



Effects of Livestock Grazing Management on Grassland Birds in a Northern Mixed-Grass Prairie Ecosystem^{☆, ☆, ☆}

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ABSTRACT

Grassland birds have undergone substantial population declines throughout much of their historic ranges in North America. Most of the remaining grassland bird habitat is restricted to rangelands managed for livestock production, so grazing management has strong implications for grassland bird conservation efforts. We conducted 1830 point-count surveys at 305 sites during 2016–2017 to evaluate the relative effects of three livestock grazing systems on the abundance and community composition of grassland birds in a northern mixed-grass prairie ecosystem of eastern Montana, United States. Our objectives were to 1) evaluate effects of grazing management on abundance and community composition of grassland obligate birds, focusing specifically on grazing systems, stocking rates, and interactions with rangeland productivity; 2) evaluate the importance of local vegetation characteristics for grassland birds within grazing systems; and 3) assess the effectiveness of rest-rotation grazing to create patch-heterogeneity in rangeland vegetation through the alteration of structural components and the response of grassland birds to these treatments. Overall, we found inconsistent responses in abundances of grassland birds relative to livestock grazing systems and no discernable differences among grazing systems relative to community composition. However, local abundances were often driven by interactions between grazing system and rangeland production potential, suggesting the effects of livestock grazing management were generally mediated by rangeland productivity. In addition, associations between avian abundance and grazing management parameters (e.g., stocking rate) were species specific. Ubiquitous guidelines for livestock grazing systems may be inappropriate for grassland bird conservation efforts in the northern mixed-grass prairie, and high stocking rates may negatively impact populations of dense-grass obligate grassland birds in this region.

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Introduction

Grassland birds have exhibited steep population declines during the past 50 yr and are recognized as the most rapidly declining guild of terrestrial birds in North America (Knopf, 1996; Peterjohn and Sauer, 1999; Sauer et al., 2013). The alteration of native breeding and wintering habitat within North America's grassland ecosystems has been a major factor driving population declines (Knopf, 1994; Johnson and Igl, 2001; Brennan and Kuvlesky, 2005).

Intensive conversion of native grasslands to agricultural production throughout North America emphasizes the importance of maintaining grasslands managed for livestock grazing, as these rangelands comprise the majority of remaining native grassland bird habitat (Knopf, 1996; Davis et al., 2014). Implementation of rangeland management practices to improve remnant grassland habitats may act to moderate widespread grassland bird population declines.

Management practices designed to restore structural heterogeneity to prairie landscapes by mimicking historic ecological processes have recently been promoted for grassland bird conservation (Fuhlendorf and Engle, 2001; Fuhlendorf et al., 2006; Derner et al., 2009). Grassland bird communities are adapted to the variation in vegetation structure created by disturbance events on the landscape (Fuhlendorf and Engle, 2001; Pool and Austin, 2006). Spatial heterogeneity in vegetation height and density within grasslands increases diversity and abundance of native

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grassland birds, and the variations in specific vegetation structure and composition present within grasslands are important habitat conditions selected by grassland birds (Winter et al., 2005; Askins et al., 2007; Henderson and Davis, 2014; Hovick et al., 2015). Thus rangeland management practices that provide heterogeneous habitat conditions should be associated with higher densities and more diverse bird communities (Hovick et al., 2015).

Prescribed fire and livestock grazing have been promoted for grassland bird conservation in the northern mixed-grass prairie (Richardson et al., 2014). Despite research suggesting resilience of these areas to fire and supporting use of fire-grazing interactions for mimicking historical disturbance regimes, prescribed burning is not widely accepted by local land managers in semiarid regions of the mixed-grass prairie (Gates et al., 2017; Powell et al., 2018; Sliwinski et al., 2018). As a result, management to restore habitat heterogeneity for grassland wildlife communities has focused on conservation-based livestock grazing systems, such as rest-rotation grazing (e.g., Hormay, 1970; Montana FWP, 2011). Conceptually, livestock grazing systems that incorporate rotation and periods of deferment should result in structural heterogeneity on the landscape by creating areas of variable disturbance and patches of low to high vegetation height and density (Hagen et al., 2004; Derner et al., 2009; Toombs et al., 2010). However, the effects of conservation-based grazing systems on wildlife communities, specifically grassland birds, have not been evaluated in northern mixed-grass prairie habitats.

The application of livestock grazing systems for improving rangeland or wildlife habitat quality generally varies widely in the literature (Holechek et al., 1999; Briske et al., 2008; Krausman et al., 2009; Schieltz and Rubenstein, 2016). The regional evolution of grassland ecosystems to a continuum of grazing pressures, as well as large-scale differences in annual rangeland productivity, may largely contribute to these inconsistencies (i.e., a livestock grazing system that improves grassland bird habitat quality in a highly productive tallgrass prairie ecosystem) (Fuhlendorf et al., 2006; Coppedge et al., 2008) may not have a similar effect in the semiarid shortgrass prairie (Augustine and Derner, 2015). In addition, applying similar grazing intensities relative to ecoregion (e.g., shortgrass, mixed-grass, tallgrass) will result in variable levels of structural heterogeneity, where under moderate grazing intensities, rangelands in productive tallgrass prairies will have low heterogeneity compared with more diverse mixed-grass prairies (Lauenroth et al., 1999; Fuhlendorf and Engle, 2001; Ranellucci et al., 2012).

Even within a single grassland ecoregion such as the northern mixed-grass prairie, researchers have found variable responses of obligate grassland birds to livestock grazing management, ranging from no response to grazing system (Davis et al., 2014) to a positive response to rotational grazing systems (Messmer, 1990; Buskness et al., 2001) or a positive response to season-long grazing systems (Ranellucci et al., 2012). Notably, grassland birds have also shown species- or guild-specific responses to livestock grazing intensity within the context of variable rangeland productivity at the landscape scale (Lipsey and Naugle, 2017). Fine-scale variability in rangeland production potential may determine inconsistencies related to the effects of livestock grazing systems on grassland bird populations.

We conducted a 2-yr field study in eastern Montana to evaluate the relative effects of livestock grazing management, rangeland productivity, and local habitat conditions on grassland bird abundance. We conducted point-count surveys of grassland birds at sites randomly located across eight pastures (~7 300 ha) managed in one of three livestock grazing systems. Our specific objectives were to 1) evaluate the effects of livestock grazing management on abundance and community composition of grassland birds in the context of site-specific rangeland production potential, 2) estimate the importance of vegetation characteristics for grassland birds mediated by livestock grazing, and 3) assess the effectiveness of rest-rotation grazing to create patch-heterogeneity in rangeland vegetation through the alteration of

structural components and the response of grassland birds to these treatments. If rest-rotation grazing systems functioned as intended by wildlife conservation entities, we expected to find greater grassland bird species diversity and higher abundances of select focal species at these pastures, relative to pastures within the other grazing systems in our study area.

Methods

Study Area

Our research was conducted in the northern mixed-grass prairie of northeastern Montana, within an area dominated by contiguous rangelands managed for cattle grazing. The study site was centered on an ~3 000-ha Upland Gamebird Enhancement Program (UGBEP) project established by the Montana Department of Fish, Wildlife, and Parks (hereafter “Montana FWP”) in 1993, located in eastern Richland County, Montana, 20 km southeast of Sidney (48°30'N, 104°04'W; Fig. S1; available online at <https://doi.org/10.1016/j.rama.2019.08.005>). Five pastures of ~4 300 ha bordering the UGBEP were used as references, with three pastures located on private lands adjacent to the UGBEP in Montana, and two pastures located on US Forest Service National Grasslands adjacent to the UGBEP in McKenzie County, North Dakota.

Winter and summer temperatures average -7.4°C and 20.5°C , respectively, at the nearest weather station to our study area (Savage, Montana), and average ($\bar{x} \pm \text{SD}$) precipitation from 1905–2017 was 351 ± 93 mm (NOAA, 2018). Although annual precipitation is variable in this region, total precipitation during 1 yr before our 2016 and 2017 field seasons was near average, at 305 mm and 378 mm, respectively. Vegetation at the study area was composed of mainly graminoids, including western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Love), little bluestem (*Schizachyrium scoparium* [Michx.] Nash var. *scoparium*), needle-and-thread (*Hesperostipa comata* [Trin. and Rupr.] Barkworth), prairie junegrass (*Koeleria macrantha* [Ledeb.] J.A. Schultes), Kentucky bluegrass (*Poa pratensis* L.), and blue grama (*Bouteloua gracilis* [Willd. ex Kunth.] Lag. ex Griffiths). Low-height to midheight shrubs relatively common within the study area included western snowberry (*Symphoricarpos occidentalis* Hook.), silver sagebrush (*Artemisia cana* Prush), skunkbrush sumac (*Rhus trilobata* Nutt.), silver buffaloberry (*Shepherdia argentea* [Pursh] Nutt.), chokecherry (*Prunus virginiana* L.), western wild rose (*Rosa woodsii* Lindl.), and creeping juniper (*Juniperus horizontalis* Moench). Two subshrub species were also prevalent, winterfat (*Krascheninnikovia lanata* [Pursh] A. Meeuse & Smit) and fringed sage (*Artemisia frigida* Willd.).

