0.0295	0.0450	-	-
	p-value	0.0393	0.0354	0.7975	-	-
SAVS	β	0.5904	0.0195	-0.0475	-0.0040	-
(*n*=120)	SE	0.2625	0.0096	0.0207	0.0053	-
	LCL	0.1586	0.0036	-0.0816	-0.0127	-
	UCL	1.0223	0.0354	-0.0135	0.0046	-
	p-value	0.0245	0.0431	0.0217	0.4433	-
	β	1.9762	0.0988	-0.3029	-	-
SPPI	SE	2.3003	0.1136	0.3515	-	-
(*n*=11)	LCL	-1.8075	-0.0881	-0.8810	-	-
	UCL	5.7600	0.2857	0.2753	-	-
	p-value	0.3903	0.3847	0.3889	-	-
VESP	β	-0.7108	-0.0218	0.1300	-	-
(*n*=20)	SE	0.4730	0.0097	0.0222	-	-
	LCL	-1.4888	-0.0378	0.0934	-	-
	UCL	0.0671	-0.0058	0.1666	-	-
	p-value	0.1329	0.0251	<0.0001	-	-
WEME	β	1.6771	0.0145	-0.0601	-	-
(*n*=15)	SE	1.2899	0.0200	0.0898	-	-
	LCL	-0.4445	-0.0183	-0.2078	-	-
	UCL	3.7987	0.0473	0.0877	-	-
	p-value	0.1935	0.4671	0.5037	-	-

(a)



(b)

(c)

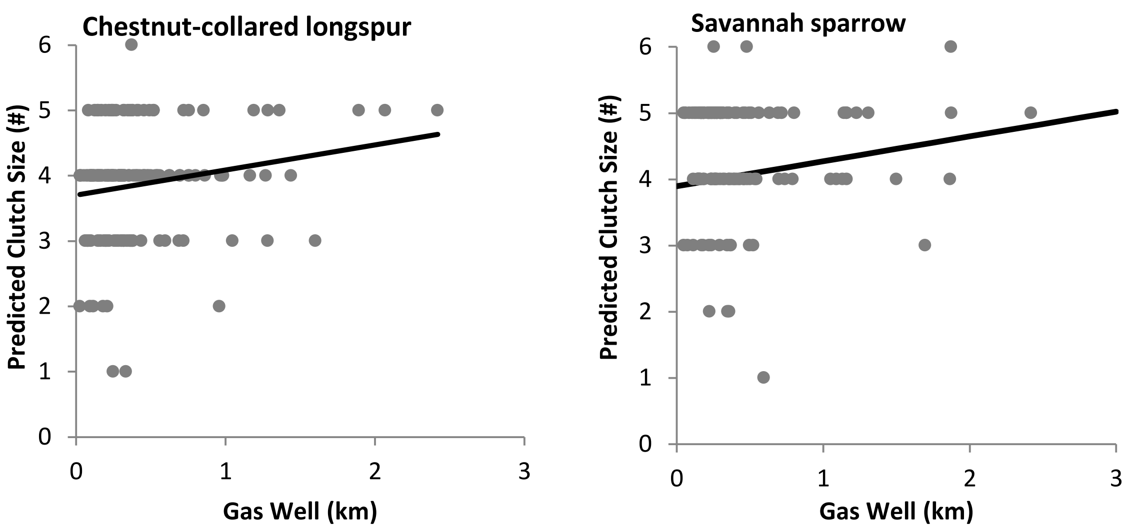
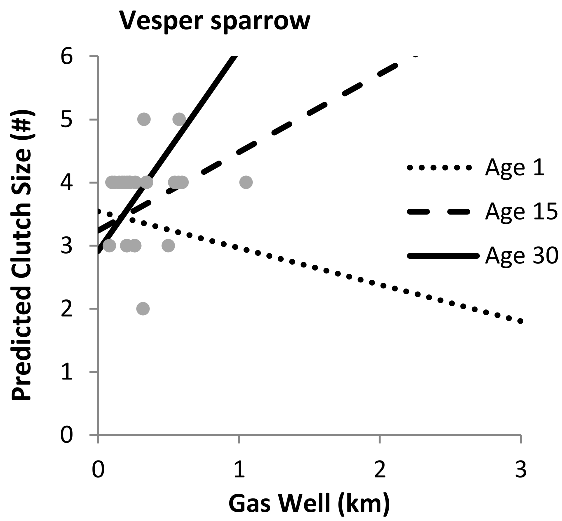


Figure 3.11. The effect of gas well pad distance on predicted clutch size, including raw data points, for (a) All combined nests for 6 grassland focal species, (b) Chestnut-Collared Longspur *(Calcarius ornatus)*, and (c) Savannah Sparrow *(Passerculus sandwichensis)*in southeastern Alberta, 2010-2012.

(a)



(b)

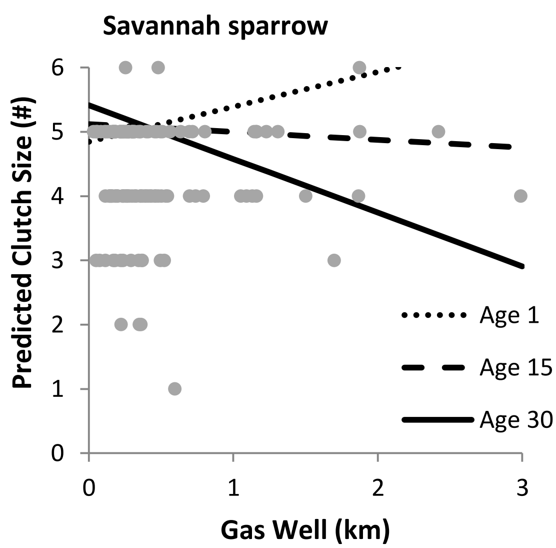


Figure 3.12. The effects of gas well pad distance and well age interaction on clutch size of (a) Vesper Sparrow *(Pooecetes gramineus)* and (b) Savannah Sparrow *(Passerculus sandwichensis)* in southeastern Alberta, 2010 – 2012.

Table 3.12. The effects of gas well pad infrastructure, associated linear features, dugout, and Julian day on the predicted number of fledglings per nest of grassland songbirds in southeastern Alberta, 2010-2012.

		Parameters					
		Distances				**Density**	**Temporal**
Species		Gas Well Pad	Road	Low Impact Road	Dugout	Gas Well Pad	Julian Days
All Species	β	-0.0905	0.0833	0.5923	0.2804	-0.0234	-0.0163
	SE	0.1303	0.1512	0.1970	0.0856	0.0166	0.0035
(*n*=172)	LCL	-0.3049	-0.1653	0.2683	0.1395	-0.0508	-0.0219
	UCL	0.1239	0.3320	0.9164	0.4213	0.0040	-0.0106
	p-value	0.4874	0.5814	0.0026	0.0011	0.1596	<0.0001
	β	0.9838	-	-	-	-0.0371	-
BAIS	SE	0.3078	-	-	-	0.0171	-
(*n*=15)	LCL	0.4775	-	-	-	-0.0651	-
	UCL	1.4901	-	-	-	-0.0090	-
	p-value	0.0014	-	-	-	0.0297	-
	β	-0.0938	0.2439	0.8020	0.0057	0.0366	-
CCLO	SE	0.1670	0.2986	0.4371	1.1631	0.0393	-
(*n*=62)	LCL	-0.3686	-0.2473	0.0831	-0.2626	-0.0280	-
	UCL	0.1809	0.7350	1.5210	0.2740	0.1011	-
	p-value	0.5744	0.4141	0.0665	0.9723	0.3518	-
	β	0.1014	0.2472	0.2407	0.2428	-0.0228	-0.0223
SAVS	SE	0.2173	0.1484	0.2151	0.1056	0.0114	0.0039
(*n*=63)	LCL	-0.2561	0.0032	-0.1131	0.0692	-0.0415	-0.0286
	UCL	0.4588	0.4913	0.5946	0.4165	-0.0042	-0.0159
	p-value	0.6409	0.0956	0.2631	0.0214	0.0443	<0.0001
	β	1.6432	-	-	-	0.1229	-
VESP	SE	0.8692	-	-	-	0.0367	-
(*n*=13)	LCL	0.2135	-	-	-	0.0626	-
	UCL	3.0728	-	-	-	0.1832	-
	p-value	0.0587	-	-	-	0.0008	-
SPPI	β	-0.8789	-	-	-	-0.1864	-
(*n*=7)	SE	0.1361	-	-	-	0.0102	-
	LCL	-1.1028	-	-	-	-0.2032	-
	UCL	-0.6550	-	-	-	-0.1696	-
	p-value	<0.0001	-	-	-	<0.0001	-
	β	2.7210	-	-	-	0.1237	-
WEME	SE	4.3591	-	-	-	0.1716	-
(*n*=8)	LCL	-4.4491	-	-	-	-0.1586	-
	UCL	9.8911	-	-	-	0.4061	-
	p-value	0.5325	-	-	-	0.4710	-

Table 3.13. The effects of gas well pad density and age interaction, Julian day, and year on predicted clutch size of grassland songbirds in southeastern Alberta, 2010-2012.

		Parameters				
		Density	**Age**	**Density and Age Interaction**	**Julian Days**	**Year**
All Species	β	-0.0206	-0.0098	0.0019	-0.0050	-
(*n*=374)	SE	0.0197	0.0106	0.0010	0.0025	-
	LCL	-0.0530	-0.0272	0.0002	-0.0091	-
	UCL	0.0118	0.0076	0.0036	-0.0009	-
	p-value	0.2963	0.3554	0.0638	0.0445	-
BAIS	β	-0.0331	-0.0290	0.0030	-	-
(*n*=24)	SE	0.0132	0.0171	0.0012	-	-
	LCL	-0.0549	-0.0572	0.0010	-	-
	UCL	-0.0113	-0.0009	0.0050	-	-
	p-value	0.0124	0.0896	0.0123	-	-
CCLO	β	-0.0582	-0.0327	0.0050	-0.0061	-
(*n*=155)	SE	0.0260	0.0119	0.0015	0.0028	-
	LCL	-0.1009	-0.0523	0.0026	-0.0106	-
	UCL	-0.0154	-0.0131	0.0075	-0.0015	-
	p-value	0.0253	0.0061	0.0006	0.0295	-
SAVS	β	-0.1328	-0.0582	0.0680	-	-
(*n*=120)	SE	0.0969	0.0525	0.0540	-	-
	LCL	-0.2922	-0.1445	-0.0207	-	-
	UCL	0.0266	0.0282	0.1568	-	-
	p-value	0.1706	0.2681	0.2072	-	-
	β	0.0455	0.0125	-0.0023	-	-
SPPI	SE	0.0407	0.0121	0.0029	-	-
(*n*=11)	LCL	-0.0214	-0.0074	-0.0070	-	-
	UCL	0.1124	0.0324	0.0024	-	-
	p-value	0.2631	0.3014	0.4250	-	-
VESP	β	0.0534	0.0447	-0.0043	-	-
(*n*=23)	SE	0.0629	0.0585	0.0069	-	-
	LCL	0.1569	-0.0515	-0.0157	-	-
	UCL	0.8500	0.7600	0.0071	-	-
	p-value	0.3964	0.4447	0.5375	-	-
WEME	β	-0.2012	-0.0912	0.0095	-	-
(*n*=15)	SE	0.0817	0.0531	0.0049	-	-
	LCL	-0.3356	0.1787	0.0014	-	-
	UCL	-0.0669	-0.0038	0.0176	-	-
	p-value	0.0137	0.0860	0.0549	-	-

