Diversity in selection patterns of five grassland songbirds in dry-mixed grasslands of Alberta

Julie P. N. Landry-DeBoer 1, Paul F. Jones 1, Brad A. Downey 1, Phillip K. Rose 1, Katheryn Taylor 2, Mike S. Verhage 1, Amanda M. MacDonald 1 and Adam J. Moltzahn 1

1Alberta Conservation Association, 2Prairie Conservation Forum

ABSTRACT. Declining grassland bird populations across North America continue to be a concern. Understanding local relationships between grassland bird abundance and vegetative and landscape characteristics will enable more prescriptive recommendations to be made to land managers. We used point count survey data collected by the MULTISAR (Multiple Species At Risk) program along with field measurements of habitat and landscape characteristics on 15 ranches in the Dry Mixed-grass Subregion in southern Alberta to improve our understandings of habitat relationships for five grassland bird species: Baird’s Sparrow (Centronyx bairdii), Sprague’s Pipit (Anthus spragueii), Thick-billed Longspur (Rhynchophanes mccownii), Chestnut-collared Longspur (Calcarius ornatus), and Grasshopper Sparrow (Ammodramus savannarum). We used generalized linear mixed models to examine the relationship between the predicted abundance of a species and covariates that represented vegetative structure (e.g., litter), management (e.g., range health), and anthropogenic features (e.g., energy development) of habitat site selection. Model results demonstrate four vegetation structure covariates were of most importance for predicting abundance, including litter, vegetation height, bare soil, and shrub cover. Quadratic relationships were found with litter amounts for the predicted abundance of Baird’s Sparrow, Chestnut-collared Longspur, and Grasshopper Sparrow. Contrastingly, higher amounts of litter reduced the predicted abundance of Thick-billed Longspur. The relationship of vegetation height was quadratic for Sprague’s Pipit and was positive for Baird’s Sparrow, but negative for Thick-billed Longspur. As bare soil percentage increased, the predicted abundance of Baird’s Sparrow and Chestnut-collared Longspur decreased, with Sprague’s Pipit showing a quadratic association. Negative relationships were found with increased amounts of shrub cover for Chestnut-collared Longspur, Sprague’s Pipit, and Thick-billed Longspur. Our results help to further understand individual grassland bird species’ habitat requirements, enabling us to provide land management recommendations for maintaining, improving, or creating the heterogenic environments needed for a variety of grassland birds in the Dry Mixed-grass Subregion.

Diversité des tendances de sélection chez cinq passereaux de prairies mixtes sèches de l’Alberta

RÉSUMÉ. Le déclin des populations d’oiseaux de prairies en Amérique du Nord reste préoccupant. La compréhension des relations locales entre l’abondance des oiseaux de prairies et les caractéristiques de la végétation et du paysage permettra de formuler des recommandations plus normatives à l’intention des gestionnaires de terres. Nous avons utilisé des données de dénombrement d’oiseaux recueillies dans le cadre du programme MULTISAR (Multiple Species At Risk) ainsi que des mesures sur le terrain de caractéristiques de l’habitat et du paysage dans 15 ranches de la sous-région de prairies mixtes sèches dans le sud de l’Alberta pour améliorer notre compréhension des relations entre l’habitat et cinq espèces d’oiseaux de prairies : le Bruant de Baird (Centronyx bairdii), le Pipit de Sprague (Anthus spragueii), le Plectrophane de McCown (Rhynchophanes mccownii), le Plectrophane à ventre noir (Calcarius ornatus) et le Bruant sauterelle (Ammodramus savannarum). Nous avons utilisé des modèles linéaires généralisés à effets mixtes pour examiner la relation entre l’abondance prédite d’une espèce et des covariables représentant la structure de la végétation (p. ex. la litière), l’aménagement (p. ex. la qualité de l’habitat) et les caractéristiques anthropogéniques (p. ex. le développement énergétique) de la sélection des sites d’habitat. Les résultats des modèles ont indiqué que quatre covariables de la structure de la végétation étaient les plus importantes pour prédire l’abondance, à savoir la litière, la hauteur de la végétation, le sol nu et la couverture arbustive. Nous avons trouvé des relations quadratiques avec la quantité de litière pour l’abondance prédite du Bruant de Baird, du Plectrophane à ventre noir et du Bruant sauterelle. En revanche, l’abondance prédite du Plectrophane de McCown était plus faible avec une quantité plus grande de litière. La relation de la hauteur de la végétation était quadratique pour le Pipit de Sprague et positive pour le Bruant de Baird, mais négative pour le Plectrophane de McCown. Lorsque la porosité du sol augmentait, l’abondance prédite du Bruant de Baird et du Plectrophane à ventre noir diminuait, tandis que le Pipit de Sprague présentait une association quadratique. Des relations négatives ont été constatées avec l’augmentation du couvert arbustif pour le Plectrophane à ventre noir, le Pipit de Sprague et le Plectrophane de McCown. Nos résultats aident à mieux comprendre les besoins en matière d’habitat des différentes espèces d’oiseaux de prairies, ce qui nous permet de formuler des recommandations en matière de gestion des terres pour maintenir, améliorer ou créer les environnements hétérogènes nécessaires à une variété d’oiseaux de prairies dans la sous-région de prairies mixtes sèches.