We surveyed grassland birds and vegetation at 610 points (305 each season) randomly located across gradients of habitat conditions within the Montana FWP UGBEP, managed under rest-rotation grazing (300 points; Hormay, 1970), and on adjacent lands managed under season-long (120 points) or 2-pasture summer-rotation (190 points) grazing systems (see Fig. S1). Of the three grazing systems evaluated, we had three replications of each rest-rotation and summer-rotation systems and two replications of season-long grazing systems. Within the three-pasture rest-rotation grazing systems, cattle were turned out to the first pasture in late May, moved to the second pasture mid-August, and removed for the season after 8–10 wk; the third pasture in the system was rested from grazing. Season-long grazing systems in the study area allowed cattle to graze continuously from May or early June through October or mid-November. Within two-pasture summer-rotation grazing systems in the study area, cattle were turned out to the first pasture in early June, moved to the second pasture after 6–8 wk, and removed early to mid-November. At the scale of each management unit, rest-rotation grazing systems had a mean annual stocking rate of 2.82 animal unit months (AUM) \bullet ha^{-1} (range 2.29–3.34 AUM \bullet ha^{-1}), summer-rotation systems

had a mean stocking rate of 1.98 AUM \bullet ha⁻¹ (range 1.61–2.66 AUM \bullet ha⁻¹), and season-long systems had a mean stocking rate of 1.24 AUM \bullet ha⁻¹ (range 0.8–1.5 AUM \bullet ha⁻¹; Table S1; available online at <https://doi.org/10.1016/j.rama.2019.08.005>).

Field Methods

Point-Count Surveys

We collected data during two grassland bird breeding seasons (May–June, 2016–2017). Avian point-count surveys began after all grassland bird species had arrived for the breeding season and were completed within a 4-wk period to assume breeding population closure. To avoid double counting of individuals and ensure statistical independence, survey points were spaced > 300 m apart. Points were located > 200 m from pasture boundaries to avoid counting birds using multiple pastures and were located > 400 m from oil pads and > 250 m from gravel roads to control for bird avoidance of these areas (Thompson et al., 2015). We conducted three consecutive yet independent 5-min point-count surveys at each point. This survey method maximized observer efficiency, while simultaneously achieving population closure between survey visits, an assumption for statistical modeling of these types of count data (Royle, 2004; Kéry et al., 2005). A single trained observer identified and tallied all birds detected visually or aurally within 100 m of the survey point (Ralph et al., 1993). At each survey location, the observer recorded the date, time, and wind speed. Point-count surveys were conducted from one-half hr before sunrise through no later than 0900h Mountain Standard Time. We did not conduct bird surveys if average wind speed exceeded 16 km/hr or during rainfall.

We defined grassland-associated species as those that have become reliant on grassland habitat for part or the entirety of their life cycle (Vickery et al., 1999). We selected three focal species as representative of three broader guilds or assemblages of grassland bird species with overlapping niche requirements within their habitats (Root, 1967), the grasshopper sparrow (*Ammodramus savannarum*), vesper sparrow (*Poocetes gramineus*), and western meadowlark (*Sturnella neglecta*). These three ground-nesting obligate grassland species have specific habitat requirements of native grasslands for breeding, recruitment, and survival throughout the summer grazing season (Davis and Lanyon, 2008; Jones and Cornely, 2002; Vickery, 1996). Habitat preferences for each of these three species are variable across ecoregion, but in the northern mixed-grass prairie, grasshopper sparrows generally select for moderate to high vegetation height, density, and litter availability (Dechant et al., 2003b; Fritcher et al., 2004; Lipsey and Naugle, 2017), thus representing the dense-grass guild at our study area. Vesper sparrows are often associated with lower vegetation densities and have a higher tolerance for shrub encroachment within grassland habitats (Browder et al., 2002; Dechant et al., 2003a) and represent the sparse-grass guild. Western meadowlarks are typically considered habitat generalists and are often one of the most common species within grassland habitats of the western United States (Davis and Lanyon, 2008), thus representing the generalist guild.

Vegetation Surveys

We measured local vegetation conditions within bird survey areas the same day point-count surveys were conducted. We established three 20-m transects of five subplots per transect within 100 m of each survey point, with one transect located at the survey point and oriented in a random direction and two transects located and oriented randomly within 100 m of the point. At each subplot, we measured visual obstruction readings (VOR) from the north at a distance of 2 m and a height of 0.5 m (Robel et al., 1970) and vegetation coverages using methods of Daubenmire (1959), where overlapping coverages of residual grass, litter, forb, and bare ground were recorded in one of six percentage classes (0–5%, 5–25%, 25–50%, 50–75%, 75–95%, and 95–100%). Midpoints of percentage classes were recorded for each

vegetation coverage measurement. We measured heights (cm) of the nearest plant to the center of the frame for each residual grass and litter. We also conducted line-intercept surveys along each transect to estimate shrub foliar cover (hereafter “shrubs cover”) within point-count survey areas. The species of each shrub intersecting the transect was recorded, as well as the height and length of the shrub as it crossed the transect (Canfield, 1941). We used ArcGIS 10.4 (ESRI, 2011) to digitize the wooded coulees and pasture fences within the study area using five-band 1-m resolution aerial imagery from the National Agricultural Imagery Program available through the US Department of Agriculture Farm Service Agency. From these digitized layers, we derived the total area of wooded coulees and fences to calculate relative densities within and surrounding bird survey areas.

In uneven terrain, randomly generated survey points are often located on hillsides, which may reduce the ability of observers to see and hear birds. We used ArcGIS Spatial Analyst extension and a 10-m digital elevation model raster layer to calculate viewshed size to model as a function of grassland bird detection probability (ESRI, 2011), defining viewshed as the area visible to the observer within 100 m of the bird survey point.

We quantified rangeland production potential associated with each bird survey area using Soil Survey Geographic Database ecological site data from the Natural Resources Conservation Service (NRCS) Web Soil Survey (Lipsey and Naugle, 2017; USDA NRCS, 2017). We used these data as a reasonable index of average rangeland productivity (Relyea et al., 2000), as rangeland managers implement long-term livestock grazing systems based on the expected annual vegetation production of their rangelands in a normal year. We calculated the weighted average rangeland production potential within 100 m of each bird survey point, effectively accounting for point count survey areas that encompassed multiple ecological sites. We selected the production values under average precipitation, as weather conditions during our study were considered normal.

We obtained livestock numbers, weights, and turn-in/turn-out dates from our collaborating ranch managers and calculated stocking rates within our pastures based on an AUM, the amount of forage, measured on a dry weight basis, to feed a 1 000-lb animal for a 30-d period (Holechek et al., 2011). Pastures within our study area were stocked with a mixture of 1 300-lb cow-calf pairs and 800-lb yearling steers and heifers, which were considered 1.3 and 0.8 AUs, respectively. Stocking rates from the previous year’s summer grazing season were used as a predictor of grassland bird abundance, as breeding territories had already been established within pastures before cattle turn-out dates in our study area (Ahlering and Merkord, 2016). In addition, grassland bird selection of breeding territory is likely relative to residual vegetation from previous growing seasons, as most of the new growth initiates after grassland bird breeding territories have been established in the northern mixed-grass prairie (Davis, 2005).

Statistical Analyses

Community Composition

We used the nonparametric Multiple Response Permutation Procedure (MRPP) to assess the effects of livestock grazing management on grassland bird community composition (Ahlering and Merkord, 2016). Multivariate analyses allow for the detection of patterns among many species within a community in relation to variables of interest, such as vegetation conditions or treatment effects (Conner and Adkisson, 1977). The MRPP evaluates differences among groups of entities and calculates a statistic of chance-corrected within-group agreement, *A* (Mielke, 1984, 1991). The *A* statistic compares observed within-group homogeneity to that which is expected by chance, where *A* = 0 is the result expected at random. We randomly selected a number of survey sites per grazing system equal to the system with the fewest number of survey points [season-long] so that sampling effort was equal and selected the

survey visit with the maximum count for each site. We then created a matrix of bird species by sites and used the Bray-Curtis distance measure (Bray and Curtis, 1957; Faith et al., 1987) within the MRPP to analyze grassland bird community composition among three grazing systems (season-long, summer-rotation, rest-rotation grazing) and among the three treatments within rest-rotation grazing systems (grazing during the growing season, grazing postgrowing season, rest from grazing). Six grassland-associated bird species (Table S2; available at <https://doi.org/10.1016/j.rama.2019.08.005>) had fewer than 5 total detections and were considered transients (nonbreeders) and excluded from the community composition analyses (Hovick et al., 2015). We displayed grassland bird community separation among grazing systems and among rest-rotation treatments using nonmetric multidimensional scaling (NMDS) ordinations (Kruskall, 1964; Minchin, 1987). Statistical analyses were conducted in program R (R Core Team, 2017). The MRPP and NMDS were conducted within R package “vegan” (Oksanen et al., 2013). Figures were created using R package “ggplot2” (Wickham, 2016).