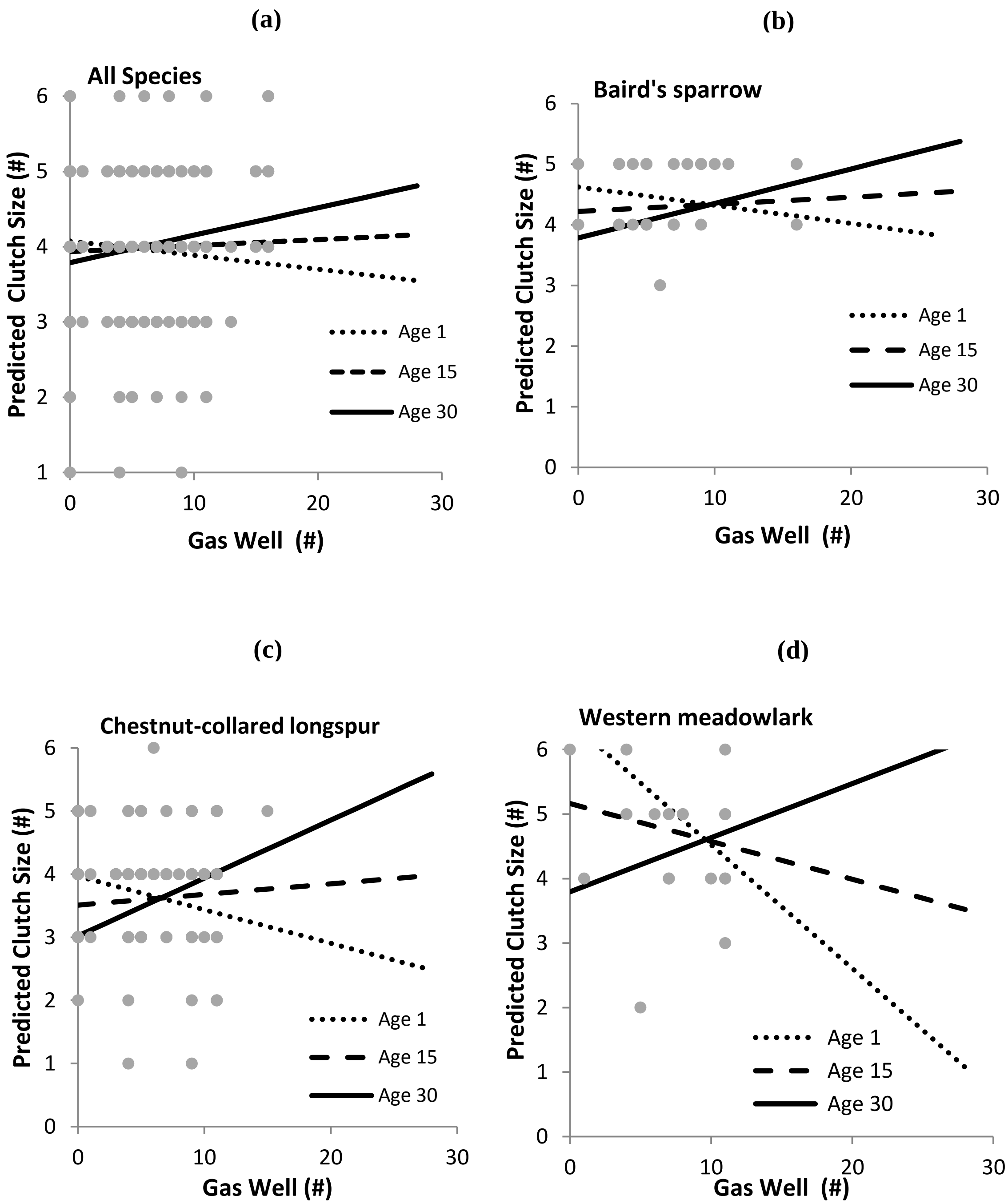


Figure 3.13. The effects of gas well pad density and well age interaction on predicted clutch size for (a) combined nests for 6 focal species and (b) Baird's Sparrow *(Ammodramus bairdii)*, (c) Chestnut-Collared Longspur *(Calcarius ornatus)* (d) Western Meadowlark *(Sturnella neglecta)* in southeastern Alberta, 2010-2012.

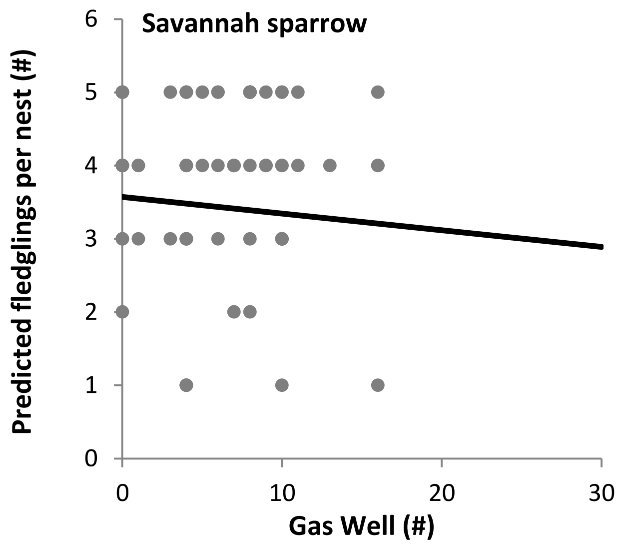


Figure 3.14. The effect of gas well pad density on the number of fledglings per nest, including raw data points for Savannah Sparrow *(Passerculus sandwichensis)* in southeastern Alberta, 2010-2012.

3.3.5 Effects of linear features and cattle water sources

Nesting success for all combined nests of the six focal species (β: 0.47, SE: 0.268, *p-value*: 0.0816) and Savannah sparrow (β: 1.02, SE: 0.548, *p-value*: 0.0674) increased further from high impact roads (Table 3.8, Figure 3.15a, 3.15b, 3.15c.). Western meadowlark experienced higher nesting success closer to high impact roads (β: -2.63, SE: 1.476, *p-value*: 0.0877) (Figure 3.15d). Savannah sparrows experienced higher nesting success further from low impact roads (β: 0.67, SE: 0.864, *p-value*: 0.0562) (Figure 3.16a). In contrast, Baird's sparrows experienced higher nesting success when nesting closer to low impact roads (β: -3.88, SE: 1.883, *p-value*: 0.0534) (Figure 3.16b).

There was no effect of high impact or low impact roads on clutch size for Savannah sparrows and chestnut-collared longspurs (Table 3.10).

Savannah sparrow fledglings per nest increased further from high impact roads (β: 0.25, SE: 0.148, *p-value*: 0.0956) (Figure 3.17). I also found fledgling numbers to increase further from low impact roads when I combined nests of all focal species (β: 0.59, SE: 0.197, *p-value*: 0.0026) and when evaluating chestnut-collared longspurs alone (β: 0.80, SE: 0.437, *p-value*: 0.0665) (Figure 3.18a; 3.18b).

No effect of distance to nearest cattle water source on nesting success was detected for any species (Table 3.8).

Clutch size increased when nesting further from water sources for all combined nests of focal species (β: 0.30, SE: 0.070, $P < 0.0001$), and when evaluating chestnut-collared longspurs (β: 0.19, SE: 0.111, *p-value*: 0.0870), and Savannah sparrows (β: 0.05, SE: 0.024, *p-value*: 0.0524) (Figure 3.19a; 3.19b; 3.19c).

Cattle water sources also influenced the number of fledglings per nest (Table 3.12). I found the number of fledglings per nest increased further from water sources when I combined nests of all focal species (β: 0.28, SE: 0.086, *p-value*: 0.0011) and when evaluating Savannah sparrow alone (β: 0.24, SE: 0.106, *p-value*: 0.0214) (Figure 3.20a; 3.20b).

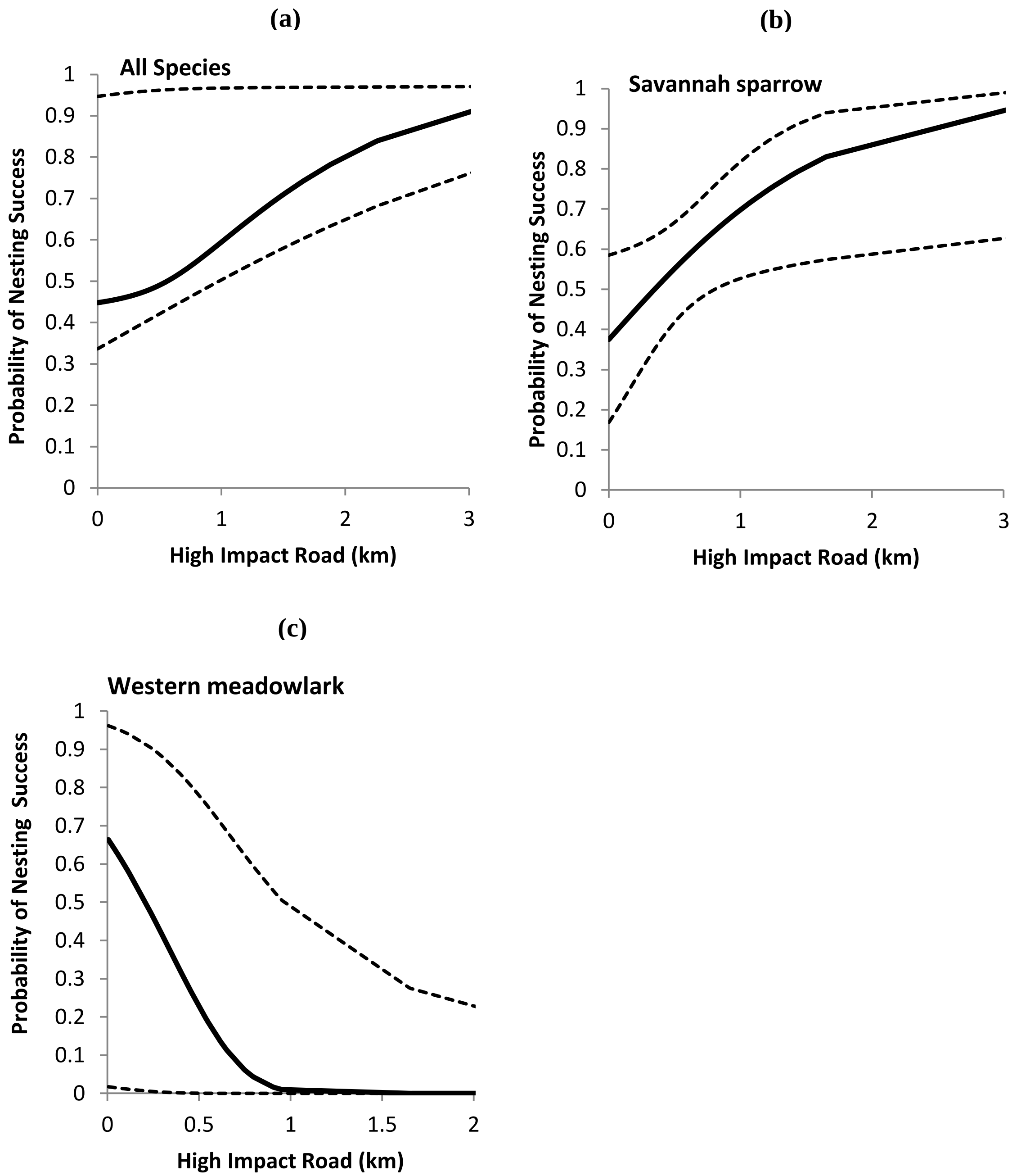


Figure 3.15. The effect of high impact roads on (a) combined nests of six focal grassland bird species nesting success and (b) Savannah Sparrow *(Passerculus sandwichensis)* nesting success (c) Western Meadowlark *(Sturnella neglecta)* nesting success in southeastern Alberta, 2010-2012.