Key Words: anthropogenic features; dry-mixed grass; grassland birds; point count; predicted abundance; range health; structure; vegetation structure

Corresponding author: Julie P. N. Landry-DeBoer, julie.landry-deboer@ab-conservation.com
INTRODUCTION

Across North America, grassland birds are the fastest declining assemblage of birds, with losses equaling more than 700 million individuals (Rosenberg et al. 2019). As of 2019, more than 40 wildlife species found in southern Alberta, including multiple grassland birds, are included on the formal list of species at risk of the Canadian Species at Risk Act (SARA 2002, Schedule 1). Habitat loss and degradation of breeding and non-breeding grounds are thought to be primary threats to our grassland bird populations (Knopf 1994, Macias-Duarte et al. 2017).

Grassland bird species selected for this work are considered native grassland specialists and may be more sensitive to changes in habitat management decisions. As such, gaining an understanding of resource use patterns and drivers of abundance has become a conservation priority for many bird species (Henderson and Davis 2014, Yoo and Koper 2017, Londe et al. 2019, Boyce et al. 2021, Rose et al. 2021).

Our objective was to examine the resource use patterns of five native grassland bird species on their breeding grounds on the Dry Mixed-grass Subregion of the Grassland Natural Region of Alberta, Canada. This subregion is of great importance because this area of the province provides habitat to many plant and wildlife species that are considered at risk in Alberta (Natural Regions Committee 2006). Although there is a growing body of work related to grassland bird habitat requirements, there are limited studies specific to the Dry Mixed-grass Subregion.

The grassland bird species selected for this work are considered native grassland specialists and may be more sensitive to changes and stressors on the landscape than generalists (Staude et al. 2021). The species are considered at-risk in Canada federally or are a species at-risk provincially on the basis of their Alberta Wild Species General Status Listing (SARA 2002, Government of Alberta [GOA] 2015). Specifically, we looked at Baird’s Sparrow (Centronyx bairdii; special concern), Grasshopper Sparrow (Ammodramus savannarum; sensitive), Chestnut-collared Longspur (Calcarius ornatus; threatened), Thick-billed Longspur (Rhynchophanes niviceps; threatened), and Sprague’s Pipit (Anthus spragueii; threatened).

We used an information theoretic approach to assess three hypotheses describing variation in grassland bird predicted abundance in the Dry Mixed-grass Subregion. Of particular interest was determining how different suites of environmental variables, including not only components of vegetation structure (e.g., litter, vegetation height) but also components of the landscape, such as anthropogenic features (e.g., roads, energy development) and management elements (e.g., range health), shape species’ abundance within this subregion. We predicted that vegetation structure elements would be important for each species because structure has previously been shown to be important for grassland birds (Madden et al. 2000, Henderson and Davis 2014, Hovick et al. 2014). Of the vegetation structure covariates we modeled, we predicted that litter and vegetation height would be important predictors of abundance for each species, although the relationship would vary by species (e.g., positive for Sprague’s Pipit and negative for Thick-billed Longspur). In addition, we predicted that the management covariates would intermittently be retained in final models on a species-by-species case because previous research has found that they predict abundance for certain species but not for others (Davis et al. 2014, Henderson and Davis 2014). For example, it has been previously documented that anthropogenic features, such as ones connected with natural resource extraction and distribution (oil and gas), may directly and indirectly affect wildlife, especially those species already affected by habitat loss and/or alteration (Hovick et al. 2014).

Resource extraction sites are scattered throughout Alberta with an estimated 162,500 active wells, 97,000 inactive wells, and 71,000 abandoned wells (GOA 2020). Grassland birds’ response to anthropogenic features (e.g., roads, oil and gas well densities) has varied, with some species selecting areas close to disturbance, others avoiding disturbed areas, and others showing no response to disturbance (Sutter et al. 2000, Bogard et al. 2014, Ludlow et al. 2015, Yoo and Koper 2017, Londe et al. 2019). Therefore, we predicted that covariates representing anthropogenic features would be retained in the final model for select species (e.g., Chestnut-collared Longspur, Thick-billed Longspur, and Grasshopper Sparrow), and if retained, the relationship would be negative, indicating abundance would decrease as the level of disturbance increased. With habitat use information determined for our five species, we aim to recommend beneficial management practices to conserve habitat. These recommendations will assist concerted efforts and partnerships between conservation groups and landholders in the conservation of grassland bird habitat. If grassland bird species continue to decline, retaining suitable landscapes is increasingly valuable (Henderson and Davis 2014, Jones et al. 2019).

METHODS

Study area
For this study, we explored the area within the Milk River and South Saskatchewan drainage basins and the internally drained Pakowki Lake basin. These basins fall within the Dry Mixed-grass Subregion in the Grassland Natural Region (46,937 km²; Adams et al. 2013). The region has flat to slightly rolling topography, at times broken up by coulees and river valleys, and is predominantly warmer and drier than the other subregions (Alberta Parks 2015). This area has brown Chernozemic and Solonetzic soils and the dominant grass species are needle and thread (Hesperostipa comata) and blue grama (Bouteloua gracilis; Adams et al. 2013). Land use for this area is predominantly cattle ranching, agricultural crop farming, and oil and gas development. We analyzed data collected from 15 different ranches ranging in size from 327 to 25,111 hectares (mean size of 7826 ha). Although many of our participating ranches also have tame grass pastures or cropland, we restricted our analysis exclusively to their native grass rangelands.

