GRASSLAND BIRD RESPONSE TO LANDSCAPE-LEVEL AND SITE-SPECIFIC VARIABLES IN THE LITTLE MISSOURI NATIONAL GRASSLAND

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

Brian James Chepulis

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Natural Resources Management

April 2016

Fargo, North Dakota

North Dakota State University
Graduate School

Title

GRASSLAND BIRD RESPONSE TO LANDSCAPE-LEVEL AND SITE-SPECIFIC VARIABLES IN THE LITTLE MISSOURI NATIONAL GRASSLAND

By

Brian James Chepulis

The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

SUPERVISORY COMMITTEE:

Edward Shawn DeKeyser
Chair

Lawrence D. Igl

Torre J. Hovick

Approved:

6 April 2016
Date

Edward Shawn DeKeyser
Department Chair

ABSTRACT

Trend analysis from the North American Breeding Bird Survey indicates that the Sprague's pipit (*Anthus spragueii*) and Baird's sparrow (*Ammodramus bairdii*) populations have experienced severe annual declines of -3.5% and -3.0%, respectively, between 1966 and 2013. The Little Missouri National Grassland (LMNG) in western North Dakota are listed as an important breeding area for the Sprague's pipit, Baird's sparrow, and other grassland birds. Our objectives for this study were to provide a better understanding of the effects of landscape-level (e.g., oil development) and site-specific (e.g., vegetation structure) variables on sensitive grassland bird populations in the LMNG. We surveyed 60 study sites twice each year (2014 and 2015) using a modified transect survey to evaluate grassland bird abundance. The results from this study contributed to understanding grassland bird responses to landscape-level and site-specific variables and identified specific mechanisms by which conservation measures for declining grassland bird populations can be improved.

ACKNOWLEDGMENTS

I would like to first thank the U.S Forest Service (USFS), Northern Prairie Wildlife Research Center (NPWRC) of the U.S. Geological Survey (USGS, North Dakota EPSCoR Graduate Research Assistantship program, and the Robert H. Levis II Cross Ranch Fellowship for generously funding my research and graduate program. I thank NPWRC for providing a travel trailer for my summer housing, and I extend a big thank you to Superintendent Valerie Naylor and Administrative Technician Kevin Melzo of the National Park Service for assistance in securing a safe place to park the trailer at the North Unit of Theodore Roosevelt National Park (TRNP). Staff at the McKenzie Ranger District office of the USFS provided logistical assistance. I especially would like to thank Kyle Dalzell of the McKenzie District office in Watford City and Chadley Prosser of the Dakota Prairie Grasslands (DPG) office in Bismarck.

I owe a debt of gratitude to Larry Igl (USGS) and Dan Svingen (USFS) for securing funding for this project when the initial funding fell through. None of this would have been possible without their support. I appreciated all of the time, advice, and editing contributed by my committee members, Drs. Larry Igl, Shawn DeKeyser, and Torre Hovick. Dr. Wesley Newton (NPWRC) was extremely helpful with statistical advice and design. I also would like to thank Betty Euliss (USGS) for her assistance with ArcMap during the early stages of study design. Phil Sjursen (USFS) of the DPG office generously provided current GIS data layers for the Little Missouri National Grassland.

I am appreciative to John Heiser (TRNP) for the advice and wisdom he provided on my study area. Joe Orr assisted me in locating potential breeding areas for Sprague's pipits in the Little Missouri National Grassland in the summer of 2013. A big thank you goes to my dedicated field assistants that worked on this project over the last two years: Joe Lamb, Brandon

Kaiser, Mason Ryckman, and Chris Sharpe. I would especially like to thank Brandon Kaiser and Joe Lamb for sticking it out during the pilot season, when we were developing our vegetation methodology and sampling scheme. Their hard work, sense of humor, and camaraderie was greatly appreciated. I also would like to extend thanks to others who kindly provided field assistance: Kyle McLean, Sarah Wilson, Sarah Pederson, David Renton, Breanna Paradeis, Shannon Regan, and Katie Heying.

I would also like to extend a thank you to the people in my life who fostered my interest in nature and sent me down this career path: my aunt, Carol Gibson; high school biology teacher, Jim Sampson; and my undergraduate advisor, Bob Anderson. Finally, I would like to thank my family and wonderful partner Katie. Without their support I would not be where I am today.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

LIST OF APPENDIX TABLES

Table Page

1. LITERATURE REVIEW

1.1. U.S. Forest service sensitive grassland bird habitat associations

1.1.1. Baird's sparrow

The Baird's sparrow (*Ammodramus bairdii*) was one of the most common birds on the northern mixed-grass prairie prior to European settlement (Green, 2002) and is now considered a species of notable conservation concern in Regions 2 and 6 of the U.S. Fish and Wildlife Service (USFWS, 2008). In a 9-month finding on a petition to list the Baird's sparrow as "Endangered" or "Threatened" under the Endangered Species Act (1973), the USFWS concluded that the listing of Baird's sparrow was not justified because the petition did not present substantial information indicating that the listing of this species as threatened was warranted (USFWS, 1999). The species also is listed as a "Sensitive Species" in Region 1 (Northern Region) of the U.S. Forest Service (USFS, 2005). The USFS defines sensitive species as species that need special management to maintain and improve their status on National Forests and Grasslands, and prevent a need for listing under the Endangered Species Act (USFS, 2005).The North Dakota Game and Fish Department (NDGFD) listed the Baird's sparrow as a "Level 1 Species of Concern" in the North Dakota State Wildlife Action Plan (Dyke and Isakson, 2015).

Baird's sparrows tend to favor idle native or introduced grasslands and lightly to moderately grazed pastures (Owens and Myres, 1973; Stewart, 1975; Kantrud and Kologiski, 1982; Skeel et al., 1995; De Smet and Conrad, 1997). The species sometimes uses planted cover (e.g., Conservation Reserve Program [CRP] and dense nesting cover), dry wetland basins, wet meadows, and dense stands of grass within hayland and cropland (Lane, 1968; Stewart, 1975; Johnson and Schwartz, 1993). Several studies have highlighted the importance of native prairie to Baird's sparrow breeding habitat (Cartwright et al., 1937; Lane, 1968; Owens and Myres, 1973; Dale, 1992; Dale et al., 1997), and some studies have shown that Baird's sparrows exhibit a preference for native grasses (Winter, 1994; Sutter et al., 1995; Madden, 1996). However, some studies have shown that Baird's sparrows respond more strongly to vegetative structure than plant species composition in Canada and did not exhibit a preference for native grasslands (Anstey et al., 1995; Sutter et al., 1995; Davis et al., 1999).

General habitat requirements for Baird's sparrow include moderately deep litter; moderate vegetation height; moderately high, but patchy forb coverage; patchy grass and litter cover; and little woody vegetation (Dechant et al., 2003). In northern mixed-grass prairies in North Dakota, Baird's sparrows were present in grasslands with higher litter depth and a lower percentage of live vegetation than in unoccupied areas (Grant et al., 2004). In North Dakota, the probability of Baird's sparrow occurrence increased with grass cover, forb cover, and native grass frequency, reaching 50% occurrence at 42% grass cover, 35% forb cover, and 0.42 native grass frequency (Madden et al., 2000). Baird's sparrows also occupied areas with significantly greater grass cover than unoccupied areas (Madden, 1996). In contrast, Baird's sparrow abundance in grazed mixed-grass prairies in North Dakota was negatively associated with the percentage of grass cover at the site-level, whereas abundance was positively associated with plant communities dominated solely by native grass (*Hesperostipa*, *Bouteloua*, *Koeleria*, and *Schizachyrium*) (Schneider, 1998). Another study in northern mixed-grass prairies found that the Baird's sparrow was present in grasslands with higher percentage cover of Kentucky bluegrass (*Poa pratensis*) than in unoccupied areas and that Baird's sparrow occurrence was not related to coverage of native grass and forb species, tame legumes, smooth brome (*Bromis inermis*) and quackgrass (*Elymus repens*) (Grant et al., 2004).

1.1.2. Sprague's pipit

The Sprague's pipit also is one of the few grassland bird species endemic to the northern Great Plains (Mengel, 1970), and is one of the least understood bird species in North America due to its small breeding range, as well as its cryptic plumage and secretive behaviors (Robbins and Dale, 1999). Sprague's pipit was a candidate for listing as "Endangered" or "Threatened" under the Endangered Species Act (1973), but the USFWS recently withdrew it from the candidate list (USFWS, 2016). Sprague's pipit is considered a "Sensitive Species" in Region 1 (Northern Region) of the USFS (2005). It also is listed as a "Level 1 Species of Concern" in North Dakota's State Wildlife Action Plan (Dyke and Isakson, 2015).

Several researchers have found that Sprague's pipits are closely associated with native grasslands throughout their breeding range (Sutter, 1996; Sutter and Brigham, 1998; Madden et al., 2000; Grant et al., 2004) and are less abundant in areas of introduced grasses than in areas of native prairie (Kantrud, 1981; Johnson and Schwartz, 1993; Dale et al., 1997; Madden et al., 2000; Grant et al., 2004). Generally, Sprague's pipits prefer higher grass and sedge cover, less bare ground, and an intermediate average grass height when compared to the surrounding landscape, <5-20% shrub and brush cover, no trees at the territory scale, and litter cover <12 cm (Sutter, 1996; Madden et al., 2000; Dieni and Jones, 2003; Grant et al., 2004).

As with other grassland birds, vegetative structure figures prominently in habitat selection by Sprague's pipit during the breeding season. In North Dakota mixed-grass prairies, Sprague's pipits were present in grasslands with lower litter depth, lower maximum vegetation height, lower percentage cover of shrubs greater than 1 m tall, and lower percentage cover of shrubs less than 1 m tall than in unoccupied grasslands (Grant et al., 2004). Another North Dakota study found that visual obstruction (i.e., vegetation height-density) was the best predictor of Sprague's pipit occurrence (Madden et al., 2000). Sprague's pipits also were found to avoid idle areas with deep litter (Madden, 1996). In northwestern North Dakota, male breeding territories were located on ridgetops with low sedge and forb densities and short grass (Robbins, 1998). In a study on the Grand River National Grassland (GRNG) in northwestern South Dakota, Sprague's pipits were present on sites that had the following characteristics: close proximity to shrubs, deeper litter, slightly higher altitudes, and higher stocking rates than unoccupied grasslands (Winter, 2007). Litter depth was shown to be the best predictor for the presence of Sprague's pipits on the GRNG (Winter, 2007).

1.2. The management history of the Little Missouri National Grassland

Although the National Grasslands were not officially designated until 1953 (Dana, 1980), the events which would spur their creation can be traced back to the mid-1800s when Congress enacted the Homestead Act (1862). The Homestead Act authorized the dispersal of 160-ac (i.e., 64.7-ha) parcels of federal land to qualified individuals in an attempt to accelerate the settlement of the Great Plains. However, much of this land was "submarginal," which led to a large number of failed farms (Aileen, 1995). Recognizing their error, Congress began investigating the issues related to submarginal lands plaguing the Great Plains in the 1920s. The resulting legislation—the National Industrial Recovery Act (1933) and the Emergency Relief Act (1935)—spurred the purchase of these "submarginal" farmlands, which became known as Land Utilization Projects (LUP). LUP lands were administered and managed by several agencies until 1938, when they were transferred to the Soil Conservation Service (SCS)—now known as the Natural Resource Conservation Service (NRCS). Under the management of the SCS, LUP lands underwent several management changes that would shape these lands into the present-day National Grasslands. Many areas that had recently been plowed under the direction of the Homestead Act were reseeded with crested wheatgrass (*Agropyron cristatum*), a non-native plant that originated from Russia (Johnson, 1986; Aileen, 1995; Moul, 2006). Perhaps the most influential management decision came when the SCS extended grazing privileges to private landowners (Aileen, 1995).

Grasslands like the Little Missouri National Grassland (LMNG) are primarily maintained by climatic variations, in particular drought (Biondini et al., 1998); however, grazing and fire also are important drivers of these grassland ecosystems (Askins et al., 2007). The historical interactions between climate, American bison (*Bison bison*) grazing, and fire, maintained a heterogeneous landscape, which provided habitat for several species of obligate grassland birds (Askins et al., 2007). The near-extinction of American bison and the resulting shifts in grazing practices has likely contributed to recent grassland bird population declines (Askins et al., 2007).

Historically, grazing by native mammals occurred naturally across much of the northern Great Plains (Lauenroth et al., 1994). Native ungulates, such as American bison, pronghorn (*Antilocapra americana*), and elk (*Cervus elaphus*), were the prominent grazing mammals on the Great Plains post-Pleistocene. However, colonial rodents, such as prairie dogs (*Cynomys* spp.) and ground squirrels (e.g., *Urocitellus richardsonii, Ictidomys tridecemlineatus, Poliocitellus franklinii*) and the now extinct Rocky Mountain locust (*Melanoplus spretus*), also were major components of the historic grazing system of the Great Plains. The historical interactions between fire and American bison resulted in a shifting mosaic of heavily grazed and undisturbed grassland patches (Fuhlendorf and Engle, 2004). Modern livestock management goals place an emphasis on maximizing forage utilization by strategically placing fencing, minerals, and water sources (Coughenour, 1991), and thus, creating a more homogenous landscape that is contrary to historic disturbance regimes (Fuhlendorf and Engle, 2001). However, habitat heterogeneity can be achieved if the selective grazing habits of cattle are implemented using lower stocking rates on larger pastures (Hart et al., 1993). Landowners have an economic incentive for heavier grazing on their lands because beef production increases with an increase in stocking rate and grazing pressure (Derner et al., 2009), although they risk the deterioration of rangelands and diminishing economic returns (Hart et al., 1988). This is not to say that patches of shorter-structured grasslands do not have a place in contemporary grassland ecosystems. Historically, American bison would preferentially select high-quality vegetation regrowth within recently burned portions of the landscape (Coppedge and Shaw, 1998). These recently burned patches of grassland would experience bouts of intensive grazing, while adjacent unburned patches received less grazing pressure (Fuhlendorf and Engle, 2001). Given that the community of grassland birds that evolved within the Great Plains requires a gradient of vegetation structure (Samson and Knopf, 1994; Fuhlendorf et al., 2006; Hovick et al., 2015), it is just as important to manage for grassland bird species at both extremes of this gradient as well as in between. For example, the long-billed curlew (*Numenius americanus*) prefers sparser vegetation (Dechant et al., 2002), whereas the Baird's sparrow prefers taller and denser vegetation (Dechant et al., 2003). Although there are many differences between historic ungulate grazing and modern cattle management, cattle can be an appropriate substitute for native ungulates when managing for grassland birds (Plumb and Dodd, 1993; Knapp et al., 1999; Derner et al., 2009).

1.3. Relationship between grazing, vegetation structure and composition, and grassland birds

Livestock grazing modifies habitat structure and plant communities in a number of different ways. Grazing reduces plant canopy height, changes plant morphology, creates grazing lawns, affects hydrology, compacts the soil, and changes the rate of litter accumulation

(Milchunas et al., 1989; Saab et al., 1995; Hartnett et al., 1997). Livestock also impact areas where they do not actively remove plant material by compacting the soil and indirectly creating bare ground (Hartnett et al., 1997). Livestock grazing also has direct impacts on the composition of plant species (Collins, 1987; Anderson and Briske, 1995), and therefore on habitat structure, due to the selection for or avoidance of certain plant species (Briske et al., 2005). These species-specific impacts can affect habitat structure because taller species that are grazed will lose dominance, allowing short-stature species to increase in abundance (Anderson and Briske, 1995). When the abundance of dominant grasses is reduced by disturbances such as grazing, the growth and survival of subdominant species can increase the diversity and evenness of the plant community (Cid et al., 1991; Hartnett et al., 1997).

Grazing intensity also influences plant diversity on rangelands. Several studies have found that diversity, richness, and evenness were highest on pastures that were lightly to moderately grazed (Collins and Barber, 1986; Hartnett et al., 1996; Collins et al., 1998; Knapp et al., 1999). Other studies concluded that diversity can either increase or decrease with grazing depending on a suite of factors, including the productivity of the grassland, the intensity of grazing, and the evolutionary history of grazing in the area (Milchunas et al., 1988, 1998; Cid et al., 1991; Bakker et al., 2006). Increased grazing intensity mainly affects grassland birds through reduced vegetation structure (i.e., lower vegetation height and density), decreased standing dead vegetation, and decreased litter accumulation (Biondini et al., 1998; Gillen et al., 2000).

The aforementioned studies have found that livestock grazing has played a large role in the structuring of grasslands. Because grassland breeding birds select sites primarily based on vegetation structure (Wiens, 1969; Fisher and Davis, 2010), it is likely that grazing affects the occurrence and abundance of grassland birds (Davis et al., 2009). Therefore land management practices—like grazing—has the potential to increase the heterogeneity of grasslands (e.g., pyric-herbivory) and may be beneficial to grassland birds that have differing vegetative structure preferences (Fuhlendorf et al., 2006).

1.4. Threats to grassland bird populations

Since 1966, 24 grassland obligate breeding birds have declined by nearly 40% (Sauer et al., 2014). Although these declines began to stabilize in the early 1990s, a sub-group of grassland birds—including Sprague's pipit and Baird's sparrow—continue steep declines (Sauer et al., 2014). Several hypotheses have been proposed to explain these declines, including conversion of prairie to agriculture-dominated landscapes and prairie fragmentation (Knopf, 1994); historic livestock grazing (Saab et al., 1995); rangeland deterioration (e.g., overgrazing, drought, fire suppression, and woody plant and exotic plant invasions) (Brennan and Kuvlesky, 2005); and anthropogenic disturbances, such as oil development and associated access roads (Hamilton et al., 2011; Ludlow et al., 2015; Thompson et al., 2015)

1.4.1. Habitat loss and fragmentation

Grassland conversion has reduced the quality and availability of suitable habitat for area sensitive species, such as Sprague's pipit and Baird's sparrow. Sprague's pipit prefers large patches of grassland, with a minimum size requirement of about 145 ha, whereas the Baird's sparrow has a minimum size requirement of about 25 ha (Davis and Brittingham, 2004). In the northern Great Plains agricultural conversion is happening five times faster than grasslands are being protected (Doherty et al., 2013; Walker et al., 2013). From 1997-2007, approximately 1% of grasslands were converted to crop production in the Great Plains (roughly 311,608 ha), whereas only 40,469 ha of cropland reverted back to grassland during this same time period

(Claassen et al., 2011). During this period, many agricultural producers took highly erodible, tillable land out of agricultural production and planted it to perennial grassland cover to help improve water quality and prevent soil erosion, via the Conservation Reserve Program (CRP) (FAPRI, 2007). A secondary objective of the CRP was to provide habitat for wildlife (Johnson, 2000). Between 1997 and 2007, roughly 1.4 million ha of cropland was placed into CRP (Claassen et al., 2011). Several researchers reported that Sprague's pipits and Baird's sparrows rarely used CRP grassland fields or other seeded cover planted for waterfowl production (Johnson and Schwartz, 1993; Prescott and Davis, 1998) and therefore these programs do little to mitigate the effects of grassland conversion on populations of Sprague's pipit or Baird's sparrow. However, CRP did benefit other grassland birds (e.g., grasshopper sparrow; Johnson and Igl, 1995; Johnson, 2000). Baird's sparrow and Sprague's pipit often are associated with native prairie (Sutter, 1996; Madden et al., 2000; Davis and Brittingham, 2004), but will occasionally use non-native grasslands that were previously cultivated if the vegetation structure is suitable (Dale et al., 1997; Sutter and Brigham, 1998).

1.4.2. Livestock grazing

Livestock grazing occurs on more than 300 million ha in the United States each year, making it one of the most widespread causes of landscape modification in the nation (Hobbs, 1996). In a study of the effects of grazing intensity on floral and faunal communities on the shortgrass steppe of Colorado, the only group of animals found to have shifted in dominant species and community composition in response to grazing intensity were grassland birds (Milchunas et al., 1988). These results emphasize that birds are particularly sensitive to grazing treatments. Because different grassland birds have different habitat requirements (Saab et al., 1995; Askins et al., 2007), there is a need to manage grazing to provide suitable habitat for multiple species (Samson and Knopf, 1996).

Grazing has a substantial influence on the structuring of grasslands in the northern Great Plains (Milchunas et al., 1988; Knopf, 1994), and, therefore, greatly influences sensitive grassland bird occurrence and abundance (Prescott and Davis, 1998). The effects of livestock grazing on the abundance and distribution of Sprague's pipits and other grassland birds depend on several factors, including livestock stocking rates, as well as environmental conditions, such as moisture, soil type, and plant species composition (Owens and Myres, 1973). Therefore, the response of grassland birds to grazing intensity and frequency likely varies by region.

Although several studies have found that Sprague's pipits tend to avoid heavily grazed grasslands (Maher, 1973; Owens and Myres, 1973; Prescott and Wagner, 1996), lightly to moderately grazed grasslands have been identified as optimal habitat for Sprague's pipits throughout much of their breeding range (Owens and Myres, 1973; Davis et al., 1999; Robbins and Dale, 1999). In North Dakota, Kantrud (1981), reported a greater abundance of Sprague's pipits in grasslands that were moderately- to heavily-grazed. In the mesic mixed-grass prairie, disturbances such as fire at appropriate intervals and grazing at appropriate rates can be used to create and maintain Sprague's pipit habitat (Kantrud, 1981; Madden et al., 1999). In the drier, less densely-vegetated mixed-grass prairie in the southwestern portions of Sprague's pipit range, some studies have shown that Sprague's pipit abundance decreased significantly with increasing grazing intensity (Maher, 1973; Dale, 1984; Robbins and Dale, 1999).

In both the moist and drier parts of the Baird's sparrow breeding range, heavy or continuous grazing that reduces residual vegetation and litter was found to be detrimental to breeding populations of Baird's sparrow (Owens and Myres, 1973; Kantrud, 1981; Anstey et al., 1995). However, Davis and others (1999) found that grazing intensity did not dramatically impact Baird's sparrow abundance, yet Baird's sparrows were still attracted more to pastures with relatively taller vegetation and lower shrub cover. In general, grazing systems which provide moderate vegetative and litter cover are suitable for Baird's sparrows (Anstey et al., 1995). Messmer (1990) found higher numbers of Baird's sparrows in pastures that implemented a rotational grazing system, than in pastures that experienced season-long grazing or short-duration grazing. In Alberta, however, Baird's sparrow presence did not significantly differ between four different grazing treatments: early-season tame (grazed from late April to mid-June); early-season native (grazed in early summer); deferred-grazed native (grazed after 15 July); and, season-long grazed native (Prescott and Wagner, 1996). Like other grassland birds, the factors that influence the occurrence of Baird's sparrows can vary by region or environmental conditions (Maher, 1973; Owens and Myres, 1973). In denser, taller habitats, or during wet years, light-to-moderate grazing can improve habitat by providing shorter, sparser vegetation (Kantrud, 1981; Messmer, 1990; Anstey et al., 1995). In Saskatchewan, over-stocking livestock nearly eliminated Baird's sparrows from the landscape during a drier than normal breeding season (Dale, 1984). However, following a moist winter and spring, new growth on grazed pastures was twice the height of the previous season's growth and Baird's sparrow populations rebounded in the area.

1.4.3. Invasive or exotic vegetation

Smooth brome and Kentucky bluegrass were planted as part of the U.S. Department of Agriculture Soil Bank Program in the 1950s and 1960s, the Cropland Adjustment Program in the 1960s (Duebbert et al., 1981), and more recently the CRP beginning in 1985 (Johnson, 2000; Fargione et al., 2012). Although the primary objectives of these Farm Bill programs were to conserve soil and water resources, an additional benefit was realized—the creation of wildlife habitat. The resulting mixed stands of native and exotic grasses and forbs provided some wildlife species refuge from the surrounding cropland-dominated landscape of the northern Great Plains (Johnson and Igl, 1995; Johnson, 2000). One benefit of these mixed plantings is the highly palatable seeds of smooth brome, which provide valuable forage for upland gamebirds and songbirds (Sedivec and Barker, 1997). Although there were some benefits from planting cool-season grasses for grassland birds, there also were some negative consequences. Smooth brome and Kentucky bluegrass spread from these and other plantings and invaded adjacent native prairie tracts (DeKeyser et al., 2013), potentially causing shifts in grassland songbird communities (Grant et al., 2006).

There is evidence which suggests that grassland birds show an affinity for exotic vegetation stands, although other grassland birds have had shown a negative response. For example, grasshopper sparrow (*Ammodramus savannarum*), clay-colored sparrow (*Spizella pallida*), and vesper sparrow (*Pooecetes graminerus*) showed a preference for stands dominated by smooth brome and Kentucky bluegrass (Wilson and Belcher, 1989). However, this apparent preference for non-native vegetation may reflect these species affinity for mesic grasslands (Madden et al., 2000). On the other hand, some grassland birds, including upland sandpiper (*Bartramia longicauda*), Sprague's pipit, western meadowlark (*Sturnella neglecta*), Baird's sparrow, bobolink (*Dolichonyx oryzivorus*), and Savannah sparrow (*Passerculus sandwichensis*), have shown a preference for native vegetation stands (Wilson and Belcher, 1989; Madden et al., 2000). Overall, studies of grassland bird habitat preferences have had mixed and often contradictory results. However, researchers tend to agree that the increasing amount of exotic vegetation is causing grassland bird populations to decline because of two factors: 1) reduced fitness, and 2) loss of vegetative heterogeneity.

Several studies show that the invasion of exotic vegetation can have adverse reproductive consequences for native animals (Schmidt and Whelan, 1999; Remeš, 2003; Lloyd and Martin, 2005). In Montana, for example, researchers found that the chestnut-collared longspur (*Calcarius ornatus*) did not prefer native vegetation over exotics (Lloyd and Martin, 2005). Longspurs nested at similar densities in both native and exotic habitats, and individuals did not appear to differentiate between the two habitats when establishing breeding territories in the spring. However, breeding success may be a better indicator of habitat quality. Lloyd and Martin (2005) found that reproductive success was lower in monocultures of exotic grass than in native prairie. They also reported that the odds of a nest surviving on native prairie sites were approximately 17% higher than exotic prairies, primarily due to increased nest predation on exotic sites.

Although several studies suggest that grassland songbirds have a preference for native habitat, there is still little evidence that vegetation community composition has a consistent influence on grassland-bird habitat use (Fisher and Davis, 2010). Instead, vegetation structure may play a larger role in grassland songbird habitat selection. Grasslands with heterogeneous structure are essential for grassland songbird diversity (Madden et al., 2000). Invasive cool-season grasses can decrease the structural composition in prairies by outcompeting native plant species and reducing species diversity that naturally creates a mosaic across the landscape (Hendrickson and Lund, 2010). The loss of vegetative structure also favors generalist species that can tolerate habitat homogeneity, therefore supporting a bird community that is less diverse than on a native prairie site (Toledo et al., 2014).

1.4.4. Anthropogenic disturbance

As global human populations continue to expand at a growth rate of 1.18% per year (i.e., approximately 83 million people annually) (UNDESA, 2015), resource exploitation is likely to continue to stress natural ecosystems, resulting in more habitat degradation and loss of biodiversity (Tilman et al., 2001). Recent population declines of grassland birds often are linked to direct habitat loss and degradation due to agricultural activities, fire suppression, and industrial and urban development (Samson and Knopf, 1994; Brennan and Kuvlesky, 2005; Askins et al., 2007). Previous research has identified a variety of sources of habitat degradation, with activities associated with energy development receiving modest attention, despite the growing number of regions affected (Dale, 1984; Askins et al., 2007). The previously inaccessible fossil fuels in the shale rock formations of the Williston Basin and Bakken formations in western North Dakota are now being extracted with new, unconventional technologies, such as hydraulic fracturing (i.e., fracking) (EIA, 2011). The North Dakota Industrial Commission (2012) predicted that 2,000 new oil wells will be drilled annually from 2014 to 2034. The Bakken formation coincides with areas of unusually high grassland bird abundance and diversity (Peterjohn and Sauer, 1999). The rapid expansion of oil development in North Dakota exacerbates conservation concerns for grassland birds that breed in the Bakken region, because many of them have experienced long-term population declines (Peterjohn and Sauer, 1999), and have demonstrated sensitivity to habitat fragmentation (Reino et al., 2009; Ribic et al., 2009) and disturbances related to oil development (Hamilton et al., 2011; Thompson et al., 2015).

In western North Dakota, Thompson and colleagues (2015) found that several species of grassland birds avoid oilfield infrastructure, including secondary access roads. The study reported reduced avian densities near roads may have resulted from heavy traffic associated with oil development in the region (Thompson et al., 2015). In grasslands of southern Alberta, Sprague's pipits did not appear to avoid low-traffic roads (Koper et al., 2009). However, sagebrush-obligate songbirds in Wyoming are significantly less common within 100 m of roads associated with oil development (Ingelfinger and Anderson, 2004). Roads associated with oil and natural gas extraction tend to experience considerably higher traffic volume than roads in most other comparable locations (Fershee, 2012). In lightly to moderately grazed native prairie in Saskatchewan, Sprague's pipits and Baird's sparrows were more abundant in grasslands alongside trails (i.e., single pair of wheel ruts) than in grasslands alongside roads (i.e., traveling surfaces with adjacent drainage ditches planted to exotic vegetation and ending with a fence 11-18 m from the traveling surface) (Sutter et al., 2000).

1.5. Project significance

1.5.1. Research gaps

There is little information regarding the distribution and abundance of bird species within the LMNG, highlighting the importance of developing monitoring programs with the aim to understand population trends and underlying factors contributing to such trends (Sparks et al., 2009). At a continental scale, the Breeding Bird Survey (BBS) offers the most extensive data on bird distributions and population trends (Robbins et al., 1989). The BBS has relatively sparse coverage in the northern Great Plains region and the restriction of survey routes to roadways leads to inadequate sampling for sensitive species, such as the Sprague's pipit (O'Connor et al., 2000). The BBS also does not reliably predict population trends at small geographic scales such as the LMNG (Sauer, 1995). For these reasons, BBS data are generally insufficient to guide local and regional management decisions (Leukering et al., 2000), such as those by National

Grassland managers. Sparks and Hanni (2009) attempted to fill this knowledge gap by surveying breeding birds on 31 transects on the Little Missouri, Sheyenne, and Grand River National Grasslands. The objectives of their monitoring program were to determine population trends and distributions for breeding birds on the Dakota Prairie Grasslands. However, their study did not explore the specific habitat features that were associated with the occurrence of the species. In addition, one of their site-selection criteria was a "minimum road access network." Thus, the effects of roads on breeding grassland birds were not explored.

Davis (2009) examined the breeding biology of Sprague's pipits in Saskatchewan, Canada. Although Davis' (2009) study provided important information about Sprague's pipit life-history parameters, it did not quantify the specific habitat features that are associated with the occurrence of the Sprague's pipit. Dieni and Jones (2003) explored nest-site selection patterns of six grassland birds in north-central Montana. The main objective of that study was to discern habitat differences at a smaller scale (i.e., nesting site). However, they did not explore landscape-level or site-specific variables that grassland birds use during their hierarchial selection of a breeding site (Johnson, 1980). Winter (2007) examined the distribution and habitat associations of sensitive grassland birds on the Grand River National Grassland, which like the LMNG, is located within the Dakota Prairie Grasslands. Winter recommended that similar studies be conducted to strengthen understanding of habitat management on sensitive grassland birds.

Several studies have explored the effects of oil extraction on grassland birds (Hamilton et al., 2011; Bogard and Davis, 2014; Ludlow et al., 2015). However, as Thompson (2015) points out, many of these studies were conducted in areas with more conventional oil development, whereas the oil development in North Dakota uses unconventional practices such as hydraulic fracturing. Infrastructure associated with hydraulic fracturing generally has different maintenance requirements (e.g., higher traffic levels), and therefore has different effects on the landscape than other, more traditional oil-extraction methods (Thompson et al., 2015).

The study presented herein will build upon earlier studies to provide a better understanding of the effects of landscape-level (e.g., percent grassland in surrounding landscape) and site-specific (e.g., slope, litter depth) variables on sensitive grassland bird populations and grassland bird diversity and community composition in the LMNG. This study also will provide information on how oil development in western North Dakota may be affecting grassland birds in the region. The results from this study will contribute to understanding grassland songbird responses to landscape-level and site-specific variables and identify specific mechanisms by which conservation measures for declining grassland bird populations can be improved.

1.5.2. Why are grassland birds important?

Biodiversity is the sum total of all biotic organisms on Earth, including their genetic and phenotypic variation, and the communities and ecosystems in which they occur (Swingland, 2001). The Earth is currently experiencing its richest and most varied biodiversity in geologic history, due to a long history of speciation (Rosenzweig, 1995); however, biodiversity is being threatened by an increasing extinction rate (May et al., 1995). Darwin (1872) was one of the first to acknowledge the importance of biodiversity, noting that several distinct genera of grasses grown together would produce more biomass than a single species growing alone. It is well documented that biodiversity losses result in ecosystem instability (Tilman, 1996; Jiang and Pu, 2009; Hector et al., 2010). Biodiversity can stabilize ecosystem productivity, and field studies have confirmed that plant species-rich plots showed less yearly variation in primary productivity (Tilman, 1996) and that productivity during a drought year declined much less in those plots than in species-poor plots (Tilman and Downing, 1994). The diversity within a functional group—such as grassland birds—is often just as important as overall species diversity (Kremen, 2005). This is not to say that individual, less abundant species are of less importance. Rare species often are overlooked but can provide an extra buffer against disturbance, environmental change, and the loss of more dominant species (Hobbs et al. 2007). The role of rare species—like the Baird's sparrow and Sprague's pipit—are important to environments where species abundances vary temporally. In these environments, rare species can contribute significantly to long-term and large-scale ecosystem functioning (Lyons et al., 2005). Ehrlich and Ehrlich (1981) offered an analogy that highlights the importance of less abundant species within an ecosystem. They compared rare species to rivets on an airplane wing. While a few missing rivets may go unnoticed, there will be a threshold at which the wing cannot lose any more rivets and a catastrophe will ensue.

Biodiversity also plays a large role in the provision of ecosystem services, although this is often a point of contention among ecologists. However, it is well documented that increased biodiversity improves ecosystem services (Minns et al., 2001; Sax and Gaines, 2003). Ecosystem services are any set of ecosystem functions that are helpful to humans. They can be critical to human life (e.g., climate regulation, air purification, crop pollination) or enhance it (e.g., aesthetics). The best, and possibly most well-known example of an ecosystem service is pollination. Honeybees (*Apis*) pollinate much of the Earth's crops, which in turn provide a service that benefits humans via the production of food. Ecosystem services provided by birds, however, are not quite as obvious. Early ornithological research in the U.S. in the late 1800's and early 1900's focused on the economic impact of birds on agriculture (e.g., Barrows, 1889; Judd, 1901). Birds were once thought to contribute little to overall ecosystem productivity

(Wiens, 1973; Holmes and Sturges, 1975), but we now know that birds serve many purposes, including predation, pollination, scavenging, seed dispersal, seed predation, and ecosystem engineering (Sekercioglu, 2006; Whelan, et al., 2015).

There are four principal types of ecosystem services: provisioning, regulating, cultural, and supporting. Perhaps one of the most important services—both monetarily and aesthetically—is birdwatching or "birding." Birdwatchers are one of the best sources of ecotourism income since they form the largest single group of ecotourists, are educated, and have above average incomes (Cordell and Herbert, 2002). In 2011, there were an estimated 47 million birders in the United States—approximately 20% of the country's population (USFWS, 2011). Birders spend money on a variety of goods and services for their trip-related and equipment-related purchases. Birding-related expenses ripple through the economy by impacting economic activity, employment, and household income. In 2011, birders spent an estimated $15 billion on their trips and $26 billion on equipment. In addition, birding generated approximately 666,000 jobs, and $13 billion in local, state, and federal tax revenue (USFWS, 2011). Birdwatching also has important conservation impacts. At a broad-scale, the growing popularity of birdwatching and their outreach has led other groups of society to consider birds. For example, consumers may be willing to pay a premium for agricultural products certified as bird-friendly (Rice, 2010). Birdwatchers actively participate in citizen science, such as the BBS (Robbins et al., 1989), the Christmas Bird Count (Dunn et al., 2005), and eBird (Sullivan et al., 2014). Because of their exposure to citizen science, birders tend to be more aware of environmental issues, and thus, they are more likely to support habitat conservation that benefits bird populations (Kronenberg, 2014). Ecotourism also provides an incentive to locals to protect sensitive bird habitat. This is evident in the growing number of private nature preserves where suitable bird habitat is protected in order to obtain income from tourists seeking to view a specific bird (Aylward et al., 1996).

1.6. References

AILEEN, L., 1995. The National Grasslands: past, present and future land management issues. *Rangelands* 17, 36–42.

ANDERSON, V. J., AND D. D. BRISKE, 1995. Herbivore-induced species replacement in grasslands: is it driven by herbivory tolerance or avoidance? *Ecological Applications* 5, 1014–1024.