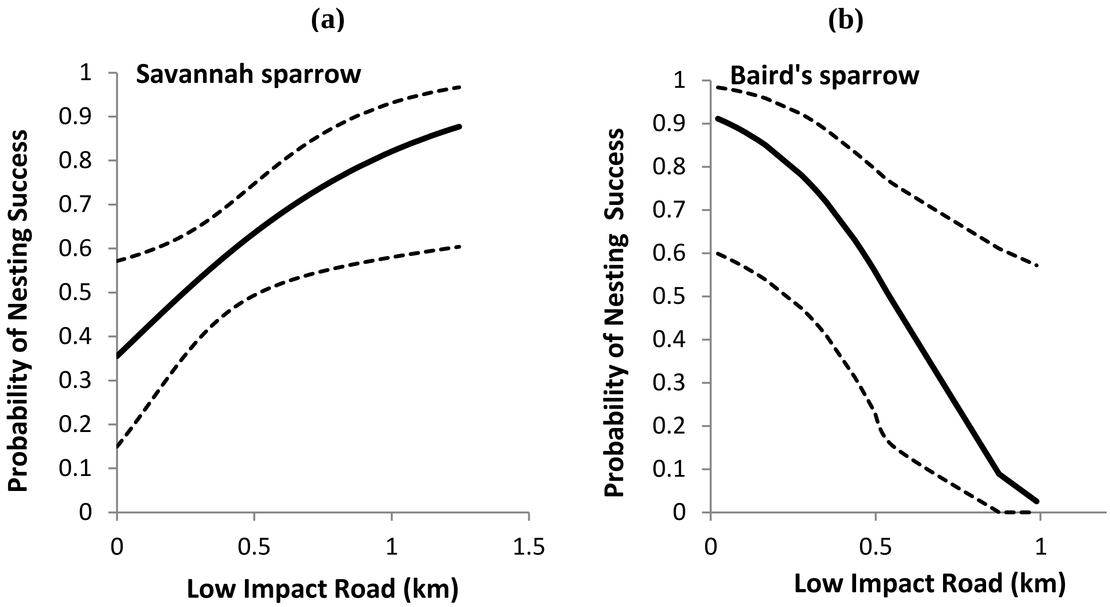


Figure 3.16. The effect of low impact road on nesting success for (a) Savannah Sparrow *(Passerculus sandwichensis)* (b) Baird's Sparrow *(Ammodramus bairdii)* in southeastern Alberta, 2010-2012.

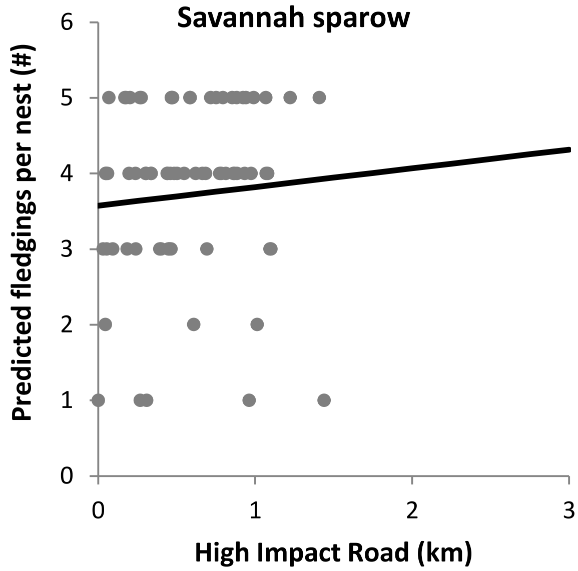


Figure 3.17. The effect of distance to high impact road on the number of fledglings per nest (#) for Savannah Sparrow *(Passerculus sandwichensis)*, including raw data points, in southeastern, Alberta, 2010-2012.

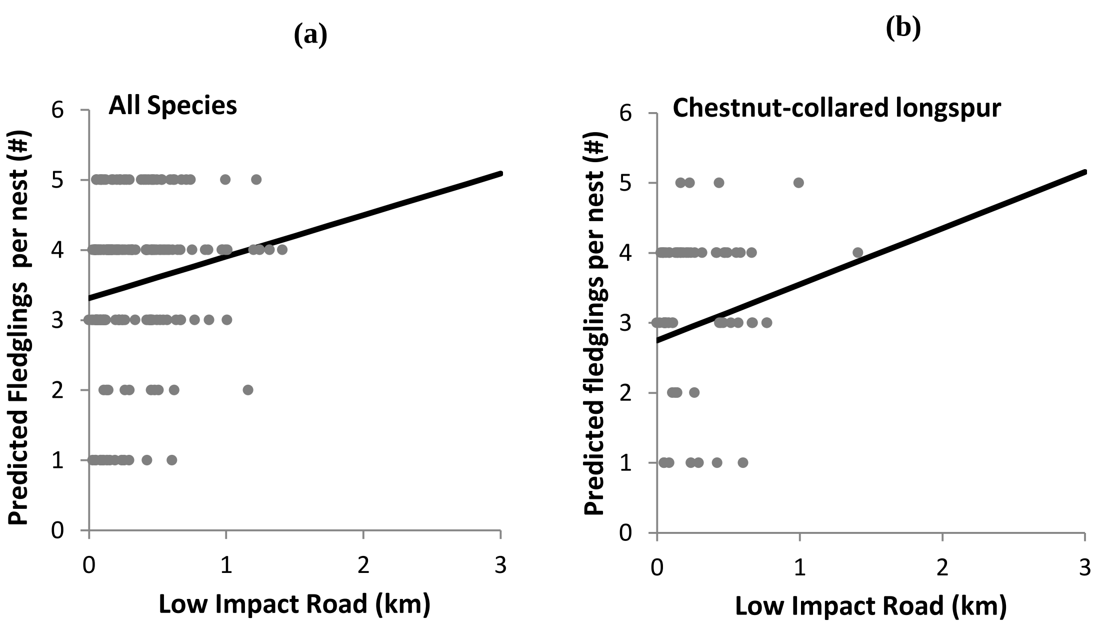


Figure 3.18. The effect of distance to low impact road on the number of fledglings per nest (#) for (a) All combined nests for 6 grassland focal species and (b) Chestnut-Collared Longspur *(Calcarius ornatus)*, including raw data points, in southeastern, Alberta, 2010-2012.

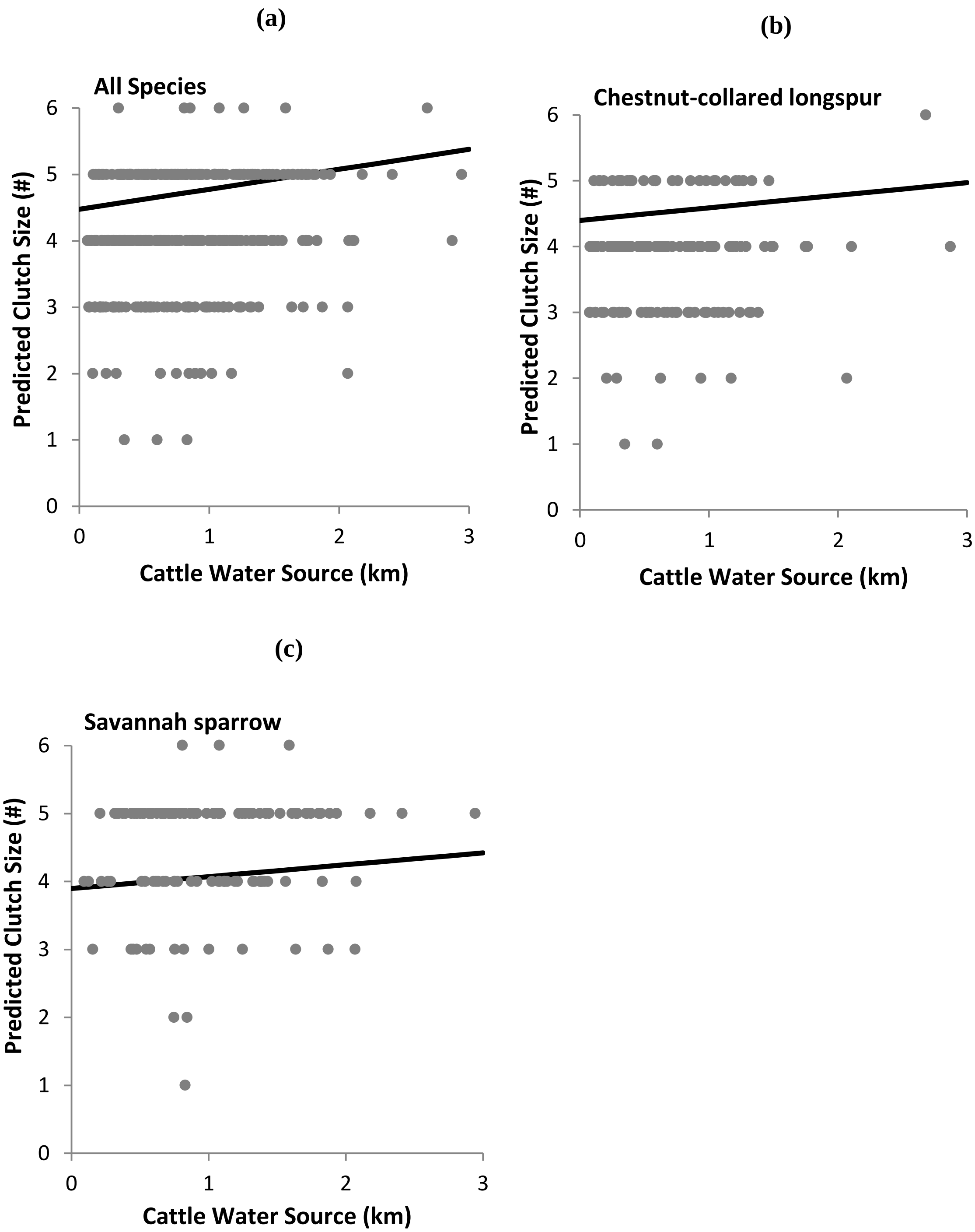


Figure 3.19. The effect of cattle water source (km) on clutch size for (a) All combined nests for 6 grassland focal species (b) Chestnut-collared longspur *(Calcarius ornatus)* and (c) Savannah sparrow *(Passerculus sandwichensis)* in southeastern Alberta, 2010-2012.