Abundance

We considered sets of competing models at three scales in our evaluation of livestock grazing on grassland bird abundance: local, landscape, and management. We evaluated the effects of specific vegetation conditions on grassland bird abundance at the local scale (within 100 m of the survey point) and landscape scale (within 500 m and 1 000 m). Implementation of livestock grazing systems, manipulation of stocking rates, and evaluation of rangeland production potential within pastures are three main considerations of range managers on an annual basis (i.e., management scale). We used R packages “unmarked” (Fiske and Chandler, 2011) and “AICcmodavg” (Mazerolle, 2013) to identify specific effects on abundance of each focal species using N-mixture abundance models (Royle, 2004). The N-mixture model simultaneously estimates detection probability (P) and abundance of unmarked individuals identified during spatially replicated counts within a closed survey period (Royle, 2004).

On the basis of hypothesized relationships for each covariate included in our models, we evaluated whether a linear, quadratic, or pseudothreshold (pseudosymptotic) effect (Franklin et al., 2000) was best supported for its influence on avian detection probability or abundance. We then used stepwise model selection techniques to identify the variables influencing detection probability and abundance for each focal grassland bird species, starting with a highly parameterized model and eliminating uninformative parameters based on their lack of influence in the model, identified by lowest $|z|$ (Montgomery et al., 2012; Ahlering and Merkord, 2016). Variables considered to influence detection probability of grassland birds were Julian day, observer, shrub cover, shrub height, time of day, viewshed, wind speed, and year. Models evaluating detection probabilities of grassland birds were fit before fitting abundance models.

The vegetation conditions we measured in the field were previously shown to influence grassland bird detection probability or local abundance (Fisher and Davis, 2010; Ahlering and Merkord, 2016), and stepwise model selection was appropriate in the absence of any a priori hypotheses. Variables considered to influence abundance of grassland birds at the local scale were bare ground cover, litter cover and depth, residual grass cover and height, shrub cover and height, wooded area, VOR, and the standard deviation of VOR (sdVOR) as a measurement of fine-scale heterogeneity in vegetation structure (Fisher and Davis, 2010; Thompson et al., 2014; Sliwinski et al., 2019). Litter cover and depth were correlated (Pearson’s correlation estimate, $r > 0.6$), so we excluded litter cover from further analyses, as it may underestimate the true amount of litter available (Ricketts and Sandercock, 2016). Two variables were considered to influence abundance of grassland birds at the landscape scale (500 m and 1 000 m): wooded area and fence density (Sutter et al., 2000; Cunningham and Johnson, 2006; Thompson et al., 2014). Nonnatural structures

such as fence posts and fence lines can function as artificial perches in grassland landscapes and may attract some species of grassland birds (i.e., western meadowlark, vesper sparrow) to broadcast their songs during the breeding season (Sutter et al., 2000; Thompson et al., 2015). We did not include multiple spatial scales in a single model to avoid issues of multicollinearity (Thompson et al., 2014).

We used Akaike’s information criterion adjusted for finite samples (AIC_c) to compare models and identify important variables to include in the final detection or abundance model for each grassland bird species. Supported models with large model weights (w_i) and AIC_c values ≤ 2 from the best-fit model were considered parsimonious (Burnham et al., 2011). When a supported model differed from

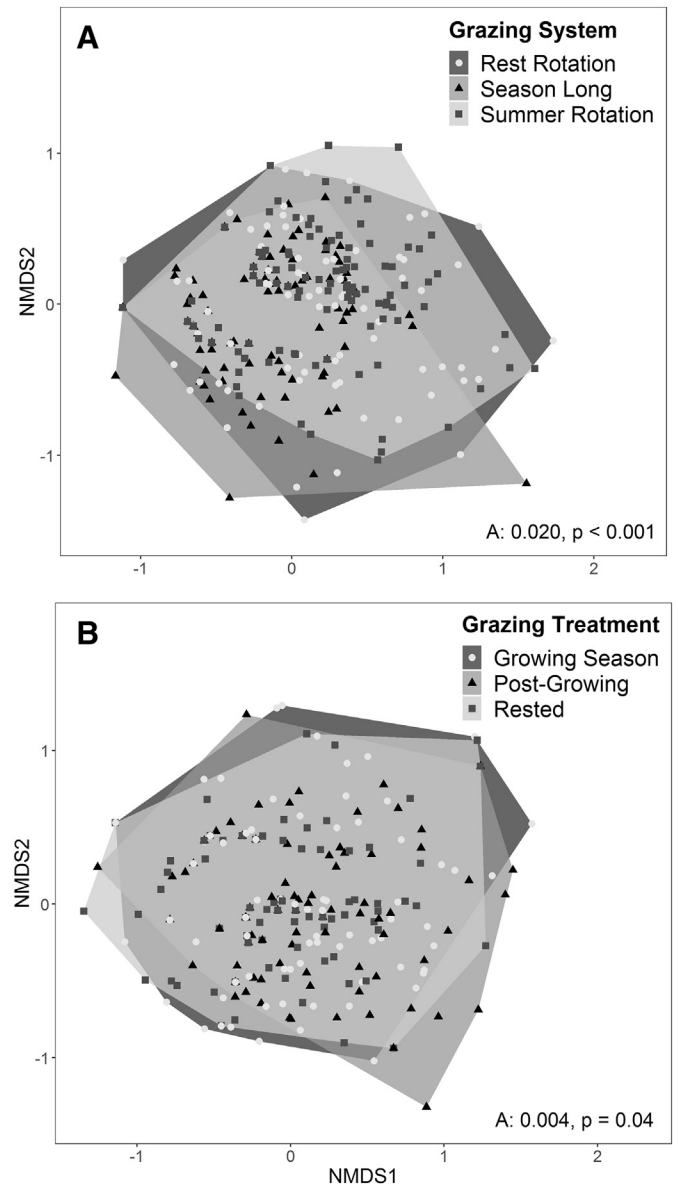


Figure 1. Grassland bird community composition among **A**, grazing systems and **B**, three treatments within rest-rotation grazing systems in eastern Montana, 2016–2017. Scores from nonmetric multidimensional scaling (NMDS) analyses, representing relative distances among bird communities at each site in 2-dimensional ordination, are displayed as the x- and y-axes. Grayscale polygons represent the grassland bird communities associated with each of three grazing systems or treatments. The A statistic from the MRPP and significance of the test (P value) are reported. **A**, ● = sites within rest-rotation grazing systems, ▲ = sites within season-long grazing systems, and ■ = sites within summer-rotation grazing systems. **B**, ● = sites within growing-season treatment, ▲ = sites within the post growing-season treatment, and ■ = sites within the rested treatment.

the best-fit model by a single parameter, we considered the additional parameter to be uninformative (Arnold, 2010). We built a candidate model set for the management-scale effects on avian abundance based on a priori hypotheses, which included additive effects, along with 2- and 3-way interactions. Factors hypothesized to affect avian abundance at the management scale were grazing system, stocking rate, and rangeland production potential.

We assessed model fit for the top model within local-, landscape-, and management-scale analyses for each focal species from 1 000 simulated datasets using the `Nmix.gof.test` function within R package “AICcmodavg” (Mazerolle, 2013). Goodness-of-fit tests indicated \hat{c} estimates between 0.75 and 1.0 and P values > 0.95 for the most parsimonious models within each model set, providing strong evidence the models adequately fit the data. The best-fit model within our local-, landscape-, and management-scale analysis was then used to generate predictions of focal species abundance over the range of values for each variable, while holding other variables included in the best-fit model at their mean. When multiple models shared support (ΔAIC_c values ≤ 2), model-averaged estimates were used to generate predictions of grassland bird detection probabilities and local abundance (Cade, 2015).

Habitat

Vegetation metrics quantifying grassland bird habitat were summarized among grazing systems and among the three treatments within rest-rotation systems and evaluated using mixed-effects analysis of variance (ANOVA). We used R package “lme4” (Bates et al., 2018) to build models and included year and site as random effects to account for potential autocorrelation resulting from repeated measures at sites in 2016 and 2017 and because 15 vegetation plots were measured at each site (Sliwinski et al., 2019).