ANSTEY, D. A., S.K. DAVIS, D.C. DUNCAN, AND M. SKEEL, 1995. Distribution and habitat requirements of eight grassland songbird species in southern Saskatchewan. Saskatchewan Wetland Conservation Corporation, Regina, Saskatchewan, Canada.

ASKINS, R.A., F. CHÁVEZ-RAMÍREZ, B. C. DALE, C. A. HAAS, J. R. HERKERT, F. L. KNOPF, AND P. D. VICKERY, 2007. Conservation of grassland birds in North America: understanding ecological processes in different regions: report of the AOU Committee on Conservation. *Ornithological Monographs* 64, 1–46.

AYLWARD, B., K. ALLEN, J. ECHEVERRIA, AND J. TOSHI, 1996. Sustainable ecotourism in Costa Rica: the Monteverde Cloud Forest Preserve. *Biodiversity and Conservation* 5, 315-343.

BAKKER, E.S., M. E. RITCHIE, H. OLFF, D. G. MILCHUNAS, AND J. M. KNOPS, 2006. Herbivore impact on grassland plant diversity depends on habitat productivity and herbivore size. *Ecological Letters* 9, 780–788.

BARROWS, W. B., 1889. The English sparrow (*Passer domesticus*) in North America, especially in its relation to agriculture. Bulletin 1. U.S. Department of Agriculture, Division of Economic Ornithology and Mammalogy, Washington, D.C., USA.

BIONDINI, M. E., B. D. PATTON, AND P. E. NYREN, 1998. Grazing intensity and ecosystem processes in a northern mixed-grass prairie, USA. *Ecological Applications* 8, 469–479.

BOGARD, H. J., AND S. K. DAVIS, 2014. Grassland songbirds exhibit variable responses to the proximity and density of natural gas wells. *Journal of Wildlife Management* 78, 471–482.

BRENNAN, L. A., AND W. P. KUVLESKY, JR., 2005. Invited paper: North American grassland birds: an unfolding conservation crisis? *Journal of Wildlife Management* 69, 1–13.

BRISKE, D.D., S. D. FUHLENDORF, AND F. E. SMEINS, 2005. State-and-transition models, thresholds, and rangeland health: a synthesis of ecological concepts and perspectives. *Rangeland Ecology and Management* 58, 1–10.

CARTWRIGHT, B. W., T. M. SHORTT, AND R. D. HARRIS, 1937. Baird's sparrow. *Contributions of the Royal Ontario Museum of Zoology* 1, 153–197.

CID, M. S., J. K. DETLING, A. D. WHICKER, M. A. BRIZUELA, 1991. Vegetational responses of a mixed-grass prairie site following exclusion of prairie dogs and bison. *Journal of Range Management* 44, 100–105.

CLAASSEN, R., F. CARRIAZO, J. C. COOPER, D. HELLERSTEIN, AND K. UEDA, 2011. Grassland to cropland conversion in the Northern Plains: the role of crop insurance, commodity, and disaster programs. Economic Research Report 120. U.S. Department of Agriculture, Economic Research Service, Washington, D.C., USA.

COLLINS, S. L., 1987. Interaction of disturbances in tallgrass prairie: a field experiment. *Ecology* 68, 1243–1250.

COLLINS, S. L., AND S. C. BARBER, 1986. Effects of disturbance on diversity in mixed-grass prairie. *Vegetatio* 64, 87–94.

COLLINS, S. L., A. K. KNAPP, J. M. BRIGGS, J. M. BLAIR, AND E. M., STEINAUER, 1998. Modulation of diversity by grazing and mowing in native tallgrass prairie. *Science* 280, 745–747.

CONNELL, J. H., 1978. Diversity in tropical rain forests and coral reefs. *Science* 199, 1302–1310.

COPPEDGE, B. R., AND J. H. SHAW, 1998. Bison grazing patterns on seasonally burned tallgrass prairie. *Journal of Range Management* 51, 258–264.

CORDELL, H. K., AND N. G. HERBERT, 2002. The popularity of birding is still growing. *Birding* 34, 54–61.

COUGHENOUR, M. B., 1991. Spatial components of plant-herbivore interactions in pastoral, ranching, and native ungulate ecosystems. *Journal of Range Management* 44, 530–542.

DALE, B. C., 1984. Birds of grazed and ungrazed grasslands in Saskatchewan. *Blue Jay* 42, 102–105.

DALE, B., 1992. North American Waterfowl Management Plan implementation program related to non-game bird studies within the Prairie Habitat Joint Venture area. Annual report 1991-1992. Unpublished report submitted to the Canadian Wildlife Service, Saskatoon, Saskatchewan, Canada.

DALE, B. C., P. A. MARTIN, P.A., AND P. S. TAYLOR, 1997. Effects of hay management on grassland songbirds in Saskatchewan. *Wildlife Society Bulletin* 25, 616–626.

DANA, S. T., 1980. Forest and range policy: its development in the United States. *Soil Science* 82, 437.

DARWIN, C., 1872. The origin of species by means of natural selection: or, the preservation of favoured races in the struggle for life and the descent of man and selection in relation to sex. J. Murray, London, United Kingdom.

DAVIS, S. K., 2009. Renesting intervals and duration of the incubation and nestling periods of Sprague's pipits. *Journal of Field Ornithology* 80, 265–269.

DAVIS, S.K., AND D. C. DUNCAN, 1999. Grassland songbird occurrence in native and crested wheatgrass pastures of southern Saskatchewan. *Studies in Avian Biology* 19, 211–218.

DAVIS, S. K., AND M. BRITTINGHAM, 2004. Area sensitivity in grassland passerines: effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. *Auk* 121, 1130–1145.

DE SMET, K. D., AND M. P. CONRAD, 1997. Management and research needs for Baird's sparrows and other grassland species in Manitoba. *In*: Holroyd G. I., G. Burns, and H. C. Smith [EDS.]. Proceedings of the second Endangered Species and Prairie Conservation Workshop. Natural History Occasional Paper 15. Provincial Museum of Alberta, Edmonton, Alberta, Canada. p. 83–86.

DECHANT, J. A., M. L. SONDREAL, D. H. JOHNSON, L. D. IGL, C. M. GOLDADE, P. A. RABIE, AND B. R. EULISS, 2002. Effects of management practices on grassland birds: long-billed curlew. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

DECHANT, J. A., M. L. SONDREAL, D. H. JOHNSON, L. D. IGL, C. M. GOLDADE, M. P. NENNEMAN, AND B. R. EULISS, 2003. Effects of management practices on grassland birds: Baird's sparrow. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

DEKEYSER, E. S., M. MEEHAN, G. CLAMBEY, AND K. KRABBENHOFT, 2013. Cool season invasive grasses in northern Great Plains natural areas. *Natural Areas Journal* 33, 81–90.

DERNER, J. D., W. K. LAUENROTH, P. STAPP, D. J. AUGUSTINE, 2009. Livestock as ecosystem engineers for grassland bird habitat in the western Great Plains of North America. *Rangeland Ecology and Management* 62, 111–118.

DIENI, J. S., AND S. L. JONES, 2003. Grassland songbird nest site selection patterns in northcentral Montana. *Wilson Bulletin* 115, 388–396.

DOHERTY, K. E., A. J. RYBA, C. L. STEMLER, N. D. NIEMUTH, AND W. A. MEEKS, 2013. Conservation planning in an era of change: state of the U.S. Prairie Pothole Region. *Wildlife Society Bulletin* 37, 546–563.

DUEBBERT, H. F., E. T. JACOBSON, K. F. HIGGINS, AND E. B. PODOLL, 1981. Establishment of seeded grasslands for wildlife habitat in the Prairie Pothole Region. U.S. Fish and Wildlife Service, Washington, D.C.

DUNN, E. H., C. M. FRANCIS, P. J. BLANCHER, S. R. DRENNAN, M. A. HOWE, D. LEPAGE, C. S. ROBBINS, D. V. ROSENBERG, J. R. SAUER, AND K. G. SMITH. 2005. Enhancing the scientific value of the Christmas Bird Count. *Auk* 122 338–346.

DYKE, S., S. JOHNSON, AND P. ISAKSON. 2015, North Dakota State Wildlife Action Plan, Draft. North Dakota Department of Game and Fish, Bismarck, North Dakota, USA.

EHRLICH, P. R., AND A. H. EHRLICH, 1981. Extinction: the causes and consequences of the disappearance of species. Random House, New York, USA.

ENERGY INFORMATION ADMINISTRATION (EIA), 2015. Annual energy outlook 2015 with projections to 2040. U.S. Department of Energy, Washington, D.C., USA.

FARGIONE, J., J. KIESECKER, M. J. SLAATS, S. OLIMB, 2012. Wind and wildlife in the northern Great Plains: identifying low-impact areas for wind development. *PLoS One* 7, e41468.

FERSHEE, J. P., 2012. Oil and gas evolution: learning from the hydraulic fracturing experiences in North Dakota and West Virginia. *Texas Wesleyan Law Review* 19, 23.

FISHER, R. J. AND S. K. DAVIS, 2010. From Wiens to Robel: a review of grassland-bird habitat selection. *Journal of Wildlife Management* 74, 265–273.

FOOD AND AGRICULTURAL POLICY RESEARCH INSTITUTE (FAPRI), 2007. Estimating water quality, air quality, and soil carbon benefits of the Conservation Reserve Program. FAPRI-UMC Report 01-07. U.S. Department of Agriculture, Farm Service Agency, Washington, D.C., USA.

FUHLENDORF, S. D., AND D. M. ENGLE, 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns we propose a paradigm that enhances heterogeneity instead of homogeneity to promote biological diversity and wildlife habitat on rangelands grazed by livestock. *BioScience* 51, 625–632.

FUHLENDORF, S. D., AND D. M. ENGLE, 2004. Application of the fire-grazing interaction to restore a shifting mosaic on tallgrass prairie. *Journal of Applied Ecology* 41:604-614.

FUHLENDORF, S. D., W. C. HARRELL, D. M. ENGLE, R. G. HAMILTON, C. A. DAVIS, AND D. H. LESLIE, JR., 2006. Should heterogeneity be the basis for conservation? Grassland bird response to fire and grazing. *Ecological Applications* 16, 1706-1716.

GILLEN, R. L., J. A. ECKROAT, AND F. T. MCCOLLUM III, 2000. Vegetation response to stocking rate in southern mixed-grass prairie. *Journal of Range Management* 53, 471–478.

GRANT, T. A., E. MADDEN, AND G. B. BERKEY, 2004. Tree and shrub invasion in northern mixed-grass prairie: implications for breeding grassland birds. *Wildlife Society Bulletin* 32, 807–818.

GRANT, T. A., E. M. MADDEN, T. L. SHAFFER, P. J. PIETZ, G. B. BERKEY, AND N. J. KADRMAS, 2006. Nest survival of clay-colored and vesper sparrows in relation to woodland edge in mixed-grass prairies. *Journal of Wildlife Management* 70, 691–701.

GREEN, M. T., P. E. LOWTHER, S. L. JONES, S. K. DAVIS AND B. C. DALE, 2002. Baird's sparrow (*Ammodramus bairdii*). In A. Poole [ED.]. The Birds of North America Online. Cornell

Lab of Ornithology, Ithaca, New York, USA Available at: http://bna.birds.cornell.edu/bna/species/638 (Accessed 22 March 2016).

GRIME, J. P., 1973. Competitive exclusion in herbaceous vegetation. *Nature* 242, 344–347.

HAMILTON, L. E., B. C. DALE, AND C. A. PASZKOWSKI, 2011. Effects of disturbance associated with natural gas extraction on the occurrence of three grassland songbirds. *Avian Conservation and Ecology* 6(1)7.

HART, R. H., M. J. SAMUEL, P. S. TEST, AND M. A. SMITH, 1988. Cattle, vegetation, and economic responses to grazing systems and grazing pressure. *Journal of Range Management* 41, 282–286.

HART, R. H., J. BISSIO, M. J. SAMUEL, AND J. W. WAGGONER, JR., 1993. Grazing systems, pasture size, and cattle grazing behavior, distribution and gains. *Journal of Range Management* 46, 81–87.

HARTNETT, D. C., A. A. STEUTER, AND K. R. HICKMAN, 1997. Comparative ecology of native and introduced ungulates, in: Ecology and Conservation of Great Plains Vertebrates. Springer, pp. 72–101.

HARTNETT, D.C., K. R. HICKMAN, K.R., AND L. E. F. WALTER, 1996. Effects of bison grazing, fire, and topography on floristic diversity in tallgrass prairie. *Journal of Range Management* 413–420.

HECTOR, A., Y. HAUTIER, P. SANER, L. WALKER, R. BAGCHI, J. JOSHI, M. SCHERER-LORENZEN, E. M. SPEHN, E. BAZELEY-WHITE, M. WEILENMANN, M. C. CALDEIRA, P. G. DIMITRAKOPOULOS, J. A. FINN, K. HUSS-DANELL, A. JUMPPONEN, C. P. MULDER, C. PALMBORG, J. S. PEREIRA, A. S. SIAMANTZIOURAS, A. C. TERRY, A. Y. TROUMBIS, B.

SCHMID, M. LOREAU, 2010. General stabilizing effects of plant diversity on grassland productivity through population asynchrony and overyielding. *Ecology* 91, 2212-2220.

HENDRICKSON, J. R., AND C. LUND, 2010. Plant community and target species affect responses to restoration strategies. *Rangeland Ecology and Management* 63, 435–442.

HOBBS, N. T., 1996. Modification of ecosystems by ungulates. *Journal of Wildlife Management* 60, 695–713.

HOBBS, R. J., S. YATES, AND H. A. MOONEY, 2007. Long-term data reveal complex dynamics in relation to climate and disturbance. *Ecological Monographs* 77, 545–568.

HOLMES, R. T., AND F. W. STURGES, 1975. Bird community dynamics and energetics in a northern hardwoods ecosystem. *Journal of Animal Ecology* 44, 175–200.

HOVICK, T. J., R. D. ELMORE, S. D. FUHLENDORF, D. M. ENGLE, AND R. G. HAMILTON, 2015. Spatial heterogeneity increases diversity and stability in grassland bird communities. *Ecological Applications* 25, 662-672.

INGELFINGER, F., AND S. ANDERSON, 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. *Western North American Naturalist* 64, 385–395.

JIANG, L., PU, Z., 2009. Different effects of species diversity on temporal stability in single-trophic and mutlitrophic communities. *American Naturalist* 174, 651–659.

JOHNSON, D. H., 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61, 65–71.

JOHNSON, D. H., 2000. Grassland bird use of Conservation Reserve Program fields in the Great Plains. *In*: L. P. Heard, W. L. Hohman and D. J. Halloum [EDS.]. A comprehensive review of Farm Bill contributions to wildlife conservation 1985-2000. U.S. Department of Agriculture, Natural Resource Conservation Service, Washington, D.C. Technical Report USDA/NRCS/WHMI-2000. p. 19–33.

JOHNSON, D. H., AND M. D. SCHWARTZ, 1993. The Conservation Reserve Program and grassland birds. *Conservation Biology* 7, 934–937.

JOHNSON, D. H., AND L. D. IGL, 1995. Contributions of the Conservation Reserve Program to populations of breeding birds in North Dakota. *Wilson Bulletin* 107, 709–718.

JOHNSON, K. L. [ed.], 1986. Crested wheatgrass: its values, problems and myths. Symposium proceedings. Utah State University, Logan, Utah, USA. p. 348.

JUDD, S., 1901. The relation of sparrows to agriculture. Bulletin 15. U.S. Department of Agriculture, Division of Economic Ornithology and Mammalogy, Washington, D.C., USA.

KANTRUD, H. A., 1981. Grazing intensity effects on the breeding avifauna of North Dakota native grasslands. *Canadian Field-Naturalist* 95, 404–417.

KANTRUD, H. A., AND R. L. KOLOGISKI, 1982. Effects of soils and grazing on breeding birds of uncultivated upland grasslands of the northern Great Plains. Wildlife Research Report No. 15. U.S. Fish and Wildlife Service, Washington, D.C. 33 p.

KNAPP, A. K., J. M. BLAIR, J. M. BRIGGS, S. L. COLLINS, D. C. HARTNETT, L. C. JOHNSON, AND E. G. TOWNE, 1999. The keystone role of bison in North American tallgrass prairie. *BioScience* 49, 39–50.

KNOPF, F. L., 1994. Avian assemblages on altered grasslands. *Studies in Avian Biology* 15, 247–257.

KOPER, N., D. J. WALKER, AND J. CHAMPAGNE, 2009. Nonlinear effects of distance to habitat edge on Sprague's pipits in southern Alberta, Canada. *Landscape Ecology* 24, 1287–1297.

KREMEN, C., 2005. Managing ecosystem services: what do we need to know about their ecology? *Ecology Letters* 8, 468-479.

KRONENBERG, J., 2014. Environmental impacts of the use of ecosystem services: case study of birdwatching. *Environmental Management* 54, 617–630.

LANE, J., 1968. Baird's sparrow (*Ammodramus bairdii*). *In* A.C. Bent life histories of North American cardinals, grosbeaks, towhees, finches, sparrows, and allies, part two. *U.S. National Museum Bulletin* No. 237, p. 603–1248.

LAUENROTH, W. K., D. G. MILCHUNAS, J. L. DODD, R. H. HART, R. K. HEITSCHMIDT, AND L. R. RITTENHOUSE, 1994. Effects of grazing on ecosystems of the Great Plains. *In*: M. Vavra, W. A. Laycock, and R. D. Pieper [EDS.]. Ecological implications of livestock herbivory in the West. Society for Range Management, Denver, Colorado. p. 69–100.

LEUKERING, T., M. F. CARTER, A. PANJABI, D. FAULKNER, AND R. LEVAD, 2000. Monitoring Colorado's birds: the plan for count-based monitoring. Rocky Mountain Bird Observatory, Brighton, Colorado. 21 p.

LLOYD, J. D., AND T. E. MARTIN, 2005. Reproductive success of chestnut-collared longspurs in native and exotic grassland. *Condor* 107, 363–374.

LUDLOW, S.M., R. M. BRIGHAM, AND S. K. DAVIS, 2015. Oil and natural gas development has mixed effects on the density and reproductive success of grassland songbirds. *Condor* 117, 64–75.

LYONS, K.G., C. A. BRIGHAM, B. H. TRAUT, AND M. W. SCHWARTZ, 2005. Rare species and ecosystem functioning. *Conservation Biology* 19, 1019–1024.

MADDEN, E. M., 1996. Passerine communities and bird-habitat relationships on prescribe-burned, mixed grass prairie in North Dakota. M.S. Thesis, Montana State University, Bozeman, Montana, USA.

MADDEN, E. M., A. J. HANSEN, AND R. K. MURPHY, 1999. Influence of prescribed fire history on habitat and abundance of passerine birds in northern mixed-grass prairie. *Canadian Field-Naturalist* 113, 627–640.

MADDEN, E. M., R. K. MURPHY, A. J. HANSEN, AND L. MURRAY, 2000. Models for guiding management of prairie bird habitat in northwestern North Dakota. *American Midland Naturalist* 144, 377–392.

MAHER, W. J., 1973. Matador Project: Birds I. Population dynamics. Canadian Committee for the International Biological Programme. Technical Report 34. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.

MAY, R. M., J. H. LAWTON, AND N. E. STORK, 1995. Assessing extinction rates. *In*: J. H. Lawton and R. M. May [EDS.]. Extinction rates. Oxford University Press, Oxford, United Kingdom. p. 1–24.

MENGEL, R. M., 1970. The North American Central Plains as an isolating agent in bird speciation. *In*: W. Dort, Jr., and J. K. Jones, Jr. [EDS.]. Pleistocene and recent environments of the central Great Plains. University Press of Kansas, Lawrence, Kansas. p. 279–340.

MESSMER, T. A., 1990. Influence of grazing treatments on nongame birds and vegetation structure in south central North Dakota. Ph.D. Dissertation, North Dakota State University, Fargo, North Dakota. 139 p.

MILCHUNAS, D. G., O. E. SALA, AND W. LAUENROTH, 1988. A generalized model of the effects of grazing by large herbivores on grassland community structure. *American Naturalist* 132, 87–106.

MILCHUNAS, D. G., W. K. LAUENROTH, P. L. CHAPMAN, AND M. K. KAZEMPOUR, 1989. Effects of grazing, topography, and precipitation on the structure of a semiarid grassland. *Vegetatio* 80, 11–23.

MILCHUNAS, D. G., W. K. LAUENROTH, AND I. C. BURKE, 1998. Livestock grazing: animal and plant biodiversity of shortgrass steppe and the relationship to ecosystem function. *Oikos* 83, 65–74.

MINNS, A., J. FINN, A. HECTOR, M. CALDEIRA, J. JOSHI, C. PALMBORG, B. SCHMID, M. SCHERER-LORENZEN, E. SPEHN, A. TROUMBIS, 2001. The functioning of European grassland ecosystems: potential benefits of biodiversity to agriculture. *Outlook on Agriculture* 30, 179–185.

MOUL, F., 2006. The National Grasslands: a guide to America's undiscovered treasures. University of Nebraska Press, Lincoln, Nebraska. p. 153.

NORTH DAKOTA INDUSTRIAL COMMISSION (NDIC), 2012. General statistics. North Dakota Industrial Commission, Bismarck, North Dakota, USA. Available at: https://www.dmr.nd.gov/oilgas/stats/statisticsvw.asp (Accessed 22 March 2016).

O'CONNOR, R. J., E. DUNN, D. H. JOHNSON, S. L. JONES, D. PETIT, D., K. POLLOCK, C. R. SMITH, J. L. TRAPP, AND WELLING, 2000. A programmatic review of the North American

Breeding Bird Survey. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel Maryland, USA.

OWENS, R.A., AND M. T. MYRES, 1973. Effects of agriculture upon populations of native passerine birds of an Alberta fescue grassland. *Canadian Journal of Zoology* 51, 697–713.

PETERJOHN, B., AND J. R. SAUER, 1999. Population status of North American grassland birds from the North American breeding bird survey. *Studies in Avian Biology* 19, 27–44.

PLUMB, G. E., AND J. L. DODD, 1993. Foraging ecology of bison and cattle on a mixed prairie: implications for natural area management. *Ecological Applications* 3, 631–643.

PRESCOTT, D. R. C., AND G. M. WAGNER, 1996. Avian responses to implementation of a complementary/rotational grazing system by the North American Waterfowl Management Plan in southern Alberta: the Medicine Wheel Project. NAWMP-018. Alberta NAWMP Centre, Edmonton, Alberta, Canada. 24 p.

PRESCOTT, D. R. C., AND S. K. DAVIS, 1998. Status report on the Sprague's pipit *Anthus spragueii* in Canada. Committee on the Status of Endangered Wildlife in Canada, Ontario, Canada.

REINO, L., P. BEJA, P. E. OSBORNE, R. MORGADO, A. FABIÃO, AND J. T. ROTENBERRY, 2009. Distance to edges, edge contrast and landscape fragmentation: interactions affecting farmland birds around forest plantations. *Biological Conservation* 142, 824–838.

REMEŠ, V., 2003. Effects of exotic habitat on nesting success, territory density, and settlement patterns in the blackcap (*Sylvia atricapilla*). *Conservation Biology* 17, 1127–1133.

Ribic, C.A., R. R. Koford, J. R. Herkert, D. H. Johnson, N. D. Niemuth, D. E. Naugle, K. K. Bakker, D. W. Sample, and R. B. Renfrew, 2009. Area sensitivity in North American grassland birds: patterns and processes. *Auk* 126, 233–244.

RICE, R., 2010. The ecological benefits of shade-grown coffee: the case for going bird friendly. Smithsonian Migratory Bird Center, Washington, D.C., USA.

ROBBINS, M. B., 1998. Display behavior of male Sprague's pipits. *Wilson Bulletin* 110:435–438.

ROBBINS, C.S., J. R. SAUER, R. S. GREENBERG, AND S. DROEGE, 1989. Population declines in North American birds that migrate to the Neotropics. *Proceedings of the National Academy of Science* 86, 7658–7662.

ROBBINS, M. B., AND B. C. DALE. 1999. Sprague's pipit (*Anthus spragueii*). *In* A. Poole, editor. The birds of North America online. Cornell Lab of Ornithology, Ithaca, New York, USA. Available at: http://bna.birds.cornell.edu/bna/species/439 (Accessed 22 March 2016).

ROSENZWEIG, M. L., 1995. Species diversity in space and time. Cambridge University Press, Cambridge, Massachusetts, USA. p. 460.

SAAB, V.A., C. E. BOCK, T. D. RICH, AND D. S. DOBKIN, 1995. Livestock grazing effects in western North America. *In*: T. E. Martin and D. M. Finch [EDS.]. Ecology and management of Neotropical migratory birds. Oxford University Press, New York, New York, USA. p. 311–353.

SAMSON, F., AND F. K. KNOPF, 1994. Prairie conservation in North America. *BioScience* 418–421.

SAMSON, F. B., AND F. L. KNOPF, 1996. Prairie conservation: preserving North America's most endangered ecosystem. Island Press, Washington, D.C., USA.

SAUER, J. R., 1995. Combining information from monitoring programs: complications associated with indices and geographic scale. *In*: R. Bonney, D. N. Pashley, R. J. Cooper, and L. Niles [EDS.]. Strategies for bird conservation: the Partners in Flight planning process. RMRS-P-16. U.S. Forest Service, Rocky Mountain Research Station, Ogden, Utah. Cornell Lab of Ornithology, Ithaca, New York, USA. p. 124–126.

SAUER, J. R., J. E. HINES, J. E. FALLON, K. L. PARDIECK, D. J. ZIOLKOWSKI, JR., AND W. A. LINK, 2014. The North American breeding bird survey, results and analysis 1966-2013. Version 01.30.2015. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, MD, USA. Available at: http://www.mbr-pwrc.usgs.gov/bbs/bbs.html (Accessed 22 March 2016).

SAX, D. F., AND S. D. GAINES, 2003. Species diversity: from global decreases to local increases. *Trends in Ecology and Evolution* 18, 561–566.

SCHMIDT, K. A., AND C. J. WHELAN, 1999. Effects of exotic *Lonicera* and *Rhamnus* on songbird nest predation. *Conservation Biology* 13, 1502–1506.

SCHNEIDER, N. A., 1998. Passerine use of grasslands managed with two grazing regimes on the Missouri Coteau in North Dakota. South Dakota State University, Brookings, South Dakota, USA. p. 94.

SEDIVEC, K. K., AND W. T. BARKER, 1997. Selected North Dakota and Minnesota range plants. Extension Bulletin 69. North Dakota State University, Fargo, North Dakota, USA. p. 270.

SEKERCIOGLU, C. H., 2006. Increasing awareness of avian ecological function. *Trends in Ecology and Evolution* 21, 464–471.

SKEEL, M. A., D. C. DUNCAN, AND S. D. DAVIS, 1995. Abundance and distribution of Baird's sparrows in Saskatchewan. Saskatchewan Wetland Conservation Corporation, Regina, Saskatchewan, Canada. p. 13.

SPARKS, R. A., D. J. HANNI, D. SVINGEN, AND T. LEUKERING, 2009. Monitoring of grassland birds on Little Missouri, Sheyenne and Grand River National Grasslands. Technical Report #M-SS-DAKPG08-02. Rocky Mountain Bird Observatory, Brighton, Colorado, USA. p. 33.

STEWART, R. E., 1975. Breeding birds of North Dakota. Tri-College Center for Environmental Studies, Fargo, North Dakota, USA. p. 295.

SULLIVAN, B. L., J. L. AYCRIGG, J. H. BARRY, R. E. BONNEY, N. BRUNS, C. B. COOPER, T. DAMOULAS, A. A. DHONDT, T. DIETTERICH, A. FARNSWORTH, D. FINK, J. W. FITZPATRICK, T. FREDERICKS, J. GERBRACHT, C. GOMES, W. M., HOCHACHKA, M. J. ILIFF, C. LAGOZE, F. A. LA SORTE, M. MERRIFIELD, W. MORRIS, T. B. PHILLIPS, M. REYNOLDS, A. D. RODEWALD, K. V. ROSENBERG, N. M. TRAUTMANN, A. WIGGINS, D. W. WINKLER, W. K. WONG, C. L. WOOD, J. YU, AND S. KELLING. 2014. The eBird enterprise: an integrated approach to development and application of citizen science. *Biological Conservation* 169: 31-40.

SUTTER, G. C., 1996. Habitat selection and prairie drought in relation to grassland bird community structure and the nesting ecology of Sprague's pipit, *Anthus spragueii*. Ph.D. Dissertation, University of Regina, Regina, Saskatchewan, Canada.

SUTTER, G. C., T. TROUPE, AND M. FORBES, 1995. Abundance of Baird's sparrows, *Ammodramus bairdii*, in native prairie and introduced vegetation. *Ecoscience* 344–348.

SUTTER, G. C., AND R. M. BRIGHAM, 1998. Avifaunal and habitat changes resulting from conversion of native prairie to crested wheat grass: patterns at songbird community and species levels. *Canadian Journal of Zoology* 76, 869–875.

SUTTER, G. C., S. K. DAVIS, AND D. C. DUNCAN, 2000. Grassland songbird abundance along roads and trails in southern Saskatchewan. *Journal of Field Ornithology* 71, 110–116.

SWINGLAND, I. R., 2001. Biodiversity, definition of. Encylopedia of Biodiversty, Ed S. A. Levin. Academic Press, San Diego, United States. p. 377-391.

THOMPSON, S. J., D. H. JOHNSON, N. D. NIEMUTH, AND C. A. RIBIC, 2015. Avoidance of unconventional oil wells and roads exacerbates habitat loss for grassland birds in the North American Great Plains. *Biological Conservation* 192, 82–90.

TILMAN, D., 1996. Biodiversity: population versus ecosystem stability. *Ecology* 77, 350–363.

TILMAN, D., AND J. A. DOWNING, 1994. Biodiversity and stability in grasslands. *Nature* 367, 363–365.

TILMAN, D., J. FARGIONE, B. WOLFF, C. D'ANTONIO, A. DOBSON, R. HOWARTH, D. SCHINDLER, W. H. SCHLESINGER, D SIMBERLOFF, AND D. SWACKHAMER, 2001. Forecasting agriculturally driven global environmental change. *Science* 292, 281–284.

TOLEDO, D., M. SANDERSON, K. SPAETH, J. HENDRICKSON, AND J. PRINTZ, 2014. Extent of Kentucky bluegrass and its effect on native plant species diversity and ecosystem services in the northern Great Plains of the United States. *Invasive Plant Science and Management* 7, 543–552.

U.S. FISH AND WILDLIFE SERVICE (USFWS), 1999. Endangered and threatened wildlife and plants; 90-day finding for a petition to list the Baird's sparrow as threatened with critical habitat. United States Department of Interior, Fish and Wildlife Service, Division of Ecological Services, Washington D.C., USA.

U.S. Fish and Wildlife Service (USFWS), 2008. Birds of conservation concern 2008. United States Department of Interior, Fish and Wildlife Service, Division of Migratory Bird Management, Arlington, Virginia, USA. 85 p.

U.S. Fish and Wildlife Service (USFWS), 2010. Endangered and threatened wildlife and plants; 12-month finding on a petition to list Sprague's pipit as endangered or threatened throughout its range. United States Department of Interior, Fish and Wildlife Service, Division of Ecological Services, Washington D.C., USA.

U. S. Fish and Wildlife Service (USFWS), 2011. Birding in the United States: a demographic and economic analysis. Addendum to the 2011 national survey of fishing, hunting and wildlife associated recreation. Report 1 – 2011. U.S. Fish and Wildlife Service. Washington D.C., USA.

U.S. Forest Service (USFS), 2005. USFS Region 1 sensitive species list – wildlife (final). Unpublished report. U.S. Department of Agriculture, Forest Service, Missoula, Montana, USA.

United Nations, Department of Economic and Social Affairs (UNDESA), 2015. World population prospects: the 2015 revision, key findings and advance tables. Working Paper No. ESA/P/WP.241.

Walker, J., J. J. Rotella, C. R. Loesch, R. W. Renner, J. K. Ringelman, M. S. Lindberg, R. Dell, K. E. Doherty, 2013. An integrated strategy for grassland easement acquisition in the Prairie Pothole Region, USA. *Journal of Fish and Wildlife Management* 4, 267–279.

WHELAN, C. J., C. H. SEKERCIOGLU, AND D. G. WENNY, 2015. Why birds matter: from economic ornithology to ecosystem services. *Journal of Ornithology* 156(Supplement 1), S227-S238.

WIENS, J. A., 1973. Pattern and process in grassland bird communities. *Ecological Monographs* 43, 237–270.

WILSON, S. D., AND J. W. BELCHER, 1989. Plant and bird communities of native prairie and introduced Eurasian vegetation in Manitoba, Canada. *Conservation Biology* 3, 39–44.

WINTER, M., 1994. Habitat selection of Baird's sparrows in the northern mixed-grass prairie. Diplomar-Beit, Tubingen Universidad, Tubingen, Germany.

WINTER, M., 2007. Distribution and habitat associations of Baird's sparrows and Sprague's pipits on the Grand River National Grassland, South Dakota. Unpublished final report submitted to the U.S. Forest Service, Bismarck, North Dakota. Available at: https://gfp.sd.gov/wildlife/funding/docs/small-grants-reports/Winter%202006.pdf (Accessed 22 March 2016).

2. GRASSLAND-BIRD RESPONSE TO LANDSCAPE-LEVEL AND SITE-SPECIFIC VARIABLES IN THE LITTLE MISSOURI NATIONAL GRASSLAND

2.1. Introduction

Grasslands are one of the most endangered ecosystems in the world (Noss et al., 1995), so it is not surprising that grassland obligate birds have experienced the steepest, most consistent, and most geographically widespread declines of any North American birds (Knopf, 1994; Herkert, 1995; Igl and Johnson, 1997). Although populations of some grassland birds have stabilized at low levels in recent years, many grassland species have continued to decline (NABCI, 2014). The Sprague's pipit (*Anthus spragueii*) and Baird's sparrow (*Ammodramus bairdii*)—grassland birds that breed exclusively in the northern Great Plains (Mengel, 1970)—are of particular concern. Wells (2010) described the pipit as "one of the fastest declining songbirds of North America." Sprague's pipits also are considered one of the least known bird species in North America, due to their restricted breeding range, cryptic plumage, and secretive behaviors (Robbins and Dale, 1999). Trend analysis from the North American Breeding Bird Survey (BBS) indicated that populations of Sprague's pipit and Baird's sparrow have experienced severe annual declines of -3.5% and -3.0%, respectively, between 1966 and 2013 (Sauer et al., 2014).

In a 12-month finding on a petition to list the pipit as endangered or threatened, the U.S. Fish and Wildlife Service (USFWS) concluded that the listing of the Sprague's pipit is warranted but is currently precluded by higher priority actions (USFWS, 2010). Based on the 12-month finding, the USFWS proposed the Sprague's pipit for listing as a candidate species under the Endangered Species Act. However, a recent status review of the Sprague's pipit prompted the USFWS to withdraw the species from the candidate list (USFWS, 2016). The USFWS declined an earlier petition to list the Baird's sparrow as threatened in 1999 because the petition did not present substantial information indicating that the listing of this species as threatened was warranted (USFWS, 1999). Both species also are included on several lists of "species of high conservation concern" by federal (e.g., USFS, 2005) and state agencies (e.g., North Dakota [Dyke et al., 2015], South Dakota [SDGFP, 2014], and Minnesota [MNDNR, 2006]) and nongovernment organizations (e.g., Partners in Flight; [Rich et al., 2004]).

The Sprague's pipit and Baird's sparrow are both considered area sensitive species that require a minimum patch size of 145 ha and 25 ha, respectively (Davis and Brittingham, 2004). Less than 18% of native grassland remains in the current breeding range of both species (Samson and Knopf, 1994; Noss et al., 1995). Large-scale losses—largely from conversion to cropland—and degradation of critical grassland habitat highlight the importance of enhancing remnant prairies and restored grasslands (Samson and Knopf, 1994). Some of the largest remaining native grassland patches in the United States portion of the northern Great Plains occur on the Little Missouri National Grassland (LMNG), which is administered and managed by the U.S. Forest Service (USFS). The USFS currently administers 20 National Grasslands, encompassing about 1.5 million ha of federal land in 13 states (Olson, 1997). The majority of the National Grasslands are found in the Great Plains states of Colorado, North Dakota, South Dakota, and Wyoming. National Grasslands in these four states alone account for 1.3 million ha (82%) of the total area of National Grasslands. The LMNG also was listed as one of the most important breeding areas for the Sprague's pipit (Wells, 2010)—further highlighting the importance of the LMNG in conserving sensitive grassland birds.