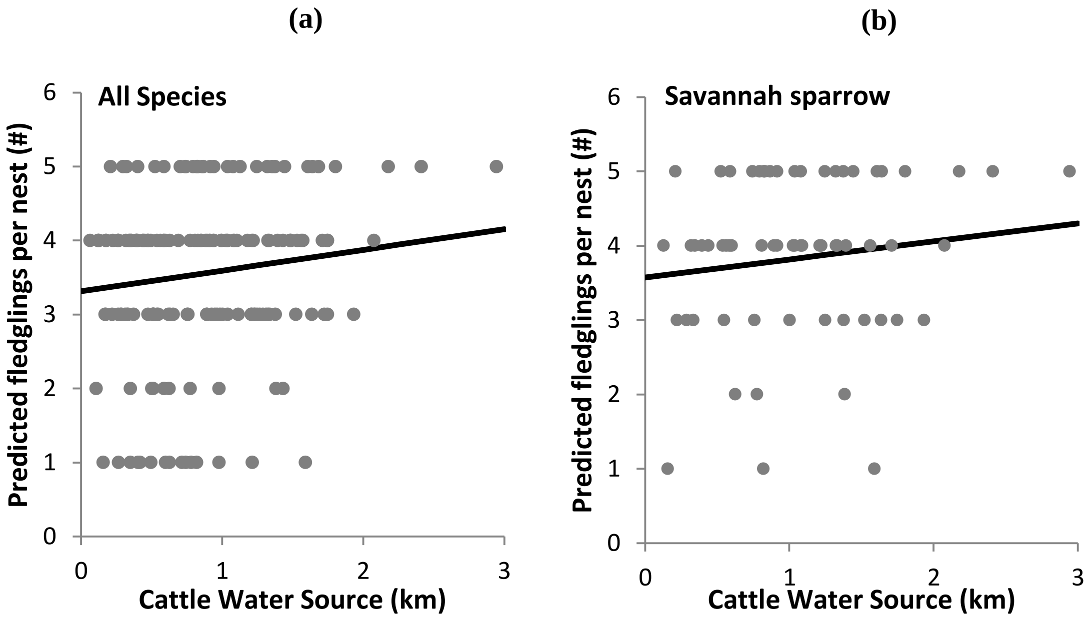


Figure 3.20. The effect of distance to cattle water source on number of fledglings per nest, including raw data points for (a) all combined nests of 6 focal grassland bird species and (b) Savannah Sparrow *(Passerculus sandwichensis)* in southeastern, Alberta, 2010-2012.

3.3.5 Seasonality on reproductive success

Savannah sparrow nesting success decreased (β: -0.02, SE: 0.013, *p-value*: 0.0637) as the breeding season progressed with overall success highest in 2010 and lowest in 2012 (Figure 3.21).

Clutch sizes were greater earlier in the breeding seasons (2010-2012) and declined as the breeding season progressed for all combined nests of focal species (β: -0.006, SE: 0.002, *p-value*: 0.0206) and chestnut-collared longspur species (β: 0.005, SE: 0.003, *p-value*: 0.0882) (Figure 3.22a; 3.22b).

The number of fledglings per nest was greater earlier in the breeding seasons (2010-2012) and declined as the breeding season progressed for all combined nests of focal species (β: -0.02, SE: 0.004, *p-value* < 0.0001) and Savannah sparrow species (β: -0.02, SE: 0.004, *p-value* < 0.001) (Figure 3.23a; 3.23b).

3.3.6 Egg-laying initiation dates and proximity to infrastructure

Baird's (β: 19.75, SE: 8.726, *p-value*: 0.0234) (Table 3.14) and Savannah sparrow (β: 9.94, SE: 3.797, *p-value:* 0.0088) (Figure 3.24a) initiated egg-laying closer to gas well pads early in the breeding season and farther away later in the season. In contrast, vesper sparrow (β: -44.87, SE: 20.230, *p-value*: 0.0266) and Sprague's pipit (β: -80.91, SE: 4.144, *p-value* < 0.001) initiated egg-laying farther from gas well pads early in the breeding season and closer to gas well pads later in the season (Table 3.14).

Vesper sparrows initiated egg-laying farther from high impact roads early in the breeding season and closer to high impact roads later in the season (β: -32.28, SE: 13.744, *p-value:* 0.0188) (Table 3.14). In contrast, Sprague's pipit initiated egg-laying closer to both high (β: 37.02, SE: 1.00, *p-value* < 0.001) and low impact roads (β: 167.01, SE: 8.102, *p-value* < 0.001) early in the breeding season and farther away later in the season (Table 3.14). When all nests were combined for the 6 focal species, egg-laying was initiated closer to low impact roads (β: 5.25, SE: 2.96, *p-value*: 0.0760) early in the breeding season and farther away later in the season (Figure 3.24b).

Vesper sparrow initiated egg-laying closer to cattle water sources (β: 15.99, SE: 1.973, *p-value* < 0.001) early in the breeding season and farther away later in the season (Table 3.14). In contrast, Sprague's pipit initiated egg-laying farther from cattle water sources (β: -24.40, SE: 1.568, *p-value* < 0.001) early in the breeding season and closer to water sources later in the season (Table 3.14).

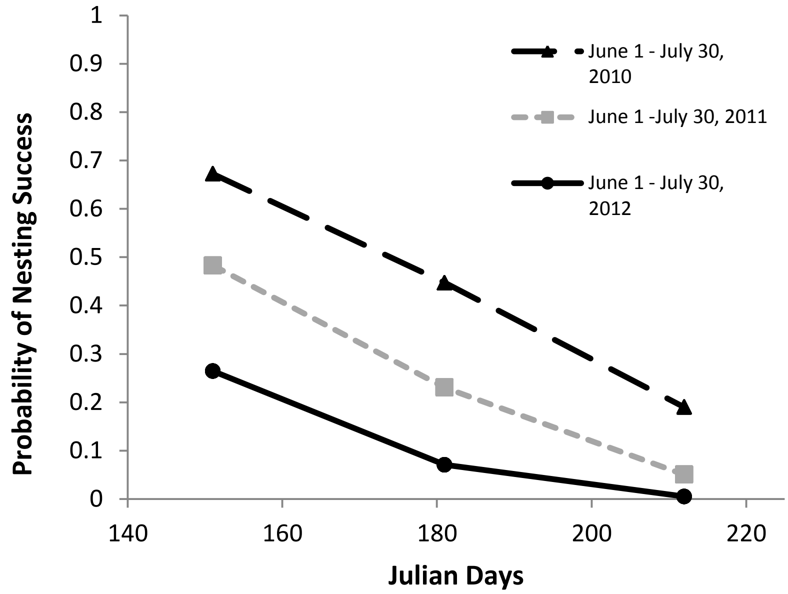


Figure 3.21. The probability of Savannah Sparrow *(Passerculus sandwichensis)* nesting success during each breeding season (2010-2012) in southeastern Alberta.

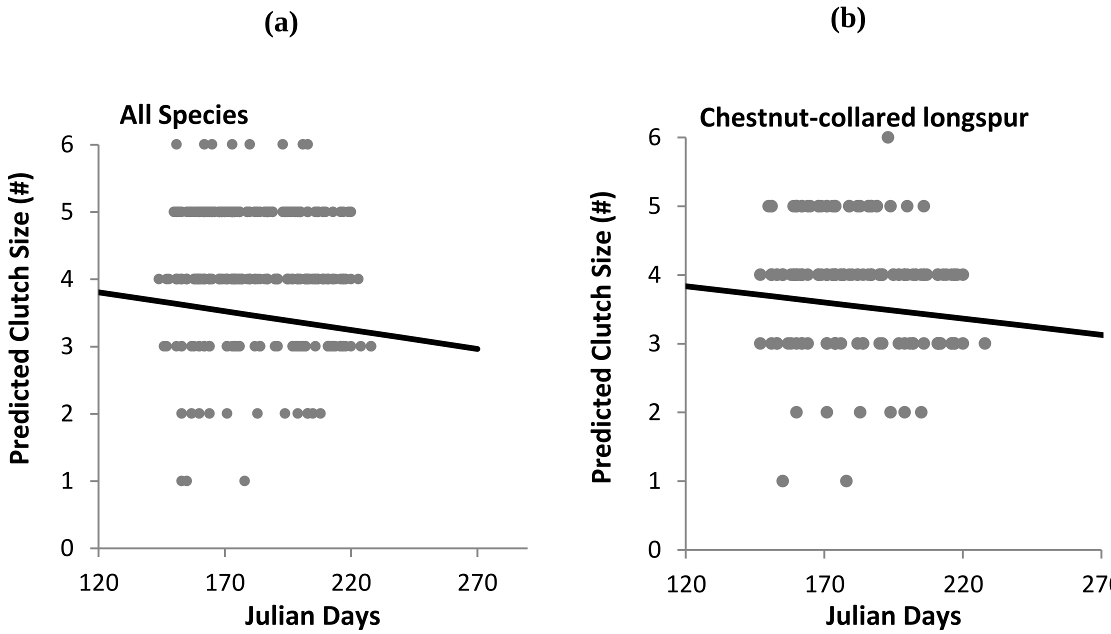


Figure 3.22. Predicted clutch size for the breeding seasons, including raw data points, for (a) All combined nests for 6 grassland focal species and (b) Chestnut-collared longspur *(Calcarius ornatus)* in southeastern Alberta, 2010 – 2012.

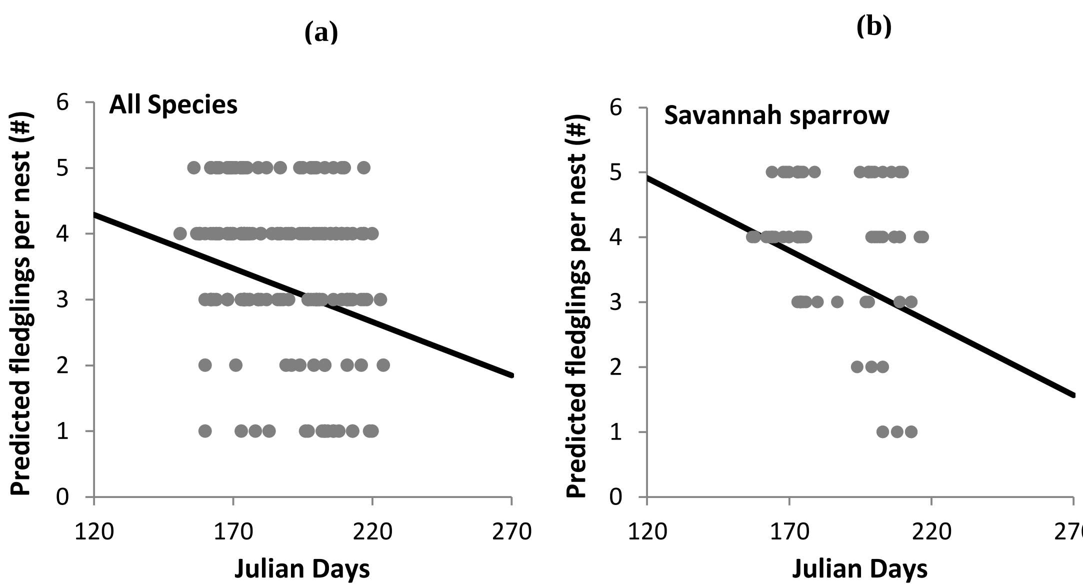
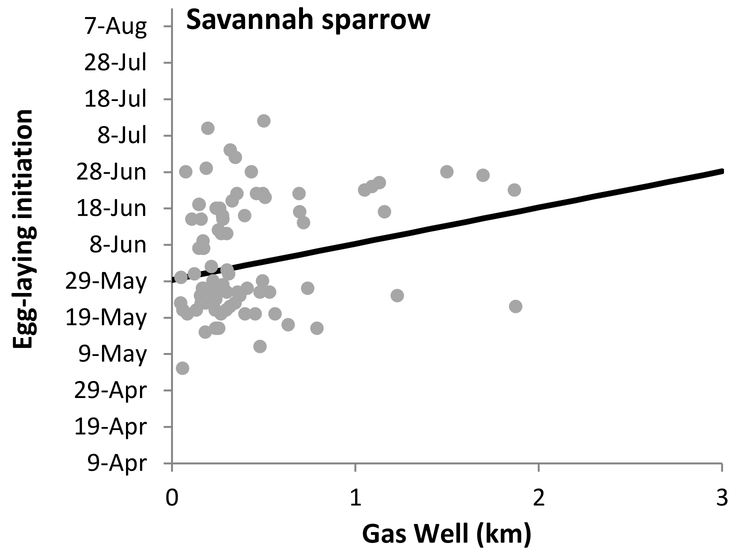


