Effects of Grazing on Songbirds, Sage-grouse, and Invertebrates in Central Montana

Annual Report

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EXECUTIVE SUMMARY

The sagebrush steppe of the western US is one of the most imperiled ecosystems in North America. Corresponding declines in sagebrush avifauna mirror their disappearing sagebrush habitat. Most notably, the greater sage-grouse (*Centrocercus urophasianus*; hereafter ‘sage-grouse’) has been extirpated from approximately half of its range since European settlement. Similarly, grassland and shrubland songbirds inhabiting sagebrush habitat are exhibiting precipitous declines, more so than any other avian guild in North America. Since livestock grazing is the dominant land management practice in sagebrush ecosystems, livestock grazing may offer a promising strategy for conserving and improving avian habitat in sagebrush rangelands. Rest-rotation grazing, in particular, may be useful for promoting habitat diversity. However, grazing effects, regardless of grazing regime, vary depending on ecological context. While rest-rotation grazing has been implemented in other ecosystems, its impacts on sagebrush habitat in central Montana are unknown. A decade of data collection (2011-2020) has allowed us to evaluate the long-term and short-term effects of rest-rotation grazing implemented through the Sage Grouse Initiative (SGI) on songbird reproduction and community metrics, sage-grouse vital rates and habitat, and arthropod biomass.

Songbird species richness, composition, diversity, and reproduction metrics in SGI pastures were largely unchanged relative to non-SGI grazing pastures. However, estimates of abundance for the five most common species suggest species-specific responses to the two grazing systems. For instance, thick-billed longspurs (*Rhynchophanes mccownii*) were most abundant on lands using SGI grazing, while observations of western meadowlarks (*Sturnella neglecta*) were higher on non-SGI plots during the early years of our study. For our three focal species, Brewer’s sparrow (*Spizella breweri*), vesper sparrow (*Pooecetes gramineus*), and thick-billed longspur, we located 40% of nests on lands using non-SGI grazing, compared to 60% of nests on lands using SGI grazing. Estimated nest density was higher on SGI grazing plots for thick-billed longspur while nest densities for both Brewer’s and vesper sparrows were higher on non-SGI plots. For all focal species, nest success showed little difference between SGI and non-SGI. Both nest density and nest success varied more annually than between SGI and non-SGI.

To better understand the reproductive performance of the three focal songbird species, we developed a novel time-to-event nest success and abundance model (TNSAM; see Reintsma et al. 2023 for detailed methods and results). The TNSAM estimated nest detection, nest success, and nest abundance within the range of past estimates for these species. The average daily nest detection by species was 0.46 (CRI: 0.41–0.5), 0.48 (CRI: 0.41–0.55), and 0.52 (CRI: 0.47–0.57) for Brewer’s sparrow, thick-billed longspur, and vesper sparrow, respectively. Average nest success by species was 0.47 (CRI: 0.41–0.53), 0.31 (CRI: 0.23–0.39), and 0.41 (CRI: 0.35–0.46) for Brewer’s sparrow, thick-billed longspur, and vesper sparrow, respectively. Brewer’s sparrow had an estimated 692 (CRI: 630–783) total nests, thick-billed longspur an estimated 491 (CRI: 403–646) total nests, and vesper sparrow an estimated 699 (CRI: 644–776) total nests. We also used the TNSAM model to identify the influence of remotely sensed environmental factors and field-based grazing metrics on the nest success and nest detection of the three focal species. The final models for each species showed nest success and detection were primarily influenced by covariates associated with productivity (e.g., initiation day and its quadratic effect, temperature, and precipitation; Figure 2) over the active period of the nest at broad spatial resolution (i.e., 1 km). The exception to this pattern was the relatively small negative effect of growing season leaf area index (LAI) and annual AUMs (Figure 2) on vesper sparrow nest detection and success at 30 m.

Findings related to sage-grouse habitat are complete and indicate minor differences between SGI rest-rotation grazing and non-SGI grazing regimes. SGI plots tended to have greater herbaceous vegetation than non-SGI plots. However, this difference was not statistically significant and was less than interannual and pasture-level variation in vegetation, suggesting that SGI grazing management in this study area has negligible effects on vegetation in comparison to the other grazing systems. Similarly, based on mixed-effect generalized linear models, grazing metrics tended to have smaller effects on rangeland biomass and productivity compared to environmental factors.

For sage-grouse vital rates, our results suggest that annual variation affects hen and chick survival more than grazing management. Annual chick survival rate estimates were highly variable among years (range: 0.19–0.62). Chick mortality risk was relatively unassociated with brood hen age, weather, vegetation, and anthropogenic variables. Female chicks tended to survive better than males, though this relationship was not significant. Additionally, our analysis suggests that lands enrolled in SGI grazing management may have increased the probability of chick mortality risk, though these results should be interpreted with caution because vegetation covariates did not further explain these differences. Nest success did not differ between grazing categories. Grazing (specifically, used animal unit months) may have had a slight positive effect on hen habitat selection; however, overall, hens exhibited stronger selection for shrub cover and annual forb and grass cover across grazing treatments and seasons. Predictive maps of the relative probability of sage-grouse use across the study area show that the habitat characteristics sage-grouse selected for are widely available. Annual hen survival estimates were also highly variable among years (range: 0.42-0.80). Further analysis, in progress, will investigate the effects of intersecting environment and management-based covariates on this interannual variation in hen survival. The mean annual population growth rate derived from a female-based matrix population model was 0.90 and less variable that the population growth rate derived from from male-based lek count data, which was 1.16. These estimates suggest contrasting population trends; a declining trend from the matrix model and an increasing trend from the lek counts. We caution against the use of lek counts to make management decisions due to the possibility that they could overestimate the population growth rate.Our final goal, related to sage-grouse demographic rates, will be to generate an integrated population model that incorporates sage-grouse vital rates and habitat covariates.

A related study objective to improve the predictive spatial model of invertebrate biomass has also been completed. Models were developed and tested for improving invertebrate biomass predictions across the sage-grouse and songbird study areas. A variety of climate and topographic predictor variables were introduced into the models to assess the potential for improving prediction performance within and across years. Additional grazing metrics (SGI enrollment and grazing timing, frequency, and duration) were tested for importance in previous models (Mitchell et al. 2021), but these variables failed to increase predictive power and were not retained in models detailed within this report. Covariates in the most parsimonious model included: April snowpack, precipitation coefficient of variation, max temperature standard deviation, max temperature coefficient of variation, and accumulated degree days. Despite intensive biomass sampling efforts in the field, prediction improvement was limited. Additional model testing rejected the hypothesis that advanced machine learning algorithms could compensate for the strong influence of multi-scale temporal variability on prediction performance over relatively large study areas.

Overall, the effects of SGI rest-rotation grazing were similar to non-SGI grazing regimes for most metrics examined. The songbird and invertebrate study objectives are complete. Sage-grouse objectives are mostly complete; the final objectives in progress include assessing the drivers of interannual variability in hen survival and developing an integrated population model. For in-progress objectives, we report preliminary results and projected status of completion. Final deliverables for each of the songbird, sage-grouse, and invertebrate projects are expected to be completed by June 2024.

INTRODUCTION

The sagebrush steppe once covered over 62 million hectares in the western US and southwestern Canada but is now among the most imperiled ecosystems in North America (Noss et al. 1995). Conifer encroachment (Miller et al. 2011), exotic annual grass invasion (Chambers et al. 2014; D’Antonio and Vitousek 1992), altered fire regimes (Baker 2011), cropland conversion (Smith et al. 2016), and energy development (Walker et al. 2007; Walston et al. 2009) all contribute to the highly fragmented and disappearing sagebrush biome (Davies et al. 2011; Knick et al. 2003). Sagebrush habitat loss and degradation increase the risk of local and regional extirpations of sagebrush-dependent wildlife, the consequences of which are currently transpiring via emphatic avifaunal declines. Most notably, the greater sage-grouse (*Centrocercus urophasianus*; hereafter ‘sage-grouse’) has been extirpated from approximately half of its range since European settlement (Schroeder et al. 2004). Long-term declines in sage-grouse abundance and distribution (Connelly and Braun 1997; Schroeder et al. 2004) have warranted multiple evaluations for listing under the Endangered Species Act (U.S. Fish & Wildlife Service, 2015). Similarly, grassland and shrubland songbirds are exhibiting precipitous declines, more so than any other avian guild in North America (Rosenberg et al. 2019; Sauer et al. 2017), with many of these species associated with sagebrush habitat. Rangeland management practices that conserve and improve remnant sagebrush habitats may be a promising strategy for mitigating widespread population declines of sagebrush birds.