Changes in grassland bird populations can be associated with modern livestock management methods that reduce variability in vegetation structure, thus reducing suitable vegetation for both grazing-intolerant and grazing-dependent bird species (Saab et al., 1995). Before European settlement, the interactions of grazing by American bison (*Bison bison*) and prairie dogs (*Cynomys* spp.), fire, and climate, created and maintained patches of different plant communities in the Great Plains resulting in a mosaic of vegetation structure and composition that sustained a diverse grassland bird community (Knopf, 1996; Brennan and Kuvlesky, 2005; Fuhlendorf et al., 2009). These interactions have largely been replaced by management practices emphasizing even distribution of livestock and uniform use (Holechek et al., 1995), creating a more homogenous landscape that favors generalist bird species (Toledo et al., 2014). The decoupling of grasslands from historic disturbances has decreased both temporal and spatial heterogeneity of grasslands (Fuhlendorf and Engle, 2001), and with the suppression of wild fires, grazing has played an increasingly larger role in the structuring of grasslands. Because livestock grazing remains an important economic activity on the LMNG—and has shown to be compatible with wildlife management (Willms and Jefferson, 1993; Brown and McDonald, 1995; Derner et al., 2009)—it is important to further understand the effects of grazing on the structuring of grasslands and breeding populations of sensitive grassland birds.

Bird species' response to management, such as grazing and prescribed burning, have been well documented (Kantrud, 1981; Madden et al., 1999; Owens and Myres, 1973). However, management that may work well in one region may not work in another due to differences in environmental conditions. Therefore it remains difficult to summarize effects of management on individual bird species (Madden et al., 2000). For example, in North Dakota, the Sprague's pipit was most abundant in moderately and heavily grazed areas (Kantrud, 1981), whereas in Alberta, pipits were most abundant in ungrazed or lightly grazed grasslands (Owens and Myres, 1973). Verner and others (1986) proposed using habitat models based on vegetation attributes instead of summarizing the effects of management on birds. Vegetation attributes are known to determine grassland bird abundance (Wiens, 1973; Whitmore, 1981), and can be easily manipulated by land managers. Land managers can use information on grassland bird habitat preferences to implement management tools (e.g., grazing) that will produce suitable habitat for either a species of concern, or a group of species.

Oil and gas development also has an effect on grassland bird populations (Kalyn Bogard and Davis, 2014; Ludlow et al., 2015; Thompson et al., 2015). In the last decade, western North Dakota has experienced an oil boom in an area that has unusually high grassland bird abundance and diversity (Peterjohn and Sauer, 1999). We hope to provide land managers with more information on the effects of oil extraction on grassland birds in order to minimize the impacts of such development.

2.1.1. Research questions and objectives

There were two main questions in this study. Our first question was "how does livestock grazing affect vegetation structure and composition, sensitive grassland bird abundance, and overall grassland bird diversity on the LMNG?" The second question "how does the rapid expansion of oil and natural gas extraction affect grassland birds on the LMNG?" Three objectives were met to address these questions:

1. Estimated abundance and diversity of grassland birds and vegetation structure and composition in the LMNG (2014-2015).
2. Evaluated how bird abundance and diversity are influenced by vegetation structure and composition (proxies for cattle grazing and stocking rate).
3. Assessed how oil-well and road densities (proxies for oil and natural gas extraction and development) are affecting the grassland bird community on the LMNG.

2.2. Study area

Our study was conducted on the LMNG in western North Dakota, USA (Fig. 1). At 416,334 ha, the LMNG is the largest of the National Grasslands in the United States. The LMNG is divided into two ranger districts, the McKenzie District in the north and the Medora District in the south. Due to the short duration of the breeding season for grassland birds in this region, the large area covered by the LMNG, and limited manpower, we found it was logistically impossible to survey the entire LMNG. Therefore, we focused our sampling efforts in the McKenzie Ranger District in McKenzie County, North Dakota. This also improved our chances of recording Sprague's pipits, which is more common in the northern portion of western North Dakota (Gough et al., 1998). The USFS recognizes two geographic areas within the LMNG: the Badlands Geographic Area and the Rolling Prairie Geographic Area. Our study area was confined to the Rolling Prairie Geographic Area, which encompasses approximately 125,857 ha in the McKenzie District.

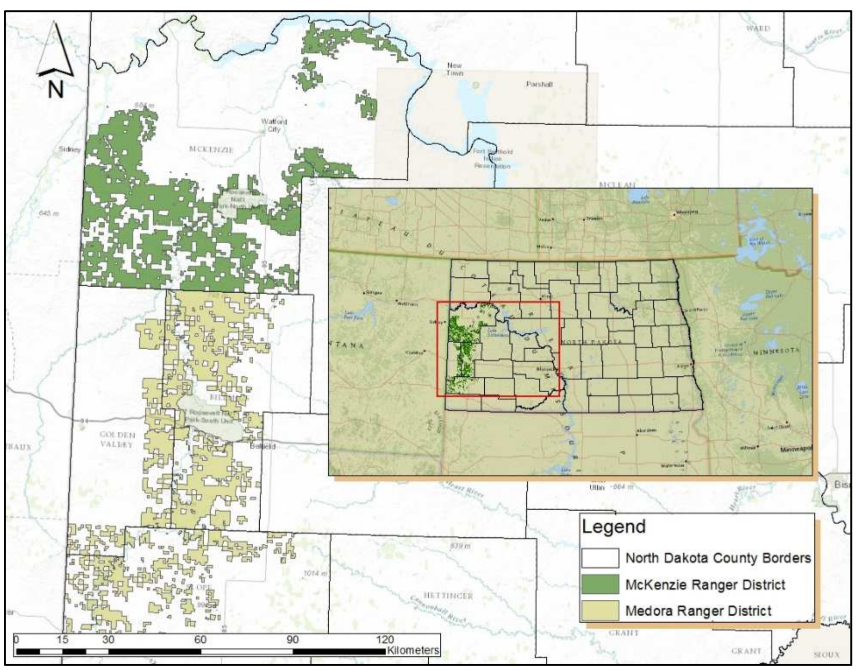

Figure 1. Little Missouri National Grassland located within McKenzie, Golden Valley, Billings, and Slope counties in western North Dakota, USA.

The climate of our study area is a typical continental climate with relatively long, cold winters; short, hot summers; and low rainfall and low humidity (Godfread, 1994). Precipitation can vary greatly among years—averaging 38 to 40 cm—with about three-quarters of that precipitation falling during the growing season that extends approximately from mid-May through mid-September (Godfread, 1994). Nearly level to rolling hills with inclusions of scattered clay buttes, "badland" landscapes, and hardwood draws are characteristic of this region's topography. The vegetation of the area is typical of mixed-grass prairies in the northern Great Plains with the dominant grasses being blue grama (*Bouteloua gracilis*) and western wheatgrass (*Pascopyron smithii*) (Whitman and Wali, 1975). Some level or nearly level grassland patches that were historically cultivated under the Homestead Act (1862) and subsequently purchased by the U.S. Government under the Bankhead-Jones Farm Tenant Act (1937) are now dominated by crested wheatgrass (Johnson, 1986; Moul, 2006). In general, shorter grasslands are dominated by blue grama and prairie Junegrass (*Koeleria pyrimidata*), whereas taller grasslands are dominated by green needlegrass (*Nassella virdula*) (Whitman and Wali, 1975). There are other non-grassland cover types that occur as intrusions into otherwise fairly continuous grassland. Most of these intrusions are hardwood draws dominated by green ash (*Fraxinus pennsylvanica*), but terraces of silverberry (*Elaeagnus commutata*) and silver sagebrush (*Artemisia cana*) also are present (Godfread, 1994), as well as a few stock ponds and black-tailed prairie dog (*Cynomys ludovicianus*) towns.

2.3. Methods

2.3.1. Study design

We used the legal quarter-section (64.74 ha or 800 × 800 m) as our study site. The quarter-section was chosen for several reasons: 1) boundaries of quarter-sections are generally well-marked by roads, trails, fence lines, or easily recognized by differences in land-use; 2) the units were small enough so that one or two observers could complete a bird survey in a relatively short period of time (i.e., 1.5 hours per sample unit on average); and 3) duplications in counts of wide-ranging birds are reduced or eliminated. A sample size of 60 sites was chosen on the basis of manpower availability and the estimated time requirements for conducting the field work. The distribution of our 60 study sites spread randomly throughout the McKenzie District using a stratified design is shown in Figure 2. All sites were located on USFS-owned grasslands.

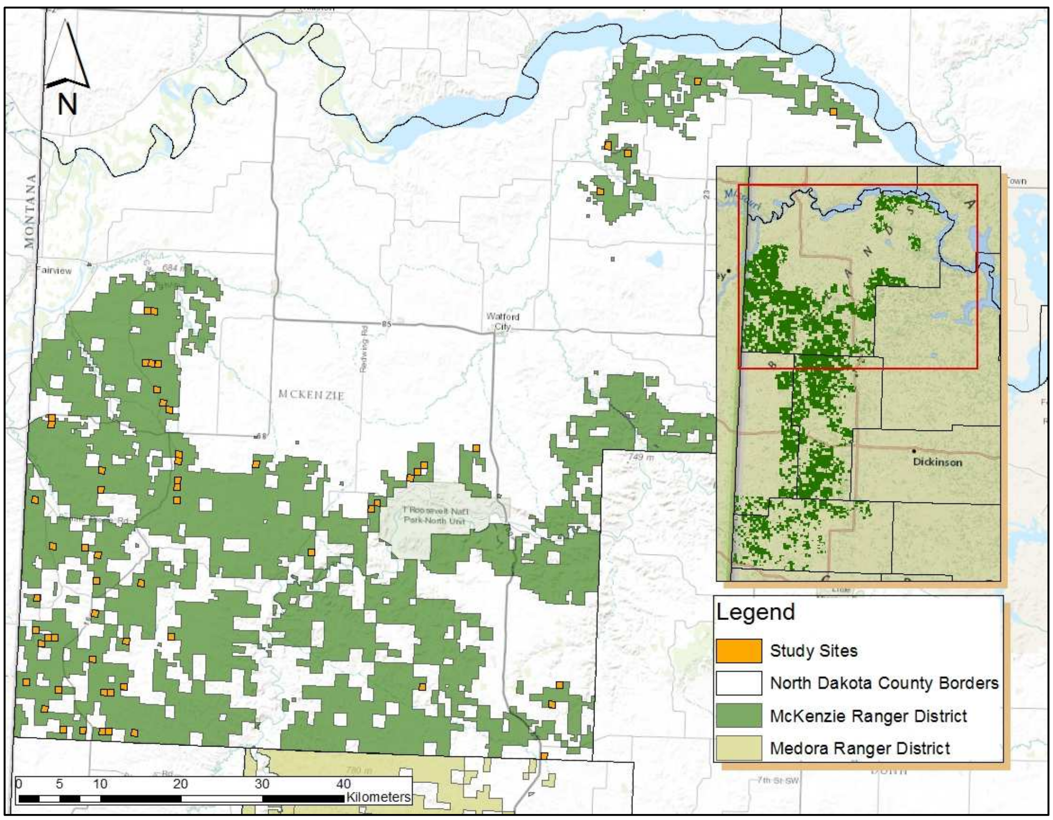

Figure 2. Research sites on the Little Missouri National Grassland in McKenzie, in western North Dakota, USA.

Before selecting our 60 study sites, we first narrowed down the 4,000+ quarter-sections in the McKenzie District to include only quarter-sections that had flat to gently rolling topography (average slope ≤15%; i.e., the topography preferred by Sprague's pipits according to literature [Government Canada 2011] and expert advice). The average percent slope of each site was calculated using a digital elevation model (DEM) in ArcGIS (Version 10.2.2; ESRI, Redlands, California). By excluding sites with an average slope greater than 15%, we were able to focus our sampling efforts to areas that Sprague pipits and other grassland birds would use for breeding. We also excluded from consideration all quarter-sections in the McKenzie District that were partially owned by private landowners. We chose our study sites using a stratified randomization design using two covariates that are known to influence Sprague's pipit occurrence and abundance: the density of roads and density of oil wells within a 1.6-km buffer around each quarter-section (Sutter et al., 2000; Ludlow et al., 2015). In this text, we refer to "oil well" or "well" as the contiguous gravel surface that houses all pumping units, storage tanks, natural gas flares, power-lines, and any other associated infrastructure. We did not differentiate between single-bore well pads and multi-bore well pads, and we also included inactive oil wells (≤12 months) because the associated infrastructure was still present. To determine road densities, we included all federal, state, county, and USFS gravel or paved roads and associated rights-of-way.

Randomization was achieved by generating a stratified design with 20 unique strata—each strata representing a distinct combination of the two covariates (i.e., 5 levels of well density and 4 levels of road density). The 20 strata ranged from low well and road density to high well and road density. A random list of available study sites was generated for each of the 20 groups. Stratifying in this manner optimizes the range in each covariate so as to maximize habitat suitability modeling (Hirzel and Guison, 2002). We selected the first three quarter-sections in each group unless the quarter-section had a high percentage of woody vegetation, in which case we selected the next quarter-section in the list (Table A1).

Unfortunately, we did not have access to grazing history or stocking rate data for any allotments in the McKenzie District during the study, and thus, could not use grazing or stocking rates as covariates in our study design and site selection. This made it difficult to develop reasonable grazing strata. Although we did not have information on the stocking rates for the individual quarter-sections, the livestock stocking rate recommended by the USFS on all of our study sites ranged from 0.5 to 2.4 stocking hectares (1.3 to 5.9 stocking acres) per animal month (Kyle Dalzell, USFS, personal communication). Pastures selected in this study were managed with several different grazing systems, including early-season crested wheatgrass (*Agropyron cristatum*) use, season long, deferred rotation, twice-over rotation, and 3- to 8-pasture rotations.

2.3.2. Bird census methods

We followed a total-area count (i.e., a modified strip-transect) protocol that was described in Stewart and Kantrud (1972) and Igl and Johnson (1997) to survey all species of breeding birds. Within each sample unit, observers followed systematic transects and were responsible for counting indicated breeding bird pairs within 100 m on either side of the transect line, ensuring coverage of the entire sample unit. We used ArcGIS (10.2.2 ESRI, Redlands, California) to generate a systematic transect route with four separate legs, each measuring 800 m in length (Fig. 3). The first transect leg was spaced 100 m from the study-site edge with subsequent transects spaced 200 m apart. The spacing of the transect route ensures that the entire study area was covered throughout the bird survey.

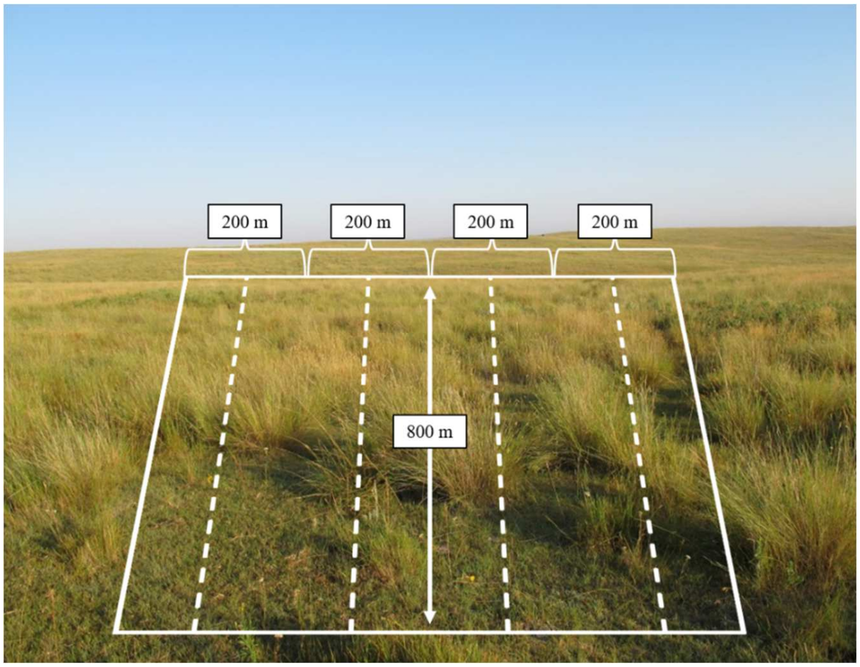

Figure 3. Schematic of site transect routes for breeding bird surveys and sampling vegetation structure in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Breeding bird surveys were conducted from late-May to mid-July each year, which coincides with the peak breeding season of breeding birds in this region (Stewart and Kantrud, 1972; Igl and Johnson, 1997). Study sites were surveyed twice each year by one or two observers walking slowly on foot, assuming a walking speed of about 1.0-1.5 km per hr. This rate of progress allows for an observer or observers to efficiently cover a study site in a relatively short period of time, and balanced the length of exposure to individual breeding pairs, which prevents duplication of counts (Igl, 2009). Bibby (2000) indicated that a walking speed of 2 km per hr was reasonable in open habitats.

When two or more random study sites were in close proximity, individual sites were surveyed more efficiently by a single observer. However, when a study site was geographically isolated, it was more efficient to survey the unit using two observers, each covering one-half of the site (i.e., two transects each). On study sites surveyed by two observers, an interval of 400 m between observers was maintained. As this distance is much greater than the distance most species travel after flushing, there was little chance that an individual bird recorded by one observer would also be recorded by the other (Stewart and Kantrud, 1972). Observers used a DeLorme Earthmate® PN-60 GPS unit to follow transects within each study site. As recommended by Stewart and Kantrud (1972), deviations from the route were allowed and sometimes necessary to adequately survey all portions of the site (e.g., rolling topography) or to track down elusive individuals to confirm identification. Large or wide-ranging birds (e.g., raptors) that flushed from the site upon the observer's arrival or during the survey were recorded as being within the site. In sites that were surveyed by two observers, observers compared field notes at the end of the survey to prevent duplication in the counts.

During the first week of each field season, we trained observers in field protocols and in the identification (aural and visual) of grassland birds. As recommended by Igl (2009), the technicians also were trained to 1) adjust their rate of travel appropriate to the conditions and topography of the quarter-section and to the densities of birds, 2) minimize confusion among individuals or pairs of the same species by observing birds in all directions as the observer moves through the quarter-section and by reconfirming locations of conspecifics as new individuals are encountered along a transect, 3) recognize that some individuals or pairs of some species (e.g., Bobolink [*Dolichonyz oryzivorus*]) might be attracted to or follow an observer and should not be counted more than once (Redmond et al., 1981; Bollinger et al., 1988), and 4) keep track of individuals that move away from an observer, including those that might move from one transect to the next within the same quarter-section (Bibby, 2000). New observers also were accompanied by an experienced observer for several surveys at the beginning of each field season to establish a consistent protocol before proceeding to collect data independently. No procedures (e.g., call broadcasts or spishing [imitating an alarm call]) were used to entice a bird to sing, call, or alter its behavior to make it more detectable (Igl, 2009).

2.3.3. Breeding bird populations

During the surveys, breeding birds were identified based on aural or visual observations of adults or the presence of an active nest. Surveys of breeding birds were conducted between 0.5 h before sunrise and the midday lull in bird activity, which varies from day to day but usually occurs in the early afternoon in this region (L. D. Igl personal communication; Igl, 2009). Observers avoided conducting surveys in adverse weather conditions (e.g., heavy precipitation, sustained winds stronger than 24 km per hr), although surveying during light drizzle was allowed if the birds were still active. As recommended by Stewart and Kantrud (1972) and Igl and Johnson (1997), we sometimes used less restrictive standards related to wind speed to provide observers with more time and dates to complete bird surveys.

Counts of birds were based primarily on the number of indicated breeding pairs on territories or home ranges. For most species, nearly all indicated pairs were observed as territorial males or as segregated pairs. In the case of wide-ranging or colonial-nesting species that are not sexually dimorphic (e.g., raptors, grouse, shorebirds, swallows), one or two individuals were considered to represent a pair, but if more than two individuals were observed on a study site, the total number of indicated pairs was derived by halving the total number of individual counts and rounding up to the nearest whole pair. We based the number of indicated pairs of brown-headed cowbird (*Molothrus ater*) on the total number of females. Birds flying overhead were only counted if they were actually using the field, such as flycatching, courtship or communal displaying, or hunting. Any pair or lone singing male that occurred on a field border or fence was counted as half a pair, based on the assumption that field edges divide the average edge territory into two equal parts (Verner, 1986).

We did not consider certain birds observed during the surveys to be using our study sites and excluded them from our results (Igl and Johnson, 1997; Igl, 2009). These included (1) migrant flocks; (2) wide-ranging colonial waterbirds (e.g., pelicans, cormorants, egrets, herons) passing high overhead; and (3) other birds passing overhead in high, direct flight. Juveniles were recorded but were not considered part of the breeding population at a site; however, a single adult or a pair of adults accompanied by one or more juveniles was counted as a single pair. Vernacular and scientific names follow the checklist of the American Ornithologists' Union (Chesser et al., 2015).

2.3.4. Vegetation sampling

Fisher and Davis (2010) reviewed literature on grassland bird habitat selection and identified 118 vegetation variables that researchers have found to be important in habitat selection by grassland birds. Of those 118 vegetation variables, nine variables appeared to be consistent predictors of grassland bird habitat use: coverage of bare ground, grass, dead vegetation, forbs, and litter; an index of vegetation density; vegetation volume; litter depth; and vegetation height. Of those nine variables, bare-ground exposure, vegetation height, and litter depth were three of the most consistent predictors of habitat use by grassland birds (Fisher and Davis, 2010). In this study, we measured all nine vegetation variables that Fisher and Davis (2010) found to be important predictors of grassland bird habitat use to reduce the number of a priori hypotheses and to ultimately provide land managers with useful decision-support tools to manage habitat for grassland birds. In addition, we also included measures of floristic composition because the literature suggested that some species of concern, including the

Sprague's pipit and Baird's sparrow, select native vegetation over non-native vegetation in grasslands (Wilson and Belcher, 1989; Madden et al., 2000).

2.3.4.1. Structural vegetation sampling

To characterize vegetation structure (e.g., visual obstruction, vegetation height, litter depth) in each quarter-section at the time of the bird surveys, we collected structural data on or near (i.e., within 3 days) the date of each bird survey. Twenty sampling stations were placed systematically along each of the four 800-m birding transect legs at 41-m intervals—80 stations per site—to get a good representation of the entire study site. Visual obstruction readings (VOR) were taken using a modified Robel pole (Robel et al., 1970; Benkobi et al., 2000). The 1-m Robel pole was marked with alternating 2.5-cm bands and numbered beginning with one at the base of the pole. A metal spike was attached to the bottom of the pole and was pushed into the ground until the bottom of the pole came into contact with the ground. The observer moved 4 m away from the pole, and then with eyes 1 m above ground level, recorded the lowest interval on the pole that was not completely obscured by vegetation (Fig. 4). A meter stick was attached to the Robel pole by a 4-m string to maintain a consistent observation distance and height. For example, if the third VOR band was visible, the VOR was recorded as 3 (i.e., 7.5 cm). At each station, two VOR measurements were recorded at opposite cardinal directions and then averaged for each point. Maximum vegetation height (cm) and litter depth (cm) also were measured at each station using a meter stick. Observers measured the height, in cm, of the highest piece of vegetation within 15 cm of the Robel pole using a meter stick. We considered litter to be any horizontal, unconsolidated plant material not anchored to the ground.

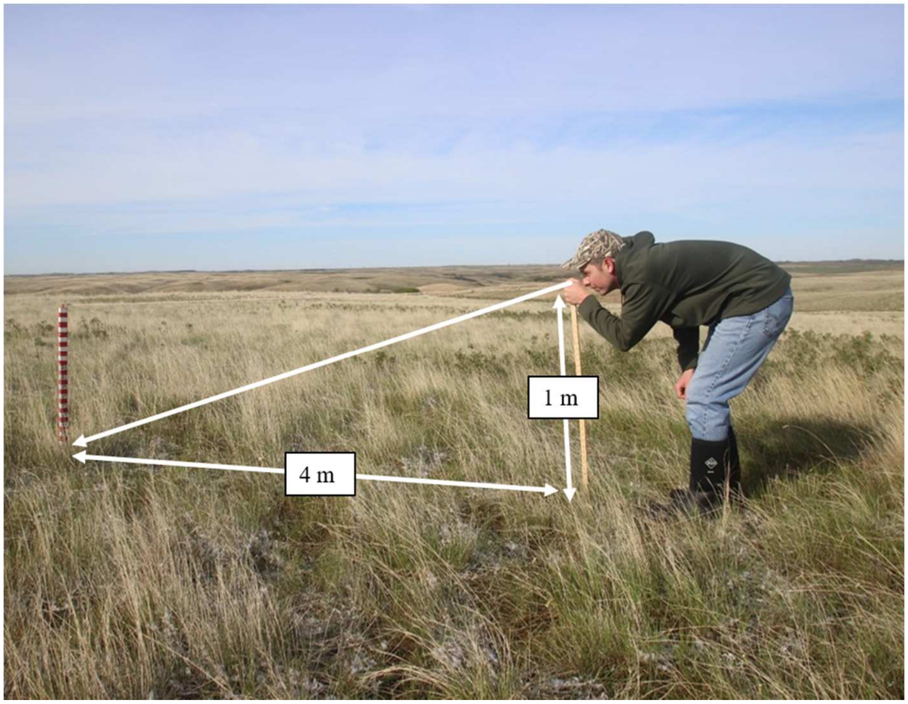

Figure 4. Observer recording visual obstruction reading using a Robel pole in the Little Missouri National Grassland in western North Dakota.

Herbage standing crop also was sampled in 2014 as a proxy for vegetation volume. Standing crop was measured directly by clipping herbage from 0.25-m^2 quadrats placed systematically along each transect at every fourth sampling station, for a total of 20 clippings per study site. Our sampling density for biomass is similar to that recommended by Uresk and Benzon (2007), who suggested a minimum of three transects with 20 stations per transect for monitoring areas ≤259 ha (i.e., legal section). Vegetation in each quadrat was clipped to ground level from the sampling station's center after other structural measurements were recorded. Vegetation samples were bagged, oven-dried for 48 hr at 110 °C, and then weighed.

2.3.4.2. Vegetation composition

Several researchers have found that some grassland bird species—Sprague's pipit and Baird's sparrow in particular—are significantly more abundant in native prairies than non-native grasslands (Wilson and Belcher, 1989; Dale, 1992; Anstey et al., 1995; Madden, 1996). To assess this assertion, we characterized the vegetation species composition of 57 study sites using a modified Whittaker plot (Stohlgren et al., 1995; fig. 5). We did not survey three of our study sites due to logistical constraints. Given that species composition does not vary appreciably from one year to the next in grasslands (Gibson and Hulbert, 1987; Tilman and Downing, 1994; DeKeyser et al., 2015), floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Three 1,000-m^2 Whittaker plots were sampled in each quarter-section. Each Whittaker plot measures 20 × 50 m (1,000 m^2) and contained nested subplots of three different sizes. A 5 × 20-m (100-m^2) subplot was placed in the plot's center, and two 2 × 5-m (10-m^2) subplots were placed in opposite corners of the plot. Presence/absence data were collected for the 10-m^2, 100-m^2, and 1,000-m^2 subplots. There also was a total of ten 0.5-m × 2-m (1-m^2) "microplots". Six of the microplots were arranged systematically inside and adjacent to the 1,000-m^2 plot perimeter, and the other four were arranged systematically outside and adjacent to the 100-m^2 subplot perimeter. Percent cover of all species and substrate variables (e.g., bare ground, litter) was visually estimated to the nearest 1% within the microplots. Species that did not comprise 1% of the microplot were given a value of 0.1%. Using ArcGIS (10.2.2 ESRI, Redlands, California), we placed ten randomized points at each site to be used as the starting point for each plot. Using their best judgment, observers would choose three points that were spatially widespread, did not fall within non-grassland features (e.g., woody draws), and gave a good representation of the entire quarter-section's vegetation composition within grasslands. Once on the point, a random number generator was used to obtain a directional bearing on which the plot would be oriented.

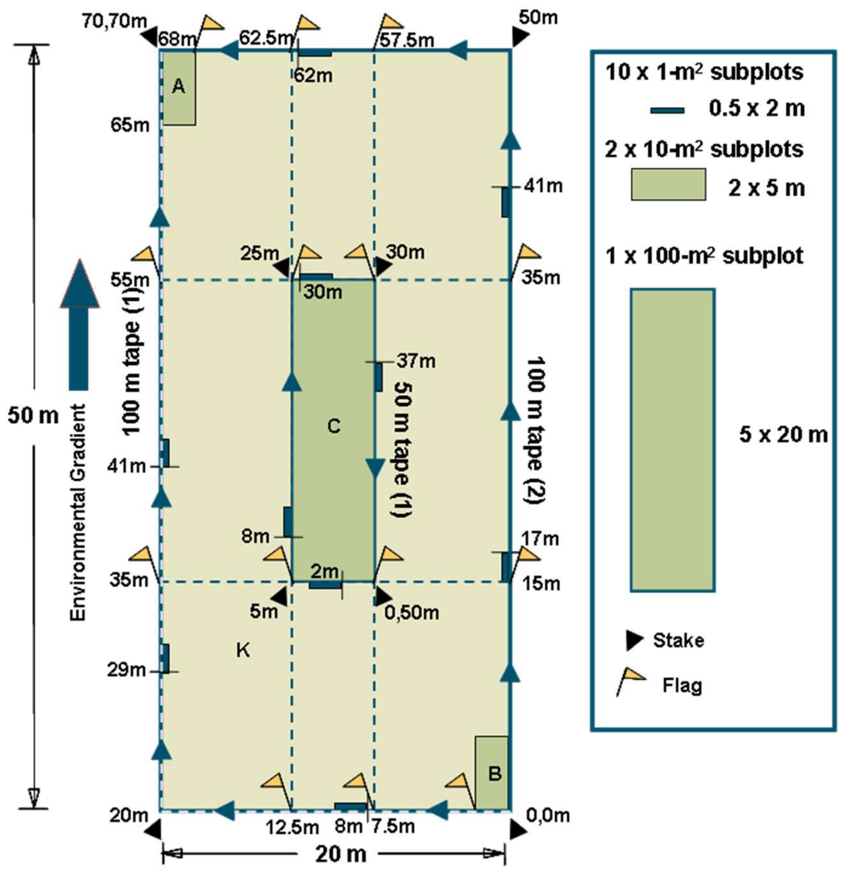

Figure 5. The layout of Modified-Whittaker plot used in this study to quantify plant species composition in the Little Missouri National Grassland, 2014 and 2015 (Stohlgren et al., 1995).

2.3.5. Statistical analyses

Breeding bird densities were calculated as the number of indicated breeding pairs observed per 100 ha and were log-transformed ($\log_e$ [bird density+1]) to normalize the data for analyses. Bird data were averaged by year between the early and late-season total-area counts. Due to time constraints, approximately one-half of the bird surveys occurred late into the breeding season in 2014 (i.e., early August). These late-season surveys were dropped from analyses because they occurred outside of the peak breeding season for birds in North Dakota (Igl and Johnson, 1997). However, we retained the late observations of Sprague's pipits because they have two periods (bimodal) of breeding activity in North Dakota, the first from late April to early June and the second from mid-July to early September (Stewart, 1975). Structural vegetation variables (i.e., VOR, maximum height, litter depth, and biomass) were averaged for each study site by year between the two survey periods. Density of oil wells, length of roads (km), and percentage of grassland within a 1.6 km buffer of the quarter-section were used to assess the level of disturbance in the surrounding landscape (i.e., landscape-level models). To calculate oil-well densities, we only included the following well statuses as described by the North Dakota Oil and Gas Commission (2016): active, drilling, inactive (≤ 12 months), not completed, and temporarily abandoned. Percent coverages of bare ground, litter, Kentucky bluegrass (*Poa pratensis*), and crested wheatgrass were calculated as an average of all cover estimates from the Whittaker microplots. We included percent coverage of Kentucky bluegrass and crested wheatgrass in our final analyses because literature suggested that these variables influence sensitive grassland bird presence or abundance (Wilson and Belcher, 1989).

We also calculated a Floristic Quality Index (FQI) (NGPFQAP, 2001) for each site using plant presence/absence data collected using the Whittaker subplots. Floristic quality assessments assign a rating to each plant species that reflects the fundamental conservatism that the species exhibits for natural habitats. We used a list of coefficients of conservatism (C values) developed for the Dakotas by the Northern Great Plains Floristic Quality Assessment Panel (2001). C values represent a plant species' pattern of occurrence (i.e., common or rare) and if it is natural-area dependent. C values range from 0-10. Ubiquitous species are given a low C value, and species that exhibit specific adaptations are given a higher C value. The FQI is obtained by multiplying mean C by the square root of the number of native species present. Thus, the FQI is a weighted species-richness estimate that uses a square root transformation of the number of native species present to limit the influence of area alone on species richness (Swink, 1974). We calculated FQI using the Universal Floristic Quality Assessment Calculator (Freyman et al., 2015).

Other researchers have detected a strong relationship between VOR and standing crop (Robel et al., 1970; Vermeire and Gillen, 2001; Woehl, 2010). Based on the recommendation of Vermeire and Gillen (2001), we ran a regression at the site level to explore the relationship between standing crop and VOR. Regression models based on the site—rather than individual observations—account for less variation because the true area measured by VOR is unknown, 3-dimensional, and may vary among points; whereas quadrat size is 2-dimensional and consistent among points. Models developed at the site level reduce this source of error by averaging both VOR and standing crop over many individual points (Vermeire and Gillen, 2001). Mean standing crop was calculated for the second year of the study by entering mean VOR's into the regression model. Definitions of all explanatory variables can be found in Table 1.

Table 1. Covariate abbreviations and corresponding descriptions for landscape and site-specific variables recorded at study sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Variable type	Covariate abbreviation.	Description
Landscape	Percent.Grass	Percentage grassland (e.g., range, hayland) within 1.6 km of site boundary.
	Wells	Well density (number of wells) within 1.6 km of site boundary.
	Roads	Total road length (km) within 1.6 km of site boundary.
Site-specific	Ltr.Depth	Litter depth (cm).
	Height	Maximum vegetation height (cm) within 15 cm of Robel pole.
	AvVOR	Average visual obstruction reading (cm).
	kgha	Standing crop or biomass (kg per ha).
	Percent.AGCI	Percentage cover of crested wheatgrass.
	Percent.POPR	Percentage cover of Kentucky bluegrass.
	Percent.BG	Percentage cover of bare ground.
	Percent.Litter	Percentage cover of litter.
	FQI	Floristic Quality Index.
	Slope	Average percent slope of quarter-section.

We selected a suite of 12 grassland bird species to evaluate the effects of landscape and site-specific variables on breeding bird densities: sharp-tailed grouse (*Tympanuchus phasianellus*), upland sandpiper (*Bartramia longicauda*), horned lark (*Eremophila alpestris*), Sprague's pipit, clay-colored sparrow (*Spizella pallida*), field sparrow (*Spizella pusilla*), vesper sparrow (*Pooecetes gramineus*), grasshopper sparrow (*Ammodramus savannarum*), Baird's sparrow, chestnut-collared longspur (*Calcarius ornatus*), bobolink, and western meadowlark (*Sturnella neglecta*). We used an information-theoretic approach (Burnham and Anderson, 2002) to model individual bird species' abundances against landscape factors (i.e., percent grassland, length of roads, and oil well density, all within 1.6 km of the border of the quarter-section) and site-specific factors (i.e., slope, VOR, maximum height, litter depth, and percentage cover of bare ground, litter, Kentucky bluegrass, and crested wheatgrass). Models were formulated as general linear models (GLMs) with an assumed Gaussian distribution based on an ln(y + 1) transformation. We ranked models using Akaike's Information Criteria (AIC) corrected for small sample size (AIC_c) by computing the difference (Δ_i) between the model with the smallest AIC_c and the model with the next smallest AIC_c (Burnham and Anderson, 2002). In general, models with $\Delta_i \leq 2$ have substantial support, those with Δ_i of 4-7 have considerably less support, and those with Δ_i >10 have essentially no support (Burnham and Anderson, 2002). Because AIC_c is a relative measure, Burnham and Anderson (1998) recommended calculating the AIC differences—or delta AIC ($\Delta_i = AIC_{c,i} - minAIC_c$)—for each candidate model. The best model has a $\Delta_{i=0}$. Akaike weights (ω_i)—relative likelihood of a model—are also reported. The relative importance of each model was assessed by computing Akaike's model weights (ω_i) and we used root-mean-squared errors (RMSE) and adjusted R^2 (Adj. R^2) to assess the goodness-of-fit of the final model(s).

Because we had limited information on which predictors might be useful a priori, we took a two-step approach for deriving potential plausible models. Following habitat selection as advocated by Johnson (1980), in the first stage, we looked at higher-level selection by examining which of three landscape predictors might explain abundance of bird species using a suite of eleven plausible models (Table 2). Year was included in all candidate models (except the null model), regardless of its importance, because grassland bird populations in this region are known to exhibit considerable annual variability in abundance from year-to-year on any particular site (Igl and Johnson, 1997, 1999; Igl et al., 2008). In the second stage, uncorrelated site-specific variables were then added to the best model from the landscape models to see if they improved the model fit (Table 3). Overall, 25 site-specific plausible models were considered. Because bird abundance and covariates, particularly site, can vary widely from year-to-year on each of the sites, we assumed independence. To account for variation in the strength of relationships between years, we included interaction terms between year and potential landscape and/or site-specific variables. Bivariate plots by year were used as a descriptive method to better understand the strength and direction of any relationships between bird abundance and covariates deemed useful from the modeling effort. All statistical analyses were conducted in Program R (version 3.2.3; R Core Team 2015). The following R packages were used: “AICcmodavg” (Mazerolle, 2016), “MuMIn” (Barton, 2016), and “vegan” (Oksanen et al., 2016).