Figure 3.23. Predicted number of fledglings per nest (#) for the breeding seasons, including raw data points, for (a) all combined nests of 6 focal grassland bird species and (b) Savannah sparrow *(Passerculus sandwichensis)* in southeastern Alberta, 2010-2012

Table 3.14. Grassland songbird egg-laying initiation dates and distance to nearest gas well pads (km), high impact road, low impact road, and cattle water source in southeastern Alberta, 2010-2012

		Parameter			
Species		Gas Well Pad	High Impact Rd.	Low Impact Rd.	Cattle Water Source
	β	1.6372	2.951	5.2455	4.5329
All species (*n*=217)	SE	3.0771	3.6752	2.9562	3.0621
	UCL	-3.4242	-3.0942	0.3829	-0.5038
	LCL	6.6987	8.9962	10.1081	9.5696
	p-value	0.5947	0.4220	0.0760	0.1388
	β	19.7545	7.3882	-6.8472	-1.3742
BAIS (*n*=19)	SE	8.7155	8.1079	5.5269	3.0090
	UCL	5.4187	-5.9481	-15.9381	-6.3236
	LCL	34.0903	20.7245	2.2437	3.5752
	p-value	0.0234	0.3622	0.2154	0.6479
	β	-3.1148	1.0922	2.3892	-0.3086
CCLO (*n*=89)	SE	3.442	6.1537	6.5052	5.8257
	UCL	-8.7764	-9.0298	-8.3109	-9.8909
	LCL	2.5468	11.2142	13.0892	9.2738
	p-value	0.3655	0.8591	0.7134	0.9578
	β	9.9448	2.3271	-2.1145	3.3087
SAVS (*n*=78)	SE	3.7966	5.6039	4.1687	3.5974
	UCL	3.6999	-6.8905	-8.9714	-2.6085
	LCL	16.1896	11.5447	4.7424	9.2259
	p-value	0.0088	0.6779	0.6120	0.3577
	β	-80.9065	37.0225	167.0092	-24.3975
SPPI (*n*=7)	SE	4.1436	1.0011	8.1017	1.5681
	UCL	-87.7221	35.3758	153.6831	-26.9768
	LCL	-74.0908	38.6691	180.3354	-21.8183
	p-value	<.0001	<.0001	<.0001	<.0001
	β	-44.8695	-32.2817	-1.1351	15.9949
VESP (*n*=16)	SE	20.2304	13.744	8.4315	1.9728
	UCL	-78.1455	-54.8885	-15.0037	12.7499
	LCL	-11.5935	-9.6749	12.7335	19.2398
	p-value	0.0266	0.0188	0.8929	<.0001
	β	-3.0118	-71.7759	62.6883	-2.5634
WEME (*n*=9)	SE	7.985	50.5288	52.4483	24.0935
	UCL	-16.1459	-154.888	-23.5815	-42.1936
	LCL	10.1223	11.3366	148.9581	37.0669
	p-value	0.7060	0.1555	0.2320	0.9153

(a)



(b)

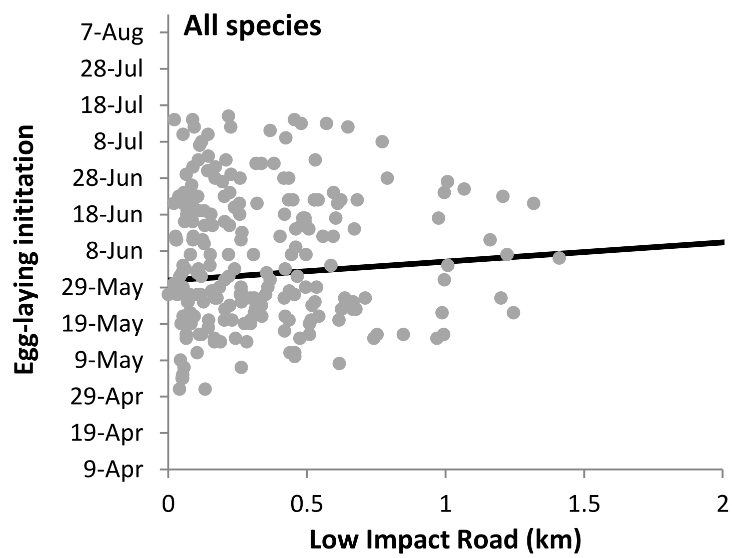


Figure 3.24. Egg-laying initiation dates and (a) distance to nearest gas well pad (km) for Savannah sparrow and (b) distance to low impact road for all nests combined of 6 focal species, including raw data points in southeastern Alberta, 2010-2012.

3.3.7 Predator Activity and Occurrence

Predator activity did not vary with gas well pad density or distance to nearest gas well pad (Table 3.15) when effect of well age was ignored; however, the effect of gas well pad density on predator occurrence did vary with well age (β: -0.02, SE: 0.010, *p-value*: 0.0696) (Table 3.15).Predators were more likely to be present and detected by motion-sensor cameras as density of younger well pads increased; however, occurrence started to decrease with increased densities of well pads over the age of 15 (Figure 3.25).

Table 3.15. The effects of gas well pad density, distance to well pad, gas well pad density interaction with well age, and gas well pad distance interaction with well age on predator activity and occurrence in southeastern Alberta, 2012.

		Parameters							
		Well Pad Density	Nearest Well Pad	Well Pad Density	Well Age	Interaction	Nearest Well Pad	Well Age	Interaction
Predator Activity (*n*=55)	β	-0.0425	-0.3740	-0.0555	-0.0303	0.0015	-0.6989	-0.005	-0.0346
	SE	0.0310	0.4369	0.0382	0.0150	0.0046	0.5437	0.0285	0.0369
	LCL	-0.0934	-1.0927	-0.1183	-0.0550	-0.0060	-0.1955	-0.0474	-0.0952
	UCL	0.0085	0.3447	0.0074	-0.0056	0.0090	1.5933	0.0465	0.0260
	p-value	0.1706	0.3921	0.1464	0.0439	0.7379	0.1987	0.9872	0.3479
Predator Occurrence (*n*=55)	β	-0.0894	0.5485	0.0430	0.0300	-0.0177	2.3935	0.0219	-0.0582
	SE	0.0777	0.8187	0.1006	0.0464	0.0098	0.9904	0.0424	0.0518
	LCL	-0.2171	-0.7982	-0.1225	-0.0464	-0.0338	0.7644	-0.0479	-0.1434
	UCL	0.0384	1.8951	0.2084	0.1063	-0.0017	4.0226	0.0917	0.0271
	p-value	0.2501	0.5029	0.6692	0.5187	0.0696	0.0157	0.6056	0.2617

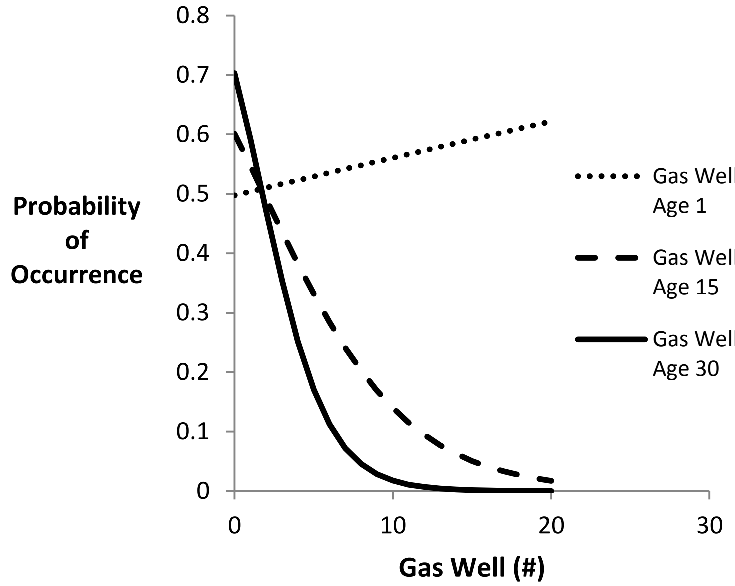


Figure 3.25. The effects of gas well pad density interaction with well age on predator occurrence in southeastern Alberta, 2012.

3.4 Discussion

Overall, gas well pads and their associated roads, as well as cattle water sources, had some impact on grassland songbird reproductive success. However, the effects differed among these features. In general, roads had a greater impact on nesting success, gas well pads primarily impacted clutch size, and cattle water sources impacted clutch size and fledgling numbers.

Effects of gas well pads and roads on nesting success

My results only partially supported my prediction that nest predation would increase with proximity to gas well pads and roads due to edge effects. The linear shape and area (0.08%-0.6%) covered by roads compared to the shape and area covered by gas well pads (a section with 16 well pads would cover approximately 0.014%-0.03% of the area) suggests these two features may impact grassland bird predators, and ultimately nest predation, differently.

Western meadowlark nesting success was quite low near new well pads but increased nearer to wells that had been on the landscape for over 15 years. In other studies gas well development has resulted in avoidance by sensitive ungulate species (less common nest predator) (Sawyer et al. 2006, 2007) and increases in raven populations (Bui et al. 2010). This suggests predator communities and distributions may shift in response to development, and impacts on nesting success may also change over time. In addition, habitats near older wells would have been more disturbed during well construction than habitats near younger wells due to changes in drilling practices (Alberta Environment 2003). Stricter regulations starting in 1993 encouraged developers to drill wells without removing topsoil, which minimizes disturbance; however, when conditions are not favorable then greater surface disturbance (removal of top soil) during drilling is allowed (Alberta Environment 2003). This suggests the presence of, or management around, the well pad itself may influence predator distribution and increase the probability of western meadowlark nest predation. However, there was no effect for most grassland birds, which suggests that overall predator response to gas well development may be small.

Surprisingly, vesper sparrow nesting success increased with more gas wells pads present on the landscape. The presence of larger-sized predators might deter or prey on smaller mammalian predators (Crooks 1999, Renfrew and Ribic 2003, Finke and Denno 2004) in this region; however, there is still a knowledge gap in how mammalian predators (large and small) are impacted by gas well development. A larger sample size of vesper sparrow nests would be required to confirm that the observed trend was not spurious.