Data collection
We used data collected through the MULTISAR (Multiple Species At Risk; http://multisar.ca) program, which works closely with landowners and land managers in Alberta’s grasslands. The program has a primary focus of striving for multispecies conservation at a landscape level while simultaneously aiming to benefit ranching operations (Jones et al. 2019). Like other programs (e.g., Wyoming Partners in Flight 2002, Hyde and
Campbell 2012), MULTISAR promotes habitat heterogeneity to benefit the greatest number of species. Multi-species point counts and range assessments have been conducted on properties over the last 20 years, resulting in thousands of point counts and range assessments. For our study, we pulled information from MULTISAR’s large dataset to investigate associations with our five grassland bird species. For consistency, we used data from one year only for each ranch in our analysis, even if we may have surveyed a property for multiple years.

**Point count data**

Prior to completing any point counts, we used ArcMap (ArcGIS 10.6.1, Esri 2018) to map selected properties, along with their associated fence lines, roads, trails, and water bodies. We applied the Alberta Grassland Vegetation Inventory (GVI) range site polygons to the maps as base survey units. These delineated landscape polygons provide information on biophysical, soil, anthropogenic, and land-use features for portions of Alberta and was built by using digital color-infrared stereo photography with 0.4-meter resolution and at a scale of 1:10,000 (Alberta Environment and Parks 2011). We randomly placed wildlife point counts within GVI polygons, ensuring that each point count radius did not overlap another GVI polygon boundary, neighboring point count locations (minimum distance apart: 200 m), fence lines, or major roads. Depending on the size of the GVI polygon, a 50-, 100-, or 200-m point count radius was employed.

Experienced bird surveyors, trained on standardized survey methods (GOA 2013) to help reduce surveyor bias, conducted point counts, one time at each location. We conducted surveys during the breeding season between the middle of May and the first week of July in the years 2013–2018. We completed point counts in a random order on a property, with several biologists surveying different parts of each property at the same time to reduce the chance of double-counting the same birds. To further standardize detection, we conducted surveys on days with no precipitation and only between one half-hour before sunrise (usually close to 5 AM) and 9:30 AM. Because of the frequency of windy conditions in southern Alberta, we deviation slightly from the recommended wind speed thresholds outlined in standard point count protocols and allowed surveys to be completed in conditions with wind speeds up to 30 km/hr (avoiding this high end when possible). When staff arrived at a point count location, a two-minute acclimation period was required to minimize the effect of the surveyor’s presence at the site. We estimated distance to songbirds (seen or heard) at each point count during point count surveys. The measurement was taken at a representative location closest to the center of the point count to quantify the amount of visual obstruction or vegetation height at the site. We used a Robel pole made of a PVC pipe marked with tape at 10 cm intervals. The single visual measurement was always taken from a four-meter extension (a string attached to the PVC pipe) and looking toward the west cardinal direction. All vegetation height measurements were taken from an eye-level of one meter above the ground, and we recorded how much of the pole was completely obstructed by vegetation.

In addition, we compiled vegetative habitat data from the MULTISAR program’s range data collected by range agrologists trained in Alberta standardized protocols (Willoughby 2007). GVI polygons were used as the basic unit of interpretation for vegetation, range site, and habitat descriptions for our range surveys. Once in the field, GVI boundaries were verified and adjusted as needed for analysis. As part of the range assessment, agrologists completed a range health assessment following the protocol of Adams et al. (2016). Data collected during the range health assessment formed the basis of our vegetation data. Specifically, plant composition and community type were determined by percent grass and forb foliar cover (estimated by using a Daubenmire frame [0.1 m²]) and percent shrub (estimated by using a 1 m² frame within a representative area in the polygon). Bare soil (percent) was estimated at the Daubenmire frame level as well as assessed in the general area of the range assessment. On average, forb, shrub, and bare soil estimates were completed in five to 10 Daubenmire frames, depending on whether a detailed transect (50 m transect with a frame every five meters) or a range health assessment was completed at the site. Litter mass (kg/ha) estimates were derived by collecting litter within one to three 0.25 m² frames and then comparing values to a visual reference chart that extrapolated litter amounts for native grassland communities (Adams et al. 2016). All information was used to determine the plant community for the individual GVI polygons and calculate range health scores. Range health for our purpose represents the ability of the site to be productive, maintain soil stability, capture and release water, and provide nutrients to diverse plant communities (Adams et al. 2016). We calculated range health scores according to the protocol of Adams et al. (2016), with scores ranging from 0% to 100%. All range data captured were then assigned to each respective GVI polygon assessed for each property. We believe that using GVI polygons as the common component for our range and wildlife surveys provides the best structure for interpreting our data because it partitions out different habitat areas; in addition, spatial GVI polygons information is available for all the native grasslands of Alberta.
Range data were collected on each ranch during summer months (i.e., June until early September) during the same year that the point counts were completed for that ranch. The resultant vegetation data from each GVI polygon assessed were then assigned to the nearest point count location within that same GVI polygon, ensuring that each point count had a unique set of vegetation data. If there were only one vegetation plot completed in a GVI polygon that contained multiple point counts, we assigned the vegetation data to the nearest point count and removed the other point count(s) data from the analysis.