Affecting 70% of land in the western US, livestock grazing is the dominant land management practice in sagebrush ecosystems (Heady et al. 1974). While overgrazing has been implicated in sagebrush deterioration (Fleischner 1994; Mack 1981), range conditions have since improved due to advancements in rangeland ecology and better administration of public lands grazing (Holechek 2011). Moreover, grazing is not a novel process in this ecosystem (Perryman et al. 2021); sagebrush steppe associated birds coevolved with variable vegetation structure created by dynamic disturbance processes, including grazing (Duchardt et al. 2018). In some systems, livestock grazing has even been promoted as a surrogate for historical ecological processes (Fuhlendorf and Engle 2001). Since changes to vegetation structure may be the primary mechanism through which grazing affects wildlife, managers may be able to manipulate grazing variables (e.g. stocking rate, timing, duration) to achieve specific habitat outcomes. However, it is difficult to predict effects of grazing prescriptions because effects vary substantially based on ecological setting (Davis et al. 2020).

To combat threats to the sagebrush biome, the Natural Resources Conservation Service (NRCS) - Sage Grouse Initiative (SGI) launched a rest-rotation grazing program designed to simultaneously support wildlife habitat and sustainable ranching (NRCS 2015). The SGI grazing system rotates livestock through different pastures for short periods (< 45 days) and shifts the annual timing of grazing each year. This method is intended to allow vegetation to recover from previous grazing disturbances (NRCS 2017). In contrast, other (i.e. non-SGI) grazing practices may entail a season-long livestock presence without annual changes in season of use (Holecheck et al. 1999). Rest-rotation grazing systems may also promote a mosaic of varying stages of disturbance where the resulting structural heterogeneity fulfills habitat requirements of numerous species (Fuhlendorf and Engle 2001; Krausman et al. 2009). However, grazing impacts are site specific. Intensity, duration, timing, livestock type, and biophysical factors (e.g. soil, climate, topography; Briske et al. 2008; Holechek et al. 1999; Lipsey and Naugle 2017; Veblen et al. 2015) all influence vegetation response to grazing. Additionally, the effects of rest-rotation grazing systems have not been closely examined in central Montana where there is a need for understanding how grazing can meet desired stakeholder and wildlife management goals. Herein, we compare SGI and non-SGI grazing regimes to determine grazing impacts on the sagebrush community within a working landscape.

Management actions applied within the sagebrush steppe are often evaluated through the lens of sage-grouse conservation objectives. Over 50 years of sage-grouse population declines prompted unprecedented conservation efforts directed towards reversing these trends and precluding protections from the Endangered Species Act. Sage-grouse have subsequently become emblematic of sagebrush conservation and are often perceived as an umbrella species for other sagebrush-dependent species (Barlow et al. 2020; Rowland et al. 2006). While single-species approaches to conservation, like that of sage-grouse, allow managers to make the most of limited resources, this umbrella may not always be adequate for co-occurring species that require separate management actions (Carlisle et al. 2018; Carlisle et al. 2020; Dinkins and Beck 2019; Smith et al. 2021). Alternatively, a multi-species strategy can broaden the protections offered by a single umbrella species since an umbrella species may be unaffected by ecological factors that inevitably limit some co-occurring species (Roberge and Anglestam 2004; Timmer et al. 2019). Systematically selecting multiple focal species that require a range of habitat types and landscape attributes across different spatial scales can provide a holistic perspective on ecosystem integrity and management impacts.

This report uses a multi-species assemblage to examine impacts of rest-rotation grazing employed through SGI. Our focal species included songbirds, sage-grouse, and invertebrates (e.g.,arthropods) because of their interrelated roles in sagebrush systems. Songbirds are integral to ecological communities because they function as predators, prey, pollinators, and seed dispersers (Whelan et al. 2008). Their sensitivity to habitat change makes songbirds effective indicators of shifting habitat conditions that may occur as a result of grazing (Canterbury et al. 2000; Coppedge et al. 2006; Milchunas et al. 1998). Sage-grouse conservation has strongly shaped land use policy and management actions that affect other sagebrush-dependent wildlife, but there remains a paucity of information regarding specific grazing effects on sage-grouse demographics and habitat in central Montana (Dettenmaier et al. 2017). Finally, arthropod communities are an important food source for sagebrush songbirds and are especially vital for sage-grouse chick development and survival (Johnson and Boyce 1990).

This annual report outlines the status of a decade (2011-2020) of research evaluating SGI rest-rotation grazing on songbird community and reproduction metrics, sage-grouse habitat and demographics, and invertebrate biomass within a central Montana sagebrush ecosystem. This research has the following long-term objectives:

Songbird

1. Investigate migratory songbird abundance, species richness, species diversity, and community composition responses to SGI versus non-SGI grazing.
2. Investigate migratory songbird breeding performance of three focal songbird species (Brewer’s sparrow, vesper sparrow, and thick-billed longspur) responses to SGI and Non-SGI grazing as a management tool.

Sage-grouse

3. Measure the vegetation response in pastures receiving different grazing and resting treatments, relative to published sage-grouse habitat needs.
4. Create habitat-based measures of fitness which can be compared among grazing treatments by measuring individual vital rates known to impact population growth in sage-grouse and relating estimated vital rates directly to habitat variables and other important drivers.
5. Identify movements by sage-grouse between grazed and rested pastures to

quantify use of treatments proportional to habitat availability and other drivers of sage-grouse resource selection.

6. Create a habitat-linked population model to:
    a. Evaluate and forecast the benefits of treatments within a rotational grazing system on sage-grouse populations in the context of other drivers of sage-grouse vital rates, so as to put the influence of grazing management on population dynamics in context, and
    b. Identify current areas that are most important to sage-grouse to prioritize locations where habitat management will have the most benefit to populations.
7. Quantify the population-level response of grazing treatments by indexing lek counts to our population modeling results, then by comparing lek counts within the Roundup study area to surrounding populations. To the extent that lek counts represent population changes reflected in population models, bird response to grazing might be forecasted in other areas where only lek count data are available.
8. Generate spatially-explicit maps for areas with high quality seasonal habitat. Specifically, we will produce maps that delineate areas with habitat attributes that define relative probability of use and that have a positive influence on vital rates during the nesting, brood-rearing, and winter periods, and extrapolate to similar landscapes to the extent that these models validate well.

Invertebrates

9. Improve the predictive spatial model of invertebrate biomass across the sage-grouse and songbird study areas.
10. Link information from the invertebrate spatial layer to sage-grouse and songbird populations.

We have successfully completed 10 years of data collection towards these objectives. Previous years' work is detailed in prior annual reports (see Dreitz et al. 2021; Berkeley et al. 2021; Mitchell et al. 2021). However, data collection in the 10th year (2020) was minimal because we were not able to hire seasonal technicians and expend our usual effort to collect data due to the coronavirus disease (COVID-19) pandemic. Songbird and invertebrate objectives have been completed. Sage-grouse objectives listed above are in progress and we will report on the preliminary results that have been completed thus far. Progress towards objectives, status of deliverables, and future goals are aggregated by project (songbird, sage-grouse, invertebrates) within this report.