Results

During 2016–2017, we conducted 1 830 point-count surveys within eight pastures managed with cattle grazing and identified a total of 68 bird species, 31 of which were grassland-associated species (see Table S2). We found that no grassland-associated species with > 5 detections (nontransient) was unique to a single grazing system. Using the rarified subset of community data, we recorded 21 grassland-associated species in pastures within rest-rotation grazing systems, 24 species in 2-pasture summer-rotation grazing systems, and 22 in season-long grazing systems. Grassland bird community separation among grazing systems was minimal, indicated by results from the MRPP and visualized by the

NMDS ordination plot of species by site polygons representing the bird communities recorded within each grazing system (Fig. 1A). The MRPP indicated 2.0% of the variation in grassland bird community composition could be attributed to livestock grazing system ($A: 0.020, P < 0.001$). In addition, community composition was similar among the three types of grazing treatments within the rest-rotation system, where 0.4% of the variation in grassland bird communities can be attributed to the differences among these three treatments ($A: 0.004, P = 0.04$; Fig. 1B). Generally, the occurrences of Baird's sparrow (*Ammodramus bairdii*), bobolink (*Dolichonyx oryzivorus*), grasshopper sparrow, horned lark (*Eremophila alpestris*), Sprague's pipit (*Anthus spragueii*), upland sandpiper (*Bartramia longicauda*), and western meadowlark were associated, and this group tended to be dissociated with occurrences of clay-colored sparrow (*Spizella pallida*), eastern kingbird (*Tyrannus tyrannus*), field sparrow (*Spizella pusilla*), lark sparrow (*Chondestes grammacus*), loggerhead shrike (*Lanius ludovicianus*), mountain bluebird (*Sialia currucoides*), mourning dove (*Zenaidura macroura*), and western kingbird (*Tyrannus verticalis*; Fig. S2; available online at <https://doi.org/10.1016/j.rama.2019.08.005>).

Focal Species

Grasshopper Sparrow

The probability of detecting a grasshopper sparrow increased with viewshed ($\beta = 0.11 \pm 0.06$), decreased with time of day from 05:00 to 09:00 ($\beta = -0.27 \pm 0.06$; see Table 4), and showed quadratic relationships with Julian day and shrub height, where the probability of detection was maximized during the middle of the survey season (~ 158 th Julian d; 7 June) and at a shrub height of ~ 30 cm (Fig. S3; available online at <https://doi.org/10.1016/j.rama.2019.08.005>). After accounting for detection probability, two models shared support ($\Delta AIC_c \leq 2, \Sigma w_i = 0.75$) for local-scale effects on grasshopper sparrow abundance (Table 1). Local abundance was maximized at $\approx 10\%$ bare ground cover, 15 cm residual grass height, and 3 cm litter depth, declined linearly with shrub height ($\beta = -0.8 \pm 0.03$), and showed a strong negative pseudoasymptotic relationship with wooded area, where predicted abundance decreased dramatically beyond 0% wooded ($\beta = -0.35 \pm 0.04$; see Table 4, Fig. 4). A single model was supported for landscape-scale effects on grasshopper sparrows ($w_i = 0.96$; Table 2). Local abundance decreased sharply with increasing fence density ($\beta = -0.08 \pm 0.03$) within a 500-m² area of the survey point and decreased sharply when wooded area within a 1 000-m² area of the point increased beyond 2% (see Fig. 4).

Table 1

Model selection results evaluating the effects of local-scale habitat conditions on abundance of grassland birds in eastern Montana, 2016–2017.

Model ^a	K^b	AIC _c	ΔAIC_c	w_i	Σw_i
Grasshopper sparrow					
RH ² + LD ² + BG ² + SH + ln(WA) ^c	16	4 159.20	0.00	0.43	0.43
RH ² + LD ² + BG ² + SH + ln(WA) + ln(RC)	17	4 159.77	0.57	0.32	0.75
Constant (null)	2	4 450.64	291.44	0.00	1.00
Vesper sparrow					
VOR + Forb + LD + BG + ln(SC)	12	3 025.45	0.00	0.28	0.28
VOR + Forb + LD + BG + ln(SC) + RH	13	3 026.22	0.77	0.19	0.48
VOR + LD + BG + ln(SC)	11	3 026.64	1.18	0.16	0.63
VOR + Forb + LD + BG + ln(SC) + RH + RC	14	3 026.99	1.53	0.13	0.77
Constant (null)	2	3 071.97	46.52	0.00	1.00
Western meadowlark					
VOR + RC + ln(LD) + BG + ln(Forb)	11	4 832.06	0.00	0.32	0.32
VOR + RC + ln(LD) + BG + ln(Forb) + RH + SC	13	4 832.93	0.87	0.21	0.53
VOR + RC + ln(LD) + BG + ln(Forb) + SC	12	4 833.01	0.95	0.20	0.73
Constant (null)	2	4 965.84	133.77	0.00	1.00

^a Only supported models with ΔAIC_c values ≤ 2.0 and the null model are presented for each species.

^b K , number of parameters.

^c BG, bare ground cover; Forb, forb cover; LD, litter depth; RC, residual grass cover; RH, residual grass height; SC, shrub cover; SH, shrub height; VOR, visual obstruction reading; sdVOR, standard deviation of VOR; WA, wooded coulee area; ², quadratic effect; ln(), pseudothreshold effect.

Table 2

Model selection results evaluating the effects of landscape-scale habitat conditions on abundance of grassland birds in eastern Montana, 2016–2017.

Model ^a	K ^b	AIC _c	ΔAIC _c	w _i	∑ w _i
Grasshopper sparrow					
WA1000 ² + ln(FD500) ^c	12	4 297.63	0.00	0.95	0.95
Constant (null)	9	4 378.75	81.12	0.00	1.00
Vesper sparrow					
ln(WA1000) + FD1000	8	3 044.03	0.00	0.57	0.57
ln(WA1000)	7	3 044.59	0.56	0.43	1.00
Constant (null)	6	3 054.34	10.31	0.00	1.00
Western meadowlark					
WA1000	7	4 896.91	0.00	0.52	0.52
WA1000 + FD500	8	4 898.41	1.49	0.24	0.76
Constant (null)	6	4 898.46	1.55	0.24	1.00

^a Only supported models with ΔAIC_c values ≤ 2.0 and the null model are presented for each species.

^b K, number of parameters.

^c FD500, fence density at the 500-m spatial scale; FD1000, fence density at the 1 000-m scale; WA500, wooded area at the 500-m scale; WA1000, wooded area at the 1 000-m scale; ², quadratic effect; ln(), pseudothreshold effect.

A single model of grasshopper sparrow abundance at the management scale had strong support ($w_i = 0.81$) and included an interaction between grazing system and rangeland production potential, as well as a negative effect of stocking rate (Table 3). Abundance was positively associated with rangeland production in season-long grazing systems ($\beta = 0.25 \pm 0.11$), while a quadratic relationship was supported in summer-rotation ($\beta_{productivity} + \beta_{productivity}^2 = 0.60 [0.08SE] - 0.30 [0.08]$) and rest-rotation grazing systems ($\beta_{productivity} + \beta_{productivity}^2 = 0.39 [0.05] - 0.18 [0.03]$), where predictions indicate abundance was maximized at intermediate values of rangeland production potential, from 1 700 to 2 000 kg ● ha⁻¹ (Table 4, Fig. 2A). Grasshopper sparrow abundance decreased with stocking rate ($\beta = -0.10 \pm 0.03$; Fig. 3), and the effect was similar among grazing systems.

Vesper Sparrow

The probability of detecting a vesper sparrow was higher in 2017 than 2016 ($\beta = 0.50 \pm 0.14$), decreased with viewshed

Table 3

Model selection results evaluating the management-scale effects of grazing system, stocking rate, and rangeland production potential on grassland bird abundance in eastern Montana, 2016–2017.

Model ^a	K ^b	AIC _c	ΔAIC _c	w _i	∑ w _i
Grasshopper sparrow					
GS × RPP ² + SR ^c	15	4 179.33	0.00	0.81	0.81
RPP ² + SR	11	4 183.35	4.02	0.11	0.92
GS + RPP ² + SR	13	4 184.75	5.42	0.05	0.97
GS × SR + RPP ²	13	4 186.20	6.87	0.03	1.00
Constant (null)	8	4 420.10	240.77	0.00	1.00
Vesper sparrow					
GS + RPP	10	3 034.13	0.00	0.59	0.59
GS + RPP + SR	11	3 035.44	1.31	0.31	0.90
GS	9	3 039.80	5.67	0.04	0.94
RPP	8	3 041.30	7.17	0.02	0.96
Constant (null)	7	3 049.63	15.50	0.00	1.00
Western meadowlark					
GS × RPP + ln(SR)	12	4 879.37	0.00	0.60	0.60
RPP + ln(SR)	10	4 880.72	1.35	0.31	0.91
GS + RPP + ln(SR)	12	4 885.32	3.91	0.08	0.91
GS × ln(SR) + RPP	12	4 885.36	3.95	0.08	0.99
Constant (null)	6	4 903.97	22.56	0.00	1.00

^a Only models with AIC_c weights (w_i) > 0.01 and the null model are presented for each species.

^b K, number of parameters.

^c GS, grazing system; RPP, rangeland production potential; SR, stocking rate; ², quadratic effect; ln(), pseudothreshold effect.