**Derived data**

After field data were collected, we used ArcMap version 10.6.1 (Esri 2018) to calculate the field size (km²) each point count was located in. We then determined the distance from each point count location to the nearest water source (e.g., river, wetland, dugout, ephemeral, etc.), agricultural field (wheat or other annual crop), arterial road (major thoroughfare, predominantly paved), collector road (minor thoroughfare, including larger trails), fence line, active well site (in use, either oil or gas), and inactive well site (abandoned or reclaimed oil or gas site; Appendix 1).

**Statistical analysis**

We used generalized linear mixed models (GLMM) from the glmTMB package (Brooks et al. 2017) for our analysis. During model development we reviewed existing literature and used an a priori approach to assist us in selecting covariates for inclusion in our model sets (Burnham and Anderson 2002). We used diagnostic tests, including histograms of the count data and q-q plots, and calculated the ratio between the variance and the mean of each species count data to determine the distribution family that best fit our data. We used a negative binomial distribution for Chestnut-collared Longspur, Baird’s Sparrow, and Thick-billed Longspur, whereas a Poisson distribution was used for Sprague’s Pipit and Grasshopper Sparrow. Prior to running models, we performed a Pearson’s pairwise correlation analysis on our continuous covariates to identify potential collinearity issues. Two of the covariates, distance to crop and distance to active well sites, considered during our anthropogenic model set selection, exhibited strong correlation (|r| > 0.7, P < 0.001). To ensure that we did not discard valuable covariates when the degrees of freedom had to be equal or less than the top model in the model subset to include new covariates in the list of final model covariates. We tested support among models at all stages (vegetation, management, anthropogenic, final model sets; Burnham and Anderson 2002) by comparing all possible combinations using a best subsets regression approach (Grueber et al. 2011) and the dredge function in the package MuMIn (Barton 2018) to determine the best model. We considered models with ΔAIC < 2 as competitive. During the second stage (final model set), if we determined that there were more than one competitive model, we reported the full model-averaged β coefficients (Grueber et al. 2011) with their 85% confidence intervals (CI; Arnold 2010). We used the 85% CI level to ensure that we did not discard valuable covariates when the interval included zero that has been demonstrated with a 95% CI (Arnold 2010). We displayed the population-level relationship between predicted abundance and informative covariates. We predicted the abundance values and associated standard errors (SEs) on the scale of the link function and then used the inverse of the link function to convert the fitted values and SE back to the response scale. All analysis was completed in R version 4.0.3 (R Core Team 2020) and R Studio version 2022.12.0 (R Studio Team 2022).

**RESULTS**

**Point count and habitat data**

We analyzed data from 617 point counts from 2014 to 2018 across 15 ranches in the Dry Mixed-grass Subregion of Alberta. Point counts were completed by 16 different surveyors, with each surveyor completing an average of 38.6 points (SE = 6.6). From these point counts, we gleaned information for our five bird species, with Chestnut-collared Longspur having the most prominent detection (n = 915 at 256 point counts), followed by Baird’s Sparrow (n = 279 at 192 point counts), Sprague’s Pipit (n = 235 at 192 point counts), Grasshopper Sparrow (n = 141 at 114 point counts), and Thick-billed Longspur (n = 90 at 42 point
Table 1. Top model(s) plus the null model for five grassland bird abundance in the Dry Mixed-grass Subregion of southern Alberta, 2013–2018. Competitive models had a ΔAIC < 2.0. AIC, Akaike information criterion.

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counts). Range health assessments were completed in the same GVI polygon as the point counts, and scores ranged from 35% to 100%. The minimum and maximum value ranges for all habitat covariates measured or derived can be found in Appendix 1.

Model set assessments
The number of covariates in the top vegetation structure model set for all birds ranged from one to five (Appendix 2). The litter covariate was important for all five bird species, with three species having quadratic relationships (Baird's Sparrow, Chestnut-collared Longspur, Grasshopper Sparrow), one species having a positive linear relationship (Sprague's Pipit), and one species having a negative linear relationship (Thick-billed Longspur). The next most prevalent covariate was vegetation height for four of five species. Thick-billed Longspur and Chestnut-collared Longspur had a negative relationship to vegetation height, Baird's Sparrow had a positive association, and Sprague's Pipit had a quadratic relationship. Based on the management model set analysis, range health was the only important covariate, with Baird's Sparrow occurrences more likely with increased range health and Thick-billed Longspur less likely to occur with increased range health (Appendix 2). For the anthropogenic model set for each grassland songbird, the number of covariates ranged from zero to four (Appendix 2). For Thick-billed Longspur and Grasshopper Sparrow, the null model was found to be competitive (ΔAIC < 2); therefore, no anthropogenic covariates were included in the final model set for these two species.

Final model set per species

Baird's Sparrow
There were five competing top models for Baird's Sparrow, with three covariates associated with vegetation structure and three associated with anthropogenic features (Table 1). Baird's Sparrow predicted abundance was positively related to increased vegetation height, increased distance to crop fields and fences, whereas it was negatively associated with increased bare soil and increased distance to inactive wells. Confidence intervals did overlap zero for all anthropogenic covariates, rendering them uninformative in their relationship with Baird's Sparrow predicted abundance (Appendix 3). Baird's Sparrow was found to have a quadratic relationship with litter (Fig. 1), with peak predicted abundance occurring between 673 and 785 kg/ha. Baird's Sparrow predicted abundance increased with increasing vegetation height and decreased with increasing bare soil (Figs. 2 and 3). The top five models carried a total model weight of 23%.