STUDY AREA

The study area was in central Montana in rolling topography that ranged from 975-1,250m in elevation (Smith et al. 2018b) and covered approximately 150,000 hectares in Musselshell and Golden Valley counties (Figure 1). The vegetation was consistent with big sagebrush steppe, the most widely distributed sagebrush system in Montana. Wyoming big sagebrush (*Artemisia tridentata ssp. wyomingensis*) and silver sagebrush (*A. cana*) were both common and co-dominant, with a mix of perennial bunchgrasses, perennial rhizomatous grasses, and forbs composing up to 25% of cover (Montana Natural Heritage Program 2021). This region has cooler soil temperature and higher soil moisture than other parts of the sage-grouse range (Pyke et al. 2015). The average monthly temperature in Roundup (2009-2020) ranged from a low of -3.8º Celsius (25.1º Fahrenheit) in January to a high of 21.8º Celsius (71.2º Fahrenheit) in July (National Centers for Environmental Information 2021). Average monthly precipitation in Roundup (2009-2020) ranged from a low of 9.40 millimeters (0.37 inches) in January to a high of 73.41 millimeters (2.89 inches) in June (National Centers for Environmental Information 2021). The climate is cold semi-arid (Pyke et al. 2015), with distinct seasons that include cool and wet springs, hot and dry summers, cool and wet autumns, and cold, snowy winters. The study area is a mosaic of public (federal, state, and county) and private ownership dominated by cattle rangeland, with some sheep rangeland and some dryland farming (Smith et al. 2018a, Smith et al. 2018b).

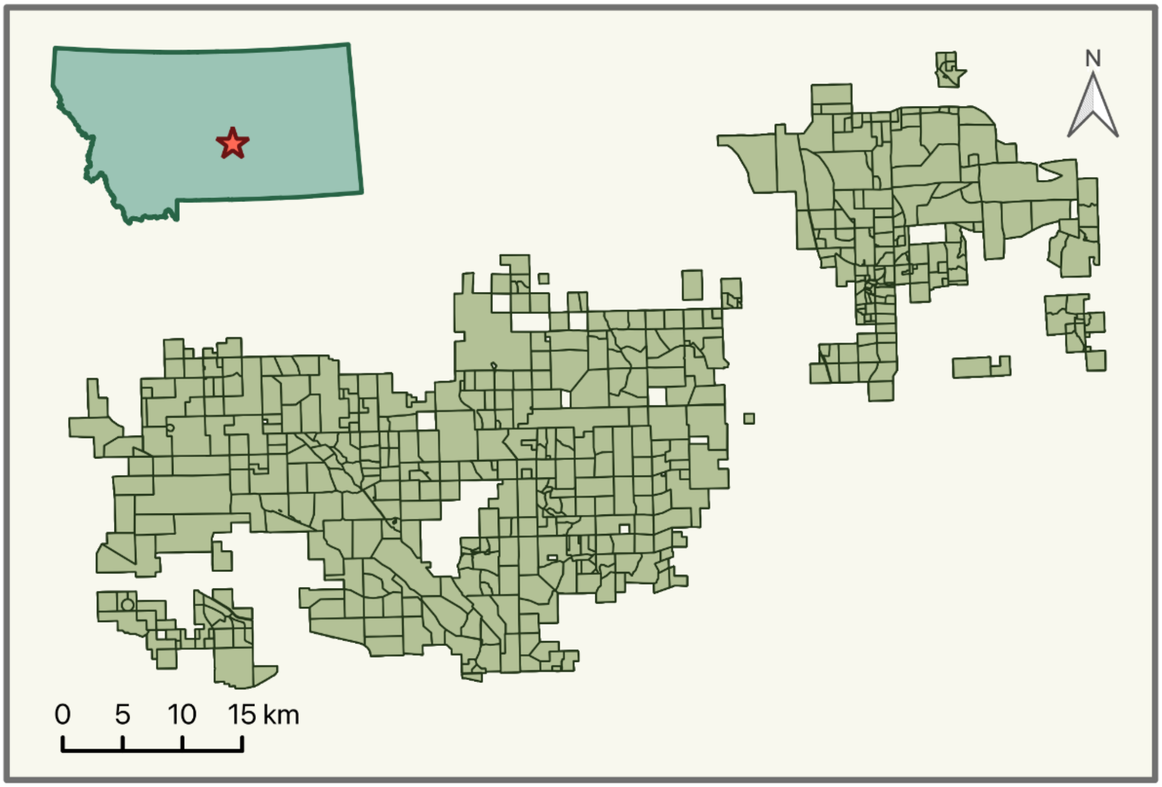


Figure 1: Livestock pasture boundaries within the study area in Golden Valley and Musselshell Counties, Montana, USA during 2011-2020.

THE SAGE GROUSE INITIATIVE (SGI) GRAZING PROGRAM

The SGI grazing program in central Montana focused on improving livestock production and rangeland health while simultaneously alleviating threats to and improving habitat for greater sage-grouse (NRCS 2015). The SGI program was implemented on private ranches containing potential sage-grouse habitat as defined by topography and sagebrush canopy cover ≥5% (NRCS pers. comm.) within sage-grouse core areas (Figure 2). FWP has designated core areas in Montana as locations of highest conservation value for sage-grouse based on habitat and number of breeding males. FWP has estimated that the core areas included ~76% of the displaying males in Montana as of 2013.

Livestock producers enrolled in the SGI program implemented an approximately three-year grazing regime developed with NRCS range management specialists. SGI grazing regimes were rotational and used a combination of rest and deferment to increase vegetation cover for nesting hens (Doherty et al. 2014, Smith et al. 2018b), in addition to other strategies. Range management specialists suggested pasture rest, pasture deferment, changed the number of animal units, or installed fences or water sources to adjust pasture size or livestock distribution. SGI grazing regimes were tailored to each ranch and varied by needs of the producer or pasture condition while following the NRCS Conservation Practice Standard for Prescribed Grazing (Natural Resources Conservation Service 2017, Smith et al. 2018b). Additionally, plans align with four minimum criteria intended to support sage-grouse habitat:

1. Grazing utilization rates of ≤50% of the current year's key forage species growth,
2. ≥20-day shift annually in the timing of grazing,
3. A plan to address unexpected circumstances like drought or fire, and
4. ≤45-day continuous grazing within any one pasture (Smith et al. 2018b).

Our work evaluated the effects of these recommendations to determine if this program yields biologically-relevant benefits to songbirds, sage-grouse, and their invertebrate food sources. We categorized enrolled pastures into before, during, and after implementation of SGI grazing to disentangle direct and indirect effects of SGI grazing. Non-SGI grazing involved multiple types of grazing systems with less intensively managed and slower rotations, usually lacking annual changes in use.

SONGBIRD COMMUNITY AND REPRODUCTION

From 2013-2019 we collected field data to evaluate the relationships between grazing and sagebrush steppe songbird community composition and demographic parameters related to SGI's rotational grazing regime. Detailed methods and results can be found in the Migratory Songbird Grazing Study Final Report (P-R grant W-165-R-1 to FWP; Dreitz et al. 2021). This study had two objectives, which are detailed below.

Objective 1: Investigate migratory songbird abundance, species richness, species diversity, and community composition responses to SGI versus Non-SGI grazing.

We conducted avian count transect surveys using the dependent double-observer method. During 2013–2019, the total number of individuals we observed in the study area, regardless of grazing regime, ranged from 5,954–14,097, and the total number of species ranged from 72–88. We observed low variation in avian community composition amongst years, suggesting a relatively stable species richness in our study area over time. The migratory songbird species observed most often since 2013 were: thick-billed longspur (*Rhynchophanes mccownii;* previously named McCown's longspur), vesper sparrow (*Pooecetes gramineus*), Brewer's sparrow (*Spizella breweri*), horned lark (*Eremophila alpestris*), and western meadowlark (*Sturnella neglecta*). Estimates of abundance for the five most common species suggest species-specific responses to grazing (see Dreitz et al. 2021 for specific categorizations of SGI and non-SGI pastures used in songbird community analyses). For instance, thick-billed longspurs were most abundant on lands using SGI grazing, while observations of western meadowlarks were higher on non-SGI plots during the early years of our study.