We also used the aforementioned GLM modeling selection to assess the effects of explanatory variables on overall grassland bird diversity by calculating Shannon Diversity (*H*) and using it as the dependent variable in the models. We restricted our analysis to the 12 most common grassland birds detected on our sites. This approach allowed for simple interpretation of the effects of the 13 explanatory variables on grassland bird diversity.

Table 2. Plausible models using landscape-level variables including well density (Wells), total length of roads (Roads), and percentage grass within 1.6 km of quarter-section edge (Percent.Grass). Refer to Table 1 for covariate descriptions.

Model No.	Model description
1	Null
2	Year
3	Year + Wells
4	Year + Wells + Year×Wells
5	Year + Roads
6	Year + Roads + Year×Roads
7	Year + Percent.Grass
8	Year + Percent.Grass + Year×Percent.Grass
9	Year + Year×Percent.Grass + Year×Wells
10	Year + Year×Percent.Grass + Year×Roads
11	Year + Year×Roads + Year×Wells

Table 3. Plausible models using site-specific variables including average visual obstruction reading (AvVOR), percent slope (Slope), Native Floristic Quality Index (Native.FQI), and percentage cover of crested wheatgrass (Percent.AGCR), Kentucky bluegrass (Percent.POPR), bare ground (Percent.BG), and litter (Percent.Litter). Refer to Table 1 for covariate descriptions.

Model No.	Model description
12	Best + AvVOR
13	Best + AvVOR + Year×AvVOR
14	Best + Slope
15	Best + Slope + Year×Slope
16	Best + FQI
17	Best + FQI + Year×FQI
18	Best + Percent.AGCR
19	Best + Percent.AGCR + Year×Percent.AGCR
20	Best + Percent.POPR
21	Best + Percent.POPR + Year×Percent.POPR
22	Best + Percent.BG
23	Best + Percent.BG + Year×Percent.BG
24	Best + Percent.Litter
25	Best + Percent.Litter + Year×Percent.Litter
26	Best + Ltr.Depth
27	Best + Ltr.Depth + Year×Ltr.Depth

2.4. Results

2.4.1. General

Average herbaceous standing crop among sites ranged from 846 to 2406 kg per ha. We used the slope and intercept of the regression model to calculate standing crop estimates for 2015 (Fig. 6).

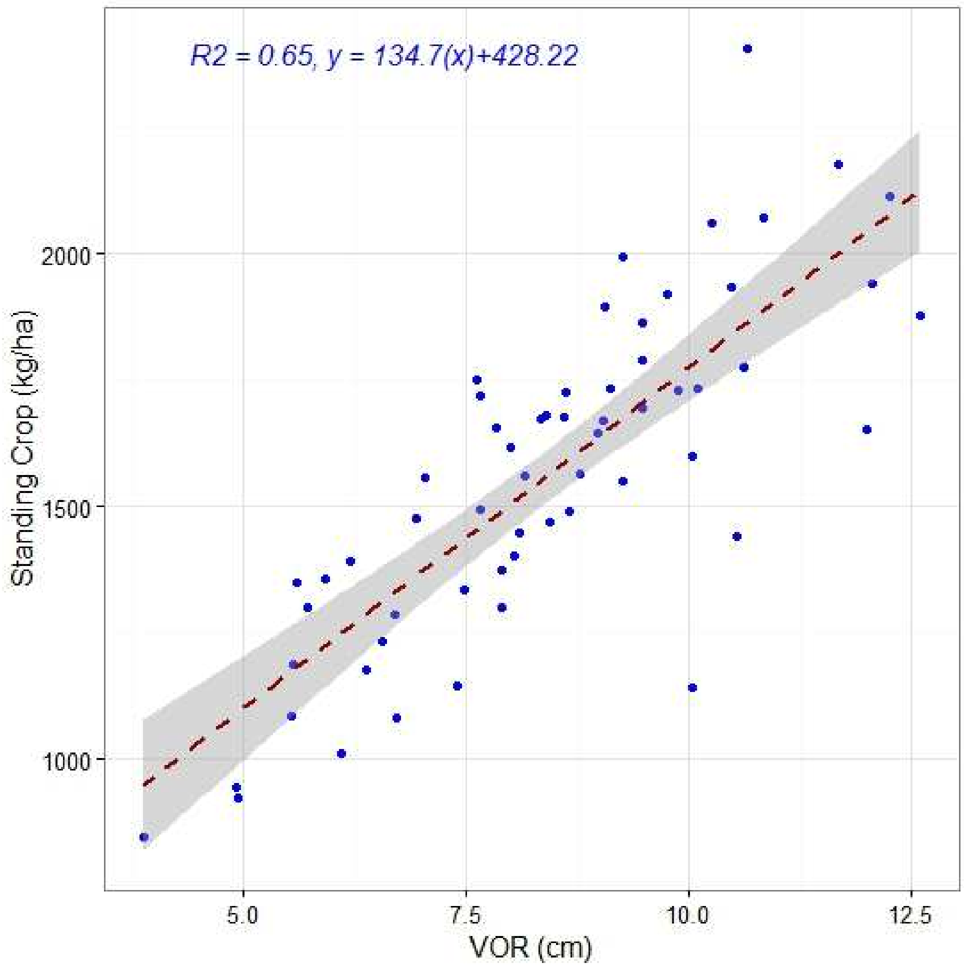

Figure 6. Linear regression plot between mean standing crop (biomass) and mean visual obstruction readings (VOR) with 95% confidence intervals for 60 quarter-section sites in the Little Missouri National Grassland, 2014 and 2015.

Patterns of correlation among the 13 explanatory variables were explored by calculating Pearson's correlation coefficients. The following explanatory variables were found to be correlated ($r \geq 40\%$) (Table 4): VOR, maximum vegetation height, and biomass; FQI and percent cover of crested wheatgrass; and percent bare ground and percent litter cover. Accordingly, we did not include any of the correlated variables within the same plausible models. VOR was used in place of vegetation height and biomass in the models because height and biomass were highly correlated with VOR ($r \geq 70\%$). Summary statistics for the 13 explanatory variables can be found in Table 4.

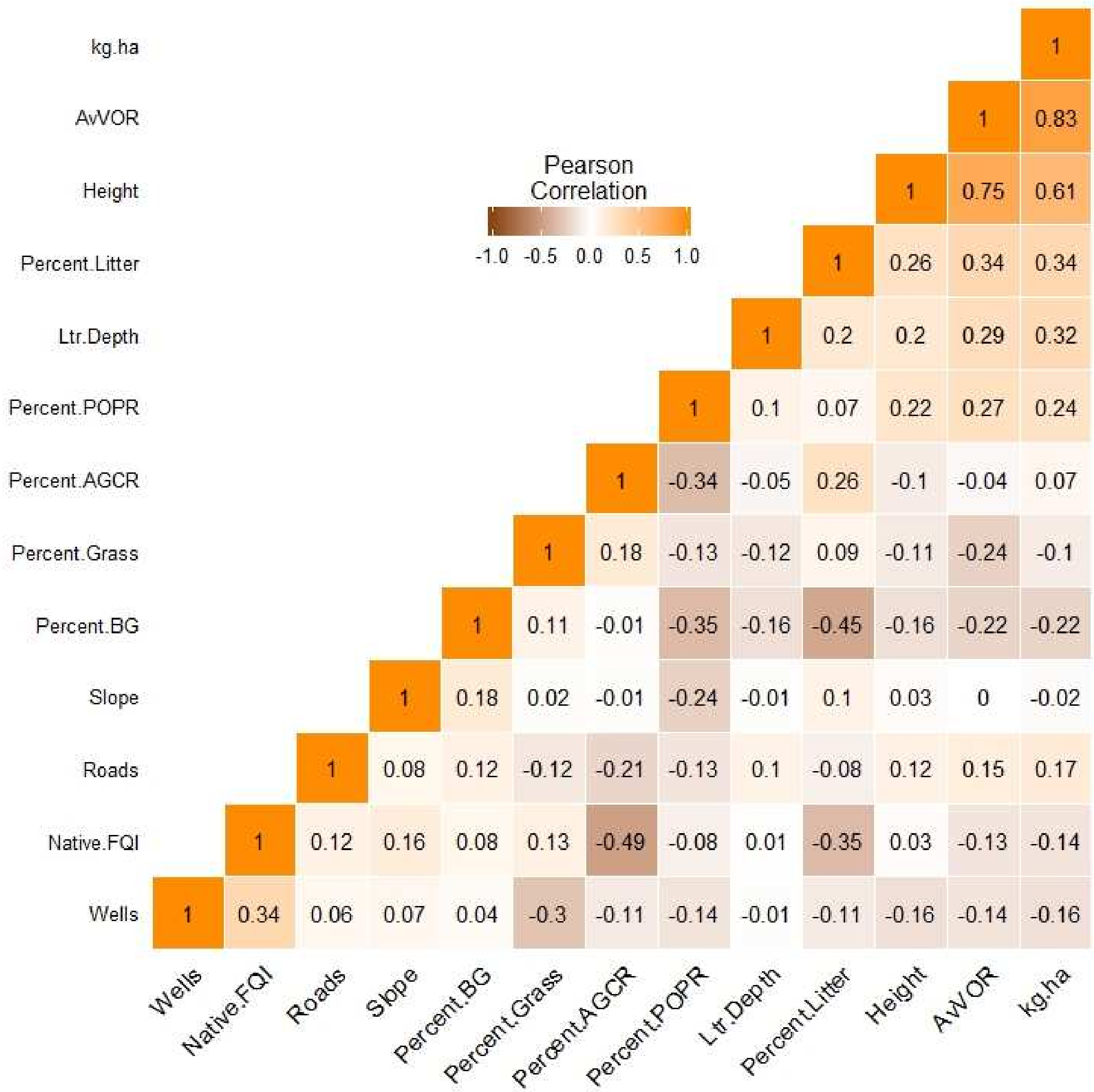

Figure 7. Correlation heatmap with Pearson correlation coefficients for landscape and site-specific covariates (n = 57). Positive correlations are displayed in orange and negative correlations are in brown. Color intensity is proportional to the correlation.

Table 4. Summary statistics for 13 explanatory variables collected on 57 sites on the Little Missouri National Grassland in western North Dakota from late-May through mid-August 2014, and 2015.

	2014			2015		
Variable	Range	$\bar{x}$	SD	Range	$\bar{x}$	SD
Landscape variables:						
Percent.Grass	33.6-97.4	77.1	12.9	33.6-97.4	77.1	12.9
Wells	0.0-17.0	2.0	3.5	0.00-17.00	2.0	3.5
Roads	0.0-18.8	12.1	4.1	0.00-18.80	12.1	4.1
Site-specific variables:						
Ltr.Depth (cm)	0.54-3.24	1.8	0.6	1.9-5.0	3.6	0.8
Height (cm)	22.8-57.1	44.2	7.5	27.9-59.8	41.6	5.7
AvVOR (cm)	4.4-13.2	8.8	2.1	4.3-11.9	7.8	1.8
kg.ha	1019.6-2202.5	1613.9	288.0	1004.9-2023.6	1477.8	245.6
Percent..AGCR	0-25.9	4.9	7.0	0-25.9	4.9	7.0
Percent.POPR	0-20.4	5.9	5.7	0-20.4	5.9	5.7
Percent.BG	0.2-40.5	7.8	8.0	0.2-40.5	7.8	8.0
Percent.Litter	10.8-72.9	46.2	11.8	10.8-72.9	46.2	11.8
FQI	23.4-52.2	39.2	6.7	23.4-52.2	39.2	6.7
Slope	2.6-14.9	9.4	2.6	2.6-14.9	9.4	2.6

During the breeding seasons of 2014 and 2015, we detected 69 and 76 bird species, respectively. We observed 7,789 breeding pairs representing 82 bird species over the course of the study (Table A2). The most frequently observed species were the grasshopper sparrow and western meadowlark, which were detected on 100% of the study sites, vesper sparrow (97%), and mourning dove (*Zenaida macroura* [88%]). The 20 most frequently observed species are summarized in Table 5. The suite of 12 grassland birds selected for further analyses all occurred on >20% of the study sites. Sensitive species detected in USFS Region 1 over the duration of this monitoring program include: burrowing owl (*Athene cunicularia*), loggerhead shrike (*Lanius ludovicianus*), Sprague's pipit and Baird's sparrow. Other birds we observed that are considered sensitive by the USFS were burrowing owl (*Athene cunicularia*) and loggerhead shrike (*Lanius ludovicianus*). We also observed two breeding pairs of long-billed curlew (*Numenius americanus*) near one of our study sites during both years of the study; however, they were never observed using any of the study sites during our breeding bird surveys.

We recorded 195 plant species in 171 modified Whittaker plots on 57 study sites in 2014 and 2015 (Table A3). Native species accounted for 86.7% (169 species) of the total plant community, whereas non-native species accounted for 13.3% (26 species) of the total plant community. The average Native Mean C value for the study area is 5.1 and the average FQI is 39.2. Forbs comprised 65.6% of the plant community; grasses and sedges combined for 20.5% of the plant community; shrubs and trees accounted for 11.8% of the plant community; and ferns, bryophytes, and vines, combined for 2% of the plant community. FQI for individual sites ranged from 23.4 to 52.2 (Table A4). The five vegetation composition variables with the highest percent cover (averaged across all sites) were: litter (46.4%), bare ground (7.8%), western wheatgrass (5.9%), Kentucky bluegrass (5.9%), and crested wheatgrass (4.7%)

Table 5. Summary statistics for the 20 most frequently observed breeding bird species during surveys conducted on the Little Missouri National Grassland in western North Dakota between 23 May to 25 July 2014 and 19 May to 17 July 2015. The species are ordered by frequency of occurrence.

Species	Sites observed[1]	Frequency occurrence	Average densities (no. pairs per 100 ha)	Density SD	Density range
Grasshopper sparrow	119	1.00	30.92	12.8	3.9-65.0
Western meadowlark	119	1.00	22.53	8.1	0.8-38.0
Vesper sparrow	116	0.97	6.80	4.4	0.0-22.8
Mourning Dove	108	0.88	2.28	1.8	0.0-7.9
Eastern kingbird	100	0.82	2.18	1.8	0.0-7.7
Bobolink	95	0.77	4.22	4.2	0.0-17.0
Brown-headed cowbird	92	0.75	1.83	1.9	0.0-9.3
Clay-colored sparrow	91	0.74	3.32	5.0	0.0-28.3
Sharp-tailed grouse	89	0.72	1.70	2.0	0.0-11.6
Yellow warbler	88	0.71	2.54	2.6	0.0-14.0
Spotted towhee	81	0.66	2.34	2.9	0.0-14.8
Field sparrow	79	0.64	2.27	2.7	0.0-14.8
Upland sandpiper	75	0.61	1.23	1.3	0.0-4.7
Brown thrasher	65	0.52	0.79	1.0	0.0-3.8
Horned lark	58	0.46	1.85	3.5	0.0-18.9
House wren	52	0.41	0.98	1.6	0.0-7.0
Red-winged blackbird	47	0.37	0.94	2.2	0.0-14.3
Sprague's pipit	44	0.34	1.61	3.1	0.0-13.2
Baird's sparrow	40	0.31	1.31	2.8	0.0-13.9
Chestnut-collared longspur	32	0.24	1.66	4.9	0.0-33.2

[1] n = 60 site-by-year combination.

2.4.2. Modeling results

2.4.2.1. Grassland bird community

The best supported and most parsimonious landscape model for grassland bird diversity had weak evidence ($\omega_i = 0.38$, $R^2 = 0.06$) that diversity is associated with Percent.Grass (Table 6). One site-specific variable (VOR) improved the best-supported landscape model ($\omega_i = 0.51$), and explained 12% of the variation in grassland bird diversity. The best-supported site-specific model did not include any Year interactions, therefore the relationship between grassland bird diversity and the explanatory variables did not vary from year-to-year. Grassland bird diversity showed a slight decline with increasing percentage cover of grassland within 1.6 km of the site edge and average VOR (Fig. 8).

2.4.2.2. Sharp-tailed grouse

The best supported and most parsimonious landscape model for the sharp-tailed grouse included Year and Wells (Table 7). However, the evidence that sharp-tailed grouse abundance is a function of Year and Wells is weak ($\omega_i = 0.23$, $R^2 = 0.03$). One site-specific variable (Ltr.Depth) improved the best-supported landscape model relative to other models ($\omega_i = 0.39$), but only explained 7% of the variation in sharp-tailed grouse abundance. The best site-specific model did not include any Year interactions, thus the relationship between sharp-tailed grouse abundance and Ltr.Depth did not vary substantially from year-to-year. Although many sites had zero sharp-tailed grouse across the range of Wells and Ltr.Depth, sharp-tailed grouse abundance declined with increasing well density (Fig. 9). Sharp-tailed grouse abundance slightly increased with increasing litter depth in 2014 and 2015.

Table 6. Model-selection results for models relating grassland bird diversity (Shannon [*H*]) to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod7	Year + Percent.Grass	4	-307.2	0.0	0.38344	0.06062	0.06
mod8	Year + Percent.Grass + Year * Percent.Grass	5	-305.3	2.0	0.14438	0.06056	0.05
mod10	Year + Year * Percent.Grass + Year * Roads	7	-305.1	2.2	0.12933	0.05943	0.07
mod5	Year + Roads	4	-304	3.3	0.07446	0.06150	0.03
mod9	Year + Year * Percent.Grass + Year * Wells	7	-303.8	3.4	0.06966	0.05975	0.06
mod2	Year	3	-303.3	4.0	0.05233	0.06227	0.02
mod4	Year + Wells + Year * Wells	5	-302.8	4.4	0.04169	0.06122	0.03
mod1	Null	2	-302.3	5.0	0.03195	0.06312	0.0
mod3	Year + Wells	4	-301.9	5.3	0.02646	0.06206	0.02
mod6	Year + Roads + Year * Roads	5	-301.8	5.5	0.02493	0.06150	0.02
mod11	Year + Year * Roads + Year * Wells	7	-301.5	5.8	0.02138	0.06037	0.04
Best landscape model plus site-specific models:							
mod12	Year + Percent.Grass + AvVOR	5	-313.2	0.0	0.50792	0.05850	0.12
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	-311	2.2	0.17025	0.05849	0.11
mod24	Year + Percent.Grass + Percent.Litter	5	-309.1	4.1	0.06557	0.05956	0.09
mod17	Year + Percent.Grass + Native.FQI + Year * Native.FQI	6	-308.9	4.3	0.05973	0.05903	0.09
mod16	Year + Percent.Grass + Native.FQI	5	-308.2	4.9	0.04305	0.05978	0.08
mod26	Year + Percent.Grass + Ltr.Depth	5	-307.8	5.4	0.03479	0.05989	0.08
mod7	Year + Percent.Grass	4	-307.2	5.9	0.02636	0.06062	0.06
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	-307.1	6.1	0.02435	0.05950	0.08
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	-305.6	7.5	0.01177	0.05988	0.07
mod18	Year + Percent.Grass + Percent.AGCR	5	-305.5	7.6	0.01123	0.06049	0.06
mod22	Year + Percent.Grass + Percent.BG	5	-305.3	7.8	0.01008	0.06055	0.05
mod14	Year + Percent.Grass + Slope	5	-305.3	7.9	0.00983	0.06056	0.05
mod20	Year + Percent.Grass + Percent.POPR	5	-305.1	8.1	0.00900	0.06061	0.05
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	-303.9	9.3	0.00487	0.06034	0.05
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	-303.8	9.4	0.00464	0.06037	0.05
mod15	Year + Percent.Grass + Slope + Year * Slope	6	-303.3	9.9	0.00359	0.06050	0.05
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	-302.9	10.3	0.00296	0.06061	0.04

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

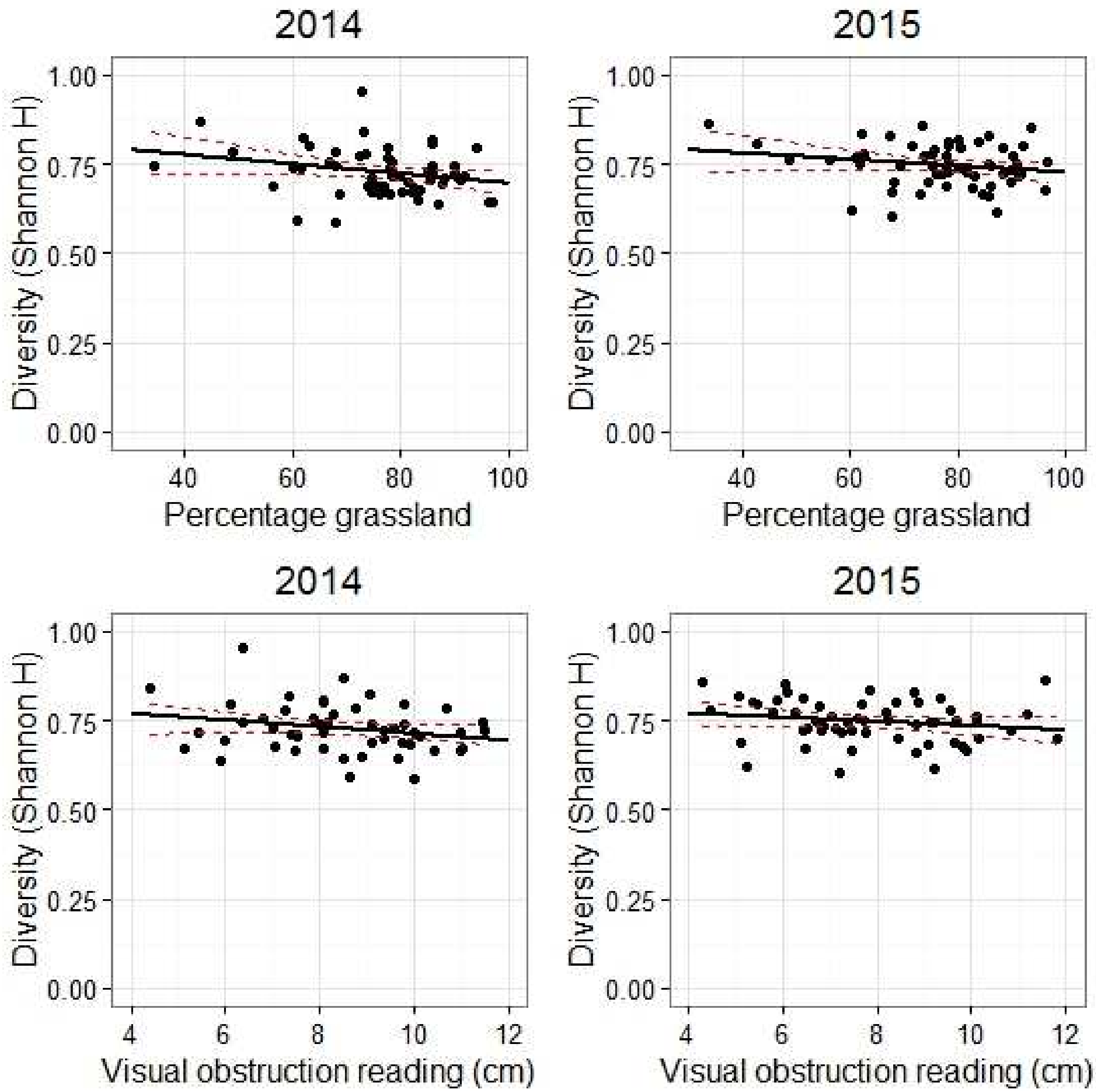

Figure 8. Model results showing relationship (black line with red-dashed 95% confidence intervals) between grassland bird diversity (Shannon [*H*]) and percentage grassland and visual obstruction reading (cm).

Table 7. Model-selection results for models relating sharp-tailed grouse abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod3	Year + Wells	4	223.6	0.0	0.23247	0.62191	0.03
mod7	Year + Percent.Grass	4	224.2	0.6	0.17222	0.62355	0.02
mod2	Year	3	224.3	0.7	0.16065	0.62983	0.01
mod1	Null	2	224.6	1.0	0.14256	0.63636	0.00
mod4	Year + Wells + Year * Wells	5	225.6	2.0	0.08497	0.62143	0.02
mod8	Year + Percent.Grass + Year * Percent.Grass	5	225.6	2.0	0.08485	0.62144	0.02
mod5	Year + Roads	4	226.4	2.8	0.05639	0.62968	0.00
mod9	Year + Year * Percent.Grass + Year * Wells	7	227.8	4.3	0.02768	0.61530	0.02
mod6	Year + Roads + Year * Roads	5	228.6	5.0	0.01889	0.62968	-0.01
mod10	Year + Year * Percent.Grass + Year * Roads	7	229.9	6.3	0.00983	0.62092	0.00
mod11	Year + Year * Roads + Year * Wells	7	230.0	6.4	0.00948	0.62111	0.00
Best landscape model plus site-specific models:							
mod26	Year + Wells + Ltr.Depth	5	219.6	0.0	0.38544	0.60523	0.07
mod27	Year + Wells + Ltr.Depth + Year * Ltr.Depth	6	221.5	1.9	0.15038	0.60431	0.07
mod16	Year + Wells + FQI	5	222.4	2.8	0.09576	0.61267	0.05
mod3	Year + Wells	4	223.6	4.0	0.05192	0.62191	0.03
mod21	Year + Wells + Percent.POPR + Year * Percent.POPR	6	223.7	4.1	0.04967	0.61021	0.05
mod12	Year + Wells + AvVOR	5	223.7	4.2	0.04814	0.61637	0.04
mod24	Year + Wells + Percent.Litter	5	223.9	4.3	0.04422	0.61683	0.03
mod17	Year + Wells + FQI + Year * FQI	6	224.3	4.7	0.03614	0.61191	0.04
mod20	Year + Wells + Percent.POPR	5	225.4	5.8	0.02108	0.62085	0.02
mod14	Year + Wells + Slope	5	225.5	5.9	0.01988	0.62117	0.02
mod18	Year + Wells + Percent.AGCR	5	225.7	6.2	0.01778	0.62178	0.02
mod22	Year + Wells + Percent.BG	5	225.8	6.2	0.01738	0.62191	0.02
mod19	Year + Wells + Percent.AGCR + Year * Percent.AGCR	6	225.9	6.3	0.01640	0.61617	0.03
mod13	Year + Wells + AvVOR + Year * AvVOR	6	225.9	6.3	0.01619	0.61624	0.03
mod25	Year + Wells + Percent.Litter + Year * Percent.Litter	6	226.1	6.5	0.01476	0.61674	0.03
mod23	Year + Wells + Percent.BG + Year * Percent.BG	6	227.3	7.7	0.00833	0.61984	0.02
mod15	Year + Wells + Slope + Year * Slope	6	227.7	8.2	0.00653	0.62117	0.01

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

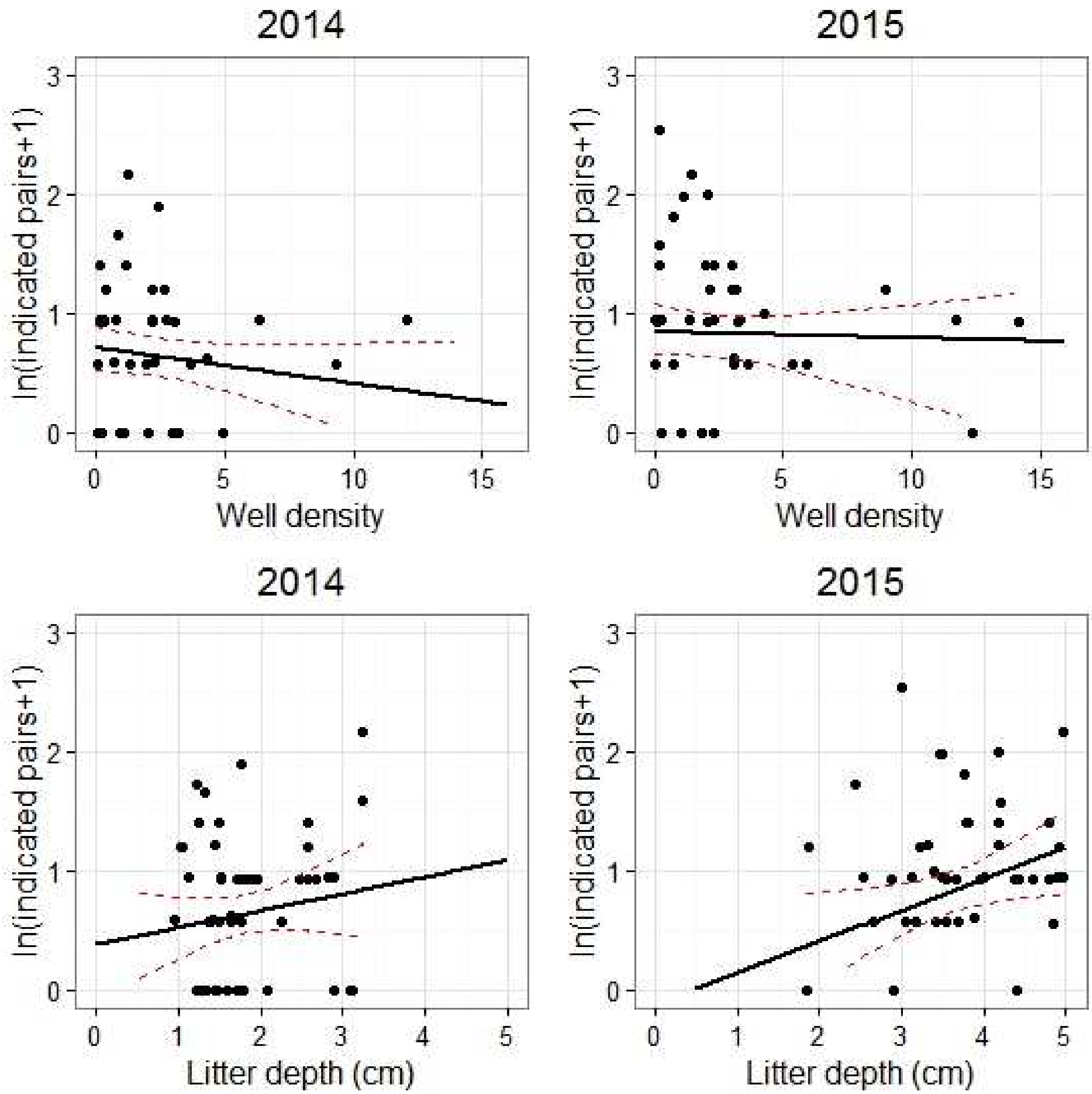

Figure 9. Model results showing relationship (black line with red-dashed 95% confidence intervals) between sharp-tailed grouse abundance and well density and litter depth (cm). Only strongly supported relationships are shown.

2.4.2.3. Upland sandpiper

The landscape model for upland sandpiper indicated that sandpiper densities were a function of Year and Percent.Grass (ω_i = 0.54, Adj. R^2 = 0.10). The association, albeit weak, with Year and Percent.Grass indicates that Percent.Grass affects upland sandpiper abundance consistently between the two years (Table 8). One site-specific variable (Percent.BG) improved the best-supported landscape model (ωi = 0.47), which explained 16% of the variation in upland sandpiper abundance. The best site-specific model did not include an interaction between Percent.Grass or Percent.BG and Year, indicating that upland sandpiper densities were associated with Percent.Grass and Percent.BG but the direction and strength of the relationship did not vary with year. There is some evidence of an interaction between Year and Percent.BG (ω_i = 0.35, Adj. R^2 = 0.17), but the site-specific model with the most weight and lowest Δ_i included only Year, Percent.Grass, and Percent.BG. Although many sites had zero abundance across the range of Percent.Grass and Percent.BG, upland sandpiper abundance tended to increase consistently with increasing grassland cover in the surrounding landscape (i.e., within 1.6 km of the study site) and increased with increasing bare ground cover in both years (Fig. 10).

2.4.2.4. Horned lark

Only Year was associated with horned lark densities at the landscape level (Table 9). There is good evidence suggesting that horned lark densities are associated with Year and Ltr.Depth (ω_i = 0.70, Adj. R^2 = 0.30) at the site-specific level. Although horned larks were absent from many sites across the range of Ltr.Depth, horned lark abundance tended to decrease with increasing litter depth with this relationship being fairly consistent between the two years (Fig. 11).

Table 8. Model-selection results for models relating upland sandpiper abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod7	Year + Percent.Grass	4	214.4	0.0	0.54234	0.59730	0.10
mod10	Year + Year * Percent.Grass + Year * Roads	7	216.1	1.7	0.22655	0.58448	0.11
mod8	Year + Percent.Grass + Year * Percent.Grass	5	216.5	2.1	0.18558	0.59718	0.09
mod9	Year + Year * Percent.Grass + Year * Wells	7	220.5	6.2	0.02500	0.59589	0.08
mod5	Year + Roads	4	223.9	9.6	0.00456	0.62287	0.02
mod2	Year	3	224.1	9.7	0.00420	0.62922	0.01
mod1	Null	2	224.2	9.9	0.00393	0.63544	0.00
mod3	Year + Wells	4	224.4	10.0	0.00362	0.62413	0.02
mod6	Year + Roads + Year * Roads	5	225.6	11.2	0.00200	0.62141	0.02
mod4	Year + Wells + Year * Wells	5	226.2	11.8	0.00145	0.62315	0.01
mod11	Year + Year * Roads + Year * Wells	7	227.5	13.1	0.00077	0.61440	0.02
Best landscape model plus site-specific models:							
mod22	Year + Percent.Grass + Percent.BG	5	207.1	0.0	0.47086	0.57302	0.16
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	207.7	0.6	0.35714	0.56882	0.17
mod18	Year + Percent.Grass + Percent.AGCR	5	210.8	3.7	0.07531	0.58230	0.14
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	212.7	5.6	0.02936	0.58142	0.13
mod24	Year + Percent.Grass + Percent.Litter	5	213.8	6.7	0.01662	0.59007	0.11
mod7	Year + Percent.Grass	4	214.4	7.3	0.01240	0.59730	0.10
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	215.8	8.6	0.00626	0.58935	0.11
mod14	Year + Percent.Grass + Slope	5	216.2	9.1	0.00504	0.59628	0.10
mod26	Year + Percent.Grass + Ltr.Depth	5	216.3	9.1	0.00486	0.59647	0.09
mod12	Year + Percent.Grass + AvVOR	5	216.3	9.2	0.00467	0.59668	0.09
mod20	Year + Percent.Grass + Percent.POPR	5	216.5	9.4	0.00421	0.59722	0.09
mod16	Year + Percent.Grass + FQI	5	216.6	9.5	0.00416	0.59729	0.09
mod15	Year + Percent.Grass + Slope + Year * Slope	6	217.8	10.6	0.00230	0.59457	0.09
mod17	Year + Percent.Grass + FQI + Year * FQI	6	218.1	11.0	0.00191	0.59553	0.09
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	218.3	11.2	0.00174	0.59603	0.09
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	218.5	11.4	0.00160	0.59644	0.09
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	218.5	11.4	0.00157	0.59654	0.09

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

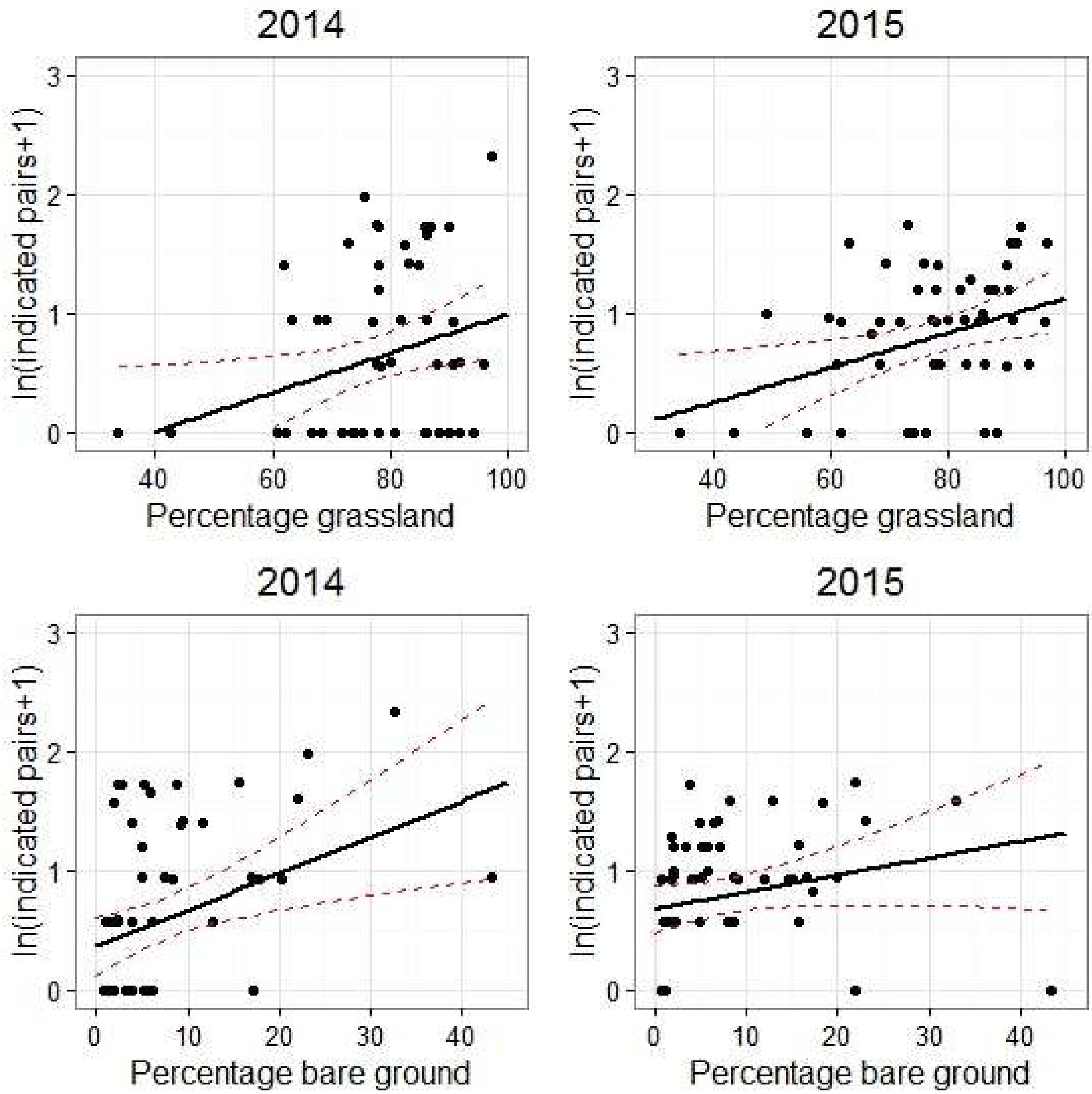

Figure 10. Model results showing relationship (black line with red-dashed 95% confidence intervals) between upland sandpiper abundance and percentage grassland and bare ground.