Sprague's Pipit
There were four competing top models with ΔAIC < 2 for Sprague's Pipit, containing only covariates from the vegetation structure model set (Table 1). Predicted abundance of Sprague's Pipit was positively related to increased litter, negatively associated with increased shrub and forb cover, and had a quadratic relationship to bare soil. The 85% beta confidence intervals for forb and litter overlapped zero, making these factors uninformative in their relationship with Sprague's Pipit predicted abundance (Appendix 3). Sprague's Pipit predicted abundance decreased as percent shrub increased (Fig. 4) and we found Sprague's Pipit predicted abundance had a quadratic relationship with vegetation height, with predicted abundance peaking between nine and 12 cm (Fig. 2). There was also a quadratic relationship for bare soil with peak Sprague's Pipit predicted abundance occurring at 10% (Fig. 3). The top four models carried a total model weight of 42%.

Chestnut-collared Longspur
There were two competing top models for Chestnut-collared Longspur, containing four covariates associated with vegetation structure and one associated with anthropogenic features (Table
Fig. 1. Population level predicted abundance and 85% confidence intervals of grassland species in the Dry Mixed-grass Subregion of southern Alberta, 2013–2018, for the informative covariate litter. Note that our original count data for each species were not adjusted for detection.

1). Chestnut-collared Longspur predicted abundance was negatively associated with increased distance to crop, increased bare soil, increased vegetation height, and increased shrub cover. However, the relationship with vegetation height is uninformative because the confidence intervals overlapped zero (Appendix 3). Chestnut-collared Longspur had a quadratic relationship with litter (Fig. 1), with predicted abundance peaking at 112–224 kg/ha. The top two models carried 86% of the model weight.

**Thick-billed Longspur**

There was only one top model for Thick-billed Longspur, which contained three covariates associated with vegetation structure (Table 1). Thick-billed Longspur was negatively associated with all three of these covariates: litter, vegetation height, and shrub cover (Appendix 3). Thick-billed Longspur predicted abundance decreased with increasing litter, vegetation height, and shrub cover (Figs. 1, 2, and 4). The top model carried 47% of the model weight.

**Grasshopper Sparrow**

Within the Grasshopper Sparrow model sets for management and anthropogenic features, the null models were found to be competitive and therefore the final model analysis contained only covariates from the vegetation structure model set (Table 1). The final model contained only one covariate: a quadratic relationship...
with litter amounts (Appendix 3), with Grasshopper Sparrow predicted abundance peaking at 448–560 kg/ha (Fig. 1). The top model carried 23% of the model weight.

**DISCUSSION**

On the breeding grounds in the Dry Mixed-grass Subregion of southern Alberta, we initially examined three model sets (vegetation structure, management, and anthropogenic) and used important covariates from these models to predict overall species predicted abundance for five grassland birds. We utilized model sets because they represent different attributes that have previously been deemed important to grassland birds. Our model results clearly demonstrate that abundance for the five grassland birds is predominately predicted by vegetation structure. Vegetation structural covariates have previously been demonstrated to be important for predicting grassland bird abundance (Prescott and Murphy 1996, Murray et al. 2008, Bogard and Davis 2014, Henderson and Davis 2014, Pulliam et al. 2020). Four vegetation structure covariates were of importance for predicting grassland bird abundance. First, litter was the most important covariate, being present in all five species' final models (though as an uninformative covariate for Sprague's Pipit, because its CI overlapped zero). Second, vegetation height was in four of the species' top models. Last, shrub cover and bare soil were in three of the species' final models. Although these four covariates were important in predicting abundance, the relationship (for or against) varied by species, providing further evidence that grassland bird resource use occurs along a continuum of structural characteristics (Knopf 1996).

The associations between grassland birds and habitat features may offer insight as to why songbird populations are declining (Davis et al. 1999). Some of our prairie bird species are grassland specialists or obligates (Shaffer and DeLong 2019), displaying fine-scale habitat selection, which allows many different species to coexist. Vegetation structural elements are often used to place grassland birds along a continuum, from those that prefer areas of sparse vegetation to those that prefer areas with adequate ground cover (i.e., high amounts of litter), to those that prefer more structure (i.e., high shrub cover and vegetation height; Knopf 1996). This diversity of adaptation allows for many grassland bird species to coexist by selecting varying areas based on preferences of habitat structural characteristics. Our results provide further support for maintaining vegetation structural heterogeneity on the landscape in order to provide pertinent habitat for various species of grassland birds. For example, maintaining areas of short and sparse vegetation and other areas with high litter values and intermediate vegetation height within the same pasture will provide habitat for both Thick-billed Longspur and Sprague's Pipit. Individual species habitat requirements further emphasize the need for managing for habitat heterogeneity and working with land managers to create this diversity in habitat to abate the decline of wildlife species across the grasslands (Fuhlendorf et al. 2006, Murray et al. 2008).