Table 4

Effects of standardized local habitat, landscape-scale habitat, and management-scale variables on the abundance of three focal species in eastern Montana, 2016–2017. Also included are the effects of year, Julian day, time of day, shrub height, and wind speed on probability of detection.^{a,b}

	Grasshopper sparrow		Vesper sparrow		Western meadowlark	
	β	SE	β	SE	β	SE
Detection ^c						
Intercept	1.65	0.08	-0.46	0.13	0.13	0.09
Yr, 2017			0.50	0.14	0.37	0.11
Day	0.01	0.05	0.08	0.07	-0.32	0.05
Day ²	-0.12	0.04	0.16	0.06		
Time	-0.27	0.06				
Viewshed	0.11	0.06	-0.19	0.07	0.10	0.05
Shrub height	0.04	0.07				
Shrub height ²	-0.08	0.03				
Wind speed			-0.15	0.07		
ln(Wind speed)					-0.08	0.05
Abundance, local habitat						
Intercept	0.86	0.04	0.06	0.06	0.96	0.04
Residual grass cover					-0.11	0.04
Residual grass height	0.06	0.04				
Residual grass height ²	-0.06	0.02				
Litter depth	0.20	0.04	0.11	0.05		
Litter depth ²	-0.05	0.02				
ln(Litter depth)					0.22	0.05
Bare ground	-0.10	0.04	0.16	0.06	-0.09	0.04
Bare ground ²	-0.07	0.03				
Shrub height	-0.08	0.03				
ln(Wooded coulee)	-0.35	0.04				
VOR			-0.11	0.05	-0.16	0.03
Forb			0.08	0.04		
ln(Forb)					0.09	0.03
ln(Shrub cover)			0.17	0.05		
Abundance, landscape						
Intercept	0.92	0.04	0.07	0.06	1.00	0.04
Wooded coulee (1 000 m)	-0.15	0.04			-0.06	0.03
Wooded coulee ² (1 000 m)	-0.18	0.04				
ln(Wooded coulee; 1 000 m)			0.15	0.05		
Fence density (1 000 m)			-0.07	0.04		
ln(Fence density; 500 m)	-0.08	0.03				
Abundance, management						
Intercept	0.86	0.04	0.03	0.07	1.02	0.04
Season-long GS			-0.17	0.14		
Summer-rotation GS			0.25	0.10		
Stocking rate	-0.10	0.03				
ln(Stocking rate)					-0.09	0.03
RPP			-0.13	0.05		
Season-long GS × RPP	0.25	0.11			0.11	0.06
Season-long GS × RPP ²	-0.02	0.07				
Summer-rotation GS × RPP	0.60	0.08			-0.01	0.06
Summer-rotation GS × RPP ²	-0.30	0.08				
Rest-rotation GS × RPP	0.39	0.05			0.15	0.04
Rest-rotation GS × RPP ²	-0.18	0.03				

^a Abundance covariates are presented on the log-scale and detection covariates on the logit scale.

^b Bold numbers indicate the 95% confidence intervals did not overlap 0.

^c GS, grazing system; RPP, rangeland production potential; SR, stocking rate; VOR, visual obstruction reading; ², quadratic effect; ln(), pseudothreshold effect.

($\beta = -0.19 \pm 0.07$) and wind speed ($\beta = -0.15 \pm 0.07$; see Table 4), and exhibited a quadratic relationship with Julian d, where detection probability was lowest during the middle of the survey season (~4 June; Fig. S4; available online at <https://doi.org/10.1016/j.rama.2019.08.005>). Four models shared support ($\Delta AIC_c \leq 2$) for local-scale effects on abundance of vesper sparrows (see Table 1). Models including the main effects of bare ground, litter depth, shrub cover, and visual obstruction had the majority of support ($\Sigma w_i = 0.77$). Abundance increased with bare ground cover up to 75% ($\beta = 0.16 \pm 0.06$) and litter depth up to 5 cm ($\beta = 0.11 \pm 0.05$), decreased with visual obstruction from 0 to 5 dm ($\beta = -0.11 \pm 0.05$), and showed a positive pseudoasymptotic relationship to shrub cover, where

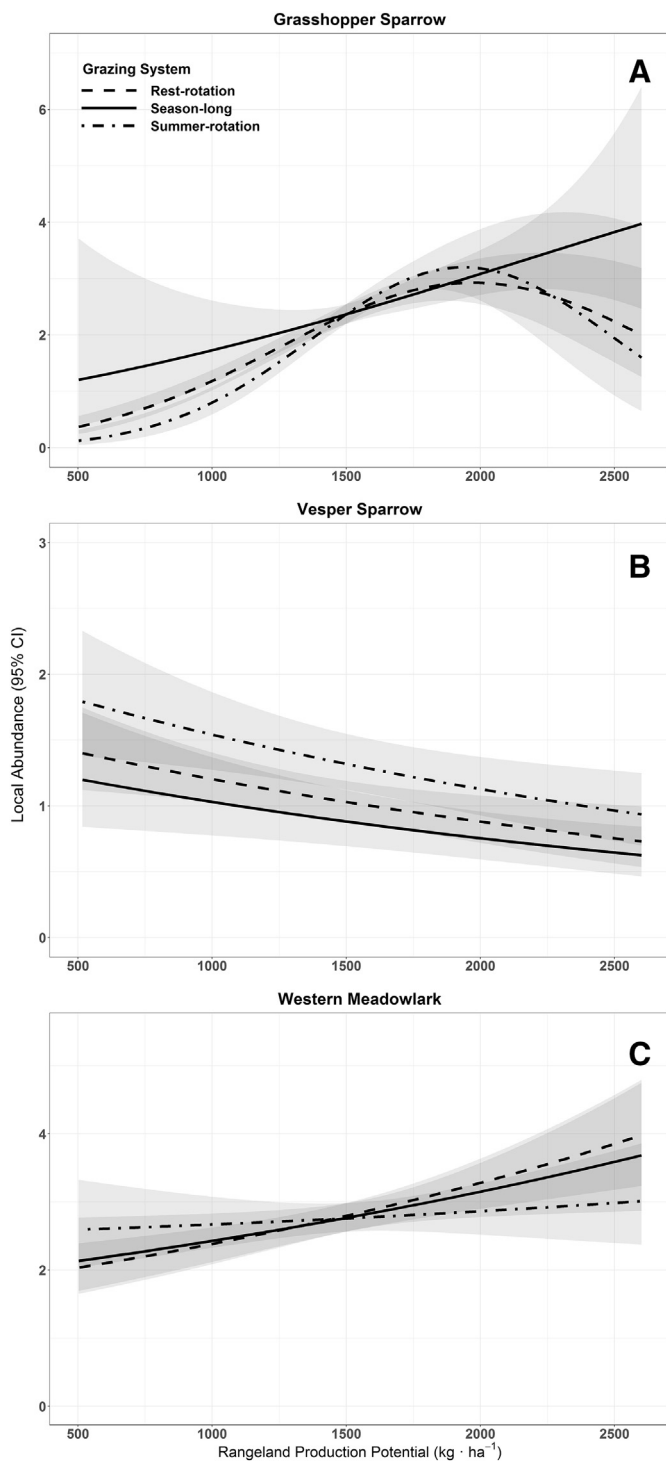


Figure 2. Relationships between rangeland production potential and predicted local abundance of **A**, grasshopper sparrow, **B**, vesper sparrow, and **C**, western meadowlark among three grazing systems in eastern Montana, 2016–2017.

abundance increased sharply from 0% to 5% cover but was similar beyond 5% ($\beta = 0.17 \pm 0.05$; see Table 4, Fig. 5). Models including landscape-scale variables wooded coulee area and fence density shared support ($\Delta AIC_c \leq 2.0$; see Table 2). Local abundance increased asymptotically with wooded area ($\beta = 0.15 \pm 0.05$) within 1 000-m² of the survey point, up to 6% wooded (see Fig. 5). Vesper sparrow abundance decreased with fence density ($\beta = -0.07 \pm 0.04$) within 1 000-m² area of the survey point.

Two models shared support ($\Delta AIC_c < 2.0$) for management-scale effects on vesper sparrow abundance (see Table 3). The top-ranked model ($w_i = 0.59$) included main effects of grazing system and rangeland production potential, while the next top model ($w_i = 0.31$) included the additional main effect of stocking rate, a parameter that may be uninformative. Relative to rest-rotation grazing systems, abundance of vesper sparrow was higher in summer-rotation grazing systems ($\beta = 0.25 \pm 0.10$) and similar in season-long systems ($\beta = -0.17 \pm 0.14$; see Table 4, Fig. 2B). Vesper sparrow abundance decreased with rangeland production potential at the study area from 500 to 2 500 kg \bullet ha⁻¹ ($\beta = -0.13 \pm 0.05$), and the effect was similar among grazing systems (see Fig. 2B). A model that included a negative effect of stocking rate on abundance of vesper sparrows was supported ($\beta = -0.04 \pm 0.05$; see Table 3), but the 95% confidence interval of the effect overlapped 0 (-0.13 – 0.05).