Table 9. Model-selection results for models relating horned lark abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod2	Year	3	285.5	0.0	0.22260	0.82353	0.01
mod1	Null	2	285.5	0.1	0.21655	0.83138	0.00
mod5	Year + Roads	4	286.5	1.0	0.13608	0.81933	0.01
mod3	Year + Wells	4	286.5	1.0	0.13538	0.81937	0.01
mod7	Year + Percent.Grass	4	287.4	1.9	0.08525	0.82270	0.00
mod6	Year + Roads + Year * Roads	5	287.5	2.1	0.07873	0.81541	0.01
mod4	Year + Wells + Year * Wells	5	288.5	3.1	0.04830	0.81891	0.00
mod8	Year + Percent.Grass + Year * Percent.Grass	5	288.9	3.5	0.03952	0.82035	0.00
mod11	Year + Year * Roads + Year * Wells	7	290.6	5.2	0.01681	0.81037	0.01
mod10	Year + Year * Percent.Grass + Year * Roads	7	291.4	6.0	0.01121	0.81326	0.00
mod9	Year + Year * Percent.Grass + Year * Wells	7	291.8	6.3	0.00957	0.81439	0.00
Best landscape model plus site-specific models:							
mod26	Year + Ltr.Depth	4	246.7	0.0	0.69716	0.68821	0.30
mod27	Year + Ltr.Depth + Year * Ltr.Depth	5	248.6	1.9	0.26844	0.68736	0.30
mod13	Year + AvVOR + Year * AvVOR	5	253.8	7.1	0.02010	0.70317	0.27
mod12	Year + AvVOR	4	254.5	7.8	0.01430	0.71207	0.25
mod24	Year + Percent.Litter	4	278.8	32.1	0.00000	0.79222	0.08
mod25	Year + Percent.Litter + Year * Percent.Litter	5	280.7	34.0	0.00000	0.79132	0.07
mod14	Year + Slope	4	281.9	35.3	0.00000	0.80329	0.05
mod15	Year + Slope + Year * Slope	5	283.0	36.3	0.00000	0.79936	0.05
mod2	Year	3	285.5	38.8	0.00000	0.82353	0.01
mod22	Year + Percent.BG	4	285.6	38.9	0.00000	0.81628	0.02
mod18	Year + Percent.AGCR	4	285.6	38.9	0.00000	0.81636	0.02
mod20	Year + Percent.POPR	4	286.5	39.8	0.00000	0.81953	0.01
mod23	Year + Percent.BG + Year * Percent.BG	5	287.2	40.5	0.00000	0.81402	0.02
mod16	Year + FQI	4	287.5	40.8	0.00000	0.82307	0.00
mod19	Year + Percent.AGCR + Year * Percent.AGCR	5	287.7	41.0	0.00000	0.81578	0.01
mod21	Year + Percent.POPR + Year * Percent.POPR	5	288.5	41.8	0.00000	0.81889	0.00
mod17	Year + FQI + Year * FQI	5	288.9	42.2	0.00000	0.82013	0.00

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

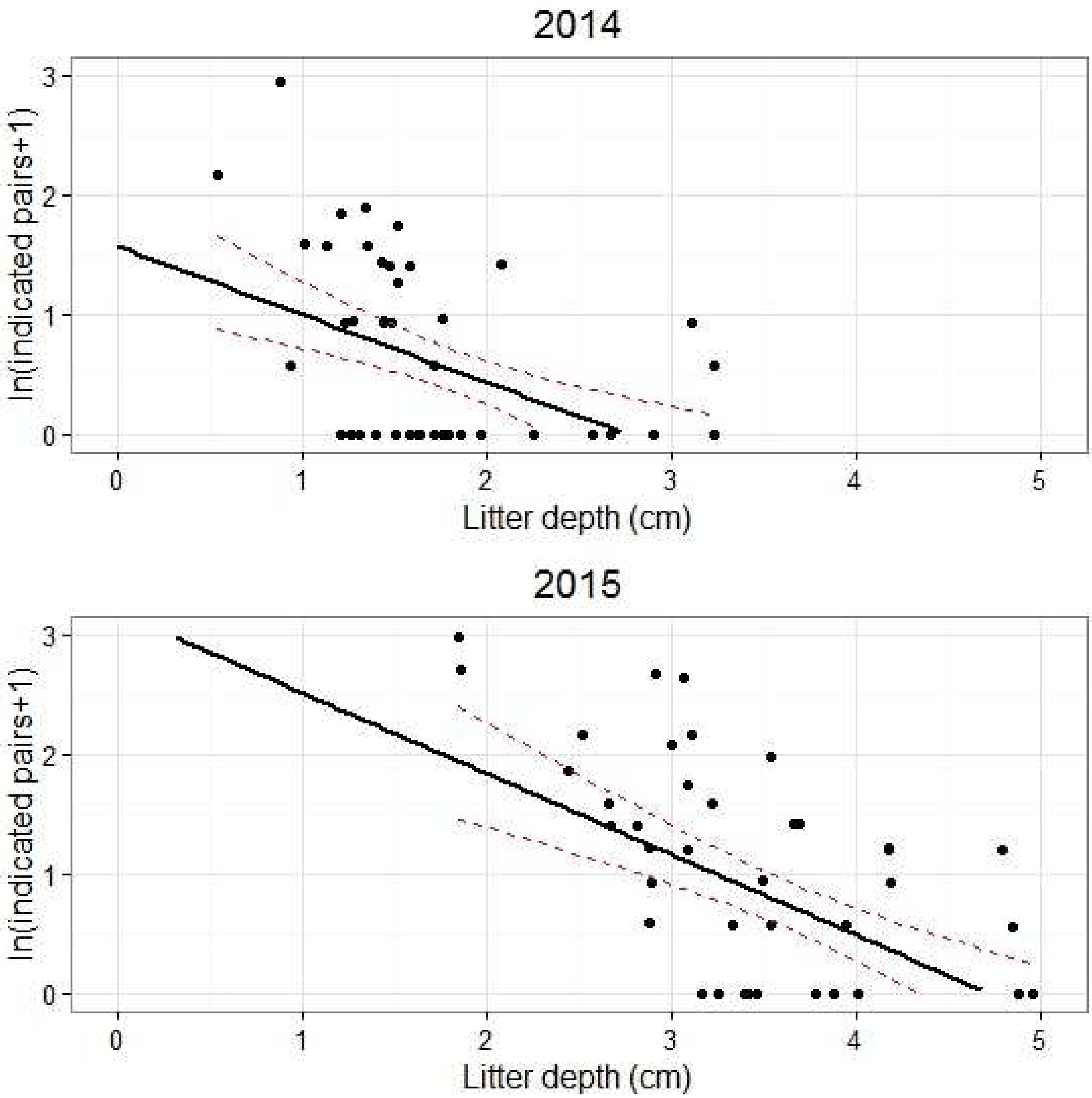

Figure 11. Model results showing relationship (black line with red-dashed 95% confidence intervals) between horned lark abundance and litter depth.

2.4.2.5. Sprague's pipit

For the Sprague's pipit, the best supported and most parsimonious landscape model, based on Δ_i and ω_i, included Year and Roads ($R^2 = 0.13$), indicating that Sprague's pipit abundance is weakly associated with roads and that this association is consistent between the two years (Table 10). There is some evidence ($\omega_i = 0.22$, Adj. $R^2 = 0.12$) that Sprague's pipit densities are associated with the interaction between Year and Roads, but the landscape model with the most weight included only Year and Roads. One site-specific variable (AvVOR) improved the landscape model ($\omega_i = 0.60$, $R^2 = 0.23$). Within the range of roads and VOR sampled, Sprague's pipit abundance declines with increasing road densities and VOR. These declines were fairly consistent from year-to-year (Fig. 12).

2.4.2.6. Clay-colored sparrow

For the clay-colored sparrow, the best supported and most parsimonious landscape model included Year, the interaction between Year and Percent.Grass, and the interaction between Year and Wells. This indicated that clay-colored sparrow abundance is associated with the percentage of grassland and density of wells within 1.6 km of the study site and that this association varied between the two years (Table 11). One site-specific variable (FQI) improved the best-supported landscape model ($\omega i = 0.38$, $R^2 = 0.31$). The best site-specific model included all of the interactions from the best landscape model but did not include interactions between the site-specific variable (FQI) and Year, indicating that clay-colored sparrow densities were associated with FQI and the strength of the relationship did not vary with year. Across the range of grassland cover sampled, Clay-colored sparrow abundance decreased with increasing grassland cover, especially in 2014 (Fig. 13). Abundance also tended to increase with increasing well density and increasing FQI.

Table 10. Model-selection results for models relating Sprague's pipit abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod5	Year + Roads	4	274.1	0.0	0.67242	0.77618	0.13
mod6	Year + Roads + Year * Roads	5	276.3	2.2	0.22625	0.77614	0.12
mod10	Year + Year * Percent.Grass + Year * Roads	7	278.6	4.5	0.07252	0.76860	0.12
mod11	Year + Year * Roads + Year * Wells	7	280.6	6.4	0.02678	0.77535	0.11
mod1	Null	2	287.6	13.5	0.00078	0.83909	0.00
mod7	Year + Percent.Grass	4	288.3	14.2	0.00056	0.82593	0.01
mod2	Year	3	289.5	15.4	0.00030	0.83828	-0.01
mod8	Year + Percent.Grass + Year * Percent.Grass	5	290.4	16.3	0.00020	0.82565	0.01
mod3	Year + Wells	4	291.6	17.4	0.00011	0.83789	-0.02
mod4	Year + Wells + Year * Wells	5	293.6	19.4	0.00004	0.83717	-0.02
mod9	Year + Year * Percent.Grass + Year * Wells	7	294.5	20.4	0.00002	0.82433	-0.01
Best landscape model plus site-specific models:							
mod12	Year + Roads + AvVOR	5	261.5	0.0	0.59542	0.72728	0.23
mod13	Year + Roads + AvVOR + Year * AvVOR	6	262.9	1.4	0.28838	0.72480	0.23
mod26	Year + Roads + Ltr.Depth	5	266.8	5.3	0.04182	0.74443	0.19
mod24	Year + Roads + Percent.Litter	5	267.2	5.8	0.03349	0.74588	0.19
mod27	Year + Roads + Ltr.Depth + Year * Ltr.Depth	6	268.9	7.5	0.01418	0.74421	0.18
mod25	Year + Roads + Percent.Litter + Year * Percent.Litter	6	269.2	7.8	0.01217	0.74521	0.18
mod14	Year + Roads + Slope	5	271.3	9.8	0.00437	0.75931	0.16
mod16	Year + Roads + FQI	5	271.6	10.1	0.00383	0.76020	0.16
mod17	Year + Roads + FQI + Year * FQI	6	272.7	11.3	0.00213	0.75668	0.16
mod15	Year + Roads + Slope + Year * Slope	6	273.5	12.1	0.00144	0.75931	0.15
mod5	Year + Roads	4	274.1	12.6	0.00107	0.77618	0.13
mod18	Year + Roads + Percent.AGCR	5	275.7	14.2	0.00049	0.77406	0.13
mod22	Year + Roads + Percent.BG	5	276.1	14.7	0.00039	0.77561	0.12
mod20	Year + Roads + Percent.POPR	5	276.2	14.7	0.00038	0.77579	0.12
mod19	Year + Roads + Percent.AGCR + Year * Percent.AGCR	6	277.9	16.4	0.00017	0.77385	0.12
mod21	Year + Roads + Percent.POPR + Year * Percent.POPR	6	278.1	16.7	0.00014	0.77485	0.12
mod23	Year + Roads + Percent.BG + Year * Percent.BG	6	278.3	16.8	0.00013	0.77543	0.11

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

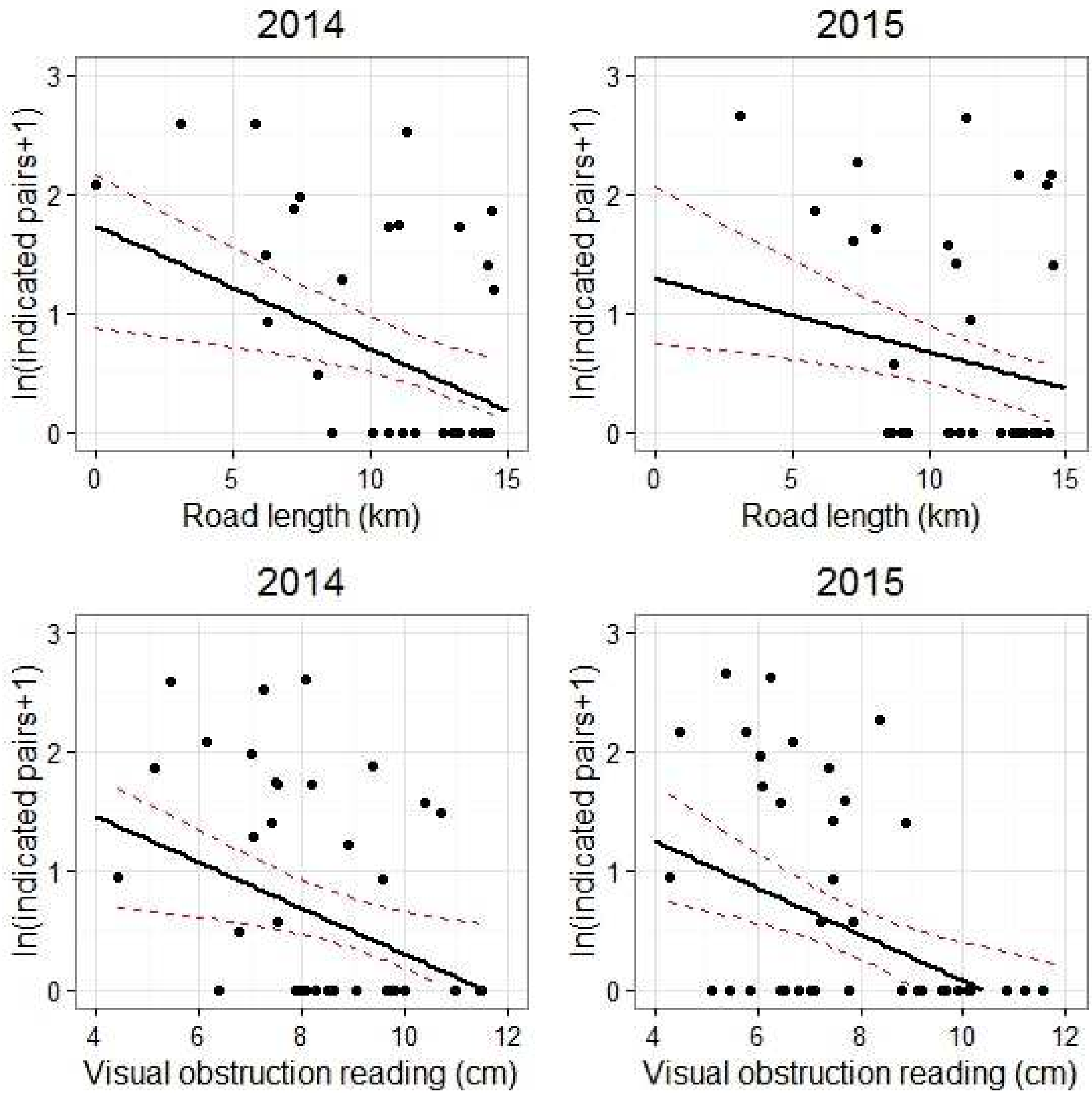

Figure 12. Model results showing relationship (black line with red-dashed 95% confidence intervals) between Sprague's pipit abundance and road length and visual obstruction reading.

Table 11. Model-selection results for models relating clay-colored sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod9	Year + Year * Percent.Grass + Year * Wells	7	272.8	0.0	0.94035	0.74942	0.25
mod7	Year + Percent.Grass	4	279.4	6.6	0.03522	0.79429	0.18
mod8	Year + Percent.Grass + Year * Percent.Grass	5	281.5	8.7	0.01201	0.79416	0.17
mod3	Year + Wells	4	282.4	9.6	0.00790	0.79334	0.16
mod4	Year + Wells + Year * Wells	5	284.5	11.7	0.00269	0.80477	0.16
mod10	Year + Year * Percent.Grass + Year * Roads	7	285.8	13.0	0.00142	0.80465	0.15
mod11	Year + Year * Roads + Year * Wells	7	288.4	15.5	0.00040	0.80230	0.14
mod1	Null	2	299.7	26.9	0.00000	0.88465	0.00
mod2	Year	3	301.8	29.0	0.00000	0.88465	-0.01
mod5	Year + Roads	4	303.0	30.1	0.00000	0.88083	-0.01
mod6	Year + Roads + Year * Roads	5	305.1	32.3	0.00000	0.88080	-0.02
Best landscape model plus site-specific models:							
mod16	Year + Year * Percent.Grass + Year * Wells + FQI	8	264.3	0.0	0.38695	0.71460	0.31
mod26	Year + Year * Percent.Grass + Year * Wells + Ltr.Depth	8	265.8	1.5	0.18401	0.71928	0.30
mod17	Year + Year * Percent.Grass + Year * Wells + FQI + Year * FQI	9	266.6	2.3	0.12021	0.71454	0.30
mod27	Year + Year * Percent.Grass + Year * Wells + Ltr.Depth + Year * Ltr.Depth	9	266.6	2.4	0.11883	0.71461	0.30
mod12	Year + Year * Percent.Grass + Year * Wells + AvVOR	8	267.2	2.9	0.09125	0.72372	0.29
mod18	Year + Year * Percent.Grass + Year * Wells + Percent.AGCR	8	269.0	4.8	0.03563	0.72971	0.28
mod13	Year + Year * Percent.Grass + Year * Wells + AvVOR + Year * AvVOR	9	269.3	5.1	0.03092	0.72310	0.29
mod19	Year + Year * Percent.Grass + Year * Wells + Percent.AGCR + Year * Percent.AGCR	9	271.0	6.8	0.01322	0.72851	0.28
mod9	Year + Year * Percent.Grass + Year * Wells	7	272.8	8.5	0.00544	0.74942	0.25
mod20	Year + Year * Percent.Grass + Year * Wells + Percent.POPR	8	273.4	9.1	0.00409	0.74371	0.25
mod22	Year + Year * Percent.Grass + Year * Wells + Percent.BG	8	274.7	10.4	0.00212	0.74800	0.24
mod14	Year + Year * Percent.Grass + Year * Wells + Slope	8	274.9	10.7	0.00186	0.74884	0.24
mod24	Year + Year * Percent.Grass + Year * Wells + Percent.Litter	8	275.0	10.8	0.00178	0.74916	0.24
mod21	Year + Year * Percent.Grass + Year * Wells + Percent.POPR + Year * Percent.POPR	9	275.6	11.4	0.00133	0.74335	0.25
mod25	Year + Year * Percent.Grass + Year * Wells + Percent.Litter + Year * Percent.Litter	9	276.5	12.2	0.00088	0.74606	0.24
mod15	Year + Year * Percent.Grass + Year * Wells + Slope + Year * Slope	9	276.7	12.4	0.00079	0.74677	0.24
mod23	Year + Year * Percent.Grass + Year * Wells + Percent.BG + Year * Percent.BG	9	276.9	12.6	0.00072	0.74737	0.24

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

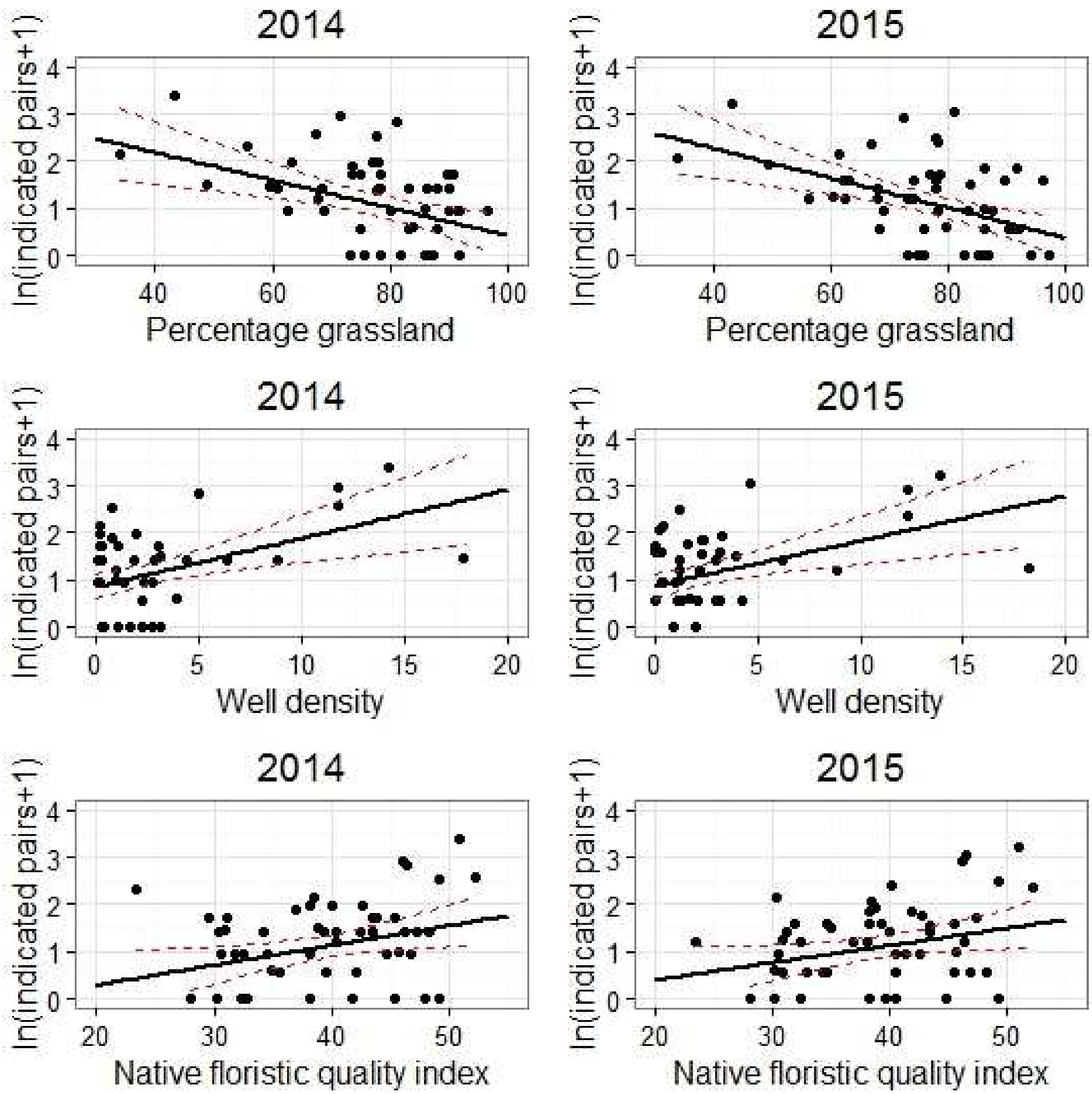

Figure 13. Model results showing relationship (black line with red-dashed 95% confidence intervals) between clay-colored sparrow abundance and percentage grassland, well density, and FQI.

2.4.2.7. Field sparrow

The best supported and most parsimonious landscape model, albeit weak ($\omega_i = 0.63$, $R^2 = 0.07$), for field sparrow abundance included Year and Percent.Grass (Table 12). One site-specific variable (Percent.AGCR) improved the best-supported landscape model ($\omega_i = 0.66$). However, the final model only explained 16% of variation in field sparrow abundance. The best site-specific model did not include any interactions with year, and thus the relationship between field sparrow abundance and the explanatory variables did not vary with year. Although many sites had zero abundance across the range of Percent.Grass and Percent.AGCR, field sparrow abundance tended to decline with increasing percentage of grassland in the surrounding landscape and the percentage of crested wheatgrass at the site level (Fig. 14).

2.4.2.8. Vesper sparrow

The best supported and most parsimonious landscape model for the vesper sparrow based on Δ_i and ω_i, included Year and Wells ($R^2 = 0.07$), indicating that vesper sparrow abundance is weakly associated with the density of wells within 1.6 km of the study site and that this association is fairly consistent between the two years (Table 13). One site-specific variable (FQI) improved the best-supported landscape model ($\omega_i = 0.24$, $R^2 = 0.17$). There also is evidence that the association between vesper sparrow abundance and FQI varies from year-to-year ($\omega_i = 0.22$, Adj. $R^2 = 0.18$); however, the best model based on Δ_i does not include this interaction. Although many sites had zero abundance across the range of Wells and FQI, vesper sparrow abundance tended to decrease with increasing oil well density in the surrounding landscape and FQI at the site level, with some tendency for the relationship to be stronger in 2015 (Fig. 15).

Table 12. Model-selection results for models relating field sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod7	Year + Percent.Grass	4	284.0	0.0	0.63184	0.81044	0.07
mod8	Year + Percent.Grass + Year * Percent.Grass	5	285.9	1.9	0.23980	0.80955	0.06
mod10	Year + Year * Percent.Grass + Year * Roads	7	289.7	5.7	0.03566	0.80710	0.05
mod9	Year + Year * Percent.Grass + Year * Wells	7	289.9	5.9	0.03266	0.80773	0.05
mod1	Null	2	290.2	6.2	0.02856	0.84846	0.00
mod2	Year	3	291.9	8.0	0.01180	0.84718	-0.01
mod5	Year + Roads	4	292.8	8.8	0.00766	0.84243	0.00
mod3	Year + Wells	4	293.3	9.3	0.00602	0.84421	-0.01
mod4	Year + Wells + Year * Wells	5	294.8	10.9	0.00277	0.84211	-0.01
mod6	Year + Roads + Year * Roads	5	294.9	10.9	0.00268	0.84185	-0.01
mod11	Year + Year * Roads + Year * Wells	7	298.1	14.1	0.00055	0.83724	-0.02
Best landscape model plus site-specific models:							
mod18	Year + Percent.Grass + Percent.AGCR	5	273.2	0.0	0.66040	0.76560	0.16
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	275.1	1.9	0.24948	0.76465	0.16
mod14	Year + Percent.Grass + Slope	5	278.7	5.6	0.04072	0.78454	0.12
mod15	Year + Percent.Grass + Slope + Year * Slope	6	280.9	7.8	0.01360	0.78442	0.11
mod16	Year + Percent.Grass + FQI	5	281.5	8.3	0.01023	0.79411	0.10
mod12	Year + Percent.Grass + AvVOR	5	283.0	9.9	0.00478	0.79943	0.09
mod20	Year + Percent.Grass + Percent.POPR	5	283.4	10.2	0.00398	0.80071	0.09
mod17	Year + Percent.Grass + FQI + Year * FQI	6	283.5	10.3	0.00374	0.79336	0.09
mod7	Year + Percent.Grass	4	284.0	10.8	0.00300	0.81044	0.07
mod26	Year + Percent.Grass + Ltr.Depth	5	284.1	11.0	0.00276	0.80329	0.08
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	285.2	12.0	0.00164	0.79911	0.08
mod22	Year + Percent.Grass + Percent.BG	5	285.4	12.2	0.00146	0.80779	0.07
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	285.6	12.4	0.00133	0.80057	0.08
mod24	Year + Percent.Grass + Percent.Litter	5	286.1	12.9	0.00104	0.81020	0.06
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	286.2	13.0	0.00099	0.80268	0.07
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	287.5	14.3	0.00051	0.80730	0.06
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	288.3	15.1	0.00034	0.81013	0.05

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

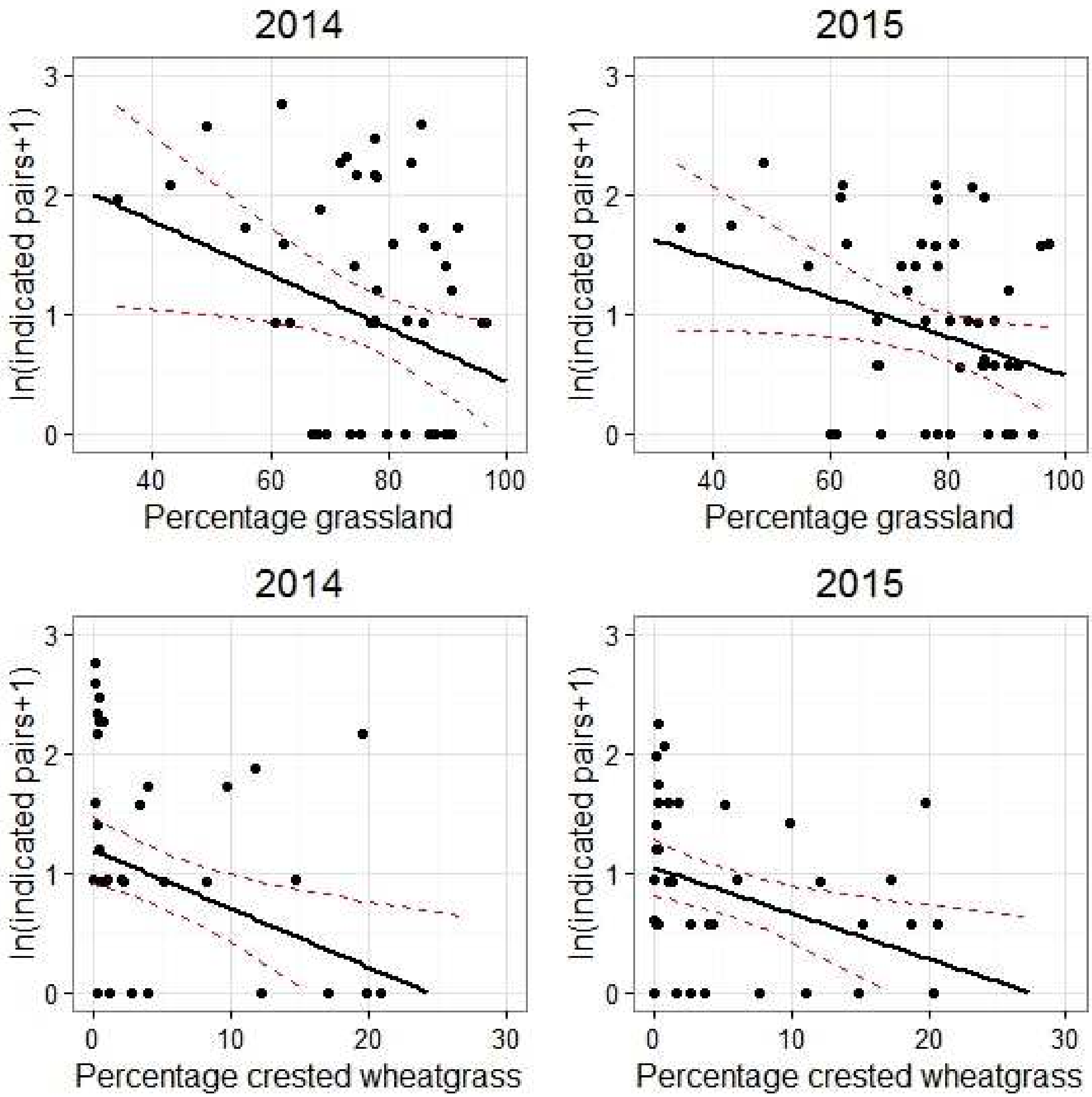

Figure 14. Model results showing relationship (black line with red-dashed 95% confidence intervals) between field sparrow abundance and percentage grassland and crested wheatgrass.