As expected, grassland bird abundance was predicted by litter cover, with three species having a positive relationship, one a negative relationship, and one that was uninformative because its CI overlapped zero. Chestnut-collared Longspur peak predicted abundance occurred in areas with lower amounts of litter, which has previously been documented (Davis et al. 2014). However, our prediction of abundance based on litter values was significantly lower than those reported in the mixed grass prairie of Montana (Pulliam et al. 2020). Grasshopper Sparrow preferred areas with moderate levels of litter, whereas Baird's Sparrow preferred areas with high amounts, which is consistent for this species (Dechant et al. 2002, Pulliam et al. 2020). Baird's Sparrow nesting site selection has been found to be influenced by amounts of residual cover (Davis 2005). As expected, Thick-billed Longspur in our study area was distinct in having higher predicted abundance in areas with no to very little litter (Henderson and Davis 2014, Pulliam et al. 2020). Sprague's Pipit is a grassland species that has previously been shown to select areas with higher litter amounts (Prescott and Murphy 1996, Davis and Duncan 1999), and our results indicate Sprague's Pipit predicted abundance increased over the range of litter values found in our study area. Surprisingly, though, litter was considered an uninformative covariate in the Sprague's Pipit final model because its 85% CI slightly overlapped zero. Residual cover was also found to be an uninformative covariate in Sprague's Pipit models by Pulliam et al. (2020). Henderson and Davis (2014) found Sprague's Pipit abundance decreased over their range of litter values in Saskatchewan, whereas Lusk and Koper (2013) found Sprague's Pipit nest survival to be negatively associated with litter depth.

Whereas litter can be thought of as a measure of ground cover, vegetation height can be thought of as vertical structure and cover. Two of our grassland species had a positive relationship between predicted abundance and vegetation height, whereas two had a negative relationship. Sprague's Pipit predicted abundance peaked between 9 and 12 cm, preferring taller vegetation, which is consistent with other findings (Davis et al. 1999, Madden et al. 2000, Lusk and Koper 2013, Henderson and Davis 2014). Baird's Sparrow predicted abundance increased over the range of vegetation height seen in our study area, consistent with other findings (Davis et al. 1999, Lusk and Koper 2013, Henderson and Davis 2014). However, our results for Baird's Sparrow contradict those of Madden et al. (2000) who found that the presence of Baird's Sparrow declined as vegetation height increased in the mixed grass prairie of North Dakota. We found a negative relationship between vegetation height and predicted abundance for Chestnut-collared Longspur and Thick-billed Longspur, with the relationship stronger for Thick-billed Longspur. These negative relationships are as expected because both species prefer areas with shorter vegetation (Felske 1971, Bogard and Davis 2014, Henderson and Davis 2014).

Our last two covariates found in most species' final models were shrub cover and bare soil. Shrub cover had a negative relationship with three of our five songbirds, with Sprague's Pipit, Thick-billed Longspur, and Chestnut-collared Longspur being less abundant as shrub cover increased, which is consistent with other findings (Davis et al. 1999, Davis 2004, Grant et al. 2004, Davis et al. 2014, Henderson and Davis 2014). Of the three species, Thick-billed Longspurs most consistently avoided shrubby areas, whereas Sprague's Pipit was the most tolerant of shrubs. Bare soil explained predicted abundance variation for Chestnut-collared Longspur, Baird's Sparrow, and Sprague's Pipit, but did not appear to influence the predicted abundance of Thick-billed Longspur or Grasshopper Sparrow. Increasing bare soil negatively influenced the predicted abundance of Chestnut-collared Longspur and Baird's Sparrow and held a quadratic
relationship with Sprague’s Pipit, which showed the greatest intolerance for bare soil. Our results for Baird’s Sparrow are consistent with those of Henderson and Davis (2014) who also found abundance to decrease as bare soil increased. Davis (2004) found a positive relationship between bare soil and Sprague’s Pipit abundance during one of two years of his study in Saskatchewan, and Strasser et al. (2019) found Sprague’s Pipit selected for areas with more bare ground on the Chihuahuan Desert non-breeding grounds. Thick-billed Longspur predicted abundance was not explained by bare soil, which was opposite of Henderson and Davis (2014) who found the occurrence of Thick-billed Longspur increased with bare soil.

Surprisingly, we did not find that anthropogenic covariates drove predicted abundance in our study. Within our study area, roughly 45% of the well sites were inactive at the time of survey and were in various stages of reclamation (Alberta Environment and Parks 2019). We saw no large avoidance to either active or inactive well sites by any of our five species. Similar to our results, Bogard and Davis (2014) reported that Baird’s Sparrow and Sprague’s Pipit abundance was not largely affected by gas wells but, in contrast, they found that Grasshopper Sparrow, Thick-billed Longspur, Chestnut-collared Longspur were affected either positively or negatively by the closeness of wells or the density of wells. Yoo and Koper (2017) found that density and distance to gas well structures had little effect on nest success of Chestnut-collared Longspur, but the size of nest clutches was smaller closer to these structures. We did not complete any nest searches because it was beyond the scope of our project.