Roads impacted nesting success for several species. Almost all sites were bordered by edge habitat created by a 1.6 km high impact road on at least one side. Low impact roads were located on the border of some sites, but were mostly found within sites. The presence of low impact roads within sites may create smaller prairie fragments. Habitat edges created by roads can change plant or animal species distribution which can lead to numerous ecological effects (Ries et al. 2004) such as supporting a greater diversity of predator species (ground squirrels, weasels, badgers, foxes, coyotes, skunks, raccoons, deer, crows, and hawks) (Gates and Gysel 1978), perhaps leading to greater predation rates in smaller prairie fragments (100ha) (Winter et al. 2000), and increased predator activity (Frey and Conover 2006). Savannah sparrow nests had higher failure rates when nesting closer to both high and low impact roads. A greater diversity of predator species does not necessarily equate to increased predation, but coupled with increased habitat edge present on the landscape could increase overall probability of predation events. In contrast, western meadowlark and Baird's sparrow experienced greater nesting success closer to high and low impact roads. Habitat near high impact roads was found to be patchy with greater bare ground, shorter grass, and reduced grass cover; however, less bare ground near low impact roads (Rogers 2013). Prey searching behaviors most likely differ by predator species and also play a role in how susceptible nests are to depredation in edge habitat. For example, raccoons found fewer eggs and spent more time searching in patchy heterogeneous (bare ground with dense grassy clumps) habitats compared to homogeneous habitats (Bowman and Harris 1980).

In addition to predator distribution, activity, and behavioral responses to roads and gas well development, grassland nest concealment and bird behavior can also play a major role in detection of nests by predators and may affect nest outcomes differently. Baird's sparrow are secretive and nest in dense grass, making them less detectable by some predators due to better concealment or better evasion techniques (Davis and Sealy 1998, Wiggins 2006, Ludlow 2013). This may be one reason why Baird's sparrow had fewer nest failures closer to low impact roads, while Savannah sparrows experienced greater nest failure. Conspecific and interspecific competition among grassland birds may occur when establishing territories (Smith and Shugart 1987), causing some birds to nest in edge habitat or in general closer to well pads or roads. The proximity to infrastructure may increase opportunity for predation (Gates and Gysel 1978) or lower productivity (Smith and Shugart 1987). Furthermore, the levels of aggression displayed by specific bird species may deter some predators attempting to depredate nests (Ellison and Ribic 2012), for instance closely related eastern meadowlarks (*Sturnella magna*) vigorously defended nests against relatively large snakes. The variable outcomes for different species highlights that identifying actual nest predators near these infrastructure, whether due to habitat, infrastructure type, or combination of both, will allow for better management decisions when implementing conservation strategies for specific grassland bird species.

Effects of gas well pads and roads on clutch size and number of fledglings per nest

Non-native vegetation and changes to vegetation structure may partially explain smaller clutch sizes near gas well pads. Almost all grassland birds in this study, except western meadowlark, laid more eggs (0.5-1.5 / 1 km) in clutches that were farther from gas well pads. Studies have found arthropod abundance is 60% higher in native grass habitat in comparison to areas with non-native vegetation (Flanders et al. 2006). Crested wheatgrass occurred within 25m of gas well pads, a likely result of well installation, in our study sites (Rodgers 2013, Koper et al. 2014). This suggests food availability and abundance may be lower within 25m of well pads due to decreased native vegetation.

Cattle presence and grazing near gas well pads may also reduce insect abundance, and subsequently clutch size, closer to gas wells. Intense grazing can negatively impact vegetation structure, insect diversity (Jepson -Innes and Bock 1989, Fielding et al. 1995, Debano 2006) and seed production (Lacey et al. 1992), which are primary food sources for birds during the breeding season (Cody 1985, Kaspari and Joern 1993, Ehrlich et al. 1998). It can create shorter grass and homogenize plant structures across the landscape, which removes habitat needed by a variety of insect species (Kruess and Tscharntke 2002). At our study sites, cattle presence and grazing was found to impact vegetation surrounding newer gas well pads as far as 200-m away (Koper et al. 2014) by increasing bare ground and reducing grass height (Rogers 2013).

Similar but smaller effects were seen for older well pads (Koper et al. 2014). This suggests cattle spend more time near wells pads than the surrounding area perhaps due to food preference or the novelty of something new on the landscape (Launchbaugh and Howery 2005), which might simultaneously reduce insect habitat when grazing near well pads. Therefore, smaller clutch sizes near gas wells pads may be in response to a decrease in insect and seed abundance as a result of grazing.

The trend for clutches to be smaller near wells could not be explained by clutch initiation dates. This suggests birds might be food limited near infrastructure and birds nesting closer to infrastructure may be forced through competition to forage in lower quality habitat. This might be particularly true for chestnut-collared longspurs since they select short and sparse vegetation, and areas with greater cattle dung, for nests (Davis 2005), which tends to occur near wells (Koper et al. 2014). Habitat selection and territory competition could restrict chestnut-collared longspurs to forage near well pads, which might have other consequences in terms of food availability.

To explain the differences in clutch sizes beyond 200-m from gas well pads, one likely reason is that wells are not evenly distributed within sites; therefore, some areas may have higher concentrations of gas wells pads closer together relative to the rest of the pasture. This cumulative impact on the surrounding vegetation in one part of a pasture could explain effects reaching beyond 200-m.

Gas well pad densities as low as 10 well pads per site had negative effects on clutch size for up to 15 years after well installment for chestnut-collared longspur, Baird's sparrow, western meadowlark, and when nests were combined for all species. Since large-sized predators avoid greater densities of older well pads, perhaps grassland birds are responding to lowered predation risk with higher clutch sizes over time (Zanette et al. 2013). Further studies are needed to better understand the effects of interactions between food availability, cattle, predators, and gas well pads on clutch size.

Roads had no impact on clutch size for Savannah sparrow and chestnut-collared longspurs. Although food availability may be lower near roads due to changes in vegetation and composition (Ingelfinger and Anderson 2004), these changes may be too localized to have an effect on clutch size. In addition, cattle were found in higher concentrations near roads, but the effect on vegetation was much weaker compared to those of gas well pads (Koper et al. 2014 submitted). Roads cover more surface area than gas well pads creating more area to attract cattle and more evenly spread the impact on vegetation compared to gas well pads.

The potential for higher predator risk is indicated by greater nest failure near high impact roads in this study. It is possible adults of successful nests spent more time and energy being vigilant (expending energy by alarm calling, nest flushing, time away from nest) due to high predator risk closer to roads. This vigilant behavior takes time away from what would normally be spent foraging for themselves and young (Martin 1995, Zanette et al. 2013), and fewer feeding events could result in fewer nestlings fledging. Because higher clutch sizes did not occur further from roads, the trend of greater fledglings per nest further from roads is likely not a factor of initial large clutch sizes. However, more studies are needed to understand the effect of roads on fledgling numbers.

Effects of cattle water sources on reproductive success

Cattle water sources seemed to have a strong impact on reproductive output of grassland songbirds. Most grassland songbirds experienced greater clutch sizes and fledgling numbers farther from water sources. Cattle are known to concentrate near water sources (White et al. 2001, Tate et al. 2003). Reduced vegetation cover, litter, and greater bare ground occur near water sources (Kruess and Tscharntke 2002, Fontaine et al. 2004) probably increased cattle grazing and trampling of vegetation. This may result in lower insect abundance due to reduced vegetation height and structure (Kruess and Tscharntke 2002) and could contribute to lower clutch sizes. Even though cattle are herbivores they have been documented to intentionally depredate nests (Nack and Ribic 2005). Because nest predation did not vary with proximity to water it is likely cattle are not intentionally seeking nests; however, nests may be partially depredated at both egg and nestling stages as they are incidentally found while cattle graze near water sources. Partial predation by cattle and other predators may additionally contribute to lower clutch and fledgling numbers.

Seasonality

Lower nesting and reproductive success during the breeding season is consistent with other studies demonstrating greater nesting success, larger clutch sizes, and higher numbers of fledglings per nest earlier in the season (Lack 1947, Daan et al. 1988, Lloyd and Martin 2005, Zanette et al. 2006). This might be due to changes in parental investment later in the season in order to optimize fitness for each nestling or clutch size based on resource availability and predation risk (Daan 1990, Verboven and Tinbergen 2002, Zanette et al. 2006, 2013). Further studies are needed for vesper sparrow, western meadowlark, and Sprague's pipit to better examine a wider range of gas well pad infrastructure effects on clutch size and fledgling numbers.

4.0 Conclusion

Some grassland birds are being impacted by gas wells and associated linear features. Predation was the primary reason for nest failure, but my results show that there is very little correlation or influence of gas well pads on predation of grassland songbird nests in this study. Activity of medium to large sized predators was influenced by the presence of gas wells pads, although this did not lead to an increase in nest predation. However, nest depredation did increase closer to roadsides associated with gas well development. Predator distribution and prey interactions near roads are most likely being altered. Since I was unable to identify nest predators, studies that identify songbird predators during depredation events will help shed light on the interactions between habitat, predators, and nest predation. With this knowledge, managers will be better informed to implement proper conservation methods dealing with population decline for specific grassland birds.

Because grassland songbird populations are in decline, the variation in clutch size and number of fledglings per nest by species in response to gas well pads are of concern and important from a management perspective, particularly species at risk chestnut-collared longspur and Sprague's pipit. Avian life history traits suggest that quickly maturing species such as grassland songbirds investment into reproduction (i.e. greater clutch sizes) reflects population growth as opposed to investment into fewer and larger sized eggs (Saether and Bakke 2000, Stahl and Oli 2006). This means a simple reduction in one egg per clutch, experienced by many species in this study, may dampen the rate of population growth of many grassland songbirds. Both positive and negative trends appeared for Sprague's pipit in response to gas well pad density and distance and are worth exploring in future studies.

Post-fledging survival was not studied and combined with adult return rates can lead to better indicators of survival (Martin 1995). More studies are needed on grassland bird reproductive success in relation to gas well pads and roads with an emphasis on post-fledging success rates to better understand population estimates.

5.0 Management Implications

Due to the complex interactions between nest predators, infrastructure, habitat, and nest depredation, it seems particularly important to identify predator species near infrastructure. Predator response to roads and its edge habitat most likely has the largest impact on nesting success for grassland birds in this region. Understanding these predator-prey interactions and the mechanisms driving the presence of certain predator species as opposed to others may become useful when developing management strategies that attempt to reduce chances of nest failure. Often predator control is a direct management tool for protecting endangered or listed species populations (Cote and Sutherland 1997). Thus knowing which predators are responsible for nest failure could be useful for managing grassland birds in the future.

An increase in roads caused by new gas well exploration and development is likely to occur in prairie habitat, particularly in areas where roads do not already exist. According to my results, grassland songbird predators respond to roads in a way that increases predation events closer to high impact roads. Fewer high impact roads should increase reproductive success of grassland songbirds. Therefore, mitigation plans that involve well development should require the fewest number of new roads to be developed and well maintenance checks to be done on foot, if possible. Since many roads already exist in southeastern Alberta, one way to reduce fragmentation and edge effects could be to retire and restore less traveled roads (paved, gravel, or low impact) that were once used at old development sites. Simmers and Galatowitsch (2010) found old roads restored from oil gas well development in semi-arid conditions were low in habitat quality in comparison to the surrounding landscape and that seeding choices should be carefully selected and well planned, as those factors may be critical in driving habitat quality and long-term ecological impacts. Greater amounts of intact prairie may not only benefit grassland birds (Davis 2004, Koper et al. 2009) but grassland species in general (Hebblewhite 2011, Nasen et al. 2011, Naugle and Copeland 2011)

Grassland songbirds responded more strongly to short and long-term habitat changes caused by gas well development, rather than the presence of gas well pads themselves, with many negative effects declining as wells aged. The decrease in chestnut-collared longspur clutch size near gas well pads and particularly in low densities of young well pads is particularly important and of concern. Mitigation measures used during well installment may be critical in minimizing both short and long-term effects on grassland birds. Since 1993, stricter gas well drilling guidelines set by Alberta government recommend implementation of methods to retain native habitat, minimize or eliminate the destruction of native vegetation, and reseed with native vegetation. It is critical industry follow guidelines as closely as possible so that long-term effects can be reversed or minimized in the future if energy development continues.