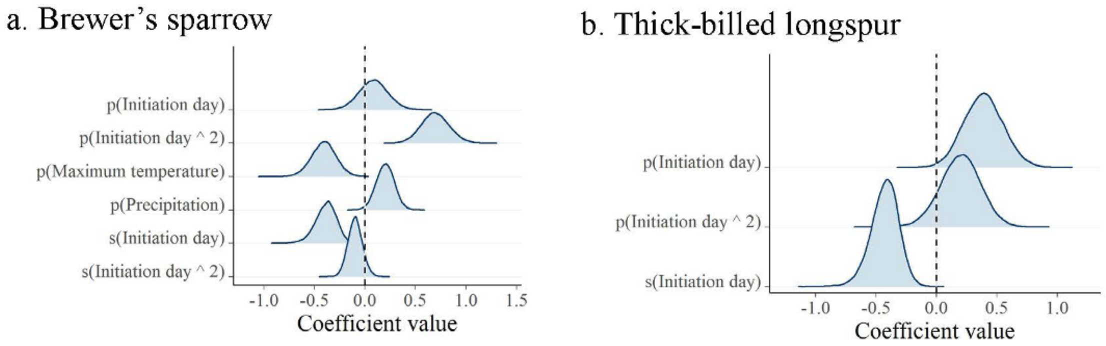
Objective 2: Investigate migratory songbird breeding performance of three focal songbird species responses to SGI and Non-SGI grazing as a management tool.

We identified three focal species, each associated with one of the three most common vegetation characteristics in sagebrush (*Artemisia* spp.) steppe. We conducted nest searches and monitored nesting activity of Brewer's sparrow (sagebrush nester), vesper sparrow (generalist ground nester), and thick-billed longspur (grassland ground nester). For our three focal species, we located 40% of nests on lands using non-SGI grazing, compared to 60% of nests on lands using SGI grazing. Estimated time-to-event nest density was higher on SGI grazing plots for thick-billed longspur while time-to-event nest densities for both Brewer's and vesper sparrows were higher on non-SGI plots. For all focal species, time-to-event nest success showed little difference between SGI and non-SGI (see Dreitz et al. 2021 for specific categorizations of SGI and non-SGI pastures used in songbird reproduction analyses). Both time-to-event nest density and nest success varied annually.

To better understand the reproductive performance of the three focal species, we developed a novel time-to-event nest success and abundance model (TNSAM; see Reintsma et al. 2023 for detailed methods and results). This model can use nest data collected with any nest survey method (i.e., opportunistic or structured surveys) given the nest age is recorded and the nest is monitored until success or failure. We assessed the model performance using simulations and validated the model using nest data collected from the three focal species during 2013-2019. The nest data consisted of a total of 1,148 nests from the three species where approximately half of the nests were found opportunistically. The TNSAM performed well for these species, with little bias under a range of conditions (i.e., detection, survival, abundance), and estimated nest detection, nest success, and nest abundance within the range of past estimates. Over the 7 years, average daily nest detection by species was 0.46 (CRI: 0.41–0.5), 0.48

(CRI: 0.41–0.55), and 0.52 (CRI: 0.47–0.57) for Brewer's sparrow, thick-billed longspur, and vesper sparrow, respectively. Average nest success by species was 0.47 (CRI: 0.41–0.53), 0.31 (CRI: 0.23–0.39), and 0.41 (CRI: 0.35–0.46) for Brewer's sparrow, thick-billed longspur, and vesper sparrow, respectively. Brewer's sparrow had an estimated 692 (CRI: 630–783) total nests, thick-billed longspur an estimated 491 (CRI: 403–646) total nests, and vesper sparrow an estimated 699 (CRI: 644–776) total nests.These findings suggest that the TNSAM can estimate nest success, detection, and abundance using data commonly collected for time-to-event nest success and is easily extended to other nesting species or study interests. Thus, the TNSAM provides a tool for improving understanding of reproduction, which is a vital rate influential to the growth or decline of many populations.

We also used the TNSAM model to identify the influence of remotely sensed environmental factors and field-based grazing metrics on the nest success and nest detection of the three focal species. Despite the distinct habitat associations of the focal species, the final models for each species showed nest success and detection were primarily influenced by covariates associated with productivity (e.g., initiation day and its quadratic effect, temperature, and precipitation; Figure 2) over the active period of the nest at broad spatial resolution (i.e., 1 km). The exception to this pattern was the relatively small negative effect of growing season leaf area index (LAI) and annual AUMs (Figure 2) on vesper sparrow nest detection and success at 30 m. Overall, these results reiterate previous studies that have found reproduction of songbirds to be influenced by vegetation productivity and variables that influence productivity such as temperature and precipitation (Wilson et al. 2013; e.g., Mickey 1943; Felske 1971; Rotenberry and Weins 1991).



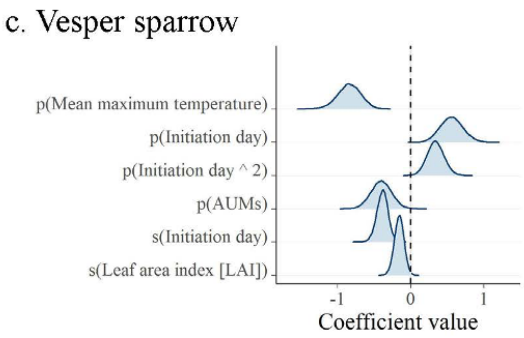


Figure 2. The covariate effects included in the final models for estimating nest detection (p), success (s), and abundance for Brewer’s sparrow (a), thick-billed longspur (b), and vesper sparrow (c).

Future Goals:

We have completed the songbird community and reproduction study objectives. Future work will focus on producing peer-reviewed publications detailing the development of the time-to-event nest success and nest abundance model and its use in determining factors that influence sagebrush songbird reproduction.

Deliverables:

Objectives	Description	Status
Objective 1	Investigate migratory songbird abundance, species richness, species diversity, and community composition responses to SGI versus Non-SGI grazing.	**Complete**
Objective 2	Investigate migratory songbird breeding performance of three focal songbird species responses to SGI and Non-SGI grazing as a management tool.	**Complete**

Student	Description	Status
MS Student	Individual officially enrolled at the University of Montana in August 2016 (year 1). Student participated in 2016, 2017, and 2018 field seasons, year 1, 2, and 3 respectively.	**Completed**: Degree awarded May 2019
PhD Student	Selected PhD candidate in spring 2017 (year 2). Individual officially enrolled at the University of Montana in August 2017 and received their graduate degree in Spring 2023.	**Completed**: Degree awarded May 2023

Publications	Status
Reintsma, K.M., et al. Time-to-event nest success and nest abundance model: a novel integrated Bayesian framework for estimating reproductive metrics with one datasource.	**In Progress:** Expected to submit by Dec 2023
Reintsma, K.M., et al. Using songbird reproduction metrics to identify high-quality habitat to support biodiversity in the sagebrush steppe of Montana.	**In Progress:** Expected to submit by Dec 2023
Ruth, K. A., L. I. Berkeley, K. M. Strickfaden, and V. J. Dreitz. In Review. Density dependence of songbird demographics in grazed sagebrush steppe. PLoS ONE.	**Accepted**
Reintsma, K.M., A.H. Harrington, V.J. Dreitz. 2019. Validation of a novel time-to-event nest density estimator on passerines: An example using Brewer's sparrows (Spizella breweri). PLoS ONE 12:e0227092	**Complete**
Reintsma, K.M., V.J. Dreitz, L.I. Berkeley. 2022. Thick-billed Longspur (Rhynchophanes mccownii) reproduction shows minimal short-term response to conservation-based program. Wilson Journal of Ornithology. 134 (2): 365–372	**Complete**
Golding, J.D., J.J. Nowak, and V.J. Dreitz. 2017. A multispecies dependent double-observer model: A new method for estimating multispecies abundance. Ecology and Evolution 7:3425–3435.	**Complete**
Golding, J.D. and V.J. Dreitz. 2017. Songbird response to rest-rotation and season-long cattle grazing in a grassland sagebrush ecosystem. Journal of Environmental Management 204: 605-612.	**Complete**
J.D. Golding and V.J. Dreitz. 2016. Comparison of removal-based methods for estimating abundance of five species of prairie songbirds. Journal of Field Ornithology 87: 417–426 (PDF)	**Complete**

GREATER SAGE-GROUSE DEMOGRAPHICS AND HABITAT

We evaluated the effectiveness of SGI rotational grazing systems to manage sage-grouse habitat in central Montana. To do so, we measured sage-grouse vital rates (including nest success, chick survival, and hen survival) within these grazing systems and compared them with vital rates in non-SGI grazing systems. We included factors describing vegetation structure and composition to evaluate the effects of grazing on sage-grouse habitat. Data collection occurred during 2011-2020. Detailed methods and results can be found in the "The Effects of Grazing on Greater Sage-Grouse Population Dynamics and Habitat in Central Montana" report (PR grant W-158-R to FWP; Berkeley et al. 2021). For in-progress objectives, we report preliminary results and projected status of completion.