Conversion of native prairie to agricultural crop fields can result in direct habitat loss for grassland birds and has been linked to songbird declines (Pool et al. 2014, Lipsey et al. 2015). The conversion of native prairie to crop fields has a direct effect on grassland birds (i.e., km² of habitat lost) but can also have indirect effects, such as the use of pesticides on crops for insect control reducing food availability for grassland birds (Stanton et al. 2018). We found that the distance from crop was a predictor of predicted abundance for only two of our five grassland songbirds, but the relationship was weak with Chestnut-collared Longspur preferring to be closer and Baird’s Sparrow farther from cropland. Other studies report contrasting trends in the occurrence and abundance of Chestnut-collared Longspur (Wellicome et al. 2014, Lipsey et al. 2015). Sliwinski and Koper (2012) found the abundance of Chestnut-collared Longspur declined by 25% at sites that were closer to cropland edge. Although our results showed that Chestnut-collared Longspur predicted abundance was higher near crop, the result is not biologically meaningful. The average distance from our point count locations to crops was over three kilometers and therefore we feel that biologically this distance is irrelevant to Chestnut-collared Longspur abundance. However, the fact that predicted abundance of Chestnut-collared Longspur was higher closer to crop is not unusual because Chestnut-collared Longspur have previously been detected in crop (Dale et al. 2005). We did not find a relationship with Thick-billed Longspur and distance to crop fields, unlike other findings (McMaster and Davis 1998, Dale et al. 2005), or with Grasshopper Sparrow, which were found at sites closer to cropland (Davis and Duncan 1999).

Although we have been able to show unique relationships and confirm other relationships between grassland bird abundance and our measured covariates, we do caution the reader in their interpretation of our results based on two factors. The first factor relates to our methodology and the discrepancy between where point counts and vegetation plots were completed. Although both sources of data were collected in the same pasture, they were predominantly not at the exact same location. Therefore, there is likely noise or nuances between the vegetation characteristics found at the vegetation plot versus the characteristics that would have been found at the point count location. Although these differences are acknowledged, we feel the noise they add to the data is minor and should not influence our overall results significantly because the range data are collected inside the same GVI polygon (habitat/land use type) as the bird point count and the trained agrologist selected a location to complete the range transect that is representative of the polygon. The second factor potentially influencing our results is the fact the grassland bird data were collected by 16 different observers and were not corrected statistically for detectability. We attempted to reduce the effects of grassland bird detection variability by restricting point counts to a specific time of day and standardized weather conditions, and by ensuring all bird data were collected by competent birders (Morelli et al. 2022). We therefore feel our predicted abundance estimates are acceptable but caution the reader when comparing our abundance estimates to other studies that have corrected their abundance estimates.

Conservation of grassland birds will require collaboration with landholders because the occurrence of grassland birds is intertwined and depends on well-managed rangelands (Henderson et al. 2014, Jones et al. 2019). Beneficial management practices and strategies within programs such as MULTISAR may be able to contribute to grassland bird conservation by promoting habitat heterogeneity. Understanding individual species’ requirements will allow for recommendations to maintain, improve, or create heterogeneity of the grasslands, ensuring habitat is available for a variety of grassland birds (Rose et al. 2021). MULTISAR recommends the use of several different grazing management tools (e.g., water development, fencing) to create suitable habitat conditions for various species, producing heterogeneity on the landscape. Similarly, other programs provided general recommendations for conserving or promoting grassland bird habitat (e.g., Wyoming Partners in Flight 2002, Hyde and Campbell 2012). For example, Thick-billed Longspur likely responds positively to grazing (Bock et al. 1993) and small areas of heavier grazing can create preferred habitat with fewer shrubs, low amounts of litter, and low visual obstruction. Similarly, Chestnut-collared Longspur was found to prefer lower amounts of litter and shrub and were the most tolerant of bare soil. At the other end of the grazing regime, Sprague’s Pipit appears to favor light to moderate grazing (Dechant et al. 2002), preferring intermediate vegetation height, higher amounts of litter, few shrubs, and little bare soil. Comparably, Baird’s Sparrow is positively associated with higher litter and visual obstruction values and low levels of bare ground. In general, the MULTISAR program aims to promote grassland bird abundance and species diversity by encouraging vegetation structural diversity (heterogeneity) on the landscape when working with land
managers. Our results provide the opportunity to assist land managers with more prescriptive recommendations. For example, if the goal is to improve habitat for Sprague's Pipit in the Dry Mixed-grass Subregion, we could recommend to landholders to maintain litter and vegetation height between nine and 12 cm. On the other hand, if the goal is to maintain Chestnut-collared Longspur habitat then the recommendation would be to maintain litter between 112 and 336 kg/ha range while limiting vegetation height. Recommending to landholders these litter amounts can be accomplished by using the photos in the Rangeland Health Assessment for Grassland (Forest and Tame Pasture) and other information in Rangeland Plant Communities and Range Health Assessment Guidelines for the Dry Mixed-grass Subregion of Alberta (Adams et al. 2013, 2016). These photos would provide landowners a visual of litter amounts needed by the different grassland species when they are in the field. This would then create a common language between biologists and landholders for maintaining or improving habitat for grassland birds (Henderson and Davis 2014, Jones et al. 2019) given that litter is essential for both grassland bird habitat and residual forage and drought protection for ranching operations.

Acknowledgments:

Firstly, we thank the many landowners and land managers who are the stewards of native habitats. We also thank them for allowing us to conduct surveys on their properties. Many individuals from various organizations contributed to MULTISAR’s project management, data collection, and GIS support over the years and in particular: B. Adams, F. Blouin, C. DeMaere, M. Didkowsky, B. L. Downey, R. Ehlerl, S. Jaffray, D. Jarina, M. Jensen, J. Richman, C. Koenig, L. Moltzahn, K. Pitcher, A. Miller, J. Nicholson, K. Rumbolt Miller, A. Olson, R. Quinlan, B. Skagen, and R. Whitehouse. A special thank you to C. Schwarz for the open discussion and advice on our statistical analysis. Thank you to the Managing Editor, Dr. Judit Szabo and three anonymous reviewers for the review of earlier drafts of this paper. Thank you to the partners of the MULTISAR project including landholders, Alberta Conservation Association, Alberta Environment and Parks, Prairie Conservation Forum, Cows and Fish, Canadian Roundtable for Sustainable Beef, Alberta Beef Producers, and Canadian Cattlemen’s Association. Funding for MULTISAR has been provided by partners identified above and various funding sources over the years, such as Alberta Fish and Game Association Minister’s Special License Program, Shell Canada, AltaLink, Canadian Natural Resources Limited, and by Environment and Climate Change Canada.