Cattle concentrations near gas well pads have a large impact on the surrounding habitat. Therefore, a greater number of well pads concentrated in a small area may exacerbate effects on grassland songbirds. Directional drilling (one well head with many underground pipes) is commonly used by developers (CAPP 2013), and should continue to be used as a mitigation method to reduce the number of gas well pads on the landscape. Reducing the density of gas well pads, associated roads, and using minimal surface disturbance techniques should minimize the impacts on reproductive success for many grassland bird species. Oil development also occurs regularly in this region, suggesting there may be cumulative impacts on grassland birds from both gas and oil development. Therefore, a reduction in new gas well pads and roads may reduce cumulative impacts of the overall impacts from both types of energy development.

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APPENDIX I

Study sites (1.6 km x 1.6 km) located in southeastern Alberta for nest data collection in May-August 2010, 2011, and 2012 with corresponding gas well pad densities.

Site	Well Pad Density (wells/section)	Site	Well Pad Density
1	0	23[∞]	7
2[*]	0	24	7
3[~]	0	25[∞]	7
4[∞]	0	26[∞]	7
5[*]	0	27	8
6	0	28[∞]	8
7	0	29[∞]	9
8[+]	1	30	9
9[∞]	1	31[∞]	9
10[∞]	1	32	9
11[§]	3	33[1∞]	9
12	3	34[∞]	10
13[∞]	3	35[∞]	10
14[∞]	4	36[∞]	10
15	4	37[2∞]	10
16[∞]	4	38[∞]	11
17[∞]	4	39[∞]	11
18	4	40[∞]	11
19	5	41[∞]	15
20	5	42	16
21[∞]	6		
22[∞]	6		

[§] Only surveyed in 2010
[*] Only surveyed in 2011
[+] Only surveyed in 2012
[∞] Surveyed in 2010 & 2011
[~] Surveyed in 2011 & 2012

[1] Ducks Unlimited
[2] Kinbrook Island Provincial Park

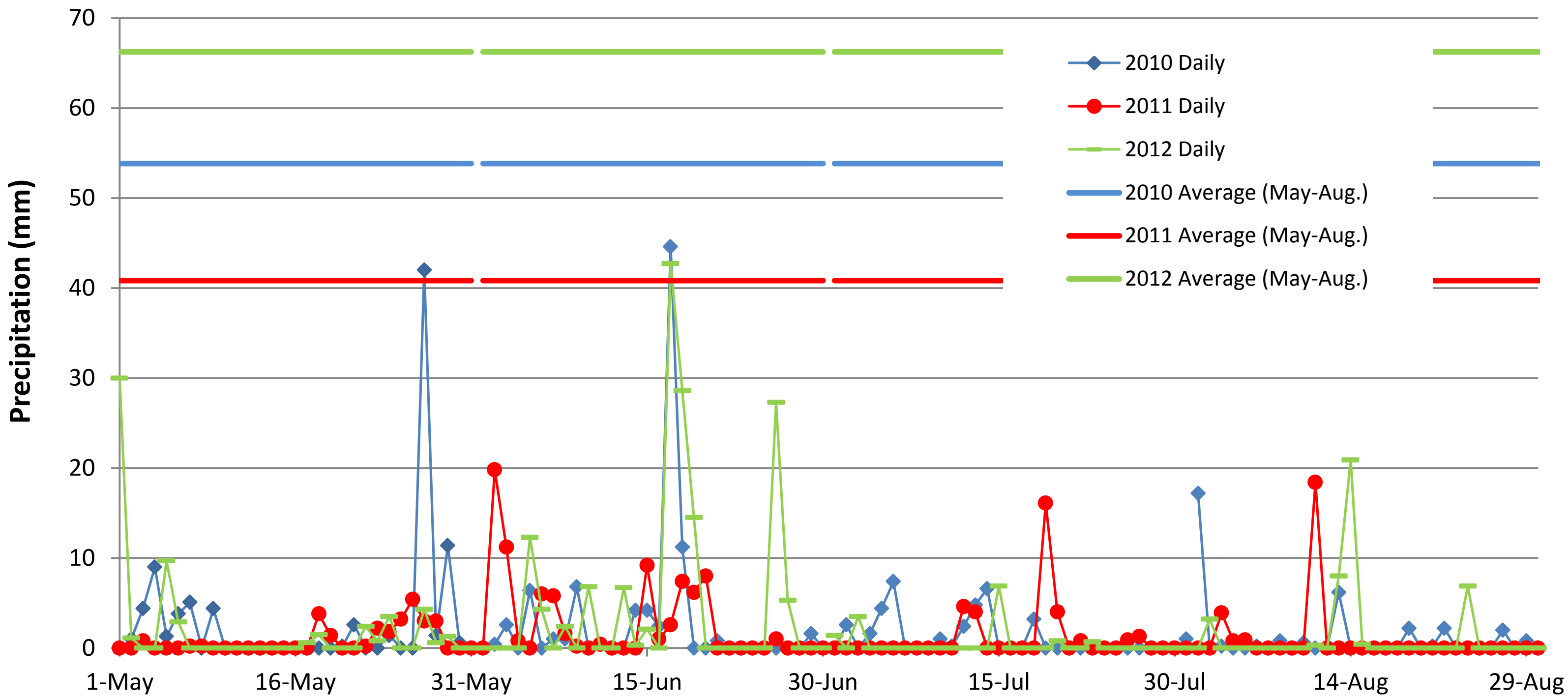
APPENDIX II

Predator activity, average predator activity of camera surveys by site with standard deviation, and average predator activity per total site survey hours. Includes the number of motion sensor cameras and total survey hours per site.

Site (# of rounds)	Number of well pads	Number of motion sensor cameras and total survey hours	Predator activity (#)	Average predator activity of camera surveys by site with standard deviation (SD) (includes zero predator detection hours)	Average predator activity per total site survey hours
Site 6 (2)	0	4; 430	4	0.0079±0.01171	0.0093
Site 3 (2)	0	4; 236	3	0.0189±0.0232	0.0127
Site 7 (2)	0	4; 301	6	0.0163±0.0143	0.0200
Site 1 (2)	0	6; 391	5	0.0164±0.0206	0.0128
Site 8 (1)	1	2; 238	2	0.0084±0	0.0084
Site 12 (1)	3	4; 259	1	0.0031±0.0087	0.0039
Site 18 (2)	4	6; 536	9	0.0158±0.0207	0.0168
Site 15 (2)	4	3; 228	2	0.0081±0.0140	0.0088
Site 20 (2)	5	5; 296	4	0.0108±0.0148	0.0135
Site 19 (1)	5	3; 197	2	0.0101±0.0175	0.0102
Site 24 (2)	7	5; 368	7	0.0154±0.0344	0.0190
Site 27 (1)	8	1; 65	0	0.0±0.0	0.0000
Site 30 (1)	9	4; 408	0	0.0±0.0	0.0000
Site 42 (2)	16	5; 280	2	0.0117±0.0189	0.0072
Total 23	-	56;	47		

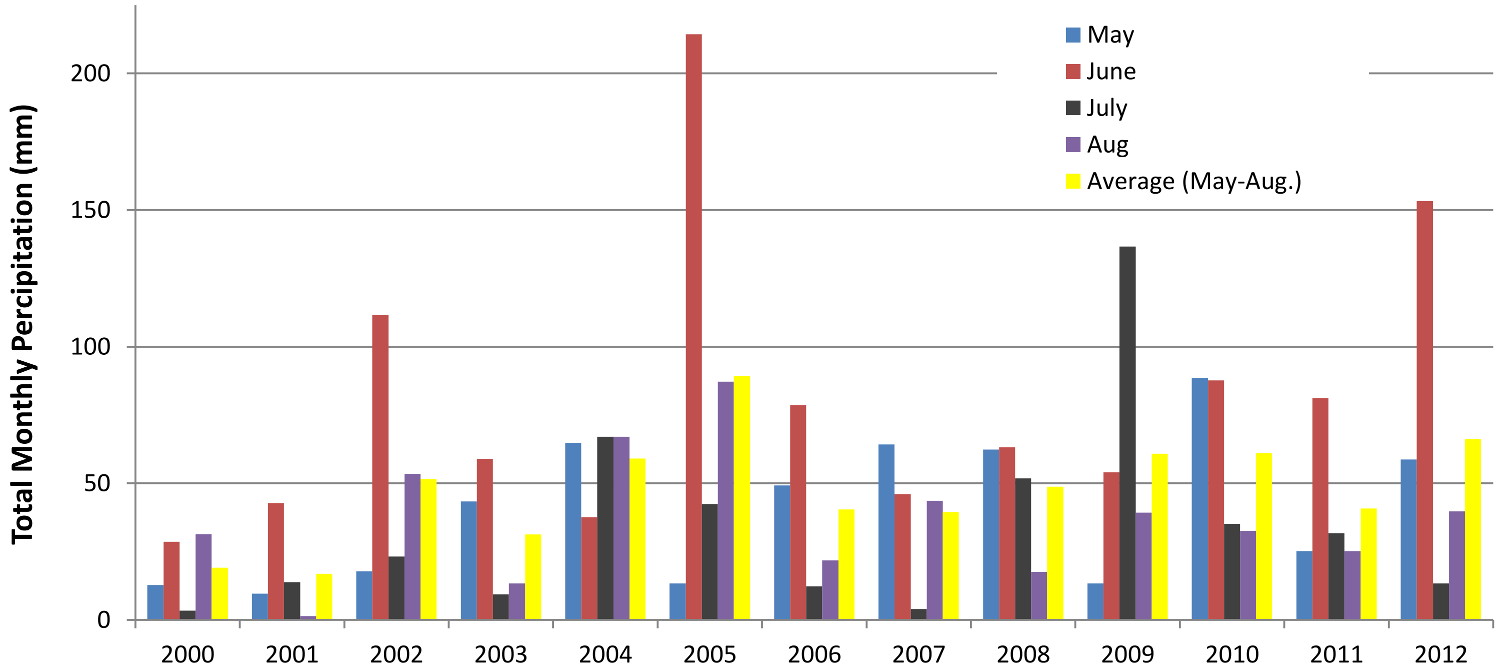
APPENDIX III

Daily and average precipitation in Brooks, Alberta, from May-August 2010, 2011, and 2012.



APPENDIX IV

Total monthly (May, June, July, and August) and average precipitation from May-August in Brooks, Alberta from 2000-2012.



APPENDIX V

Relationship between nest vegetation and grassland bird nest success in southeastern Alberta, 2010-2012.