Objective 1: Measure the vegetation response in pastures receiving different grazing and resting treatments, relative to published sage-grouse habitat needs.

During 2012-2019, we measured herbaceous vegetation in potential sage-grouse habitat using the line-intercept technique at a set of random field plots stratified by grazing system (SGI and non-SGI) to test for differences in vegetation metrics across the project area. While effects were not statistically significant, we observed tendencies for total herbaceous vegetation, live grass height, annual perennial forb cover (derived from the Rangeland Analysis Platform, or RAP), and RAP-derived shrub cover to vary with SGI grazing management, and an effect of SGI grazing management on RAP-derived litter cover, indicating that there was more herbaceous vegetation and less forb and shrub cover present in pastures currently being grazed according to the SGI program protocols. The variation among years and pastures was greater than differences observed in these metrics, reflecting the wide variation in vegetation growth. Our results are consistent with preliminary analyses from Smith et al. (2018a) that found negligible effects of SGI grazing management on vegetation in sage-grouse habitat.

Since the completion of the 2021 sage-grouse PR report (see Berkeley et al. 2021), we have continued analyses of vegetation in the study area. We used mixed-effect generalized linear models to test for effects of grazing management on rangeland biomass and productivity metrics while accounting for environmental factors. In these models, remotely sensed productivity measures were response variables and field-based grazing data combined with remotely sensed abiotic and biotic environmental factors were explanatory variables. We found point-level field measures of grazing (e.g., cow patties, percentage of dung in Daubenmire plots, and number of plants grazed) showed positive effects, especially on perennial plant rangeland responses. Grazing measures at the pasture-level showed a small negative effect on annual plant rangeland responses. Grazing metrics tend to have smaller covariate effects on rangeland biomass and productivity compared to environmental factors, indicating a greater importance of environmental factors in influencing rangeland productivity and biomass in this study area.

Objective 2: Create habitat-based measures of fitness which can be compared among grazing treatments by measuring individual vital rates known to impact population growth in sage-grouse and relating estimated vital rates directly to habitat variables and other important drivers.

We collected nest data from 2011-2019 on sage-grouse hens, including yearling (second-year) females and adult (after-second-year) females. Sage-grouse nests were located by monitoring pre-nesting females using radio telemetry ≥2 times per week at the onset of the nesting season. Nests were classified as either failed (eggs were either destroyed or missing) or successful (≥1 hatched egg had a detached membrane, Wallestad and Pyrah 1974). We monitored 736 nests, 397 of which failed. Across all years, 37% of nests were located in SGI pastures, and 63% were located in non-SGI pastures. We estimated sage-grouse nest daily survival rate (DSR) accounting for exposure days (e.g., days between field observations) and derived an estimate of nest success. The SGI status and grazing treatment of each nest location was used to investigate livestock grazing effects on estimated DSR. We used a logistic exposure nest survival model in a Bayesian framework (e.g. Schmidt et al. 2010, Smith et al. 2018b**,** Specht et al. 2020) to estimate the effects of SGI grazing program and grazing-related covariates on sage-grouse nest success. Nest success across the 37-day nesting period averaged 0.36 (95% CI = 0.31-0.40) from 2011-2019. We found weak to no evidence for an effect of SGI grazing systems, distance to nearest fence, number of cow patties, proportion of vegetation grazed, or senesced grass height on sage-grouse nest success. Overall, annual variation demonstrated the strongest effect on sage-grouse nest success.

Chicks were monitored using VHF radio transmitters that were attached to four randomly selected chicks per brood during 2011-2019. We used a Kaplan-Meier survival function to evaluate chick survival with staggered entry designs and right-censoring for individuals with unknown fates, dropped transmitters, or that survived until their transmitters expired. Log-rank models were used to test for differences in survival among categorical variables, including chick sex and hen age. We used a Cox proportional hazards model to assess the effects of time-varying and continuous covariates on chick mortality risk including body condition index of the brood hen; chick mass; weather; vegetation cover metrics extracted from the Rangeland Analysis Platform (RAP); other remotely sensed variables including slope, compound topographic index, vector ruggedness measure, herbaceous vegetation heights, shrub heights; distance to crops or roads; remotely sensed anthropogenic disturbance metrics including human structure density and human disturbance index; and grazing metrics including measures of direct and indirect effects of SGI and non-SGI grazing regimes. For all years combined, the Kaplan-Meier median survival time for the 125-day monitoring period was 46 d (95% CI = 34–60 days). Annual survival rate estimates for 510 chicks were highly variable among years (range: 0.19–0.62; Figure 3). Sage-grouse chick survival was relatively unassociated with brood hen age, weather, vegetation, and anthropogenic variables. Female chicks tended to survive better than males, though this relationship was not significant. Additionally, our analysis suggests that lands enrolled in SGI grazing management may have increased the probability of chick mortality risk, though these results should be interpreted with caution because vegetation covariates did not further explain these differences. We therefore do not recommend implementing grazing management as defined under the SGI program to increase sage-grouse chick survival.

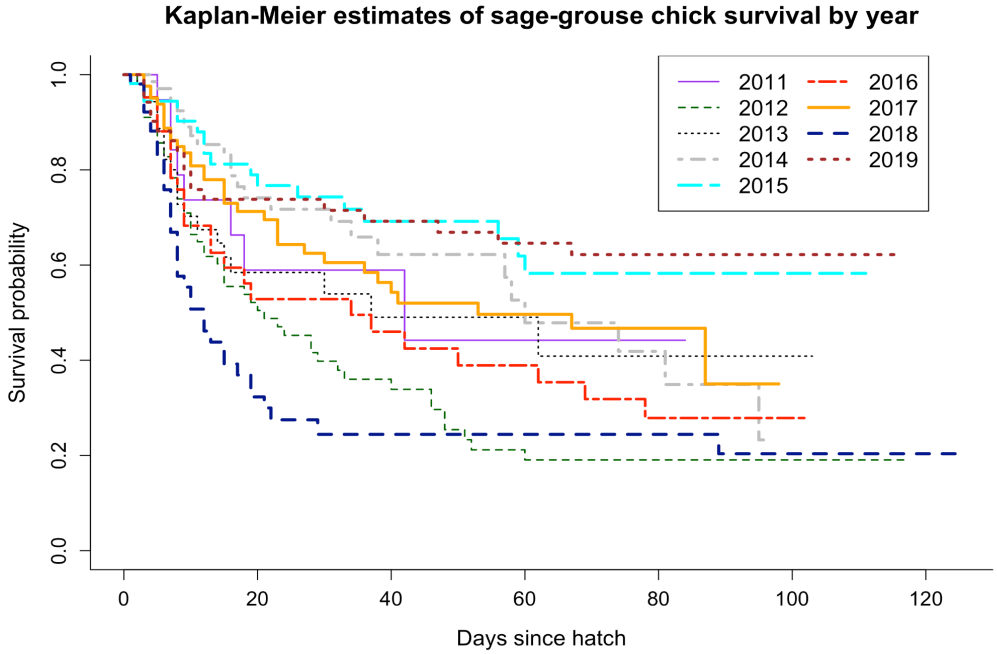


Figure 3: Kaplan-Meier survival curves by year (2011-2019) for marked greater sage-grouse chicks in Golden Valley and Musselshell Counties, MT. The 95% confidence intervals were removed to facilitate interpreting the figure.