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Felske, B. E. 1971. The population dynamics and productivity of McCown’s Longspur at Matador, Saskatchewan. Thesis. University of Saskatchewan, Saskatoon, Saskatchewan, Canada.


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<table>
<thead>
<tr>
<th>Category</th>
<th>Covariate Name</th>
<th>Covariate Description</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Distance to Water</td>
<td>Distance to the nearest water including all lentic and lotic temporary, seasonal, ephemeral, and permanent systems. This covariate includes natural and anthropogenic water sources such as dugouts (Alberta Environment and Parks 2011). Measured in kilometers.</td>
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<td>Structure</td>
<td>Bare Soil</td>
<td>Percent of exposed bare soil naturally occurring as well as exposed soil affecting the stability of the site due to things such as grazing, trails, etc.</td>
</tr>
<tr>
<td></td>
<td>Litter</td>
<td>Standing or fallen dead plant material. Measured in kilograms per hectare.</td>
</tr>
<tr>
<td></td>
<td>Vegetation Height</td>
<td>Visual Obstruction Method used to estimate vegetation structure. Recorded the lowest interval in centimeters that was completely obscured by vegetation.</td>
</tr>
<tr>
<td></td>
<td>Shrub Cover</td>
<td>Percent shrub cover in the plant community</td>
</tr>
<tr>
<td></td>
<td>Forb Cover</td>
<td>Percent forb cover in the plant community</td>
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<tr>
<td>Anthroponic</td>
<td>Field Size</td>
<td>Measure of pasture sizes in square kilometers.</td>
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<td></td>
<td>Distance to Crop</td>
<td>Distance in kilometers from the point count to the nearest crop field (Alberta Environment and Parks 2011)</td>
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<td>Distance to Arterial Roads</td>
<td>Distance in kilometers from the point count to nearest arterial road which is a major thoroughfare with medium to large traffic capacity and in our study area, was 80% paved, 20% gravel. (Government of Canada 2005).</td>
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<tr>
<td>Distance to Collector Roads</td>
<td>Distance in kilometers from the point count to nearest collector road which is a minor thoroughfare mainly used to access properties and to feed traffic. Collector roads in our study area are 83% gravel roads. In some locations included larger trails and short stretches of paved roads. (Government of Canada 2005).</td>
<td></td>
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<tr>
<td>---------------------------</td>
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<td></td>
</tr>
<tr>
<td>min-max: 0 – 6.7km</td>
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<td></td>
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<tr>
<td>Distance to Fences</td>
<td>Distance in kilometers from the point count to nearest fence.</td>
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<td>min-max: 0.1 – 2.4km</td>
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<tr>
<td>Distance to Active Wells</td>
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<tr>
<td>min-max: 0 – 11.7km</td>
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<tr>
<td>Distance to Inactive Wells</td>
<td>Distance in kilometers from the point count to nearest inactive well at the time the point-count was completed. Includes abandoned and reclaimed sites. (Alberta Environment and Parks 2019).</td>
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<tr>
<td>min-max: 0 – 4.0km</td>
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Appendix 2. Covariates determined to be important for the three model sets of structure, management, and anthropogenic features for five grassland birds in the Dry Mixed-grass Subregion of southern Alberta, 2013–2018.

<table>
<thead>
<tr>
<th>Species</th>
<th>Management model set</th>
<th>Structure model set</th>
<th>Anthropogenic model set</th>
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<tbody>
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<td></td>
<td>Range Health to Water</td>
<td>Bare Soil</td>
<td>Litter</td>
</tr>
<tr>
<td>Sprague’s Pipit</td>
<td>Q§</td>
<td>+++†</td>
<td>Q</td>
</tr>
<tr>
<td>Thick-billed Longspur</td>
<td>- -</td>
<td>- -</td>
<td>- -</td>
</tr>
<tr>
<td>Baird’s Sparrow</td>
<td>+++</td>
<td>- -</td>
<td>Q</td>
</tr>
<tr>
<td>Chestnut-collared Longspur</td>
<td>N/A</td>
<td>N/A</td>
<td>- -</td>
</tr>
<tr>
<td>Grasshopper Sparrow</td>
<td>N/A</td>
<td>N/A</td>
<td>Q</td>
</tr>
</tbody>
</table>

+† Positive relationship, -‡ Negative relationship, Q§ quadratic relationship, N/A\(^1\) null model within ΔAIC < 2 so not significant relationships
Appendix 3. Standardized beta coefficients and 85% confidence interval for the covariates in the top model(s) for five grassland bird abundance in the Dry Mixed-grass Subregion of southern Alberta, 2013–2018. Covariates with 85% confidence intervals that overlap 0 are considered non-informative.