				Density		**% Cover**						**Presence/Absence**		
Species		Height	Litter Depth	Dead Grass	Live Grass	Dead Grass	Live Grass	Bare ground	Forb	Lichen or Moss	Shrub	Bare ground	CWG	y
	β	0.1206	0.7789	-	-	-	-	-	-	-	-	0.8516	-	-
BAIS	SE	0.0943	0.9152	-	-	-	-	-	-	-	-	1.7820	-	-
(*n*=21)	LCL	-0.0455	-0.8330	-	-	-	-	-	-	-	-	-2.2871	-	-
	UCL	0.2867	2.3909	-	-	-	-	-	-	-	-	3.9902	-	-
	p-value	0.2217	0.4090	-	-	-	-	-	-	-	-	0.6401	-	-
	β	0.0122	-0.2691	-0.1102	0.0940	0.0040	-0.0028	-0.0243	0.0168	-0.0056	-	-	-	-
CCLO	SE	0.0250	0.2061	0.1061	0.1197	0.0308	0.0291	0.0497	0.0320	0.0294	-	-	-	-
(*n*=137)	LCL	-0.0303	-0.6198	-0.2907	-0.1102	-0.0484	-0.0466	-0.1089	-0.0377	-0.0556	-	-	-	-
	UCL	0.0547	-0.0815	0.0703	0.2972	0.0565	0.0523	0.0603	0.0712	0.0445	-	-	-	-
	p-value	0.6292	0.2022	0.3077	0.4415	0.8967	0.9227	0.6288	0.6047	0.8517	-	-	-	-
	β	-0.0030	-0.0262	-0.0071	-0.1333	0.0487	0.0639	-	0.0440	-	-	0.3519	-	-0.0547
SAVS	SE	0.2893	0.2016	0.1039	0.1286	0.0310	0.0314	-	0.0347	-	-	0.1840	-	0.4343
(*n*=124)	LCL	-0.0461	-0.3668	-0.1826	-0.2306	-0.3668	0.0108	-	-0.0146	-	-	0.0410	-	-0.7885
	UCL	0.0516	0.3144	0.1685	0.2039	0.1010	0.1170	-	0.1026	-	-	0.6628	-	0.6790
	p-value	0.9245	0.8972	0.9462	0.9180	0.1248	0.0499	-	0.2128	-	-	0.0641	-	0.9005
		0.2276	-	-	-	-	-	-	-	-	-	0.0956	-	-

	β													
SPPI	SE	0.2635	-	-	-	-	-	-	-	-	-	0.2440	-	-
(*n*=11)	LCL	-0.2345	-	-	-	-	-	-	-	-	-	-0.3785	-	-
	UCL	0.7897	-	-	-	-	-	-	-	-	-	0.5700	-	-
	p-value	0.3327	-	-	-	-	-	-	-	-	-	0.7087	-	-
	β	0.1545	-	-	-	-	-	-0.1360	-0.0285	-	-	-	-	-
VESP	SE	0.0978	-	-	-	-	-	0.0607	0.0585	-	-	-	-	-
(*n*=21)	LCL	-0.0210	-	-	-	-	-	-0.2450	-0.1336	-	-	-	-	-
	UCL	0.3301	-	-	-	-	-	-0.0271	0.0765	-	-	-	-	-
	p-value	0.1422	-	-	-	-	-	0.0465	0.6354	-	-	-	-	-
	β	0.2153	-	0.1357	-	-	-	40.030	-	-	-	-	-	-
WEME	SE	0.1616	-	0.4058	-	-	-	20361	-	-	-	-	-	-
(*n*=15)	LCL	-0.0808	-	-0.6282	-	-	-	-37285	-	-	-	-	-	-
	UCL	0.5115	-	0.8796	-	-	-	37365	-	-	-	-	-	-
	p-value	0.2154	-	0.7458	-	-	-	0.9985	-	-	-	-	-	-

APPENDIX VI

The effects of gas well pad density and well age interaction, year, and Julian day in nesting success for grassland songbird species in southeastern Alberta, 2010-2012.

Species		**Parameter** Well Pad Density	Age of Gas Well	Interaction	Year	Julian Day
	β	-0.0187	-0.0068	0.0015	n/a	n/a
All Species	SE	0.0411	0.0219	0.0024	n/a	n/a
($n_{interval}$=1082)	LCL	-0.0866	-0.0429	-0.0025	n/a	n/a
	UCL	0.0492	0.0293	0.0055	n/a	n/a
	p-value	0.6501	0.7559	0.5338	n/a	n/a
	β	-0.0620	-0.0393	0.0030	n/a	n/a
CCLO	SE	0.0692	0.0443	0.0052	n/a	n/a
($n_{interval}$=415)	LCL	-0.1767	-0.1127	-0.0057	n/a	n/a
	UCL	0.0527	0.0340	0.0116	n/a	n/a
	p-value	0.3721	0.3757	0.5725	n/a	n/a
	β	-0.0727	0.0067	0.0015	n/a	n/a
BAIS	SE	0.2235	0.0940	0.0087	n/a	n/a
($n_{interval}$=86)	LCL	-0.4572	-0.1549	-0.0135	n/a	n/a
	UCL	0.3119	0.1684	0.0166	n/a	n/a
	p-value	0.7482	0.9435	0.8640	n/a	n/a
	β	-0.0621	-0.0236	0.0043	-0.1971	-0.0138
SAVS	SE	0.0778	0.0338	0.0038	0.2994	0.0112
($n_{interval}$=373)	LCL	-0.1913	-0.0797	-0.0021	-0.6942	-0.0324
	UCL	0.0671	0.0326	0.0107	0.3000	0.0048
	p-value	0.4270	0.4872	0.2706	0.5118	0.2195
	β	-0.3656	-0.0569	0.0321	n/a	n/a
SPPI	SE	0.3708	0.1552	0.0356	n/a	n/a
($n_{interval}$=56)	LCL	-1.0454	-0.3413	-0.0332	n/a	n/a
	UCL	0.3141	0.2276	0.0974	n/a	n/a
	p-value	0.3499	0.7225	0.3914	n/a	n/a
	β	0.4259	0.3224	-0.0346	n/a	n/a
VESP	SE	0.3424	0.3499	0.0408	n/a	n/a
($n_{interval}$=88)	LCL	-0.1697	-0.2863	-0.1055	n/a	n/a
	UCL	1.0215	0.9312	0.0363	n/a	n/a
	p-value	0.2304	0.3697	0.4074	n/a	n/a
	β	-0.1271	0.0548	0.0033	n/a	n/a
WEME	SE	0.2605	0.1321	0.0163	n/a	n/a
($n_{interval}$=52)	LCL	-0.5860	-0.1779	-0.0253	n/a	n/a
	UCL	0.3317	0.2874	0.0320	n/a	n/a
	p-value	0.6331	0.6847	0.8415	n/a	n/a

APPENDIX VII

The effects of gas well pad distance and well age interaction, and Julian day on the number of fledglings per nest for grassland bird species in southeastern Alberta, 2010-2012.

		Parameter			
		Distance	Age	Distance and Age interaction	Julian Days
All Species	β	0.0459	0.0031	-0.0149	-0.0145
(*n*=195)	SE	0.2553	0.0107	0.0279	0.0047
	LCL	-0.3741	-0.0144	-0.0608	-0.0222
	UCL	0.4658	0.0206	0.0310	-0.0068
	p-value	0.8575	0.7710	0.5930	0.0020
BAIS	β	0.0668	-0.0530	0.0971	-
(*n*=15)	SE	0.5762	0.0186	0.0729	-
	LCL	-0.8810	-0.0837	-0.0228	-
	UCL	1.0146	-0.0224	0.2169	-
	p-value	0.9077	0.0044	0.1830	-
CCLO	β	0.3386	0.0265	-0.0558	-
(*n*=69)	SE	0.3175	0.0167	0.0394	-
	LCL	-0.1837	-0.0009	-0.1206	-
	UCL	0.8608	0.0539	0.0090	-
	p-value	0.2863	0.1120	0.1566	-
SAVS	β	0.6522	0.0085	-0.0407	-0.0222
(*n*=73)	SE	0.4253	0.0151	0.0414	0.0060
	LCL	-0.0473	-0.0163	-0.1088	-0.0321
	UCL	1.3518	0.0332	0.0275	-0.0123
	p-value	0.1251	0.5742	0.3261	0.0002
	β	-	-	-	-
SPPI	SE	-	-	-	-
(*n*=7)	LCL	-	-	-	-
	UCL	-	-	-	-
	p-value	-	-	-	-
VESP	β	1.0591	0.0323	-0.0386	-
(*n*=13)	SE	1.2136	0.0200	0.0470	-
	LCL	-0.9370	-0.0005	-0.1159	-
	UCL	3.0553	0.0652	0.0386	-
	p-value	0.3828	0.1055	0.4108	-
WEME	β	12.6992	0.1340	-1.0072	-
(*n*=8)	SE	9.6383	0.1027	0.8027	-
	UCL	28.5528	0.3029	0.3132	-
	p-value	0.1876	0.1919	0.2096	-

APPENDIX VIII

The effects of gas well pad density and well age interaction, and Julian day on the number of fledglings for grassland bird species in southeastern Alberta, 2010-2012.

		Gas Well Pad Density and Age Interaction			
		Density	Age	Density and Age Interaction	Julian Days
All Species (*n*=195)	β	-0.0055	0.0022	-0.0003	-0.0153
	SE	0.0293	0.0180	0.0015	0.0045
	LCL	-0.0536	-0.0275	-0.0028	-0.0226
	UCL	0.0427	0.0319	0.0021	-0.0079
	p-value	0.8520	0.9041	0.8253	0.0006
BAIS (*n*=15)	β	-0.0060	-0.1010	0.0034	-
	SE	0.0731	0.0682	0.0048	-
	LCL	-0.1263	-0.2133	-0.0044	-
	UCL	0.1143	0.0112	0.0112	-
	p-value	0.9345	0.1387	0.4731	-
CCLO (*n*=69)	β	0.0459	0.0295	-0.0032	-
	SE	0.0396	0.0221	0.0025	-
	LCL	-0.0192	-0.0068	-0.0073	-
	UCL	0.1111	0.0658	0.0009	-
	p-value	0.2464	0.1811	0.2036	-
SAVS (*n*=73)	β	-0.0210	-0.0139	0.0009	-0.0201
	SE	0.0258	0.0244	0.0017	0.0058
	LCL	-0.0634	-0.0541	-0.0018	-0.0296
	UCL	0.0214	0.0262	0.0037	-0.0107
	p-value	0.4154	0.5678	0.5874	0.0005
	β	-	-	-	-
SPPI	SE	-	-	-	-
(*n*=7)	LCL	-	-	-	-
	UCL	-	-	-	-
	p-value	-	-	-	-
VESP (*n*=13)	β	0.0732	0.0121	0.0016	-
	SE	0.0376	0.0149	0.0020	-
	LCL	0.0114	-0.0124	-0.0018	-
	UCL	0.1350	0.0366	0.0049	-
	p-value	0.0515	0.4178	0.4438	-
WEME (*n*=8)	β	-0.0331	-0.0229	0.0028	-
	SE	0.0433	0.0358	0.0034	-
	LCL	-0.1044	-0.0818	-0.0029	-
	UCL	0.0381	0.0360	0.0085	-
	p-value	0.4445	0.5225	0.4168	-