Table 13. Model-selection results for models relating vesper sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
	Landscape models:						
mod3	Year + Wells	4	222.9	0.0	0.33684	0.62003	0.07
mod4	Year + Wells + Year * Wells	5	223.5	0.6	0.24861	0.61575	0.08
mod2	Year	3	225.3	2.4	0.10332	0.63242	0.04
mod7	Year + Percent.Grass	4	225.4	2.5	0.09527	0.62694	0.05
mod5	Year + Roads	4	226.4	3.4	0.06006	0.62948	0.04
mod11	Year + Year * Roads + Year * Wells	7	227.0	4.1	0.04248	0.62661	0.04
mod9	Year + Year * Percent.Grass + Year * Wells	7	227.3	4.4	0.03697	0.61314	0.07
mod8	Year + Percent.Grass + Year * Percent.Grass	5	227.5	4.6	0.03385	0.61389	0.06
mod6	Year + Roads + Year * Roads	5	228.4	5.5	0.02148	0.62911	0.03
mod1	Null	2	229.0	6.1	0.01562	0.64897	0.00
mod10	Year + Year * Percent.Grass + Year * Roads	7	231.1	8.2	0.00551	0.62422	0.03
	Best landscape model plus site-specific models:						
mod16	Year + Wells + FQI	5	210.5	0.0	0.24085	0.58160	0.17
mod17	Year + Wells + FQI + Year * FQI	6	210.7	0.1	0.22352	0.57632	0.18
mod14	Year + Wells + Slope	5	210.7	0.2	0.22072	0.58205	0.17
mod19	Year + Wells + Percent.AGCR + Year * Percent.AGCR	6	211.0	0.5	0.18398	0.57730	0.18
mod15	Year + Wells + Slope + Year * Slope	6	212.8	2.3	0.07681	0.58174	0.17
mod18	Year + Wells + Percent.AGCR	5	213.8	3.3	0.04686	0.59001	0.15
mod24	Year + Wells + Percent.Litter	5	218.7	8.2	0.00405	0.60282	0.11
mod25	Year + Wells + Percent.Litter + Year * Percent.Litter	6	220.6	10.1	0.00156	0.60198	0.11
mod3	Year + Wells	4	222.9	12.4	0.00049	0.62003	0.07
mod12	Year + Wells + AvVOR	5	224.1	13.6	0.00026	0.61743	0.07
mod26	Year + Wells + Ltr.Depth	5	224.8	14.3	0.00019	0.61929	0.06
mod22	Year + Wells + Percent.BG	5	224.9	14.4	0.00018	0.61960	0.06
mod20	Year + Wells + Percent.POPR	5	225.1	14.6	0.00017	0.61995	0.06
mod21	Year + Wells + Percent.POPR + Year * Percent.POPR	6	225.4	14.9	0.00014	0.61480	0.07
mod13	Year + Wells + AvVOR + Year * AvVOR	6	226.0	15.5	0.00011	0.61638	0.06
mod27	Year + Wells + Ltr.Depth + Year * Ltr.Depth	6	227.0	16.5	0.00006	0.61907	0.06
mod23	Year + Wells + Percent.BG + Year * Percent.BG	6	227.2	16.7	0.00006	0.61959	0.06

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

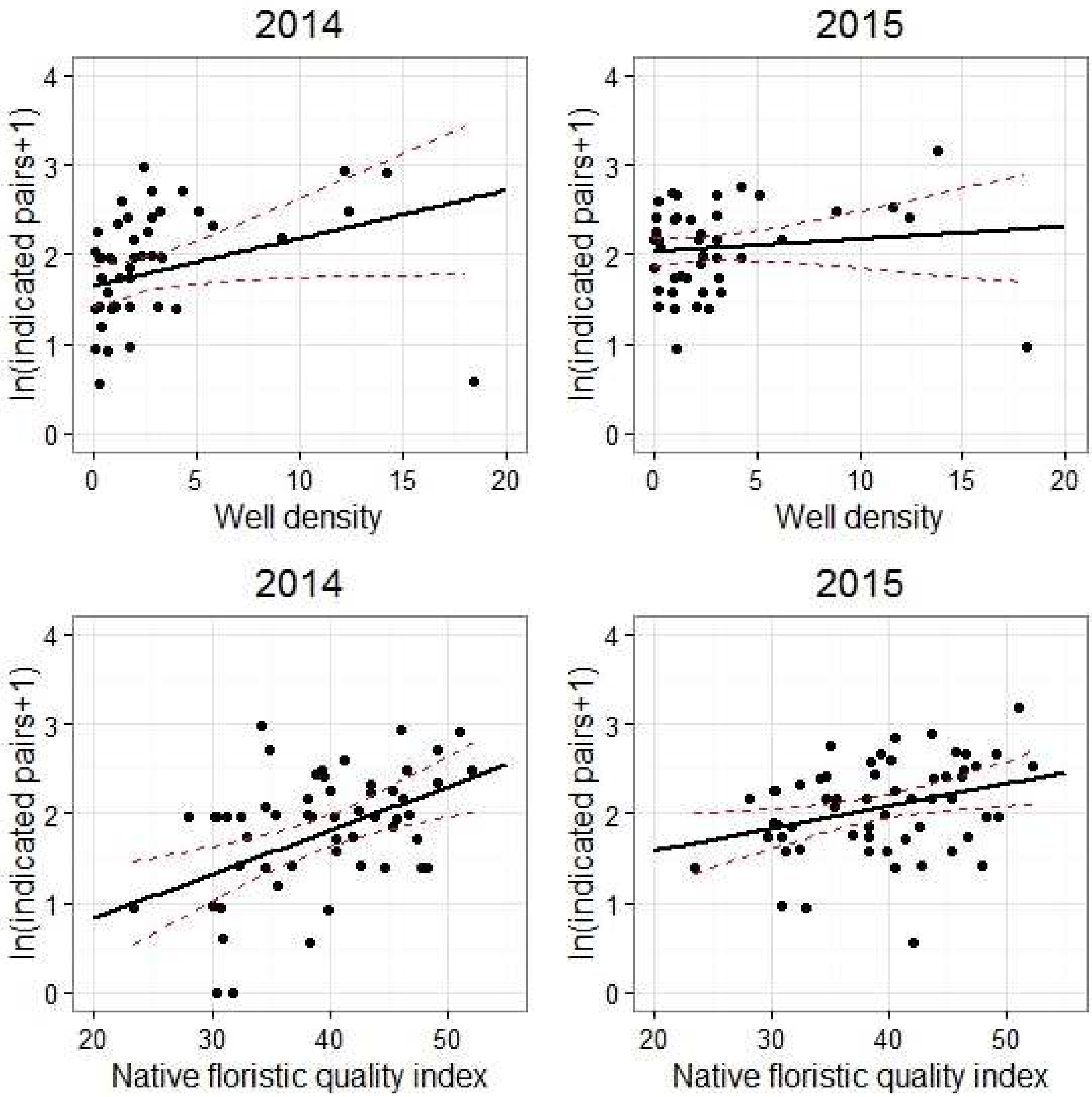

Figure 15. Model results showing relationship (black line with red-dashed 95% confidence intervals) between vesper sparrow abundance and well density and FQI.

2.4.2.9. Grasshopper sparrow

Grasshopper sparrow densities were not associated with any of the landscape variables (i.e., none of the landscape-level models was better than the null model; Table 14). The best site-specific model included Year and Slope ($\omega_i = 0.67$, Adj. $R^2 = 0.07$). Grasshopper sparrow densities tended to decline with increasing Slope; this relationship was consistent between the two years but variation in abundance was slightly greater in 2014 (Fig. 16).

2.4.2.10. Baird's sparrow

For the Baird's sparrow, the best supported and most parsimonious landscape model, based on Δ_i and ω_i, included Year and Roads ($R^2 = 0.10$), indicating that Baird's sparrow abundance is weakly associated with roads and that this association is consistent between the two years (Table 15). However, there is some evidence ($\omega_i = 0.31$, Adj. $R^2 = 0.12$) that Baird's sparrow densities are associated with Percent.Grass and the interaction between Year and Percent.Grass (i.e., the percentage of grassland within 1.6 km of the sample-unit) and Year and Roads, but the landscape model with the most weight included only Year and Roads. One site-specific variable (Slope) improved the best-supported landscape model ($\omega_i = 0.75$). The best site-specific model did not include interactions between Slope and Year, indicating that Baird's sparrow densities were associated with Roads and Slope but the direction and strength of the relationship did not vary with year. The final model explained 27% of the variation in Baird's sparrow abundance. Although many sites had zero abundance across the range of Roads and Slope, Baird's sparrow abundance tended to decline with increasing road density and increasing slope (Fig. 17).

Table 14. Model-selection results for models relating grasshopper sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod1	Null	2	113.5	0.0	0.49800	0.39101	0.00
mod2	Year	3	115.6	2.1	0.17694	0.39094	-0.01
mod5	Year + Roads	4	117.2	3.7	0.08002	0.38997	-0.01
mod3	Year + Wells	4	117.5	4.0	0.06749	0.39056	-0.02
mod7	Year + Percent.Grass	4	117.7	4.2	0.06162	0.39087	-0.02
mod6	Year + Roads + Year * Roads	5	118.7	5.2	0.03717	0.38886	-0.02
mod4	Year + Wells + Year * Wells	5	118.9	5.4	0.03358	0.38969	-0.02
mod8	Year + Percent.Grass + Year * Percent.Grass	5	119.2	5.7	0.02915	0.38920	-0.02
mod11	Year + Year * Roads + Year * Wells	7	122.2	8.7	0.00642	0.38717	-0.03
mod10	Year + Year * Percent.Grass + Year * Roads	7	122.6	9.1	0.00538	0.38777	-0.03
mod9	Year + Year * Percent.Grass + Year * Wells	7	123.1	9.5	0.00423	0.38860	-0.03
Best landscape model plus site-specific models:							
mod14	Year + Slope	4	107.4	0.0	0.67240	0.37353	0.07
mod15	Year + Slope + Year * Slope	5	109.5	2.2	0.22520	0.37353	0.06
mod1	Null	2	113.5	6.2	0.03080	0.39101	0.00
mod22	Year + Percent.BG	4	115.3	7.9	0.01276	0.38675	0.00
mod26	Year + Ltr.Depth	4	115.7	8.3	0.01036	0.38746	0.00
mod18	Year + Percent.AGCR	4	116.5	9.1	0.00707	0.38876	-0.01
mod20	Year + Percent.POPR	4	116.7	9.3	0.00628	0.38916	-0.01
mod16	Year + FQI	4	116.7	9.4	0.00616	0.38922	-0.01
mod12	Year + AvVOR	4	117.0	9.6	0.00556	0.38958	-0.01
mod23	Year + Percent.BG + Year * Percent.BG	5	117.1	9.8	0.00512	0.38614	0.00
mod24	Year + Percent.Litter	4	117.6	10.2	0.00412	0.39061	-0.02
mod27	Year + Ltr.Depth + Year * Ltr.Depth	5	117.7	10.4	0.00373	0.38721	-0.01
mod21	Year + Percent.POPR + Year * Percent.POPR	5	118.5	11.2	0.00253	0.38853	-0.01
mod19	Year + Percent.AGCR + Year * Percent.AGCR	5	118.7	11.3	0.00237	0.38875	-0.02
mod17	Year + FQI + Year * FQI	5	118.9	11.5	0.00214	0.38910	-0.02
mod13	Year + AvVOR + Year * AvVOR	5	119.0	11.6	0.00200	0.38933	-0.02
mod25	Year + Percent.Litter + Year * Percent.Litter	5	119.7	12.4	0.00140	0.39055	-0.02

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

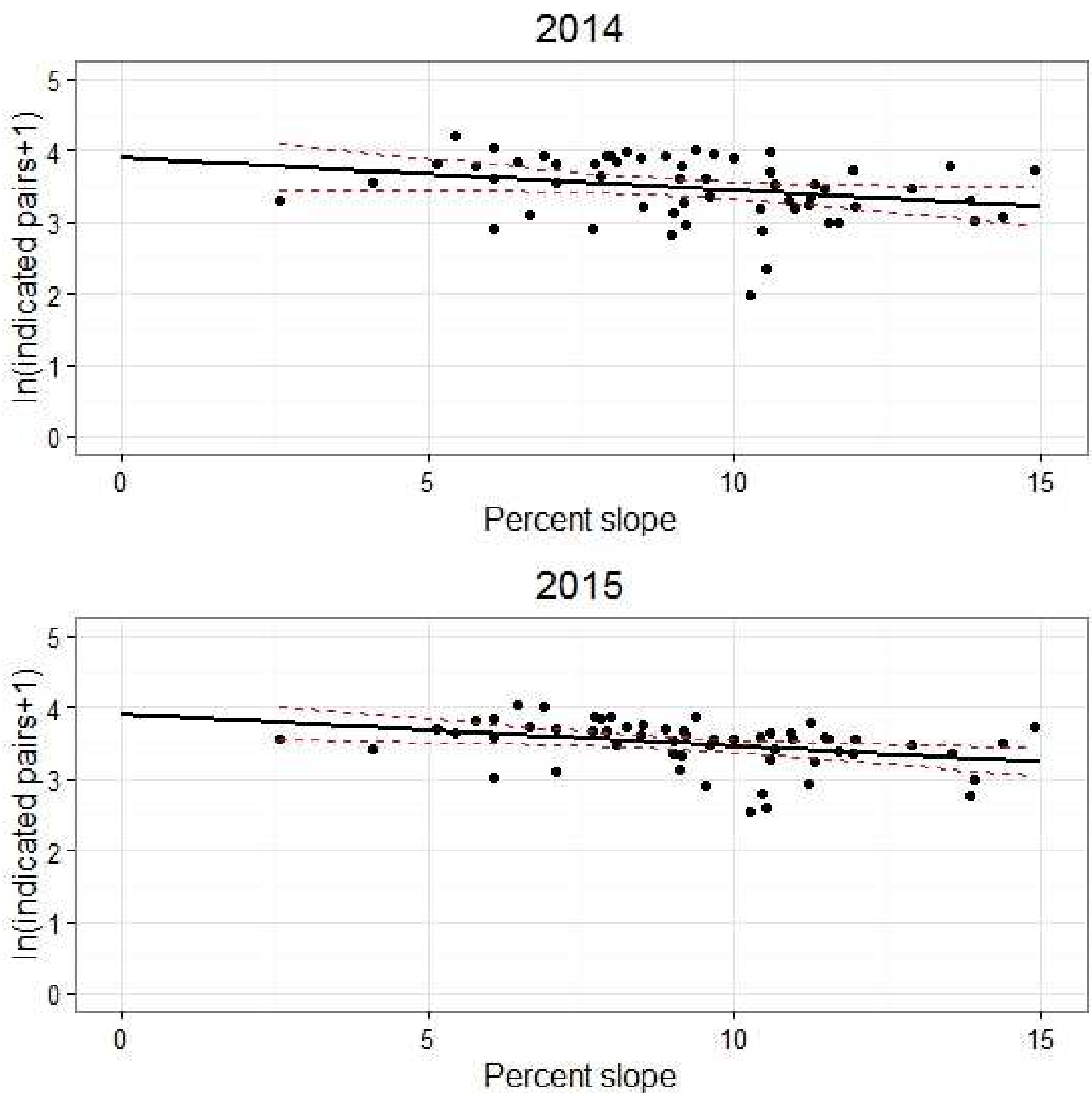

Figure 16. Model results showing relationship (black line with red-dashed 95% confidence intervals) between grasshopper sparrow abundance and slope.

Table 15. Model-selection results for models relating Baird's sparrow sparrow abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
	Landscape models:						
mod5	Year + Roads	4	259.4	0.0	0.41658	0.72754	0.10
mod10	Year + Year * Percent.Grass + Year * Roads	7	259.9	0.6	0.31183	0.70830	0.12
mod6	Year + Roads + Year * Roads	5	260.9	1.5	0.19606	0.72537	0.10
mod11	Year + Year * Roads + Year * Wells	7	263.2	3.9	0.05961	0.71866	0.10
mod7	Year + Percent.Grass	4	267.9	8.5	0.00584	0.75529	0.03
mod8	Year + Percent.Grass + Year * Percent.Grass	5	268.6	9.3	0.00405	0.75048	0.04
mod1	Null	2	269.3	10.0	0.00288	0.77432	0.00
mod2	Year	3	271.1	11.8	0.00116	0.77333	-0.01
mod3	Year + Wells	4	271.6	12.2	0.00092	0.76761	0.00
mod9	Year + Year * Percent.Grass + Year * Wells	7	272.4	13.0	0.00061	0.74810	0.02
mod4	Year + Wells + Year * Wells	5	273.0	13.7	0.00045	0.76510	0.00
	Best landscape model plus site-specific models:						
mod14	Year + Roads + Slope	5	236.4	0	0.74962	0.65147	0.27
mod15	Year + Roads + Slope + Year * Slope	6	238.6	2.2	0.25023	0.65137	0.27
mod12	Year + Roads + AvVOR	5	255.5	19.1	0.00005	0.70846	0.14
mod26	Year + Roads + Ltr.Depth	5	257.2	20.9	0.00002	0.71392	0.13
mod24	Year + Roads + Percent.Litter	5	257.5	21.2	0.00002	0.71488	0.12
mod13	Year + Roads + AvVOR + Year * AvVOR	6	257.7	21.3	0.00002	0.70836	0.13
mod5	Year + Roads	4	259.4	23	0.00001	0.72754	0.10
mod27	Year + Roads + Ltr.Depth + Year * Ltr.Depth	6	259.5	23.1	0.00001	0.71389	0.12
mod25	Year + Roads + Percent.Litter + Year * Percent.Litter	6	259.7	23.3	0.00001	0.71468	0.12
mod20	Year + Roads + Percent.POPR	5	260.4	24.1	0.00000	0.72401	0.10
mod16	Year + Roads + FQI	5	260.5	24.1	0.00000	0.72410	0.10
mod22	Year + Roads + Percent.BG	5	260.6	24.2	0.00000	0.72446	0.10
mod18	Year + Roads + Percent.AGCR	5	261.5	25.1	0.00000	0.72733	0.09
mod23	Year + Roads + Percent.BG + Year * Percent.BG	6	262.1	25.8	0.00000	0.72227	0.10
mod17	Year + Roads + FQI + Year * FQI	6	262.6	26.2	0.00000	0.72382	0.09
mod21	Year + Roads + Percent.POPR + Year * Percent.POPR	6	262.7	26.3	0.00000	0.72397	0.09
mod19	Year + Roads + Percent.AGCR + Year * Percent.AGCR	6	263.3	26.9	0.00000	0.72592	0.09

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

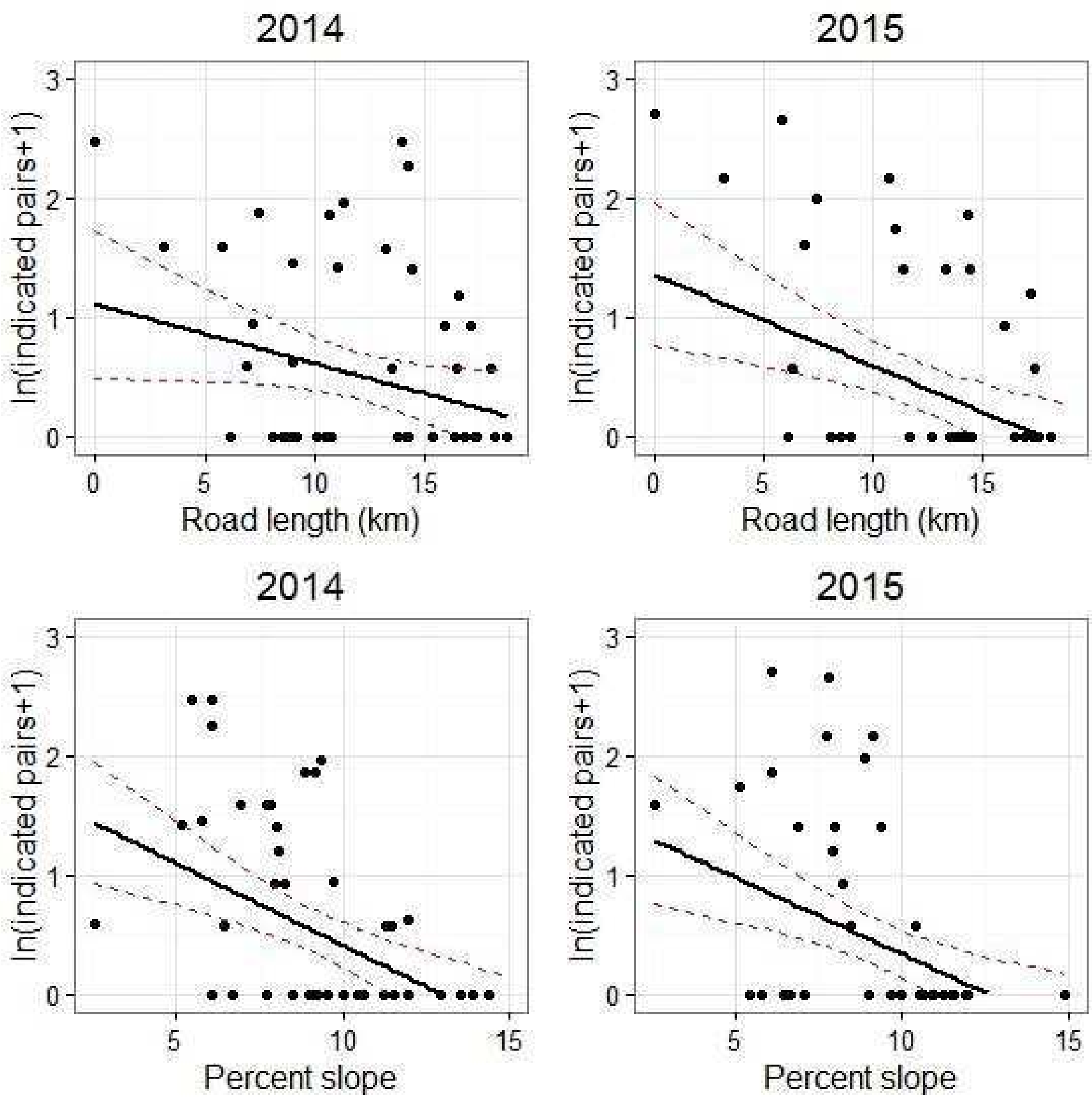

Figure 17. Model results showing relationship (black line with red-dashed 95% confidence intervals) between Baird's sparrow abundance and road length and slope.

2.4.2.11. Chestnut-collared longspur

For the chestnut-collared longspur, the best supported and most parsimonious landscape model, based on Δ_i and ω_i, included Year and Percent.Grass ($R^2 = 0.09$), indicating that longspur abundance is weakly associated with the percentage of grassland in the surrounding landscape (i.e., within 1.6 km of the study unit boundary) and that this association is consistent between the two years (Table 16). There is some evidence ($\omega_i = 0.20$, Adj. $R^2 = 0.10$) that chestnut-collared longspur densities are associated with Year and the interactions between Year and Percent.Grass and Year and Roads, but the landscape model with the most weight included only Year and Percent.Grass. One site-specific variable (AvVOR) improved the best-supported landscape model ($\omega_i = 0.41$). The best site-specific model did not include interactions between AvVOR and Year, indicating that chestnut-collared longspur densities were associated with Percent.Grass and AvVOR but the direction and strength of the relationship did not vary with year. The final model explained 22% of the variation in chestnut-collared longspur abundance. Although the chestnut-collared longspur was the least common of the 12 focal species, its abundance tended to increase with increasing grassland coverage around the site and decreased with increasing VOR (Fig. 18).

2.4.2.12. Bobolink

Bobolink densities were not associated with any of the landscape variables (i.e., none of the landscape-level models was better than the null model; Table 17). The best supported model using site-specific variables included Year and Slope. Bobolink densities tended to decline with increasing Slope (Adj. $R^2 = 0.22$); this relationship was consistent between the two years (Fig. 19).

Table 16. Model-selection results for models relating chestnut-collared longspur abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
			Landscape models:				
mod7	Year + Percent.Grass	4	284.8	0.0	0.52391	0.81324	0.09
mod10	Year + Year * Percent.Grass + Year * Roads	7	286.7	1.9	0.19981	0.79644	0.10
mod8	Year + Percent.Grass + Year * Percent.Grass	5	286.7	2.0	0.19664	0.81243	0.08
mod5	Year + Roads	4	290.7	5.9	0.02741	0.83457	0.04
mod9	Year + Year * Percent.Grass + Year * Wells	7	290.9	6.2	0.02387	0.81142	0.07
mod6	Year + Roads + Year * Roads	5	292.8	8.1	0.00919	0.83455	0.03
mod1	Null	2	293.4	8.6	0.00709	0.86045	0.00
mod2	Year	3	294.4	9.6	0.00426	0.85635	0.00
mod3	Year + Wells	4	294.5	9.7	0.00408	0.84863	0.01
mod11	Year + Year * Roads + Year * Wells	7	295.5	10.8	0.00237	0.82802	0.03
mod4	Year + Wells + Year * Wells	5	296.6	11.9	0.00137	0.84859	0.00
			Best landscape model plus site-specific models:				
mod12	Year + Percent.Grass + AvVOR	5	268.0	0.0	0.41321	0.74831	0.22
mod26	Year + Percent.Grass + Ltr.Depth	5	268.7	0.7	0.28948	0.75065	0.22
mod13	Year + Percent.Grass + AvVOR + Year * AvVOR	6	269.6	1.7	0.18095	0.74641	0.22
mod27	Year + Percent.Grass + Ltr.Depth + Year * Ltr.Depth	6	270.8	2.8	0.10255	0.75014	0.21
mod14	Year + Percent.Grass + Slope	5	276.8	8.8	0.00502	0.77782	0.16
mod24	Year + Percent.Grass + Percent.Litter	5	276.9	9.0	0.00463	0.77837	0.16
mod15	Year + Percent.Grass + Slope + Year * Slope	6	278.7	10.7	0.00195	0.77668	0.16
mod25	Year + Percent.Grass + Percent.Litter + Year * Percent.Litter	6	279.1	11.1	0.00158	0.77809	0.15
mod18	Year + Percent.Grass + Percent.AGCR	5	283.2	15.2	0.00020	0.79998	0.11
mod7	Year + Percent.Grass	4	284.8	16.8	0.00009	0.81324	0.09
mod20	Year + Percent.Grass + Percent.POPR	5	284.9	16.9	0.00009	0.80590	0.10
mod19	Year + Percent.Grass + Percent.AGCR + Year * Percent.AGCR	6	285.2	17.2	0.00008	0.79913	0.11
mod16	Year + Percent.Grass + FQI	5	286.1	18.2	0.00005	0.81037	0.09
mod22	Year + Percent.Grass + Percent.BG	5	286.1	18.2	0.00005	0.81041	0.09
mod21	Year + Percent.Grass + Percent.POPR + Year * Percent.POPR	6	286.9	18.9	0.00003	0.80504	0.09
mod23	Year + Percent.Grass + Percent.BG + Year * Percent.BG	6	288.1	20.1	0.00002	0.80929	0.08
mod17	Year + Percent.Grass + FQI + Year * FQI	6	288.4	20.4	0.00002	0.81037	0.08

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

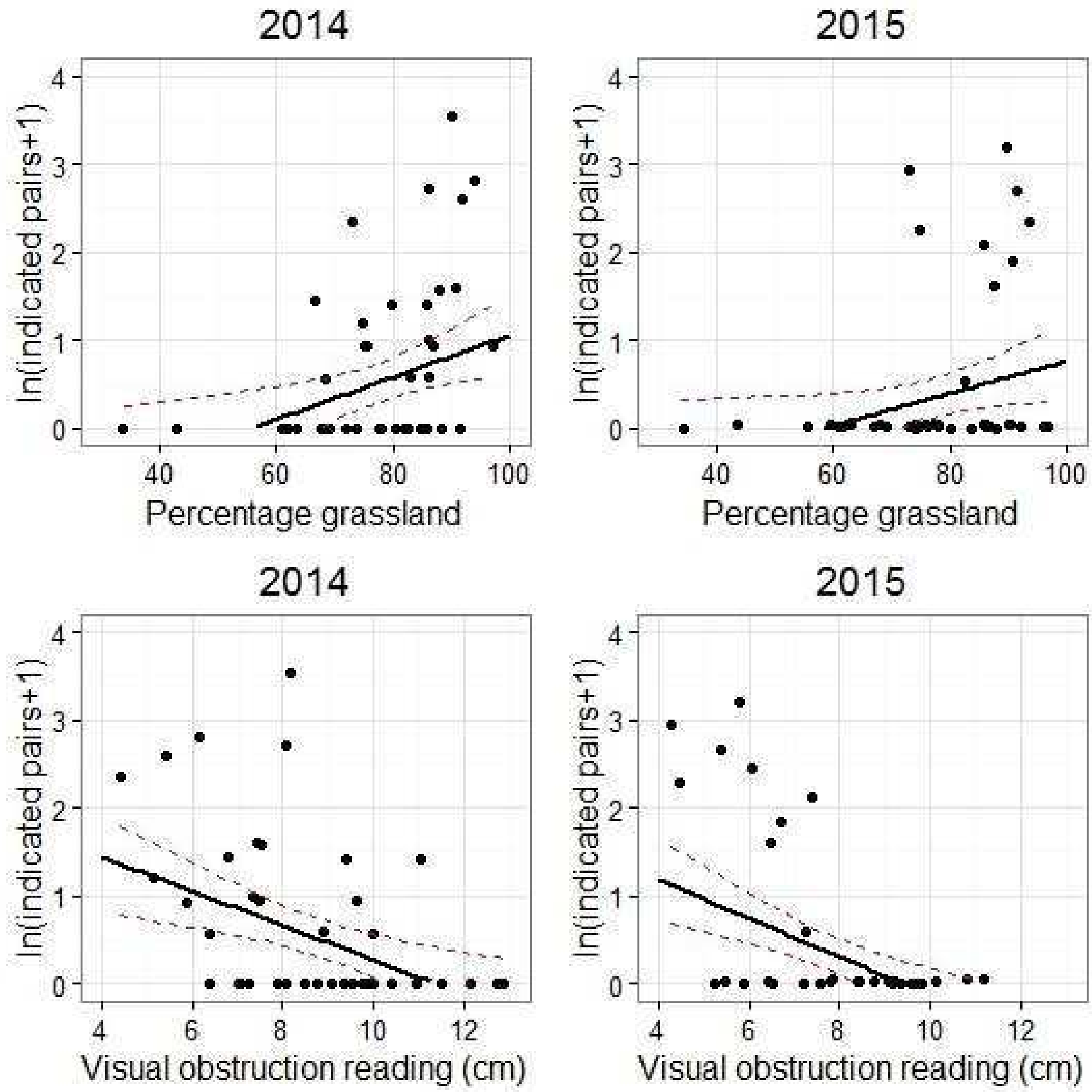

Figure 18. Model results showing relationship (black line with red-dashed 95% confidence intervals) between chestnut-collared longspur abundance and percentage grassland and visual obstruction reading.

Table 17. Model-selection results for models relating bobolink abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod1	Null	2	313.5	0.0	0.32075	0.93988	0.00
mod5	Year + Roads	4	315.0	1.5	0.15429	0.92843	0.01
mod2	Year	3	315.4	1.9	0.12176	0.93917	-0.01
mod3	Year + Wells	4	315.7	2.2	0.10865	0.93129	0.00
mod7	Year + Percent.Grass	4	315.9	2.4	0.09652	0.93225	0.00
mod6	Year + Roads + Year * Roads	5	317.1	3.7	0.05166	0.92842	0.00
mod8	Year + Percent.Grass + Year * Percent.Grass	5	317.3	3.8	0.04711	0.92918	0.00
mod4	Year + Wells + Year * Wells	5	317.8	4.4	0.03638	0.93128	-0.01
mod9	Year + Year * Percent.Grass + Year * Wells	7	318.2	4.7	0.03109	0.91434	0.01
mod11	Year + Year * Roads + Year * Wells	7	319.4	5.9	0.01676	0.91931	0.00
mod10	Year + Year * Percent.Grass + Year * Roads	7	319.6	6.1	0.01503	0.92019	0.00
Best landscape model plus site-specific models:							
mod14	Year + Slope	4	287.8	0.0	0.71700	0.82412	0.22
mod15	Year + Slope + Year * Slope	5	289.6	1.9	0.28265	0.82294	0.21
mod13	Year + AvVOR + Year * AvVOR	5	304.6	16.8	0.00016	0.87883	0.10
mod12	Year + AvVOR	4	305.2	17.4	0.00012	0.88958	0.09
mod26	Year + Ltr.Depth	4	307.7	19.9	0.00003	0.89934	0.07
mod27	Year + Ltr.Depth + Year * Ltr.Depth	5	308.0	20.3	0.00003	0.89208	0.07
mod20	Year + Percent.POPR	4	312.9	25.2	0.00000	0.92026	0.02
mod22	Year + Percent.BG	4	313.0	25.2	0.00000	0.92059	0.02
mod1	Null	2	313.5	25.7	0.00000	0.93988	0.00
mod16	Year + FQI	4	313.7	26.0	0.00000	0.92347	0.02
mod21	Year + Percent.POPR + Year * Percent.POPR	5	314.5	26.7	0.00000	0.91766	0.02
mod23	Year + Percent.BG + Year * Percent.BG	5	315.2	27.4	0.00000	0.92058	0.01
mod17	Year + FQI + Year * FQI	5	315.6	27.8	0.00000	0.92203	0.01
mod24	Year + Percent.Litter	4	316.2	28.4	0.00000	0.93346	0.00
mod18	Year + Percent.AGCR	4	317.2	29.4	0.00000	0.93756	-0.01
mod25	Year + Percent.Litter + Year * Percent.Litter	5	318.0	30.2	0.00000	0.93197	-0.01
mod19	Year + Percent.AGCR + Year * Percent.AGCR	5	318.4	30.6	0.00000	0.93337	-0.01

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

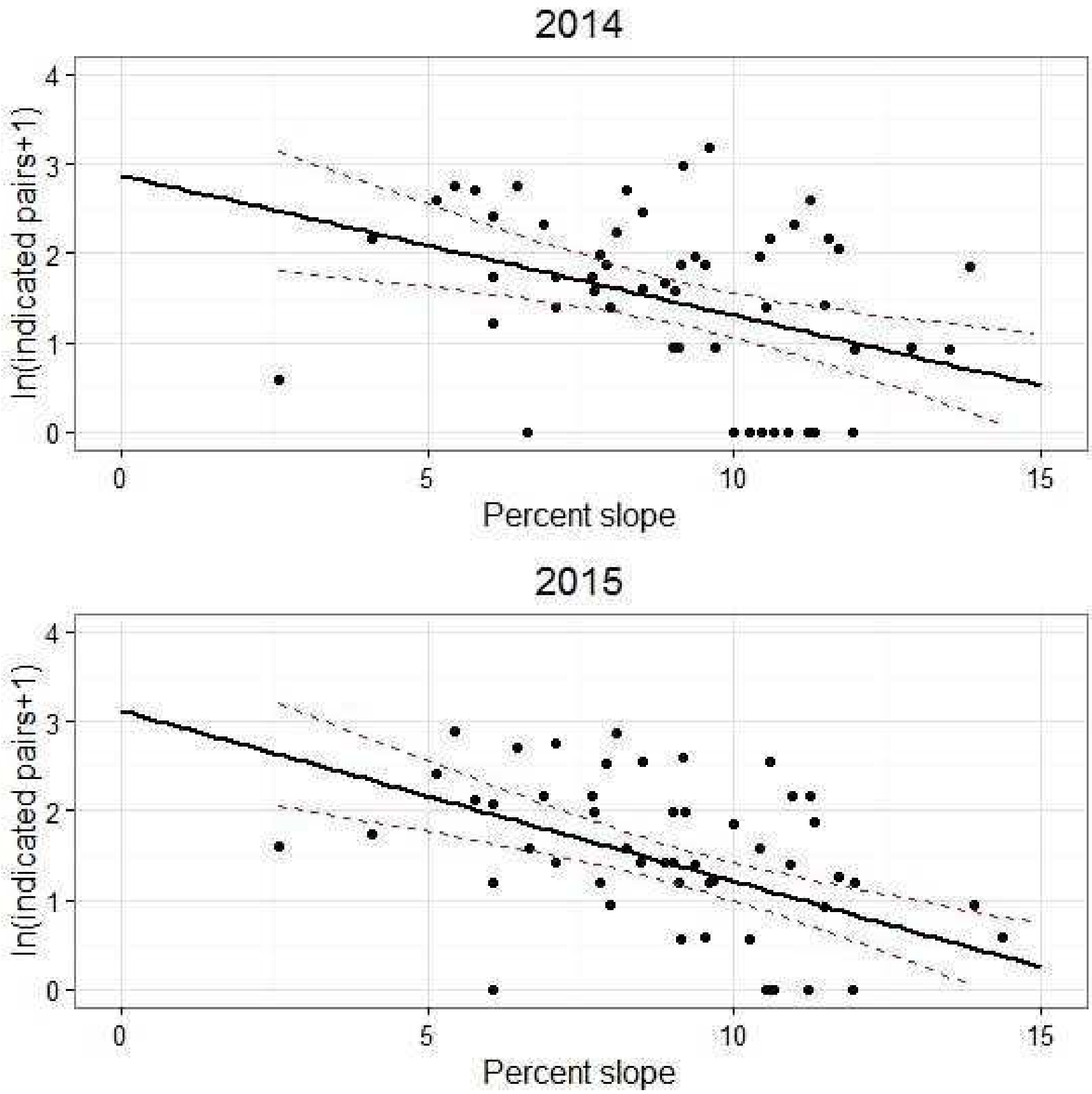

Figure 19. Model results showing relationship (black line with red-dashed 95% confidence intervals) between bobolink abundance and slope.

2.4.2.13. Western meadowlark

For the western meadowlark, the best supported and most parsimonious landscape model, based on Δ_i and ω_i, included Year, the interaction between Year and Roads, and the interaction between Year and Wells ($R^2 = 0.11$), indicating that western meadowlark abundance is weakly associated with the density of roads and wells within 1.6 km of the sample unit and that the strength of this association varied between the two years (Table 18). One site-specific variable (Percent.BG) improved the best-supported landscape model ($\omega_i = 0.54$, $R^2 = 0.18$). The best site-specific model included all of the interactions from the best landscape model but did not include interactions between the site-specific variable (Percent.BG) and Year, indicating that western meadowlark densities were associated with Percent.BG but the strength of the relationship did not vary with year. The final model explained 18% of the variation in western meadowlark abundance. Western meadowlark abundance increased with increasing road density in 2014 and 2015, but the relationship was stronger in 2014 (Fig. 19). Western meadowlark abundance increased slightly with an increase in bare ground in both years. Abundance declined in both years in relation to increasing well density (Fig. 20).

Table 18. Model-selection results for models relating western meadowlark abundance to landscape and site-specific habitat variables in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (n=114; sorted by Δ_i). Models were ranked according to Akaike's information criterion adjusted for small sample size (AIC_c). Variable definitions are given in Table 1.