Of the chicks that survived, we recaptured and monitored 45 as juveniles during the late summer, early fall. Seventeen of these juveniles survived to become yearlings (first breeding season), and 13 of these nested. Eleven nested during their first breeding season, 2 waited until their second breeding season, and 2 nested during both their first and second breeding seasons. Five of the 13 nests were successful, with one individual nesting successfully in years 1 and 2. The longest lived of these individuals was 2.5 yrs.

Hens were marked with VHF transmitters at the beginning of the breeding season (March and April) from 2011-2020 to monitor hen location and survival. After the first year, additional hens were captured to maintain about 100 hens per year. To achieve consistency in terms of how mortality was determined and the number of locations per hen, and to avoid the potential negative effects of GPS transmitters on survival, we focused the hen survival analysis on hens marked with VHF transmitters (N = 449). We used known-fate models to estimate annual survival with each year starting when the initial cohort of hens was captured in March and April and ending in February of the following year. We censored all individuals captured after March and April, that had unknown fates, that dropped their transmitters, or that survived until their transmitters expired. Annual survival estimates varied, with the highest annual survival in 2015 (0.80) and the lowest annual survival in 2020 (0.21). The overall survival for these hens was 0.57, in many of the years annual survival was close to that (2011-2014, 2016, and 2019; range: 0.54-0.61).

The hen survival analysis (in progress) will focus on how environmental and management-based factors drive interannual variation in hen survival. We will account for spatial and temporal variation in the relationships between hen survival and environmental conditions by drawing annual covariates (March-February of the following year) from each hen's annual home range across the ten years of the study. The covariates reflect three hypotheses about how annual variation in environmental conditions may affect annual hen survival. First, we will look at the mean and variation in annual temperature and precipitation, because these conditions affect sage-grouse food resources, cover for thermoregulation, and predator dynamics (Herman-Brunson et al. 2009; Webb et al. 2012; Guttery et al. 2013; Anthony et al. 2021; Hovick et al. 2014). Second, we will look at the proportion of each hen’s home range that includes mesic resources, because sage-grouse rely on mesic resources for food, especially during drought (Donnelly et al. 2016; Donnelly et al. 2018). Finally, we will calculate vegetation heterogeneity within their home range because this vegetation structure provides greater resource diversity and potentially lowers predation risk for sage-grouse (Aldridge and Boyce 2007; Popham and Gutiérrez 2003; Beers and Frey 2022; Davis et al. 2014). Looking at how annual hen survival varies across these covariates will allow us to provide managers with specific conservation objectives; for example, to use grazing practices that increase vegetation heterogeneity if that positively impacts survival.

Objective 3 & 6: Identify movements by sage-grouse between grazed and rested pastures to quantify use of treatments proportional to habitat availability and other drivers of sage grouse resource selection, and generate spatially-explicit maps for areas with high quality seasonal habitat.

We assessed the drivers of hen habitat selection, in the context of the SGI grazing program, at multiple spatial scales. This allowed us to identify the relative influence of broad-scale seasonal habitat characteristics and more fine-scale habitat characteristics (i.e., within pastures) on sage-grouse habitat selection, which can provide direction for management guidelines (Smith et al. 2020). We used location data collected from all of the VHF- and GPS-monitored hens to assess how female sage-grouse habitat selection varied at two spatial scales, within seasons at the broader home range (N=385 hens) and within seasons at the finer within-pasture habitat component extents (N=407 hens, Helm 2023). We defined the seasonal boundaries based on sage-grouse life history—nesting (April 1–May 31), brood-rearing (June 1–July 15), summer-fall (July 16–November 30), and winter (December 1–March 31). At the home-range extent, we used resource selection functions (RSFs) to assess selection for vegetation—shrub, annual, perennial, litter, bare ground, and tree cover—and topographic covariates—aspect, slope, and elevation— across seasons. Then, we used the top RSF model to generate maps of the predicted, relative probability of sage-grouse use in each season across the study area. We defined the habitat component extent by the boundaries of pastures under different grazing regimes as part of the SGI program or that were part of the study but not part of the SGI program. At the habitat component extent we used RSFs to assess how selection for vegetation—shrub and annual forb and grass cover—and grazing covariates—SGI status, used animal unit months (used AUMs), and number of days grazed—varied in different pastures.

Across all 4 seasons, sage-grouse hens selected most strongly for higher shrub cover. During all seasons except winter, sage-grouse hens also selected for higher annual forb and grass cover. During the nesting and summer-fall seasons they selected for lower bare ground cover, and during the brood-rearing and winter season they selected lower elevations. Finally, they selected for lower perennial forb and grass cover during the summer-fall season. The predictive maps based on these models (e.g. Figure 4) show that the habitat characteristics that sage-grouse hens selected are widely available in this study area and have a high relative probability of use by sage-grouse hens. Maps for all seasons will be available in a forthcoming publication of these results. Female sage-grouse located within livestock pastures selected for higher shrub cover and higher levels of used AUMs. However, selection for more shrub cover was stronger, based on the coefficient estimate for this covariate (estimate [SE] = 0.17 [0.014]), than for used AUMs (estimate [SE] = 0.06 [0.014]). These results indicate that the grazing management systems in this area are compatible with maintaining a broad distribution of important habitats for sage-grouse.

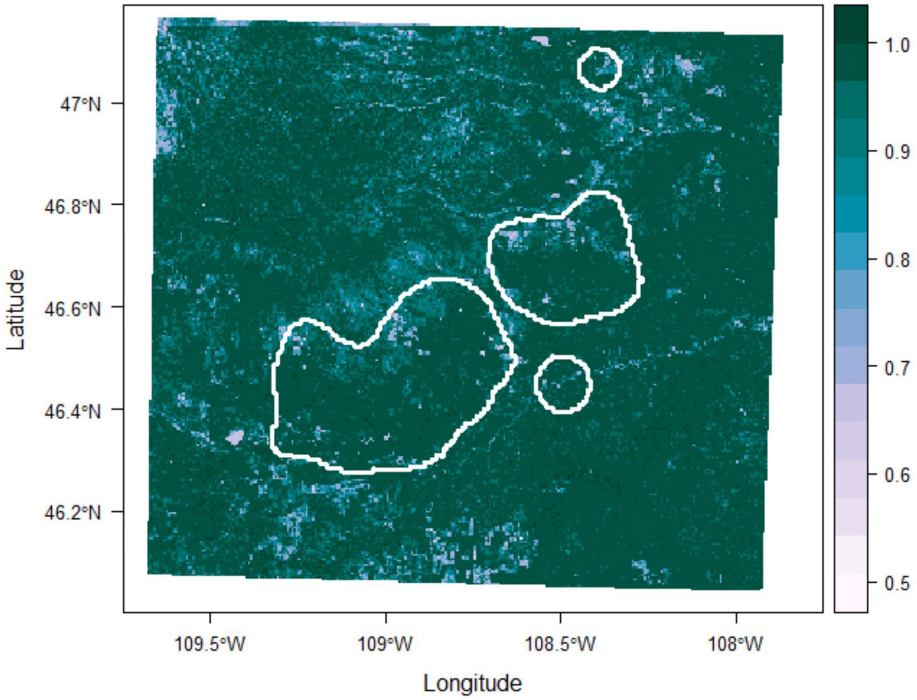


Figure 4: The habitat characteristics that sage-grouse hens select for during the nesting season—shrub and annual grass and forb cover—are well distributed across this population's home range. The map shows the relative probability of use, ranging from moderate use (light colors) to high use (dark colors). The annual home range for this population, represented by the white polygons in the center of the map, was drawn using the 95% kernel density estimate of the population across all seasons. We include predictions outside of the annual home range; however, this area is outside of where data were collected, and selection is more uncertain. Maps for the other three seasons—brood-rearing, summer-fall, and winter—will be provided in the publication of this analysis.