Western Meadowlark

The probability of detecting a western meadowlark was higher in 2017 than 2016 ($\beta = 0.37 \pm 0.11$), increased with viewshed ($\beta = 0.10 \pm 0.05$), and decreased with Julian d ($\beta = -0.32 \pm 0.05$) and wind speed ($\beta = -0.08 \pm 0.05$; see Table 4, Fig. S5; available online at (<https://doi.org/10.1016/j.rama.2019.08.005>)). Models that included the effects of visual obstruction, residual grass cover, forb cover, litter depth, and bare ground cover had the majority of support ($w_i = 0.73$) on local-scale abundance of western meadowlarks (see Table 1). Abundance increased asymptotically with litter depth from 0 cm to 5 cm ($\beta = 0.22 \pm 0.05$) and forb cover from 0% to 50% ($\beta = 0.09 \pm 0.03$) and decreased with visual obstruction from 0 dm to 5 dm ($\beta = -0.16 \pm 0.03$), residual grass cover from 0% to 80% ($\beta = -0.11 \pm 0.04$), and bare ground cover from 0% to 75% ($\beta = -0.09 \pm 0.04$; see Table 4, Fig. 6). Abundance of western meadowlark decreased ($\beta = -0.06 \pm 0.03$) with increasing wooded area within 1 000-m² area of the survey point from 0% to 7% (see Fig. 6).

Two models shared support ($\Delta AIC_c < 2.0$) for management-scale effects on western meadowlark abundance (see Table 3). The top model included an interaction between grazing system and rangeland production potential and a negative effect of stocking rate ($w_i = 0.60$). The data also supported a model that included main effects of rangeland production potential and stocking rate ($w_i = 0.31$). Model-averaged predictions show abundance of western meadowlark increased with rangeland production potential in season-long ($\beta = 0.11 \pm 0.06$) and rest-rotation grazing systems ($\beta = 0.15 \pm 0.04$; see Fig. 2C) and declined sharply with stocking rate from 0 to 0.1 AUM \bullet ha⁻¹ ($\beta = -0.09 \pm 0.03$; see Fig. 3; Table 4). Predictions from the two supported models estimate abundance of western meadowlark was highest in summer-rotation grazing systems in areas of relatively low production potential (< 1 000 kg \bullet ha⁻¹) and in season-long and rest-rotation systems in areas of relatively high production potential (> 1 500 kg \bullet ha⁻¹; see Fig. 2C).

Habitat

We analyzed the local habitat metrics collected at 9 150 plots within 610 bird survey areas among the three grazing systems, in addition to landscape-scale metrics wooded coulee area and fence density for each survey point. Several habitat components differed among grazing systems, including residual grass cover ($P < 0.01$), forb cover ($P = 0.08$), litter depth ($P < 0.01$), bare ground cover ($P < 0.01$), and shrub cover ($P = 0.01$), and height ($P < 0.01$; Table S3; available online at (<https://doi.org/10.1016/j.rama.2019.08.005>)). On average, plots in season-long grazing systems had the highest ($\bar{x} \pm SE$) residual grass cover (47.6% \pm 1.5%), residual grass height (16.3 cm \pm 0.67 cm), litter depth (1.6 cm \pm 0.07 cm), and the lowest shrub cover (3.5% \pm 0.57%) and height (18.5 cm \pm 1.2 cm). Plots in pastures managed with rest-rotation grazing had greater bare ground cover (22.4% \pm 0.81%) and lower residual grass cover (37.7% \pm 0.93%) and

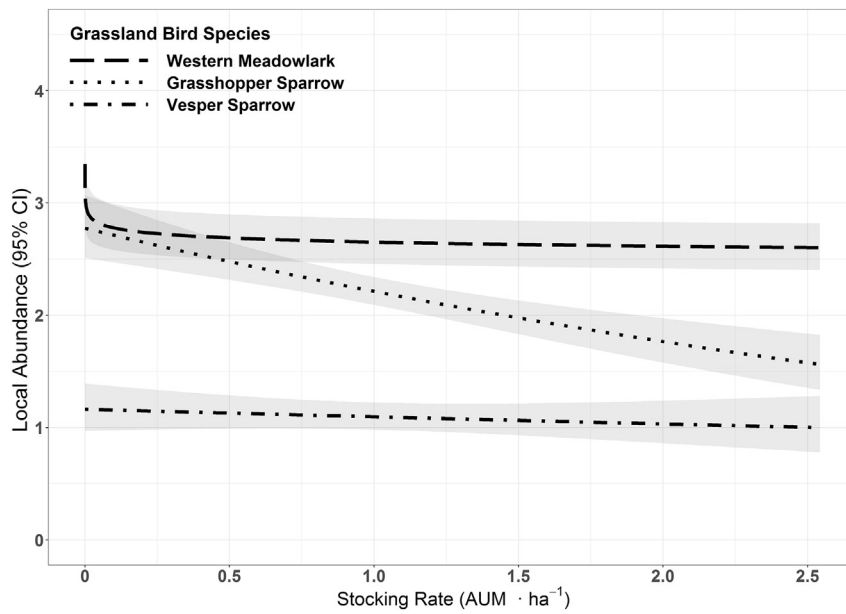


Figure 3. Relationships between stocking rate and predicted local abundance of three grassland bird species in eastern Montana, 2016–2017.

litter depth (1.3 cm ± 0.04 cm), on average. Rest-rotation systems also included greater forb cover (11.0% ± 0.32%) relative to other systems (see Table S3). Fence density at 500-m and 1 000-m scales was highest for sites within rest-rotation pastures, at 10.5 (± 0.41) and 12.9 (± 0.24) m ● ha⁻¹, respectively. Generally, residual grass

cover and litter depth were greater in 2017, and VOR, residual grass height, and forb cover were greater in 2016 (Table S4; available online at (<https://doi.org/10.1016/j.rama.2019.08.005>)).

Several local vegetation components differed among treatments within rest-rotation systems, including residual grass cover

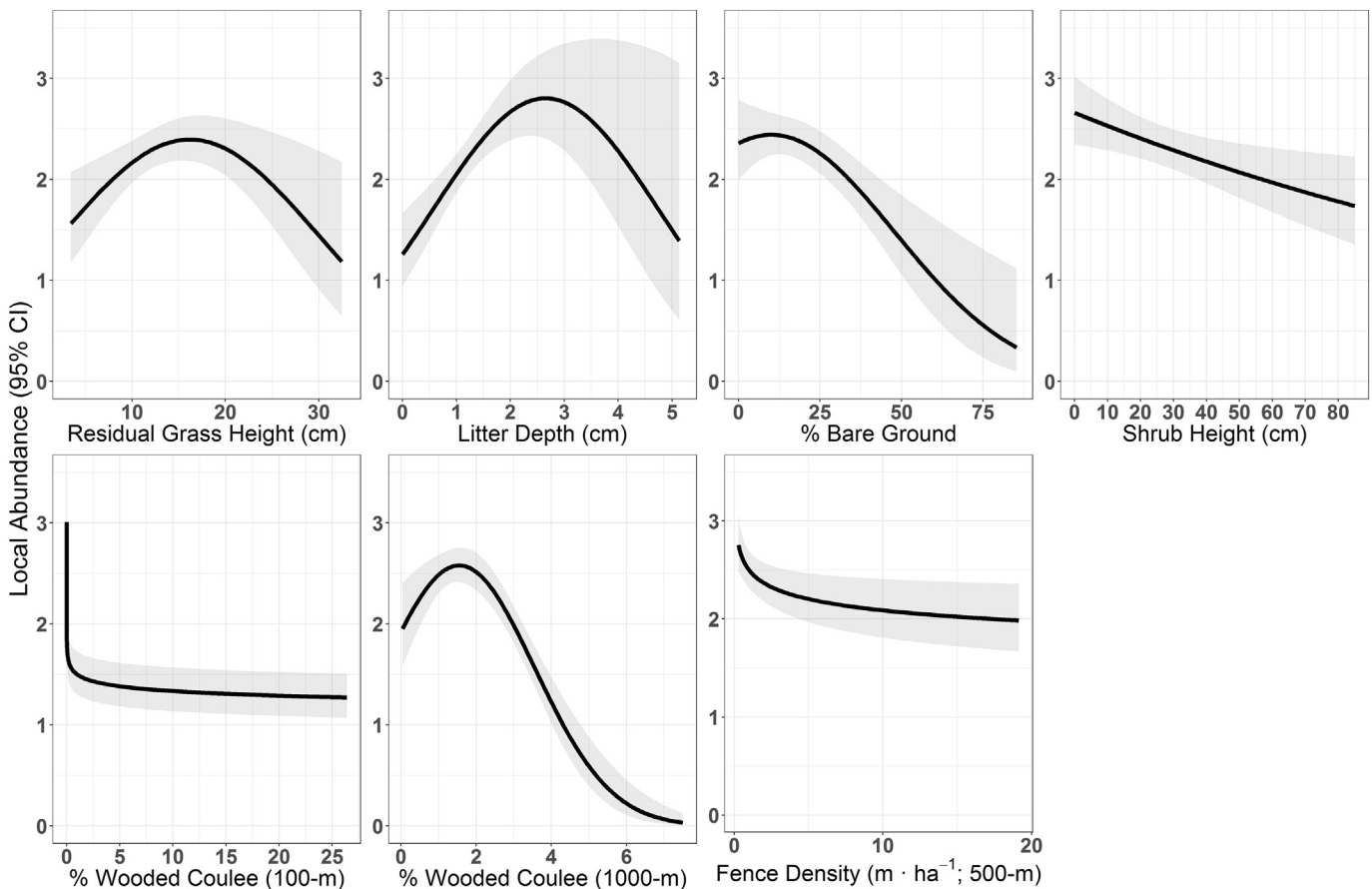


Figure 4. Predicted relationships between local- and landscape-scale habitat conditions and local abundance of grasshopper sparrow in eastern Montana, 2016–2017.