Model		K[1]	AIC_C	Δ_i[2]	ω_i[3]	RMSE[4]	Adj. R^2
Landscape models:							
mod11	Year + Year * Roads + Year * Wells	7	146.0	0.0	0.48621	0.42968	0.11
mod3	Year + Wells	4	146.7	0.7	0.33783	0.44389	0.08
mod4	Year + Wells + Year * Wells	5	148.9	2.9	0.11489	0.44383	0.07
mod9	Year + Year * Percent.Grass + Year * Wells	7	152.6	6.6	0.01788	0.46671	0.00
mod1	Null	2	153.9	7.9	0.00937	0.45435	0.03
mod6	Year + Roads + Year * Roads	5	154.2	8.2	0.00796	0.44564	0.05
mod10	Year + Year * Percent.Grass + Year * Roads	7	154.3	8.3	0.00762	0.44231	0.06
mod5	Year + Roads	4	154.6	8.6	0.00669	0.45943	0.01
mod7	Year + Percent.Grass	4	154.8	8.8	0.00593	0.45991	0.01
mod2	Year	3	155.8	9.8	0.00361	0.46629	-0.01
mod8	Year + Percent.Grass + Year * Percent.Grass	5	157.0	11.0	0.00201	0.45987	0.00
Best landscape model plus site-specific models:							
mod22	Year + Year * Roads + Year * Wells + Percent.BG	8	137.9	0.0	0.54108	0.41047	0.18
mod23	Year + Year * Roads + Year * Wells + Percent.BG + Year * Percent.BG	9	139.5	1.6	0.23944	0.40916	0.18
mod16	Year + Year * Roads + Year * Wells + FQI	8	141.8	3.9	0.07603	0.41760	0.15
mod20	Year + Year * Roads + Year * Wells + Percent.POPR	8	143.5	5.6	0.03313	0.42065	0.14
mod18	Year + Year * Roads + Year * Wells + Percent.AGCR	8	143.5	5.6	0.03271	0.42070	0.14
mod17	Year + Year * Roads + Year * Wells + FQI + Year * FQI	9	144.1	6.2	0.02398	0.41750	0.15
mod21	Year + Year * Roads + Year * Wells + Percent.POPR + Year * Percent.POPR	9	145.6	7.7	0.01148	0.42021	0.14
mod19	Year + Year * Roads + Year * Wells + Percent.AGCR + Year * Percent.AGCR	9	145.6	7.8	0.01114	0.42032	0.14
mod11	Year + Year * Roads + Year * Wells	7	146.0	8.1	0.00936	0.42968	0.11
mod26	Year + Year * Roads + Year * Wells + Ltr.Depth	8	146.8	9.0	0.00616	0.42690	0.12
mod14	Year + Year * Roads + Year * Wells + Slope	8	147.7	9.8	0.00406	0.42847	0.11
mod12	Year + Year * Roads + Year * Wells + AvVOR	8	148.1	10.2	0.00326	0.42930	0.11
mod24	Year + Year * Roads + Year * Wells + Percent.Litter	8	148.3	10.4	0.00301	0.42960	0.11
mod27	Year + Year * Roads + Year * Wells + Ltr.Depth + Year * Ltr.Depth	9	149.1	11.2	0.00199	0.42672	0.11
mod15	Year + Year * Roads + Year * Wells + Slope + Year * Slope	9	150.0	12.1	0.00125	0.42847	0.10
mod13	Year + Year * Roads + Year * Wells + AvVOR + Year * AvVOR	9	150.4	12.6	0.00102	0.42924	0.10
mod25	Year + Year * Roads + Year * Wells + Percent.Litter + Year * Percent.Litter	9	150.6	12.7	0.00092	0.42960	0.10

[1] Number of parameters.
[2] Delta AIC (measure of each model relative to the best model).
[3] Akaike weights (measure of the strength of evidence for each model).
[4] Root mean square error.

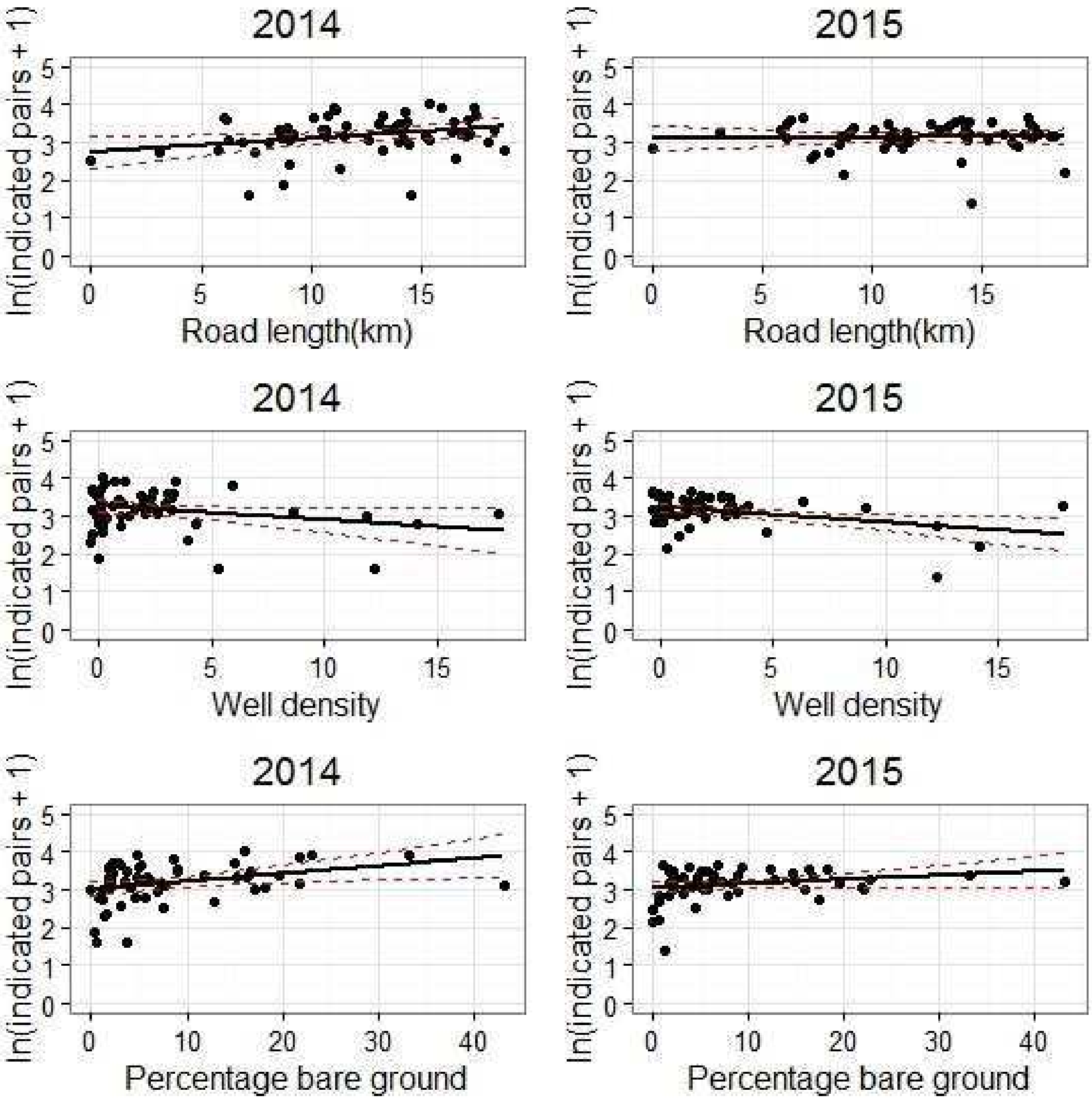

Figure 20. Model results showing relationship (black line with red-dashed 95% confidence intervals) between western meadowlark abundance and road length, well density, and percentage bare ground.

2.5. Discussion

Grassland bird diversity showed a decline with increasing grassland percentage within 1.6 km of the site edge and VOR. Biodiversity has been observed to decrease with an increasingly homogenous landscape (Benton et al., 2003; Fahrig et al., 2011). Although most of the 12 focal species are obligate grassland birds, several species are considered facultative grassland birds (e.g., Vickery et al., 1999), including clay-colored sparrow and field sparrow. These species tend to prefer grasslands with taller and denser vegetation, a shrubby vegetation component, or near a woody edge some edge (Dechant et al., 2002a, 2002b, 2002c), which may explain why overall grassland bird diversity decreased as grassland cover increased. Grassland birds also have different preferences for vegetation structure. For example, Madden and others (2000), found that Sprague's pipit used habitat with lower vegetation density (i.e., VOR) than habitats used by Bobolink. The presence of grasslands with high structural variability on the landscape increases habitat heterogeneity, which in turn increases biodiversity (Wiens, 1997). Since not all grassland birds have the same habitat requirements, it is important to manage for heterogeneity at broad spatial scales.

Grasshopper sparrow and western meadowlark were abundant and were ubiquitous (100-% frequency) on the LMNG, which made modeling habitat preferences for those two species especially difficult. Grasshopper sparrow abundance showed no associations with any of the plausible landscape models. In addition, abundances of two other common grassland birds, horned lark and bobolink, were not affected by any of the landscape variables. At the site-specific level, grasshopper sparrow abundance showed a negative, albeit weak, relationship with slope. Western meadowlark abundance changed only slightly across the gradient of well density and percentage bare ground. Western meadowlark abundance showed a positive relationship with road length in the surrounding landscape in the first year of the study, but the relationship was weaker in the second year. This result may reflect the western meadowlark's attraction to fencelines along road rights-of-way, which provide an elevated song perch (Davis and Lanyon, 2008). These results are contrary to a recent study in Saskatchewan, Canada by Ludlow and others (2015), in which western meadowlarks tended to avoid nesting within 100 m of gravel roads. However, in that study, the proximity of roads did not influence the species' density. Our results supported another study on the LMNG where western meadowlark did not show any avoidance patterns to roads or single- and multi-bore well pads (Thompson et al., 2015).

About one-half of the 12 focal bird species in this study were associated with oil-related infrastructure (wells and roads), whereas the other species were largely unaffected. Other studies of oil and gas development have found similar variation in tolerance by grassland birds (Chalfoun et al., 2002; Francis et al., 2011; Kalyn Bogard and Davis, 2014). Kalyn Bogard and Davis (2014) suggested that inconsistencies among oil development studies can be attributed to variation in infrastructure age, spatial configuration of development, and drilling infrastructure presence (Gilbert and Chalfoun, 2011); chronic industrial noise (Blickley et al., 2012); landscape context (Hamilton et al., 2011); vehicular traffic (Ingelfinger and Anderson, 2004; Lawson et al., 2011); or regional variation in bird population density (Igl and Johnson, 1997; Winter et al., 2005).

Life-history characteristics of some species may explain at least some of the species-specific variations that we observed with oil development. For example, fences around oil-well pads and along access roads often exclude livestock from grazing strips of grassland around these structures, resulting in taller or denser vegetation and perch sites that may attract species like the clay-colored sparrow (Dechant et al., 2002b). Several studies have examined the effects of energy development on prairie grouse, although much of the available research focuses on sage grouse (*Centrocercus urophasianus*) (Braun, 1986; Braun et al., 2002; Gilbert and Chalfoun, 2011). One study in North Dakota that focused on sharp-tailed grouse nest success reported that grouse nest success was higher in areas with intense oil and gas development because of a decrease in predator abundance (Burr, 2014). Another study in the LMNG found that sharp-tailed grouse did not appear to avoid areas with high oil well densities (Williamson, 2009). However, sharp-tailed grouse abundance was negatively associated with road density, which may be correlated with oil and gas development (Williamson, 2009). Our results indicate that sharp-tailed grouse abundance declined with increasing well density. In this study, we found that increased well densities had a positive effect on vesper sparrow abundance. Given that vesper sparrows exhibit an affinity for roads and that the species is typically more abundant along roads (Ownes and Myres, 1973; Sutter et al., 2000), this result was not unexpected. However, in Wyoming, Gilbert and Chalfoun (2011) showed that vesper sparrows were negatively affected by oil-well density.

In this study, the best plausible models for Sprague's pipit or Baird's sparrow abundance did not include well density, which is contrary to another study that found Sprague's pipit and Baird's sparrow abundance was negatively affected by oil development (Ludlow et al., 2015). However, increased oil well density may have indirect impacts on sensitive grassland birds via an increase in access roads in the area of oil development. We found that both of these sensitive species were negatively associated with road density. In two studies in grasslands of southern Alberta, Sprague's pipits did not appear to avoid low-traffic roads (Koper et al., 2009), and in Wyoming, sagebrush-obligate birds were significantly less common in areas within 100 m of roads associated with natural gas extraction (Ingelfinger and Anderson, 2004). It is likely that roads associated with oil and natural gas extraction experience a considerably higher volume of vehicular traffic than traditional rural roads in comparable locations, and this is the case in our study area (Fershee, 2012). Reduced grassland bird density near roads is likely a direct result of heavy traffic associated with oil development in the region (Thompson et al., 2015). In lightly to moderately grazed native prairie in Saskatchewan, Sprague's pipit and Baird's sparrow were more abundant in grasslands alongside trails (i.e., single pair of wheel ruts) than in grasslands alongside roads (i.e., traveling surfaces with adjacent drainage ditches planted to exotic vegetation and ending with a fence 11-18 m from the traveling surface) (Sutter et al., 2000).

Given that many grassland birds are area sensitive and require large blocks of grassland during the breeding season (Johnson and Igl, 2001; Ribic et al., 2009), it is not surprising that several grassland birds in this region were associated with the percentage of grassland within the surrounding landscape. The negative relationship between clay-colored sparrow and field sparrow abundance with the percentage of grassland within 1.6 km of the study sites may be attributed to the species' habitat preferences for taller and denser grasslands or grasslands with a shrubby vegetation component (Dechant et al., 2002a, 2002b). Chestnut-collared longspurs and upland sandpiper responded positively to an increasing amount of grassland in the surrounding landscape. In another study in North Dakota, chestnut-collared longspurs tended to avoid areas with shrubby vegetation (Arnold and Higgins, 1986), and thus it is not surprising that this species would prefer a landscape with more grass coverage. Our results for the upland sandpiper are consistent with other studies, which recommended maintaining large, contiguous tracts of prairie to reduce habitat edge (Herkert, 1994; Klute, 1994).

The abundance of three species—Baird's sparrow, grasshopper sparrow, and bobolink—were negatively associated with slope. The effects of slope on grassland birds is not well known.

For example, the topography preferred by the Sprague's pipit is often listed in the literature (Environment Canada, 2011) and by experts (S. Davis, pers. Comm., Canadian Wildlife Service) as flat to gently (or slightly) rolling, although the thresholds for topography are generally unknown. Winter (2007) recommended that further research be done on the role of topography or slope on the distribution of sensitive grassland birds. Even within the narrow range of slopes evaluated in this study (≤15%), we found that Baird's sparrow abundance declined as slope increased, which corresponds with Winter's findings on the Grand River National Grassland. Grasshopper sparrow abundance also declined with slope. Winter (2007) found that slope was highly correlated with the percentage of woody vegetation in her study areas. Baird's sparrows and other obligate grassland birds in this region may avoid steeper areas because of the increased amount of woody vegetation, which other studies have shown to negatively affect Baird's sparrow abundance (Lane, 1968; Winter, 1994; De Smet and Conrad, 1997). Slope did not occur in any of the best plausible models for the other nine grassland birds on this study.

Three of the focal bird species were associated with vegetation composition variables: clay-colored sparrow, field sparrow, and vesper sparrow. Clay-colored sparrow abundance increased as sites included more native plant species, whereas vesper sparrow abundance was higher on sites with fewer native plant species. For the clay-colored sparrow, our results are contrary to those from another study that found clay-colored sparrow abundance was negatively associated with native plant species (Prescott et al., 1995). In another North Dakota study, clay-colored sparrow abundance was positively associated with percentage forb cover (Schneider, 1998). On our sites, percentage forb cover was positively associated with FQI ($r = 0.48$), indicating that sites that had more native vegetation tended to have more forb cover. Wilson and Belcher (1989) also found that vesper sparrow abundance decreased with increasing cover of native vegetation (Wilson and Belcher, 1989). However, other studies have found that vesper sparrow habitat preferences are fluid, and they will use both native and tame vegetation (Anstey et al., 1995; Prescott and Wagner, 1996; Sutter and Brigham, 1998). Field sparrow abundance showed a negative relationship with percentage cover of crested wheatgrass at the site level. However, the range of crested wheatgrass cover (0-25%) for this study made it difficult to draw inferences about field sparrow abundance in relation to crested wheatgrass cover.

It was not surprising that several grassland bird species were associated with structural vegetation variables, since many studies have shown that grassland birds tend to select grassland habitats based on vegetation structure rather than composition (Davis and Brittingham, 2004; Winter, 2007). The association between sharp-tailed grouse abundance and litter depth varied between years, suggesting that the association is weak. Horned lark abundance was negatively associated litter depth. This result was somewhat expected as horned larks prefer areas with short, sparse coverage of herbaceous vegetation (Davis et al., 1999). Upland sandpiper and western meadowlark abundance were positively associated with the percentage of bare ground cover at the site level. Fuhlendorf and others (2006) found upland sandpipers were more abundant in grassland patches that had been recently disturbed, and thus had minimal litter and more bare ground. Kantrud and Kologiski (1982) found that western meadowlark abundance was highest on sites that had an average of 17-25% bare ground. However, one study in Oregon reported that western meadowlarks were negatively associated with percentage bare ground (Wiens and Rotenberry, 1981). Both the Sprague's pipit and chestnut-collared longspur were less abundant as vegetation density (VOR) increased. In North Dakota, Madden and others (2000) found that Sprague's pipit occurrence was best predicted by VOR, and that pipit abundance declined quickly as VOR increased. Also in North Dakota, Schneider (1998) reported that chestnut-collared longspur abundance was negatively associated with VOR.

2.6. Management implications

Livestock grazing has been shown to greatly influence the vegetation structure of grasslands (Wiens and Dyer, 1975; Ryder, 1980). Habitat structure is the main driver of grassland bird habitat selection (Fisher and Davis, 2010) and therefore it is important to manage livestock grazing intensity to provide structural diversity for grassland birds at both ends of the structure gradient (e.g., Fuhlendorf et al., 2006, Saab et al., 1995). The Dakota Prairie Grasslands developed a land and resource management plan (LRMP) in August 2007 (Svingen, 2009). The LRMP contained extensive direction on providing habitat for multiple species by setting vegetation structure goals for the entire LMNG. Three structure categories were set using their autumn VOR monitoring: low structure (i.e., ≤ 3.81 cm), moderate structure (i.e., 3.82-8.8 cm), and high structure (i.e., ≥ 8.9). Our results show that Sprague's pipit and chestnut-collared longspur abundance decreased on sites with a higher average VOR. These results highlight the importance of maintaining lower VOR's for some species through management tools, such as grazing. We recommend that land managers use differing grazing intensities to maintain habitat for the suite of grassland birds that breed in the LMNG. More specifically, areas with lower VOR should be maintained using higher stocking rates or specific grazing practices to maintain habitat for the sensitive species, such as the Sprague's pipit.

Baird's sparrow abundance was not associated with any of the structural vegetation measurements, however, Baird's sparrow abundance was negatively associated with areas that had higher percent slope. Although we cannot reasonably expect land managers to alter topography (i.e., slope), managers can focus their management for species—Bobolink, grasshopper sparrow, and Baird's sparrow—that prefer flatter topography.

In this study, the two grassland birds—Sprague's pipit and Baird's sparrow—considered to be "sensitive" by the USFS were negatively associated with road density. The recent oil development in western North Dakota overlaps considerably with the breeding ranges of sensitive grassland birds and impacts federally-owned grasslands that are important breeding areas for these species. Our results suggest that the access roads built to well pads may negatively affect sensitive grassland birds. When possible, we recommend that access roads be kept to a minimum by strategically placing well pads close together or using multi-bore well pads (*sensu* Thompson et al., 2015).

2.7. References

ANSTEY, D. A., S.K. DAVIS, D.C. DUNCAN, AND M. SKEEL, 1995. Distribution and habitat requirements of eight grassland songbird species in southern Saskatchewan. Saskatchewan Wetland Conservation Corporation, Regina, Saskatchewan, Canada.

ARNOLD, T.W., AND K. F. HIGGINS, 1986. Effects of shrub coverages on birds of North Dakota mixed-grass prairies. *Canadian Field-Naturalist* 100, 10–14.

Barton, K, 2016. MuMIn: multi-model inference. R package version 1.15.6. Available at: https://CRAN.R-project.org/package=MuMIn (Accessed 12 April 2016).

BENKOBI, L., D. W. URESK, G. SCHENBECK, AND R. M. KING, 2000. Protocol for monitoring standing crop in grasslands using visual obstruction. *Journal of Range Management* 53, 627–633.

BENTON, T. G., AND J. A. VICKERY, AND J. D. WILSON, 2003. Farmland biodiversity: is habitat heterogeneity the key. *Trends in Ecology and Evolution* 18, 182–188.

BIBBY, C. J., N D. BURGESS, AND D. A. HILL, 2000. Bird census techniques. Academic Press, New York, New York, USA. p. 302.

BLICKLEY, J. L., D. BLACKWOOD, AND G. L. PATRICELLI, 2012. Experimental evidence for the effects of chronic anthropogenic noise on abundance of greater sage-grouse at leks. *Conservation Biology* 26, 461–471.

BOGARD, H. J., AND S. K. DAVIS, 2014. Grassland songbirds exhibit variable responses to the proximity and density of natural gas wells. *The Journal of Wildlife Management* 78, 471-482.

BOLLINGER, E. K., T. A. GAVIN, AND D. C. MCINTYRE, 1988. Comparison of transects and circular-plots for estimating bobolink densities. *Journal of Wildlife Management* 52, 777–786.

BRAUN, C. E., 1986. Changes in sage grouse lek counts with advent of surface coal mining. Proceedings, Issues and Technology in the Management of Impacted Western Wildlife. Thorne Ecological Institute 2, 227-231.

BRAUN, C. E., O. O. OEDEKOVEN, AND C. L. ALDRIDGE, 2002. Oil and gas development in western North America: effects on sage-brush steppe avifauna with particular emphasis on sage grouse. North American Wildlife and Natural Resources Conference. Transactions 67, 337-349.

BRENNAN, L. A., AND W. P. KUVLESKY, JR., 2005. Invited paper: North American grassland birds: an unfolding conservation crisis? *Journal of Wildlife Management* 69, 1–13.

BROWN, J. H., AND W. MCDONALD, 1995. Livestock grazing and conservation on southwestern rangelands. *Conservation Biology* 9, 1644–1647.

BURNHAM, K. P., AND D. R. ANDERSON, 1998. Model selection and inference: a practical information theoretic approach. Springer-Verlag, New York, New York, USA. p. 372.

BURNHAM, K. P., AND D. R. ANDERSON. 2002. Model selection and multimodel inference: a practical information-theoretic approach, second editioin. Springer-Verlag, New York, New York, USA. p. 488

BURR, P. C., 2014. Impacts of gas and oil development on sharp-tailed grouse (*Tympanuchus phasianellus*) nest success and predator dynamics in western North Dakota. M.S. Thesis, North Dakota State University, Fargo, North Dakota, USA. p. 146.

CHALFOUN, A. D., M. J. RATNASWAMY, F. R. THOMPSON, III., 2002. Songbird nest predators in forest-pasture edge and forest interior in a fragmented landscape. *Ecological Applications* 12, 858–867.

CHESSER, R. T., R. C. BANKS, K. J. BURNS, C. CICERO, J. L. DUNN, A. W. KRATTER, I. J. LOVETTE, A. G. NAVARRO-SIGÜENZA, P. C. RASMUSSEN, J. V. REMSEN, JR., J. D. RISING, D. F. STOTZ, AND K. WINKER, 2015. Fifty-sixth supplement to the American Ornithologists' Union: Check-list of North American Birds. *Auk* 132, 748–764.

DALE, B., 1992. North American Waterfowl Management Plan implementation program related to non-game bird studies within the Prairie Habitat Joint Venture area. Annual report 1991-1992. Unpublished report submitted to the Canadian Wildlife Service, Saskatoon, Saskatchewan, Canada.

DAVIS, S. K., D. C. DUNCAN, AND M. SKEEL, 1999. Distribution and habitat associations of three endemic songbirds in southern Saskatchewan. *Wilson Bulletin* 111, 389-396.

DAVIS, S. K. AND W. E. LANYON, 2008. Western Meadowlark (*Sturnella neglecta*). *In*: A. Poole [ED.]. The Birds of North America Online (A. Poole, Ed.). Ithaca: Cornell Lab of Ornithology Available at: http://bna.birds.cornell.edu/bna/species/104 (Accessed 23 March 2016).

DAVIS, S. K., AND M. BRITTINGHAM, 2004. Area sensitivity in grassland passerines: effects of patch size, patch shape, and vegetation structure on bird abundance and occurrence in southern Saskatchewan. *Auk* 121, 1130–1145.

DAVIS, S. K., M. B. ROBBINS AND B. C. DALE, 2014. Sprague's pipit (*Anthus spragueii*). *In*: A. Poole [ED.]. The Birds of North America Online. Cornell Lab of Ornithology, Ithaca, New York. Available at: http://bna.birds.cornell.edu/bna/species/439 (Accessed 23 March 2016).

DE SMET, K. D., AND M. P. CONRAD, 1997. Management and research needs for Baird's sparrows and other grassland species in Manitoba. *In*: Holroyd G. I., G. Burns, and H. C. Smith [EDS.]. Proceedings of the second Endangered Species and Prairie Conservation Workshop. Natural History Occasional Paper 15. Provincial Museum of Alberta, Edomonton, Alberta, Canada. p. 83–86.

DECHANT, J. A., M. F. DINKINS, D. H. JOHNSON, L. D. IGL, C. M. GOLDADE, AND B. R. EULISS, 2002a. Effects of management practices on grassland birds: Vesper Sparrow. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

DECHANT, J. A., M. L. SONDREAL, D. H. JOHNSON, L. D. IGL, C. M. GOLDADE, M. P. NENNEMAN, AND B. R. EULISS, 2002b. Effects of management practices on grassland birds: Clay-colored Sparrow. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

DECHANT, J. A., M. L. SONDREAL, D. H. JOHNSON, L. D. IGL, C. M. GOLDADE, B. D. PARKIN, AND B. R. EULISS, 2002c. Effects of management practices on grassland birds: Field Sparrow. U.S. Geological Survey, Northern Prairie Wildlife Research Center, Jamestown, North Dakota, USA.

DERNER, J. D., W. K. LAUENROTH, P. STAPP, D. J. AUGUSTINE, 2009. Livestock as ecosystem engineers for grassland bird habitat in the western Great Plains of North America. *Rangeland Ecology and Management* 62, 111–118.

DEKEYSER, E. S., DENNHARDT, L. A., AND J. HENDRICKSON, 2015. Kentucky bluegrass (*Poa pratensis*) invasion in the northern Great Plains: a story of rapid dominance in an endangered ecosystem. *Invasive Plant Science and Management* 8, 255-261.

DYKE, S., S. JOHNSON, AND P. ISAKSON, 2015. North Dakota State Wildlife Action Plan, Draft. North Dakota Department of Game and Fish, Bismarck, North Dakota, USA.

ENVIRONMENT CANADA, 2011. Amendment to the final recovery strategy for the Sprague's pipit (*Anthus spragueii*) in Canada. RE: Partial identification of critical habitat in Alberta and Saskatchewan and action planning. Environment Canada, Ottawa, Canada.

FAHRIG, L., J. BAUDRY, L. BROTONS, F. G. BUREL, T. O. CRIST, R. J. FULLER, C. SIRAMI, G. M. SIRIWARDENA, AND J.-L. MARTIN, 2011. Functional landscape heterogeneity and animal biodiversity in agricultural landscapes. *Ecological Letters* 14, 101–112.

FERSHEE, J. P., 2012. Oil and gas evolution: learning from the hydraulic fracturing experiences in North Dakota and West Virginia. Texas Wesley Law Review 19. West Virginia University Law Research Paper No. 2012-14.

FISHER, R. J., AND S. K. DAVIS, 2010. From Wiens to Robel: a review of grassland-bird habitat selection. *Journal of Wildlife Management* 74, 265–273.

FRANCIS, C. D., J. PARITSIS, C. P. ORTEGA, AND A. CRUZ, 2011. Landscape patterns of avian habitat use and nest success are affected by chronic gas well compressor noise. *Landscape Ecology* 26, 1269–1280.

FREYMAN, W. A., L. A. MASTERS, AND S. PACKARD, 2015. The Universal Floristic Quality Assessment (FQA) Calculator: an online tool for ecological assessment and monitoring. Methods in Ecology and Evolution 7, 380–383.

FUHLENDORF, S. D., AND D. M. ENGLE, 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns we propose a paradigm that enhances heterogeneity instead of homogeneity to promote biological diversity and wildlife habitat on rangelands grazed by livestock. *BioScience* 51, 625–632.

FUHLENDORF, S. D., W. C. HARRELL, D. M. ENGLE, R. G. HAMILTON, C. A. DAVIS, AND D. H. LESLIE, JR., 2006. Should heterogeneity be the basis for conservation? –Grassland bird response to fire and grazing. *Ecological Applications* 16, 1706-1716.

GIBSON, D. J., AND L. C. HULBERT, 1987. Effects of fire, topography and year-to-year climatic variation on species composition in tallgrass prairie. *Vegetatio* 72, 175-185.

GILBERT, M. M., AND A. D. CHALFOUN, 2011. Energy development affects populations of sagebrush songbirds in Wyoming. *Journal of Wildlife Management* 75, 816–824.

GODFREAD, C., 1994. The vegetation of the Little Missouri Badlands of North Dakota, in: Proc. Leafy Spurge Strategic Planning Workshop, Dickinson, North Dakota, USA. pp. 17–24.

GOUGH, G. A., J. R. SAUER, AND M. ILIFF, 1998. Patuxent Bird Identification Infocenter. Version 97.1. U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland Available at: http://www. mbr-pwrc. usgs. gov/id/framlst/infocenter.html (Accessed 23 March 2016).

HAMILTON, L. E., B. C. DALE, AND C. A. PASZKOWSKI, 2011. Effects of disturbance associated with natural gas extraction on the occurrence of three grassland songbirds. *Avian Conservation and Ecology* 6(1)7.

HERKERT, J. R., 1994. Breeding bird communities of midwestern prairie fragments: the effects of prescribed burning and habitat-area. *Natural Areas Journal* 14, 128–135.

HERKERT, J. R., 1995. An analysis of Midwestern breeding bird population trends: 1966-1993. *American Midland Naturalist* 134, 41–50.

HIRZEL, A., AND A. GUISAN, 2002. Which is the optimal sampling strategy for habitat suitability modelling. *Ecological Modelling* 157, 331-341.

HOLECHEK, J. L., R. D. PIEPER, AND C. H. HERBEL, 1995. Range management: principles and practices. Prentice Hall, Englewood Cliffs, New Jersey, USA. p. 526.

IGL, L. D., 2009. Breeding bird use of grasslands enrolled in the Conservation Reserve Program in the northern Great Plains. Ph.D. Dissertation, North Dakota State University, Fargo, North Dakota, USA.

IGL, L.D., AND D. H. JOHNSON, 1997. Changes in breeding bird populations in North Dakota: 1967 to 1992-93. *Auk* 114, 74–92.

IGL, L. D., D. H. JOHNSON, AND H. A. KANTRUD, 2008. A historical perspective: changes in grassland breeding bird densities within major habitats in North Dakota between 1967 and 1992-1993. Proceedings of the North American Prairie Conference 20, 275-295.

INGELFINGER, F., AND S. ANDERSON, 2004. Passerine response to roads associated with natural gas extraction in a sagebrush steppe habitat. *Western North American Naturalist* 64, 385–395.

JOHNSON, D. H., 1980. The comparison of usage and availability measurements for evaluating resource preference. *Ecology* 61, 65–71.

JOHNSON, D. H., 2008. In defense of indices: the case of bird surveys. *Journal of Wildlife Management* 72, 857-868.

JOHNSON, D. H., AND L. D. IGL, 2001. Area requirements of grassland birds: a regional approach. *Auk* 118, 24-34.

JOHNSON, K. L. [ed.]., 1986. Crested wheatgrass: its values, problems and myths. Symposium proceedings. Utah State University, Logan, Utah, USA. p. 348.

KANTRUD, H. A., 1981. Grazing intensity effects on the breeding avifauna of North Dakota native grasslands. *Canadian Field-Naturalist* 95, 404–417.

KANTRUD, H. A., AND R. L. KOLOGISKI, 1982. Effects of soils and grazing on breeding birds of uncultivated upland grasslands of the northern Great Plains. U.S. Fish and Wildlife Service, Wildlife Research Report 15. p. 33.

KALYN BOGARD, H. J., AND S. K. DAVIS, 2004. Grassland songbirds exhibit variable responses to the proximity and density of natural gas wells. *Journal of Wildlife Management* 78, 471-482.

KLUTE, D. S., 1994. Avian community structure, reproductive success, vegetative structure, and food availability in burned Conservation Reserve Program fields and grazed pastures in northeastern Kansas. M.S. Thesis, Kansas State University, Manhattan, Kansas, USA. p. 168.

KNOPF, F. L., 1994. Avian assemblages on altered grasslands. *Studies in Avian Biology* 15, 247–257.

KOPER, N., D. J. WALKER, AND J. CHAMPAGNE, 2009. Nonlinear effects of distance to habitat edge on Sprague's pipits in southern Alberta, Canada. *Landscape Ecology* 24, 1287–1297.

KOPER, N., L. LESTON, T. M. BAKER, C. CURRY, AND P. ROSA, 2015. Effects of ambient noise on detectability and localization of avian songs and tones by observers in grasslands. *Ecology and Evolution* 6, 245-255.

LANE, J., 1968. Baird's sparrow (*Ammodramus bairdii*). *In* A.C. Bent life histories of North American cardinals, grosbeaks, towhees, finches, sparrows, and allies, part two. *U.S. National Museum Bulletin* No. 237, p. 603–1248.

LAWSON, A. L., M. L. MORRISON, AND R. DOUGLAS SLACK, 2011. Impacts of oil and gas development on wintering grassland birds at Padre Island National Seashore, Texas. *Southeastern Naturalist* 10, 303–320.

LUDLOW, S. M., R. M. BRIGHAM, AND S. K. DAVIS, 2015. Oil and natural gas development has mixed effects on the density and reproductive success of grassland songbirds. *Condor* 117, 64–75.

MADDEN, E. M., 1996. Passerine communities and bird-habitat relationships on prescribe-burned, mixed grass prairie in North Dakota. M.S. Thesis, Montana State University, Bozeman, Montana, USA.

MADDEN, E. M., A. J. HANSEN, AND R. K. MURPHY, 1999. Influence of prescribed fire history on habitat and abundance of passerine birds in northern mixed-grass prairie. *Canadian Field-Naturalist* 113, 627–640.

MADDEN, E. M., R. K. MURPHY, A. J. HANSEN, AND L. MURRAY. 2000, Models for guiding management of prairie bird habitat in northwestern North Dakota. *American Midland Naturalist* 144, 377–392.

MAZEROLLE, M. J., 2016. AICcmodavg: model selection and multimodel inference based on Q AIC_c. R package version 2.0-4. Available at: http://CRAN.R-project.org/package=AICcmodavg (Accessed 12 April 2016).

MENGEL, R. M., 1970. The North American Central Plains as an isolating agent in bird speciation. *In*: W. Dort, Jr., and J. K. Jones, Jr. [EDS.]. Pleistocene and recent environments of the central Great Plains. University Press of Kansas, Lawrence, Kansas, USA. p. 279–340.

MINNESOTA DEPARTMENT OF NATURAL RESOURCES (MNDNR), 2006. Tomorrow's habitat for the wild and rare: an action plan for Minnesota wildlife comprehensive wildlife conservation strategy. Division of Ecological Services, Minnesota Department of Natural Resources Available at: http://www.dnr.state.mn.us/cwcs/index.html (Accessed 23 March 2016).

MOUL, F., 2006. The National Grasslands: a guide to America's undiscovered treasures. University of Nebraska Press, Lincoln, Nebraska, USA. p. 153.

NORTH AMERICAN BIRD CONSERVATION INITIATIVE, U.S. COMMITTEE (NABCI). 2014. The State of the Birds 2014 Report. U.S. Department of the Interior, Washington, D.C., USA. p. 16.

NORTH DAKOTA INDUSTRIAL COMMISSION (NDIC), 2016. Oil and gas code definitions. North Dakota Industrial Commission, Bismarck, North Dakota, USA Available at: https://www.dmr.nd.gov/oilgas/codehelp.asp (Accessed 22 March 2016).

NORTHERN GREAT PLAINS FLORISTIC QUALITY ASSESSMENT PANEL. 2001. Coefficients of conservatism for the vascular flora of the Dakotas and adjacent grasslands. Information and Technology Report USGS/BRB/ITR-2001-0001. U.S. Geological Survey, Biological Resources Division, Reston, Virginia, USA. p. 32.

NOSS, R. F., E. T. LAROE, AND J. M. SCOTT, 1995. Endangered ecosystems of the United States: a preliminary assessment of loss and degradation. U.S. Department of the Interior, National Biological Service, Washington, D.C., USA.

OKSANEN, J., F. GUILLAUME BLANCHET, R. KINDT, P. LEGENDRE, P. R. MINCHIN, R. B. O`HARA, G. L. SIMPSON, P. SOLYMOS, M. H. STEVENS, AND H. WAGNER, 2016. Vegan: community ecology package. R package version 2.3-3. Available at: https://CRAN.R-project.org/package=vegan (Accessed 12 April 2016).

OLSON, E., 1997. National grasslands management: a primer. Natural Resources Division, Office of General Counsel, U.S. Department of Agriculture, Washington, D.C., USA. p. 36.

OWENS, R. A., AND M. T. MYRES, 1973. Effects of agriculture upon populations of native passerine birds of an Alberta fescue grassland. *Canadian Journal of Zoology* 51, 697–713.

PETERJOHN, B., AND J. R. SAUER, 1999. Population status of North American grassland birds from the North American breeding bird survey. *Studies in Avian Biology* 19, 27–44.