Objective 5: Quantify the population-level response of grazing treatments by indexing lek counts to our population modeling results, then by comparing lek counts within the Roundup study area to surrounding populations.

Comparing data collection techniques and analyses used to monitor managed species provides a better understanding of sources of uncertainty and variation in different methods (Dahlgren et al. 2016). Across the 10 years of this study, we compared estimates of annual population growth rates derived from matrix populations models based on demographic rates from sage-grouse chicks and female sage-grouse to estimates derived from male-based lek count data. Sage-grouse chicks and hens were monitored from 2011-2019 as described above and in Helm 2023. The matrix population model included nest initiation probability, clutch size, next success, chick survival, juvenile survival, and hen survival (all described in Helm 2023). Lek count data from 1959 -2022 was obtained from Montana Fish, Wildlife, and Parks and abundance estimates were derived from these counts as described in Helm 2023.

The geometric mean of the ten-year annual population growth rate derived from the female-based matrix population model was 0.90, which indicates an overall decline in the sage-grouse population. The geometric mean of the annual population growth rate estimated from the male-based lek count data for the same time frame was 1.16, which indicates an overall increase in the population. While the population growth rates calculated from these two methods track each other in terms of interannual increases and decreases from 2011-2019 (Figure 5), the geometric means suggest opposite trends. Overall, higher growth rate estimates from the lek count estimator suggest that managers may be less likely to detect population declines using this method than they would be using the matrix method.

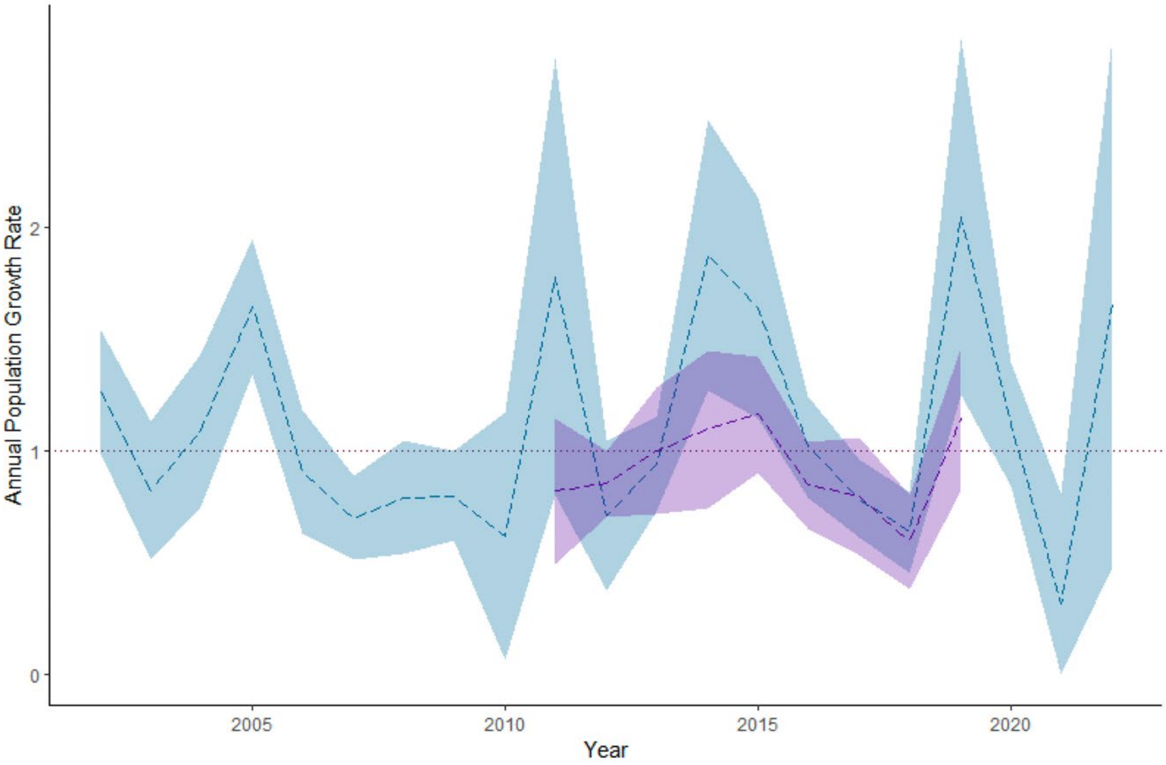


Figure 5: Annual population growth rates from a ten-year female-based matrix population model (purple dashed line) and twenty years of male lek counts (blue dashed line), plotted together. Error ribbons represent 95% confidence intervals around each annual estimate of population growth rate.

Future Goals:

Remaining products will be delivered by the end of our current PR Grant #F21AF01330. These deliverables include producing a population model that incorporates sage-grouse vital rates and habitat covariates and assesses the effects of grazing at the population level. They also include developing a hen survival analysis that looks at how environment and management (i.e. grazing) covariates affect interannual variation in female sage-grouse survival. The results from Objective #2 (e.g., vital rates of nest success, chick survival, and hen survival) will be included in population models to complete Objective 4. We aim to submit manuscripts detailing chick survival (Objective #2), hen survival (Objective #2), nest success (Objective #2), hen habitat selection (Objectives #3 & #6), and lek counts (Objective #5) by the end of September 2023.

Deliverables:

Objective	Description	Status
Objective 1	Measure the vegetation response in pastures receiving different grazing and resting treatments, relative to published sage-grouse habitat needs	**Complete**
Objective 2	Create habitat-based measures of fitness which can be compared among grazing treatments by measuring individual vital rates known to impact population growth in sage-grouse and relating estimated vital rates directly to habitat variables and other important drivers	**Complete:** Helm 2023. Dissertation and Analysis.
Objective 3	Identify movements by sage-grouse between grazed and rested pastures to quantify use of treatments proportional to habitat availability and other drivers of sage grouse resource selection	**Complete:** Helm et al. 2023. Peer-reviewed publication in progress.
Objective 4	Create a habitat-linked population model to: 1) Evaluate and forecast the benefits of treatments within a rotational grazing system on sage-grouse populations in the context of other drivers of sage grouse vital rates, so as to put the influence of grazing management on population dynamics in context, and 2) Identify current areas that are most important to sage grouse to prioritize locations where habitat management will have the most benefit to populations	**In Progress**
Objective 5	Quantify the population-level response of grazing treatments by indexing lek counts to our population modeling results, then by comparing lek counts within the Roundup study area to surrounding populations. To the extent that lek counts represent population changes reflected in population models, bird response to grazing might be forecasted in other areas where only lek count data are available	**Complete:** Helm 2023. Dissertation and analysis.
Objective 6	Generate spatially-explicit maps for areas with high quality seasonal habitat. Specifically we will produce maps that delineate areas with habitat attributes that define relative probability of use and that have a positive influence on vital rates during the nesting, brood-rearing, and winter periods, and extrapolate to similar landscapes to the extent that these models validate well	**Complete:** Helm et al. 2023. Peer-reviewed publication in progress.