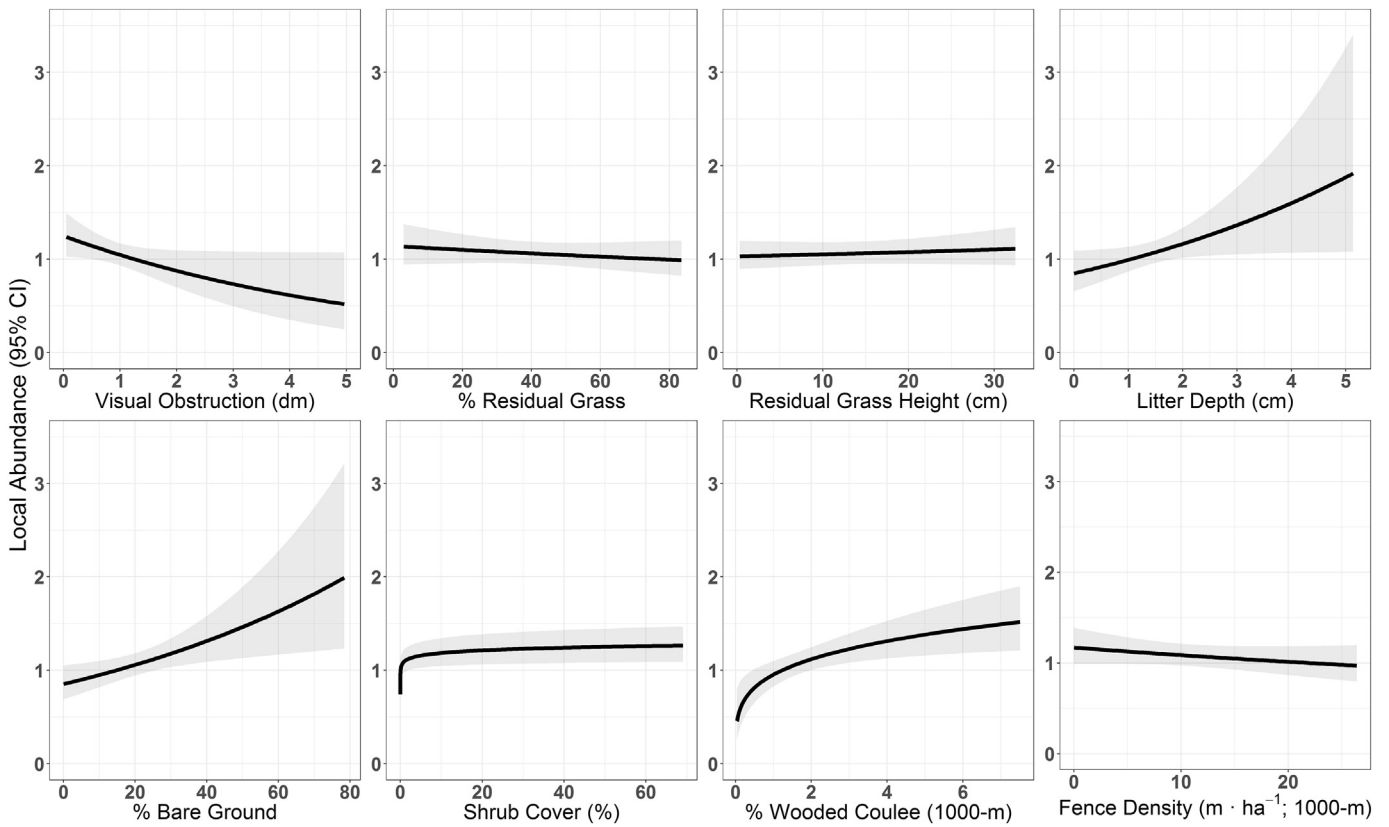


Figure 5. Predicted relationships between local- and landscape-scale habitat conditions and local abundance of vesper sparrow in eastern Montana, 2016–2017.

($P < 0.01$), residual grass height ($P < 0.01$), litter depth ($P < 0.01$), and bare ground cover ($P < 0.01$; Table S5; available online at <https://doi.org/10.1016/j.rama.2019.08.005>). Residual grass height

(15.8 cm \pm 0.34) and litter depth (1.6 cm \pm 0.08) were highest, and bare ground cover was lowest (18.3% \pm 1.2) in the pastures rested from grazing the previous year. Residual grass cover was lowest in

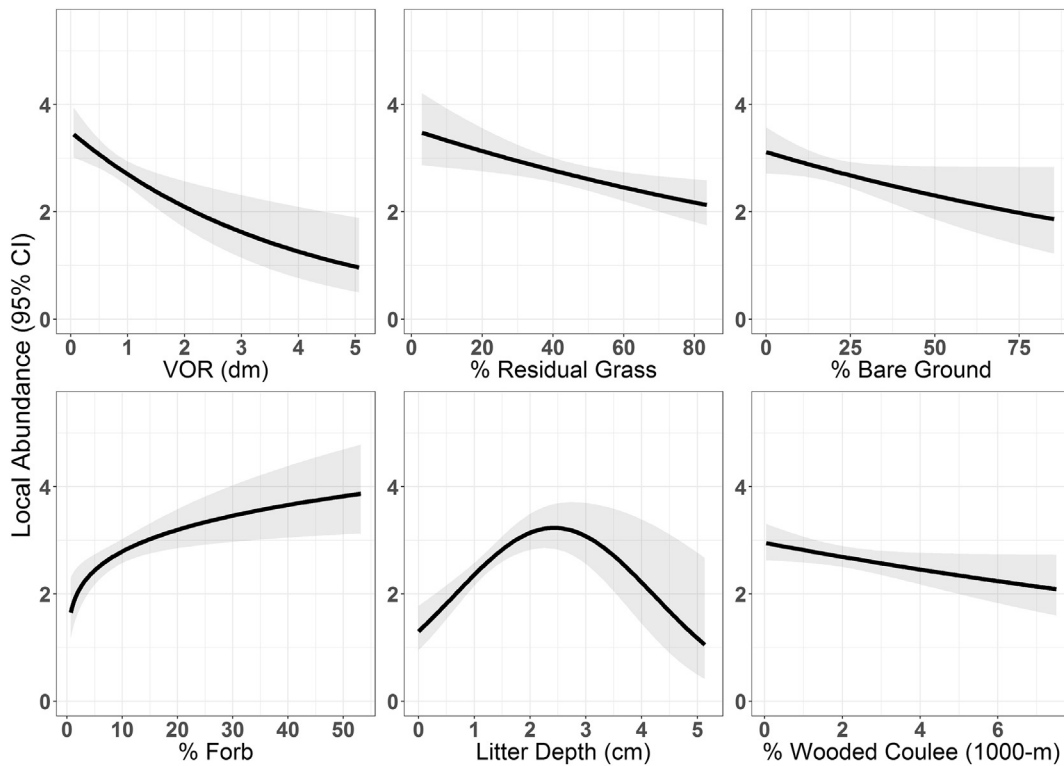


Figure 6. Predicted relationships between local- and landscape-scale habitat conditions and local abundance of western meadowlark in eastern Montana, 2016–2017.

postgrowing season treatments ($32.5\% \pm 1.3$) and similar between growing-season ($40.3 \text{ cm} \pm 1.9$) and rested treatments ($39.9 \text{ cm} \pm 1.5$).

Discussion

In contrast to our expectations, rest-rotation grazing did not support greater local abundances of three native ground-nesting grassland obligate birds nor improve grassland bird community composition relative to summer-rotation or season-long grazing systems during our 2-yr study, despite modest differences among grazing systems in vegetation composition and structure. Rather, associations among local abundance, grazing system, stocking rate, and rangeland production potential were species specific and do not support ubiquitous grazing management recommendations for grassland bird conservation. Our study is the first to evaluate the relationships among these variables, and our findings may help explain inconsistencies within published literature reporting effects of livestock grazing systems on the ecology of grassland birds in northern-mixed grass prairie systems (e.g., Messmer, 1990; Buskness et al., 2001; Ranellucci et al., 2012; Davis et al., 2014; Sliwinski et al., 2019).