PRESCOTT, D. R. C., A. MURPHY, AND E. EWASCHUK, 1995. An avian community approach to determining biodiversity values of NAWMP habitats in the aspen parkland of Alberta. Alberta NAWMP Centre, Edmonton, Alberta, Canada.

PRESCOTT, D. R. C., AND G. M. WAGNER, 1996. Avian responses to implementation of a complementary/rotational grazing system by the North American Waterfowl Management Plan in southern Alberta: the Medicine Wheel Project. NAWMP-018. Alberta NAWMP Centre, Edmonton, Alberta, Canada. 24 p.

Redmond, R.L., T. K. Bicak, and D. A. Jenni, 1981. An evaluation of breeding season census techniques for long-billed curlews (*Numenius americanus*). *Studies in Avian Biology* 6, 197–201.

RIBIC, C. A., R. R. KOFORD, J. R. HERKERT, D. H. JOHNSON, N. D. NIEMUTH, D. E. NAUGLE, K. K. BAKKER, D. W. SAMPLE, AND R. B. RENFREW, 2009. Area sensitivity in North American grassland birds: patterns and processes. *Auk* 126, 233-244.

RICH, T. D., C. J. BEARDMORE, H. BERLANGA, P. J. BLANCHER, M. S. W. BRADSTREET, G. S. BUTCHER, D. W. DEMAREST, E. H. DUNN, W. C. HUNTER, E. E. INIGO-ELIAS, J. A. KENNEDY, A. M. MARTELL, A. O. PANJABI, D. N. PASHELEY, K. V. ROSENBERG, C. M. RUSTAY, J. S. WENDT, AND T. C. WILL, 2004. Partners in Flight North American Landbird Conservation Plan. Cornell Lab of Ornithology, Ithaca, New York, USA Available at: http://www.partnersinflight.org/cont_plan/ (Accessed 23 March 2016).

ROBEL, R. J., J. N. BRIGGS, A. D. DAYTON, AND L. C. HULBERT, 1970. Relationships between visual obstruction measurements and weight of grassland vegetation. *Journal of Range Management* 295–297.

ROBBINS, M. B., AND B. C. DALE, 1999. Sprague's pipit (*Anthus spragueii*). *In* The Bird of North America, No. 439 (A. Poole and F. Gill, eds.). The Birds of North America, Inc., Philadelphia, Pennsylvania, USA.

RYDER, R. A., 1980. Effeccts of grazing on bird habitat. *In* Management of western forests and grassland for non-game birds (R. M. DeGraff and N. G. Tilghman, Eds.). U.S. Forest Service, Ogden, Utah, USA. p. 51-66.

SAAB, V.A., C. E. BOCK, T. D. RICH, AND D. S. DOBKIN, 1995. Livestock grazing effects in western North America. *In*: T. E. Martin and D. M. Finch [EDS.]. Ecology and management of Neotropical migratory birds. Oxford University Press, New York, New York, USA. p. 311–353.

SAMSON, F., AND F. K. KNOPF, 1994. Prairie conservation in North America. *BioScience* 418–421.

SAUER, J. R., J. E. HINES, J. E. FALLON, K. L. PARDIECK, D. J. ZIOLKOWSKI, JR., AND W. A. LINK, 2014. The North American breeding bird survey, results and analysis 1966-2013. Version

01.30.2015 U.S. Geological Survey, Patuxent Wildlife Research Center, Laurel, Maryland, USA.

SCHNEIDER, N. A., 1998. Passerine use of grasslands managed with two grazing regimes on the Missouri Coteau in North Dakota. M.S. Thesis, South Dakota State University, Brookings, South Dakota, USA. p. 107.

SOUTH DAKOTA DEPARTMENT OF GAME, FISH AND PARKS (SDGFP), 2014. South Dakota State Wildlife Action Plan. Wildlife Division Report 2014-03. South Dakota Department of Game, Fish and Parks, Pierre, South Dakota, USA Available at: http://gfp.sd.gov/wildlife/management/plans/wildlife-action-plan.aspx (Accessed 23 March 2016).

STEWART, R. E., 1975. Breeding birds of North Dakota. Tri-College Center for Environmental Studies, Fargo, North Dakota, USA. p. 295.

STEWART, R. E., AND H. A. KANTRUD, 1972. Population estimates of breeding birds in North Dakota. *Auk* 766–788.

STOHLGREN, T. J., FALKNER, M. B., AND L. D. SCHELL, 1995. A modified-Whittaker nested vegetation sampling method. *Vegetatio* 117,113-121.

SUTTER, G. C., AND R. M. BRIGHAM, 1998. Avifaunal and habitat changes resulting from conversion of native prairie to crested wheat grass: patterns at songbird community and species levels. *Canadian Journal of Zoology* 76, 869–875.

SUTTER, G. C., S. K. DAVIS, AND D. C. DUNCAN, 2000. Grassland songbird abundance along roads and trails in southern Saskatchewan. *Journal of Field Ornithology* 71, 110–116.

SVINGEN, D., 2009. Grassland bird management on public lands in the United States: an example from the northern Great Plains. *In* Proceedings of the Fourth International Partners in Flight Conference: Tundra to Tropics. p. 590-593.

SWINK, F., 1974. Plants of the Chicago region. Morton Arboretum, Lisle, Illinois, USA.

THOMPSON, S. J., D. H. JOHNSON, N. D. NIEMUTH, AND C. A. RIBIC, 2015. Avoidance of unconventional oil wells and roads exacerbates habitat loss for grassland birds in the North American Great Plains. *Biological Conservation* 192, 82–90.

TILAMN, D., AND J. A. DOWNING, 1994. Biodiversity and stability in grasslands. *Nature* 367, 363-365.

TOLEDO, D., M. SANDERSON, K. SPAETH, J. HENDRICKSON, AND J. PRINTZ, 2014. Extent of Kentucky bluegrass and its effect on native plant species diversity and ecosystem services in the northern Great Plains of the United States. *Invasive Plant Science and Management* 7, 543–552.

U.S. FISH AND WILDLIFE SERVICE (USFWS), 1999. Endangered and threatened wildlife and plants; 90-day finding for a petition to list the Baird's sparrow as threatened with critical habitat. United States Department of Interior, Fish and Wildlife Service, Division of Ecological Services, Washington D.C., USA.

U.S. FISH AND WILDLIFE SERVICE, 2010. Endangered and threatened wildlife and plants; 12-month finding on a petition to list Sprague's pipit as endangered or threatened throughout its range. United States Department of Interior, Fish and Wildlife Service, Division of Ecological Services, Washington D.C., USA.

U.S. FOREST SERVICE, 2005. USFS Region 1 sensitive species list – wildlife (final). Unpublished report. U.S. Department of Agriculture, Forest Service, Missoula, Montana, USA.

URESK, D.W., AND T. A. BENZON, 2007. Monitoring with a modified Robel pole on meadows in the central Black Hills of South Dakota. *Western North American Naturalist* 67, 46–50.

VERMEIRE, L.T., AND R. L. GILLEN, 2001. Estimating herbage standing crop with visual obstruction in tallgrass prairie. *Journal of Range Management* 54, 57–60.

VERNER, J., M. L. MORRISON, AND C. J. RALPH, 1986. Wildlife 2000—modeling habitat relationships of terrestrial vertebrates. University of Wisconsin Press, Madison, Wisconsin, USA.

VICKERY, P. D., P. L. TUBARO, J. M. CARDOSA DA SILVA, B. G. PETERJOHN, J. R. HERKERT, AND R. B. CAVALCANTI, 1999. Conservation of grassland birds in the Western Hemisphere. *Studies in Avian Biology* 19, 2-26.

WELLS, J. V., 2010. Birder's conservation handbook: 100 North American birds at risk. Princeton University Press, Princeton, New Jersey, USA.

WHITMAN, W. C., AND M. K. WALI, 1975. Grasslands of North Dakota. *In*: M. K. Wali [ED.]. Prairie: a multiple view. p. 53–73.

WHITMORE, R. C., 1981. Structural characteristics of grasshopper sparrow habitat. *Journal of Wildlife Management* 45, 811–814.

WIENS, J. A., 1973. Pattern and process in grassland bird communities. *Ecological Monographs* 43, 237–270.

WIENS, J.A., 1997. The emerging role of patchiness in conservation biology. *In*: S. T. A. Pickett, R. S. Ostfeld, M. Shachak, and G. E. Likens [EDS.]. The ecological basis of conservation: heterogeneity, ecosystems and biodiversity. Chapman and Hall, New York, New York, USA. p. 93–107.

WIENS, J. A., AND M. I. DYER, 1975. Rangeland avifaunas: their composition energetics, and role in the ecosystem. *In* Symposium on management of forest and range habitats for non-game birds (D. R. Smith, Ed.). U.S. Forest Service, Tucson, Arizona, USA. p. 146-182.

WIENS, J. A., AND J. T. ROTENBERRY, 1981. Habitat associations and community structure of birds in shrubsteppe environments. *Ecological Monographs* 51, 21-42.

WILLIAMSON, R.M., 2009. Impacts of oil and gas development on sharp-tailed grouse on the Little Missouri National Grasslands, North Dakota. M.S. Thesis, South Dakota State University, Brookings, South Dakota, USA. p. 118.

WILLMS, W. D., AND P. G. JEFFERSON, 1993. Production characteristics of the mixed prairie: constraints and potential. *Canadian Journal of Animal Science* 73, 765–778.

WILSON, S. D., AND J. W. BELCHER, 1989. Plant and bird communities of native prairie and introduced Eurasian vegetation in Manitoba, Canada. *Conservation Biology* 3, 39–44.

WINTER, M., 1994. Habitat selection of Baird's sparrows in the northern mixed-grass prairie. Diplomar-Beit, Tubingen Universidad, Tubingen, Germany.

WINTER, M., 2007. Distribution and habitat associations of Baird's sparrows and Sprague's pipits on the Grand River National Grassland, South Dakota. Unpublished final report submitted to the U.S. Forest Service, Bismarck, North Dakota Available at: https://gfp.sd.gov/wildlife/funding/docs/small-grants-reports/Winter%202006.pdf (Accessed March 22, 2016).

WINTER, M., D. H. JOHNSON, J. A. SHAFFER, 2005. Variability in vegetation effects on density and nesting success of grassland birds. *Journal of Wildlife Management* 69, 185–197.

WOEHL, D. D., 2010. Relationship between visual obstruction reading and herbage production for ecological sites in a semi-arid climate of the northern plains. M.S Thesis, North Dakota State University, Fargo, North Dakota, USA.

APPENDIX

Table A1. Legal land description (Township, Range, Section and Quarter) and area (ha) of 60 study sites in the McKenzie District of the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Site ID	Legal Description[1]	Quarter	Area	Site ID	Legal Description	Quarter	Area	Site ID	Legal Description	Quarter	Area
1	149 103 14	SW1/4	159.4	21	145 104 18	NE1/4	159.6	41	146 104 34	SW1/4	159.5
2	148 099 04	NW1/4	151.8	22	145 104 35	NE1/4	159.0	42	146 104 25	NE1/4	159.2
3	146 105 23	SE1/4	159.4	23	145 104 35	NW1/4	159.0	43	146 105 25	NE1/4	160.4
4	146 103 22	SW1/4	160.1	24	149 103 25	NW1/4	156.5	44	150 103 15	SE1/4	159.1
5	145 098 33	SW1/4	155.4	25	148 100 30	SE1/4	143.7	45	150 103 15	SW1/4	159.9
6	148 103 10	SW1/4	159.2	26	148 100 15	NE1/4	161.7	46	147 101 17	SE1/4	159.7
7	148 103 27	NW1/4	160.8	27	145 100 02	SE1/4	159.1	47	146 104 30	NW1/4	156.8
8	149 103 03	SW1/4	158.7	28	148 100 15	SW1/4	159.7	48	147 105 24	NE1/4	159.9
9	149 103 03	SE1/4	158.7	29	145 104 14	NE1/4	157.7	49	149 104 33	NW1/4	154.5
10	148 103 34	NW1/4	158.7	30	145 104 14	NW1/4	158.3	50	153 096 12	SE1/4	158.7
11	148 103 15	NW1/4	160.9	31	145 104 33	NE1/4	157.9	51	149 104 33	SW1/4	160.4
12	148 103 22	SW1/4	156.7	32	148 100 31	NW1/4	143.1	52	147 104 22	SW1/4	159.0
13	152 097 10	NE1/4	156.6	33	148 100 11	SW1/4	159.0	53	145 103 31	NE1/4	157.9
14	146 105 11	NE1/4	159.4	34	145 098 09	SE1/4	162.4	54	148 102 15	NW1/4	160.4
15	149 103 23	SE1/4	159.1	35	147 104 34	SW1/4	159.8	55	147 104 21	NW1/4	160.2
16	152 097 29	NE1/4	159.0	36	145 098 03	NW1/4	157.3	56	148 105 35	SW1/4	159.6
17	145 105 24	SE1/4	159.3	37	153 094 23	SW1/4	157.1	57	152 097 04	SW1/4	191.7
18	145 105 11	SW1/4	158.8	38	146 105 25	SW1/4	161.8	58	148 104 22	NW1/4	158.9
19	149 103 02	SW1/4	159.5	39	147 103 31	SE1/4	144.4	59	148 104 27	SW1/4	158.4
20	145 104 32	NW1/4	160.3	40	146 104 15	NW1/4	159.5	60	145 104 12	SE1/4	159.6

[1] Legal description includes Township Range, and Section.

Table A2. Densities (breeding pairs / 100 ha) averaged across years of 82 bird species observed during surveys conducted on the Little Missouri National Grassland between 23 May to 25 July 2014 and 19 May to 17 July 2015. The species are in taxonomic order.

Scientific name	Common name	Alpha code	Average densities (pairs per 100 ha)
Cathartes aura	Turkey vulture	TUVU	0.047
Anas strepera	Gadwall	GADW	0.007
Anas americana	American wigeon	AMWI	0.013
Anas platyrhynchos	Mallard	MALL	0.053
Anas discors	Blue-winged teal	BWTE	0.026
Aythya valisineria	Canvasback	CANV	0.052
Circus cyaneus	Northern harrier	NOHA	0.157
Buteo swainsoni	Swainson's hawk	SWHA	0.113
Buteo jamaicensis	Red-tailed hawk	RTHA	0.072
Aquila chrysaetos	Golden eagle	GOEA	0.013
Falco sparverius	American kestrel	AMKE	0.230
Falco mexicanus	Prairie falcon	PRFA	0.007
Perdix perdix	Gray partridge	GRPA	0.007
Phasianus colchicus	Ring-necked pheasant	RPHE	0.217
Tympanuchus phasianellus	Sharp-tailed grouse	STGR	1.701
Meleagris gallopavo	Wild turkey	WITU	0.040
Charadrius vociferus	Killdeer	KILL	0.375
Bartramia longicauda	Upland sandpiper	UPSA	1.228
Limosa fedoa	Marbled godwit	MAGO	0.013
Gallinago delicata	Wilson's snipe	WISN	0.026
Columba livia	Rock dove	RODO	0.099
Zenaida macroura	Mourning dove	MODO	2.276
Bubo Virginianus	Great horned owl	GHOW	0.013
Athene cunicularia	Burrowing owl	BUOW	0.027
Asio flammeus	Short-eared owl	SEOW	0.014
Chordeiles minor	Common nighthawk	CONI	0.293
Colaptes auratus	Northern flicker	NOFL	0.641
Empidonax trailii	Willow flycatcher	WIFL	0.005
Empidonax minimus	Least flycatcher	LEFL	0.236
Sayornis saya	Say's phoebe	SAPH	0.046
Tyrannus verticalis	Western kingbird	WEKI	0.300
Tyrannus tyrannus	Eastern kingbird	EAKI	2.177
Lanius ludovicianus	Loggerhead shrike	LOSH	0.196
Vireo gilvus	Warbling vireo	WAVI	0.006
Cyanocitta cristata	Blue jay	BLJA	0.006

Table A2. Densities (breeding pairs / 100 ha) averaged across years of 82 bird species observed during surveys conducted on the Little Missouri National Grassland between 23 May to 25 July 2014 and 19 May to 17 July 2015 (continued). The species are in taxonomic order.

Scientific name	Common name	Alpha code	Average densities (pairs per 100 ha)
Pica pica	Black-billed magpie	BBMA	0.276
Corvus brachyrhynchos	American crow	AMCR	0.133
Eremophila alpestris	Horned lark	HOLA	1.848
Tachycineta bicolor	Tree swallow	TRES	0.111
Riparia riparia	Bank swallow	BANS	0.006
Petrochelidon pyrrhonota	Cliff swallow	CLSW	0.014
Hirundo rustica	Barn swallow	BARS	0.274
Poecile atricapillus	Black-capped chickadee	BCCH	0.013
Salpinctes obsoletus	Rock wren	ROWR	0.065
Troglodytes aedon	House wren	HOWR	0.984
Sialia sialis	Eastern bluebird	EABL	0.014
Sialia currucoides	Mountain bluebird	MOBL	0.034
Turdus migratorius	American robin	AMRO	0.334
Dumetella carolinensis	Gray catbird	GRCA	0.566
Toxostoma rufum	Brown thrasher	BRTH	0.791
Sturnus vulgaris	European starling	EUST	0.020
Anthus spragueii	Sprague's pipit	SPPI	1.606
Bombycilla cedrorum	Cedar waxwing	CEDW	0.148
Setophaga petechia	Yellow warbler	YWAR	2.544
Geothlypis trichas	Common yellowthroat	COYE	0.452
Icteria virens	Yellow-breasted chat	YBCH	0.279
Pipilo maculatus	Spotted towhee	SPTO	2.339
Spizella passerina	Chipping sparrow	CHSP	0.013
Spizella pallida	Clay-colored sparrow	CCSP	3.321
Spizella pusilla	Field sparrow	FISP	2.270
Pooecetes gramineus	Vesper sparrow	VESP	6.805
Chondestes grammacus	Lark sparrow	LASP	0.351
Calamospiza melanocorys	Lark bunting	LARB	0.010
Passerculus sandwichensis	Savannah sparrow	SAVS	0.759
Ammodramus savannarum	Grasshopper sparrow	GRSP	30.924
Ammodramus bairdii	Baird's sparrow	BAIS	1.307
Melospiza melodia	Song sparrow	SOSP	0.013
Calcarius ornatus	Chestnut-collared longspur	CCLO	1.665
Pheucticus melanocephalus	Black-headed grosbeak	BHGR	0.013
Passerina amoena	Lazuli bunting	LAZB	0.053

Table A2. Densities (breeding pairs / 100 ha) averaged across years of 82 bird species observed during surveys conducted on the Little Missouri National Grassland between 23 May to 25 July 2014 and 19 May to 17 July 2015 (continued). The species are in taxonomic order.

Scientific name	Common name	Alpha code	Average densities (pairs per 100 ha)
Spiza americana	Dickcissel	DICK	0.020
Dolichonyx oryzivorus	Bobolink	BOBO	4.224
Agelaius phoeniceus	Red-winged blackbird	RWBL	0.942
Sturnella neglecta	Western meadowlark	WEME	22.529
Xanthocephalus xanthocephalus	Yellow-headed blackbird	YHBL	0.003
Euphagus cyanocephalus	Brewer's blackbird	BRBL	0.567
Quiscalus quiscula	Common grackle	COGR	0.152
Molothrus ater	Brown-headed cowbird	BHCO	1.826
Icterus spurius	Orchard oriole	OROR	0.033
Icterus galbula	Baltimore oriole	BAOR	0.013
Icterus bullockii	Bullock's oriole	BUOR	0.019
Spinus tristis	American goldfinch	AMGO	0.492

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value. The species are in alphabetical order.

Scientific name	Common name	C[1]	Origin	Physiognomy
Achillea millefolium subsp. lanulosa	Yarrow	3	Native	FORB
Agoseris glauca	False dandelion	8	Native	FORB
Agropyron caninum subsp. subsecundus	N/A	6	Native	GRASS
Agropyron caninum subsp. trachycaulus	Slender wheatgrass	6	Native	GRASS
Agropyron cristatum	Crested wheatgrass	*	Introduced	GRASS
Agrostis hyemalis	Ticklegrass	1	Native	GRASS
Allium textile	White wild onion	7	Native	FORB
Ambrosia psilostachya	Western ragweed	2	Native	FORB
Amorpha canescens	Lead plant	9	Native	SHRUB
Andropogon gerardii	Big bluestem	5	Native	GRASS
Andropogon hallii	Sand bluestem	5	Native	GRASS
Androsace occidentalis	Western rock jasmine	5	Native	FORB
Andropogon scoparius	Little bluestem	6	Native	GRASS
Anemone canadensis	Meadow anemone	4	Native	FORB
Anemone cylindrica	Candle anemone	7	Native	FORB
Anemone patens	Pasque flower	9	Native	FORB
Antennaria neglecta	Field pussy-toes	5	Native	FORB
Arabis hirsuta var. pycnocarpa	Rock cress	7	Native	FORB
Arabis holboellii var. collinsii	Rock cress	5	Native	FORB
Aristida purpurea var. robusta	Red three-awn	4	Native	GRASS
Arnica fulgens	Arnica	10	Native	FORB
Artemisia cana	Dwarf sagebrush	7	Native	SHRUB
Artemisia dracunculus	Silky wormwood	4	Native	FORB
Artemisia frigida	Prairie sagewort	4	Native	SHRUB
Artemisia ludoviciana var. ludoviciana	White sage	3	Native	FORB
Asclepias verticillata	Whorled milkweed	3	Native	FORB
Asclepias viridiflora	Green milkweed	8	Native	FORB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C[1]	Origin	Physiognomy
Astragalus adsurgens var. robustior	Standing milk-vetch	8	Native	FORB
Astragalus agrestis	Field milk-vetch	6	Native	FORB
Astragalus crassicarpus var. crassicarpus	Ground-plum	7	Native	FORB
Astragalus flexuosus	Pliant milk-vetch	4	Native	FORB
Astragalus gilviflorus	Plains orophaca	7	Native	FORB
Astragalus gracilis	Slender milk-vetch	8	Native	FORB
Astragalus lotiflorus	Lotus milk-vetch	6	Native	FORB
Aster oblongifolius	Aromatic aster	8	Native	FORB
Astragalus tenellus	Pulse milk-vetch	8	Native	FORB
Atriplex nuttallii	Moundscale	6	Native	SHRUB
Bouteloua curtipendula	Sideoats grama	5	Native	GRASS
Bouteloua gracilis	Blue grama	7	Native	GRASS
Bromus inermis	Smooth brome	*	Introduced	GRASS
Bromus japanicus	Japanese brome	*	Introduced	GRASS
Bromus squarrosus	Nodding brome	*	Introduced	GRASS
Buchloe dactyloides	Buffalo grass	4	Native	GRASS
Calamovilfa longifolia	Prairie sandreed	5	Native	GRASS
Calylophus serrulatus	Plains yellow primrose	7	Native	FORB
Camelina microcarpa	Small-seeded false flax	*	Introduced	FORB
Campanula rotundifolia	Harebell	7	Native	FORB
Cerastium arvense	Prairie chickweed	2	Native	FORB
Cerastium brachypodum	N/A	1	Native	FORB
Ceratoides lanata	White sage, Winter fat	8	Native	SHRUB
Chenopodium album	Lamb's quarters	*	Introduced	FORB
Chrysothamnus nauseosus subsp. nauseosus	Rabbit brush	4	Native	SHRUB
Chrysopsis villosa var. villosa	Golden aster	3	Native	FORB
Cirsium arvense	Canada thistle, Field thistle	*	Introduced	FORB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C[1]	Origin	Physiognomy
Cirsium flodmanii	Flodman's thistle	5	Native	FORB
Cirsium undulatum	Wavy-leaf thistle	7	Native	FORB
Cirsium vulgare	Bull thistle	*	Introduced	FORB
Collomia linearis	Collomia	5	Native	FORB
Comandra umbellata	N/A	8	Native	FORB
Convolvulus arvensis	Field bindweed	*	Introduced	FORB
Conyza canadensis	Horseweed	0	Native	FORB
Conyza ramosissima	Spreading fleabane	0	Native	FORB
Coryphantha vivipara	Pincushion cactus	10	Native	FORB
Carex brevior	Fescue sedge	4	Native	SEDGE
Carex eleocharis	Needleleaf sedge	4	Native	SEDGE
Carex filifolia	Thread-leaved sedge	7	Native	SEDGE
Carex heliophila	N/A	7	Native	SEDGE
Carex prairea	N/A	10	Native	SEDGE
Dalea candida var. candida	White prairie-clover	8	Native	FORB
Dalea purpurea var. purpurea	Purple prairie clover	8	Native	FORB
Descurainia sophia	Flixweed	*	Introduced	FORB
Dichanthelium wilcoxianum	Wilcox dichanthelium	8	Native	GRASS
Distichlis spicata var. stricta	Inland saltgrass	2	Native	GRASS
Echinacea angustifolia	Purple coneflower	7	Native	FORB
Echinochloa crusgalli	Barnyard grass	*	Introduced	GRASS
Elymus repens	Quackgrass	*	Introduced	GRASS
Equisetum laevigatum	Smooth scouring rush	3	Native	FERN
Erigeron annuus	Annual fleabane	3	Native	FORB
Eriogonum flavum	Yellow wild buckwheat	7	Native	FORB
Eriogonum pauciflorum var. pauciflorum	N/A	5	Native	FORB
Erigeron strigosus	Daisy fleabane	3	Native	FORB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C[1]	Origin	Physiognomy
Erucastrum gallicum	Dog mustard	*	Introduced	FORB
Erysimum asperum	Western wallflower	3	Native	FORB
Erysimum inconspicuum	Smallflower wallflower	7	Native	FORB
Euphorbia glyptosperma	Ridge-seeded spurge	0	Native	FORB
Euphorbia spathulata	N/A	5	Native	FORB
Festuca octoflora	Sixweeks fescue	0	Native	GRASS
Festuca scabrella	Rough fescue	8	Native	GRASS
Fraxinus pennsylvanica	Red ash, Green ash	5	Native	TREE
Gaillardia aristata	Blanket flower	5	Native	FORB
Galium aparine	Catchweed bedstraw	0	Native	FORB
Galium boreale	Northern bedstraw	4	Native	FORB
Gaura coccinea	Scarlet gaura	4	Native	FORB
Geum triflorum	Torch flower, Maidenhair	8	Native	FORB
Glycyrrhiza lepidota	Wild licorice	2	Native	FORB
Gnaphalium palustre	Diffuse cudweed	3	Native	FORB
Grindelia squarrosa var. quasiperennis	Curly-top gumweed	1	Native	FORB
Gutierrezia sarothrae	Snakeweed	6	Native	SHRUB
Haplopappus spinulosus	Cutleaf ironplant	7	Native	FORB
Hedeoma hispidum	Rough false pennyroyal	2	Native	FORB
Helictotrichon hookeri	Spike oat	9	Native	GRASS
Helianthus maximilianii	Maximilian sunflower	5	Native	FORB
Helianthus rigidus subsp. subrhomboideus	Stiff sunflower	8	Native	FORB
Hesperostipa comata	Needle-and-thread	6	Native	GRASS
Hesperostipa spartea	Porcupine-grass	8	Native	GRASS
Heuchera richardsonii	Alumroot	8	Native	FORB
Hordeum jubatum	Foxtail barley	0	Native	GRASS
Hymenoxys acaulis	Stemless hymenoxys	6	Native	FORB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C[1]	Origin	Physiognomy
Hymenopappus tenuifolius	Slimleaf hymenopappus	8	Native	FORB
Juniperus communis	Dwarf juniper	5	Native	SHRUB
Juniperus horizontalis	Creeping Juniper	6	Native	SHRUB
Juncus interior	Inland rush	5	Native	FORB
Juniperus scopulorum	Rocky mountain juniper	4	Native	TREE
Juniperus virginiana	Red cedar	0	Native	TREE
Kochia scoparia	Kochia, Fire-weed	*	Introduced	FORB
Koeleria pyramidata	Junegrass	7	Native	GRASS
Lactuca oblongifolia	Blue lettuce	1	Native	FORB
Lepidium densiflorum	Peppergrass	0	Native	FORB
Liatris punctata	Blazing star	7	Native	FORB
Lilium philadelphicum	Wild lily	8	Native	FORB
Linum perenne var. lewisii	Blue flax	6	Native	FORB
Linum rigidum var. rigidum	Stiffstemflax	5	Native	FORB
Lithospermum incisum	Narrow-leaved puccoon	7	Native	FORB
Lotus purshianus	Prairie trefoil, Deer vetch	3	Native	FORB
Lygodesmia juncea	Skeletonweed	2	Native	FORB
Medicago lupulina	Black medick	*	Introduced	FORB
Medicago sativa	Alfalfa	*	Introduced	FORB
Melilotus alba	White sweet clover	*	Introduced	FORB
Melilotus officinalis	Yellow sweet clover	*	Introduced	FORB
Mirabilis linearis	Narrowleaf four-o'clock	7	Native	FORB
Monarda fistulosa var. fistulosa	Wild bergamot	5	Native	FORB
Muhlenbergia cuspidata	Plains muhly	8	Native	GRASS
Nassella viridula	Green needlegrass	5	Native	GRASS
Oenothera albicaulis	Prairie evening primrose	5	Native	FORB
Oenothera biennis	Common evening primrose	0	Native	FORB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C[1]	Origin	Physiognomy
Oenothera nuttallii	White-stemmed evening primrose	8	Native	FORB
Opuntia fragilis	Little prickly pear	5	Native	SHRUB
Opuntia polyacantha	Plains prickly pear	3	Native	SHRUB
Orthocarpus luteus	Owl clover	6	Native	FORB
Oxalis stricta	Yellow wood sorrel	0	Native	FORB
Oxytropis lambertii	Purple locoweed	5	Native	FORB
Pascopyron smithii	Western wheatgrass	4	Native	GRASS
Penstemon gracilis	Slender beardtongue	6	Native	FORB
Phlox hoodii	Hood's phlox	6	Native	FORB
Plantago eriopoda	Alkali plantain	5	Native	FORB
Plantago patagonica	Patagonian plantain	1	Native	FORB
Poa compressa	Canada bluegrass	*	Introduced	GRASS
Poa palustris	Fowl bluegrass	4	Native	GRASS
Poa pratensis	Kentucky bluegrass	*	Introduced	GRASS
Poa sandbergii	Sandberg's bluegrass	8	Native	GRASS
Potentilla gracilis	Cinquefoil	5	Native	FORB
Polygala alba	White milkwort	5	Native	FORB
Polygonum convolvulus	Wild buckwheat	*	Introduced	FORB
Polygonum erectum	Erect knotweed	0	Native	FORB
Polygonum ramosissimum	Bushy knotweed	3	Native	FORB
Polygala verticillata	Whorled milkwort	8	Native	FORB
Potentilla arguta	Tall cinquefoil	8	Native	FORB
Potentilla pensylvanica	Cinquefoil	9	Native	FORB
Prunus americana	Wild plum	4	Native	SHRUB
Prunus virginiana	Choke cherry	4	Native	SHRUB
Psoralea argophylla	Silver-leaf scurf-pea	4	Native	FORB
Psoralea esculenta	Breadroot scurf-pea	9	Native	FORB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Scientific name	Common name	C[1]	Origin	Physiognomy
Ratibida columnifera	Prairie coneflower	3	Native	FORB
Rhus aromatica	Fragrant sumac, Polecat bush	7	Native	SHRUB
Rosa arkansana	Prairie wild rose	3	Native	SHRUB
Salsola iberica	Russian thistle, Tumbleweed	*	Introduced	FORB
Schedonnardus paniculatus	Tumblegrass	1	Native	GRASS
Selaginella densa	Small clubmoss	6	Native	FERN
Senecio plattensis	Prairie ragwort	6	Native	FORB
Shepherdia argentea	Buffaloberry	5	Native	SHRUB
Sisymbrium altissimum	Tumbling mustard	*	Introduced	FORB
Sisyrinchium campestre	White-eyed grass	10	Native	FORB
Solidago canadensis var. canadensis	Canada goldenrod	1	Native	FORB
Solidago missouriensis	Prairie goldenrod	5	Native	FORB
Solidago mollis	Soft goldenrod	6	Native	FORB
Solidago ptarmicoides	Sneezewort aster	8	Native	FORB
Solidago rigida	Rigid goldenrod	4	Native	FORB
Sphaeralcea coccinea	Red false mallow	4	Native	FORB
Spiraea alba	Meadow-sweet	7	Native	SHRUB
Sporobolus cryptandrus	Sand dropseed	6	Native	GRASS
Symphoricarpos occidentalis	Western snowberry	3	Native	SHRUB
Symphyotrichum ericoides	White aster	2	Native	FORB
Symphyotrichum falcatus	N/A	4	Native	FORB
Symphyotrichum laeve var. geyeri	Smooth blue aster	5	Native	FORB
Taraxacum officinale	Common dandelion	*	Introduced	FORB
Thalictrum dasycarpum	Purple meadow rue	7	Native	FORB
Thermopsis rhombifolia	Prairie buck bean, Yellow pea	6	Native	FORB
Thlaspi arvense	Field pennycress	*	Introduced	FORB
Toxicodendron rydbergii	Poison ivy	3	Native	SHRUB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A3. Plant species observed on 171 modified Whittaker plots on 57 study sites in the Little Missouri National Grassland, 2014 and 2015. Floristic composition was measured only once in the two field seasons, one-half of the study sites in the first year and one-half during the second year. Non-native species are not assigned a C value (continued). The species are in alphabetical order.

Tradescantia bracteata	Spiderwort	7	Native	FORB
Tragopogon dubius	Goat's beard	*	Introduced	FORB
Verbena bracteata	Prostrate vervain	0	Native	FORB
Vicia americana var. americana	American vetch	6	Native	FORB
Viola pedatifida	Prairie violet, Larkspur-violet	8	Native	FORB
Yucca glauca	Yucca	6	Native	SHRUB

[1] Coefficients of conservatism (C values) developed for North and South Dakota.

Table A4. Summary of average measurements of vegetation composition variables on 57 sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015.

Site	FQI	Total species	Native species	Non-native species	% Native	% Non-native
1	42.1	74	68	6	91.9	8.1
2	30.9	58	47	11	81.0	19.0
3	32.5	50	43	7	86.0	14.0
4	40.4	58	54	4	93.1	6.9
5	36.9	69	59	10	85.5	14.5
6	23.4	35	27	8	77.1	22.9
7	47.4	87	77	10	88.5	11.5
8	30.8	50	43	7	86.0	14.0
9	34.6	59	50	9	84.7	15.3
10	38.2	63	56	7	88.9	11.1
11	30.4	46	40	6	87.0	13.0
12	30.5	52	42	10	80.8	19.2
13	46.5	84	74	10	88.1	11.9
14	28.1	44	33	11	75.0	25.0
15	35.5	63	57	6	90.5	9.5
17	40.5	67	63	4	94.0	6.0
18	31.8	48	39	9	81.3	18.8
19	38.3	68	61	7	89.7	10.3
20	42.5	71	62	9	87.3	12.7
22	35.4	58	50	8	86.2	13.8
23	29.6	47	38	9	80.9	19.1
24	32.4	56	52	4	92.9	7.1
25	38.8	62	58	4	93.5	6.5
26	38.5	66	57	9	86.4	13.6
27	34.6	53	48	5	90.6	9.4
28	40.5	70	63	7	90.0	10.0
29	39.3	57	53	4	93.0	7.0
30	42.7	69	65	4	94.2	5.8
31	32.9	56	47	9	83.9	16.1
32	35.0	58	51	7	87.9	12.1
33	40.1	76	67	9	88.2	11.8
34	43.5	80	70	10	87.5	12.5
35	47.9	87	76	11	87.4	12.6
36	49.2	87	80	7	92.0	8.0
37	51.0	90	83	7	92.2	7.8
38	45.4	73	68	5	93.2	6.8
39	45.7	75	69	6	92.0	8.0
40	30.2	37	35	2	94.6	5.4
41	41.3	71	63	8	88.7	11.3

Table A4. Summary of average measurements of vegetation composition variables on 57 sites in the Little Missouri National Grassland in western North Dakota, 2014 and 2015 (continued).

Site	FQI	Total species	Native species	Non-native species	% Native	% Non-native
42	38.2	62	56	6	90.3	9.7
43	41.9	69	65	4	94.2	5.8
44	46.8	83	78	5	94.0	6.0
45	48.3	89	80	9	89.9	10.1
46	49.2	90	86	4	95.6	4.4
47	39.6	64	58	6	90.6	9.4
48	45.4	71	68	3	95.8	4.2
49	30.2	46	35	11	76.1	23.9
50	46.1	79	73	6	92.4	7.6
51	39.9	71	59	12	83.1	16.9
52	44.7	79	71	8	89.9	10.1
54	31.2	60	48	12	80.0	20.0
55	43.8	64	59	5	92.2	7.8
56	34.2	49	45	4	91.8	8.2
57	52.2	92	87	5	94.6	5.4
58	38.1	71	63	8	88.7	11.3
59	46.3	83	71	12	85.5	14.5
60	43.5	76	70	6	92.1	7.9