Grazing Systems

Local abundance was influenced by grazing system for each of three obligate grassland birds, but our results were inconsistent with our hypothesis that grassland birds would generally benefit from rest-rotation livestock grazing. Abundance of grasshopper sparrow, representing the dense-grass guild in our study area, was generally highest in season-long grazing systems; abundance of vesper sparrow, representing the sparse-grass guild, was highest in summer-rotation grazing systems; abundance of western meadowlark was similar among season-long and rest-rotation grazing systems. In addition, grassland bird community composition among the three grazing systems was similar. Community composition was also similar among the three pasture treatments within rest-rotation grazing systems; grazing during the growing season, postgrowing season, and rest from grazing. Collectively, our results conflict with previous research demonstrating positive population and community responses of grassland birds to heterogeneous rangeland management (Fuhlendorf and Engle, 2001; Hovick et al., 2015), and indicated that grassland birds within our study area did not exhibit guild-specific distinction in habitat use of the three treatments within rest-rotation grazing systems. At moderate stocking rates ($2\text{--}3 \text{ AUM ha}^{-1}$), rest-rotation grazing did not appear to create spatial heterogeneity in vegetation structure at our study area as expected (see Table S4; Vold, 2018; Milligan et al., in press). Proper functionality of the rest-rotation system should result in pastures rested from livestock grazing as having notably higher vegetation height and density than systems that do not incorporate rest from grazing. However, we found rested pastures had similar residual grass cover and height, VOR, litter depth, and bare ground cover to either season-long or summer-rotation systems. Management systems that incorporate moderate stocking rates without prescribed fire may be insufficient to influence patch-level habitat heterogeneity in the northern mixed-grass prairie (Fuhlendorf and Engle, 2001; Fuhlendorf and Engle, 2004; Sliwinski et al., 2019). In our study, effects of stocking rate and rangeland productivity were more important drivers of grassland bird abundance than was grazing system alone. Nevertheless, our study was limited to 2 yr and patterns of breeding abundance of birds may be influenced by environmental conditions at nonbreeding habitats (Vickery and Herkert, 2001).

Site Production Potential

In the absence of fire, rangeland productivity, annual precipitation, and grazing are typically the main factors affecting grassland vegetation structure at the landscape scale (Vermeire et al., 2008; Lwiwinski et al., 2015; Lipsey and Naugle, 2017). Our results support those of previous research and suggest grassland birds displayed guild-specific (dense-grass vs. sparse-grass) habitat use along gradients of rangeland productivity (Lipsey and Naugle, 2017). Abundance of grasshopper sparrows (dense-grass) and western meadowlarks (generalists) generally increased, and abundance of vesper sparrows (sparse-grass) decreased with rangeland production potential. Notably, the support for an interaction between grazing system and rangeland production potential for multiple species in our analysis suggests that the response of grassland birds to grazing systems may not be similar across areas of variable rangeland productivity within grassland ecosystems. Rather, the effects of grazing systems on grassland bird ecology may be mediated by rangeland production, a result that could provide some indication for the regional inconsistencies in the literature regarding these effects of livestock grazing systems in the northern Great Plains (e.g., Buskness et al., 2001; Ranellucci et al., 2012; Davis et al., 2014). Significant variability in large-scale regional responses of grassland birds to livestock grazing are well documented, such that species-specific responses will differ in arid short-grass compared with productive tallgrass prairies (Askins et al., 2007). Our results suggest that interactions among livestock grazing, rangeland productivity, and precipitation can influence grassland bird populations even at spatial scales much smaller than previously observed and have implications for the management of individual ranches within grassland ecosystems of the northern Great Plains.

Stocking Rate

Unlike previous research occurring in a more productive prairie ecosystem (Ahlering and Merkord, 2016), we did not find a positive response to stocking rate in abundance of our three representative obligate grassland birds. In contrast, local abundances of grasshopper sparrows and western meadowlarks declined with increases in stocking rate, and we observed no relationship between stocking rate and the abundance of vesper sparrows. Sliwinski and Koper (2015) found similar responses of dense-grass obligates to stocking rate in the northern mixed-grass prairie. Notably, we found no support for an interaction between stocking rate and grazing system, indicating the effect of stocking rate on local abundances of grassland birds was consistent across grazing systems within our study area. The consistently negative response of grasshopper sparrow to increasing stocking rates, coupled with the quadratic response of this species to residual grass height and litter depth and negative response to bare ground cover, supports previous research and suggests that suitable habitat may be available for the dense-grass guild of grassland birds under light to moderate grazing intensities in the northern mixed-grass prairie (Bock et al., 1993; Sutter et al., 1995; Sliwinski and Koper, 2015). In contrast, more intensive disturbances by grazing or fire are required to create suitable habitat for grassland birds in more productive ecoregions (e.g., tallgrass prairie; Temple et al., 1999; Rahmig et al., 2009; Ahlering and Merkord, 2016).

Landscape-Scale Responses

Several species of grassland birds have exhibited negative responses to edge effects within prairie ecosystems, including the avoidance of edges or lower nesting success near edges, often as a result of either increased predation or parasitism along edges (Johnson and Temple, 1990; Winter et al., 2000; Patten et al., 2006). In our study area, both dense- (grasshopper sparrows) and sparse-grass (vesper sparrows) species exhibited a consistently negative relationship with

increasing fence density on the landscape. Fence lines are often associated with stark changes in vegetation structure among pastures and may be perceived as habitat edges within contiguous rangelands. Intensive grazing systems, such as rest-rotation or short-duration systems, increase the amount of fencing on the landscape by dividing large pastures into multiple smaller pastures and may negatively affect grassland bird use on the basis of these subtle edge effects (Vold, 2018). In addition, if areas near fence lines function to increase predator use (Pedlar et al., 1997), grassland birds may avoid areas in close proximity to fences to reduce the perceived risk of predation.

Implications

Our results suggest that interactions between livestock grazing management and local rangeland production potential generally limit broad-scale livestock management recommendations for conservation of grassland birds in northern mixed-grass prairie ecosystems. Overall, we did not find support for rest-rotation grazing as a rangeland management practice to improve the abundance or diversity of grassland birds, relative to traditional season-long or summer-rotation grazing at our study area in northeastern Montana. Grazing systems alone may fail to create heterogeneity in vegetation structure at the scale grassland birds require. Therefore, the conservation benefits of a specific grazing system to single species or even general guilds of grassland birds will be limited at regional scales. Rather, we suggest management occur at the local scale, within the context of the surrounding landscape. For example, areas of low rangeland production potential within a broader matrix of variable productivity may never be suitable for dense-grass obligate birds, regardless of the prescriptive livestock grazing system applied. Rather, understanding how grazing may interact with rangeland productivity within a management-unit will help identify optimal rangeland management techniques to employ for the benefit of grassland bird conservation.

Ultimately, effective management of rangelands for grassland bird conservation in the northern mixed-grass prairie appears to require continuous consideration of 1) species or guilds (sparse-grass, dense-grass, etc.) of management concern, 2) variable rangeland productivity at the local (e.g., management-unit) scale, 3) local annual precipitation before the summer grazing season and the interaction of rangeland productivity and precipitation at the pasture level, and 4) livestock utilization of rangeland vegetation within a specific pasture in the context of each of these variables. Universal implementation of particular rangeland management practices in the northern mixed-grass prairie may fail to reach conservation goals due to this need for local-scale management considerations rather than general, wildlife-friendly rangeland management (Davis et al., 2014). Nevertheless, the single most important management-controlled variable in our study was the stocking rate of livestock, which was negatively associated with the abundance of grassland birds, specifically dense-grass obligates, at our study area. Thus, high stocking rates (> 2 AUM ha^{-1}) should be avoided when managing for these birds in the northern mixed-grass prairie. However, further research should be conducted on additional sparse-grass species (e.g., chestnut-collared longspur [*Calcarius ornatus*]) to evaluate whether the innate environmental stochasticity within northern mixed-grass prairie landscapes provides habitat conditions required by sparse-grass obligates without the implementation of high stocking rates.

Although our results do not provide support for widespread implementation of conservation-focused rest-rotation grazing management in the northern mixed-grass prairie, our study was limited to 2 yr of average precipitation conditions. Researchers have suggested that heterogeneity-based rangeland management may provide ecological benefits in the face of increasingly variable

annual precipitation, especially in drought years (Allred et al., 2014; Ricketts and Sandercock, 2016; Fuhlendorf et al., 2017). Further research may be necessary to evaluate the response of grassland birds to livestock grazing management, specifically conservation-based rangeland management such as rest-rotation grazing, in years of extreme environmental conditions. Nevertheless, reversing the decline of grassland bird populations in the northern mixed-grass prairie depends on our ability to preserve large tracts of contiguous grassland habitat (Davis, 2004) and sustain appropriate grassland configuration (Lockhart and Koper, 2018). The contiguous tracts of grasslands evaluated in our study, regardless of grazing system, provided suitable habitat for many native grassland bird species and guilds. Conservation programs that promote or maintain contiguous grassland landscapes in northern mixed-grass prairie ecosystems should be prioritized over those requiring specific livestock grazing systems.

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.rama.2019.08.005>.

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