Student	Description	Status
PhD Student	Selected PhD candidate in fall 2018. Individual officially enrolled at the University of Montana in August 2018 and received their graduate degree in Spring 2023.	**Completed:** Degree awarded May 2023

Publications	Status
Hen Survival Manuscript (Objective 2)	**In Progress:** Expected to submit by Nov 2023
Helm, J.E., E.G. Simpson, L.I. Berkeley, S.P. Coons, M. Szczypinski, V.J. Dreitz. Greater sage-grouse habitat selection across seasons, conservation-based grazing regimes, and spatial scales. (Objectives 3 & 6)	**In Progress:** Submitted Aug 2023
Helm, J.E., L.I. Berkeley, M. Szczypinski, S.P. Coons, V.J. Dreitz. Using livestock to manage greater sage-grouse (*Centrocercus urophasianus*) nest success on sagebrush rangelands. (Objective 2)	**In Progress:** Expected to submit by Oct 2023
Berkeley, L.I., M. Szcyzpinksi, S.P. Coons, V.J. Dreitz, J.A. Gude. Greater sage-grouse chick survival and livestock grazing in central Montana. (Objective 2)	**In Progress:** Submitted Aug 2023
Habitat-linked Population Model Manuscript (Objective 4)	**In Progress:** Expected to submit by Jun 2024
Helm et al. Estimating greater sage-grouse population growth rate in central Montana: A comparison of methods with implications for future monitoring. (Objective 5)	**In Progress:** Expected to submit by Oct 2023
Reintsma, K.M., M. Szczypinski, S.W. Running, S.P. Coons, V.J. Dreitz. Grazing effects on rangeland productivity while accounting for environmental complexity.	**In Progress:** Submitted Aug 2023
Smith, J.T., J.D. Tack, L.I. Berkeley, M. Szczypinski, and D E. Naugle. 2018a. Effects of Rotational Grazing Management on Nesting Sage-Grouse. Journal of Wildlife Management, 82:103-112. doi:10.1002/jwmg.21344.	**Complete**
Smith, J.T., J.D. Tack, L.I. Berkeley, M. Szczypinski, and D.E. Naugle. 2018b. Effects of Livestock Grazing on Nesting Sage-Grouse in Central Montana. Journal of Wildlife Management, 82:1503-1515. doi:10.1002/jwmg.21500.	**Complete**
Smith, J.T., J.D. Tack, K.E. Doherty, B.W. Allred, J.D. Maestas, L.I. Berkeley, S. Dettenmaier, T.A. Messmer, D.E. Naugle. 2017. Phenology largely explains taller grass at successful nests in greater sage-grouse. Ecology and Evolution, 8:356-364. doi: 10.1002/ece3.3679.	**Complete**

INVERTEBRATE BIOMASS PREDICTIVE SPATIAL LAYER

The objective of this project was to create a predictive spatial layer of invertebrate biomass across the sage-grouse (PR grant #F15AF00490 “MT Sage-Grouse Grazing Evaluation”) and songbird (PR grant #F16AF00294 “Migratory Songbird Grazing Study”) grazing project study areas in central Montana to provide invertebrate food availability data for sage-grouse grazing project vital rate, habitat use, and population models, and songbird grazing project reproduction, community, and abundance models. We completed data collection during spring/summer 2020 and generated a predictive invertebrate biomass spatial layer in 2021 for the sage-grouse and songbird study areas (Mitchell et al. 2021). Results reported herein represent further analysis and fine-tuning of the invertebrate biomass spatial layer for PR grant #F21AF01330. Detailed methods and results can be found in “Predictive Spatial Layer of Invertebrate Biomass for Sage-Grouse and Songbird Grazing Studies in Central Montana” report (PR grant W-164-R-1 to FWP; Mitchell et al. 2021).

Objective 1: Create a spatial layer that predicts invertebrate biomass for the sage-grouse and songbird grazing project study areas.

Building on previous work (see Mitchell et al. 2021), we focused on identifying meaningful predictors of arthropod biomass that fit the sampling strategy employed during the 2019 and 2020 field seasons. While arthropod biomass data were collected for 2012-2020, we constrained observations to 2019 and 2020 because these years had identical sampling frameworks. Previous years used both pitfall and sweep-net samples, whereas 2019 and 2020 used only sweep nets. We represented each sampling location as a point feature and extracted variables related to cumulative growing degree-days, soil moisture, extreme weather, and late spring snow since these are important drivers of arthropod growth (Shaftel et al. 2021; Telfer and Hassall 1999; Wu et al. 2021). These variables were used to compare the predictive power of temporally-static versus dynamic variables. For the biomass data, we aggregated individual survey events by location and date/time to get total biomass for each site. Biomass was then log-transformed. To standardize interpretation of effect sizes, the log-transformed biomass plus all other numeric variables were scaled to have a mean and standard deviation values of 0 and 1, respectively. We used these data to predict log biomass using spatiotemporal variables in ordinary-least-squares (OLS) and linear mixed effects models.

We produced four models to explain the variance of arthropod biomass and used Akaike Information Criterion (AIC) (Akaike 1991) to measure bias and select the most parsimonious model. The first model was a linear mixed effects model containing 20 predictors (Table 1; Table 2) and fixed effects for each year. The conditional R^2 was 0.66, Intra-class Correlation was 0.54, and the AIC value was 996.33. While this model had decent predictive power and reasonable within-year correlation, it had a high degree of bias, and many of the predictors were insignificant. The second model was a mixed effects model with annual fixed effects. This model contained topographic variables (slope; Topographic Wetness Index (TWI); elevation) and the most significant predictors from the first mixed effects model, including the coefficient of variation of precipitation[1], standard deviation of daily max temperature[1], coefficient of variation of daily max temperature[1], total precipitation[1], and cumulative degree days[2] (with a 17.8 degree C threshold) (Brust, 2009). A conditional R^2 of 0.63, Intra-class Correlation of 0.47, and lower AIC of 955.9 indicates a more parsimonious model, but there is still a high degree of bias. To reduce bias, we fit two OLS models. To compensate for the observed intra-class correlation in the mixed models that could not be replicated in an OLS model, we incorporated total April snowfall[3] as a predictor. This approach theoretically provided some of the information lost in the annual effects since April snowfall differed significantly between 2019 and 2020 ($p < 0.0001$). The first OLS model had the same predictors as the previous mixed effects model and produced an adjusted R^2 of 0.64, and a lower AIC of 940.9. For the second OLS model, we removed redundant topographic predictors. This final model yielded an adjusted R^2 of 0.65 and the lowest AIC value of 928, indicating the most parsimonious model yet using only weather-related covariates (Table 2).

Given the large spatial extent and lack of repeat site visits, we were unable to disentangle individual observations from the temporal window in which they were taken. This is due to mechanistic relationships between weather and arthropod life stages, coupled with a sample size of 1 for each unique site (Brust et al. 2009; Shaftel et al. 2021). Previous studies that have attempted to predict arthropod biomass with remote sensing have used drones, as the timing of imagery acquisition must be nearly identical to that of the field sampling for reliable results (Traba et al. 2022). Results from this study indicate that future sampling efforts should include static plots with repeat sampling at regular intervals to reduce temporal confounding of spatial covariates.

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[1] Variable was calculated for the 60 days prior to the sample date, roughly equal to the average lifespan of the most abundant arthropods (Orthoptera).

[2] Variable was calculated from the start of the calendar year.

[3] Variable was extracted for a single month in the year of sampling.

Table 1: Climate, topographic, and field data predictor variables used in invertebrate model development.

Climate Predictors	Source	Spatial Resolution	Temporal Resolution
Average maximum June temperature between 2011 and 2020	Daymet (Thornton et al. 2020)	1 km	1 day
Average maximum July temperature between 2011 and 2020	Daymet	1 km	1 day
Average maximum August temperature between 2011 and 2020	Daymet	1 km	1 day
Average maximum June precipitation (water equivalent) between 2011 and 2020	Daymet	1 km	1 day
Average maximum July precipitation (water equivalent) between 2011 and 2020	Daymet	1 km	1 day
Average maximum August precipitation (water equivalent) between 2011 and 2020	Daymet	1 km	1 day
Total precipitation in water equivalency during 60 days prior to sampling	Daymet	1 km	1 day
Cumulative degree days: sum of differences between temperature threshold (17 C) and daily average temperature	Daymet	1 km	1 day
Daily max temperature coefficient of variation 60 days prior to sampling	Daymet	1 km	1 day
Daily precipitation coefficient of variation 60 days prior to sampling	Daymet	1 km	1 day
Number of days within 60 days before the survey where the temperature dropped one standard deviation below the mean temperature	Daymet	1 km	1 day
Number of days within 60 days before the survey where the max daily temperature increased one standard deviation above the mean temperature	Daymet	1 km	1 day
Daily max temperature standard deviation 60 days prior to sampling	Daymet	1 km	1 day
Daily precipitation standard deviation 60 days prior to sampling	Daymet	1 km	1 day
Average total snow water equivalent (SWE) between 2011 and 2020	SNODAS (NOHRSC 2004)	1 km	1 day
April SWE of the sample year	SNODAS	1 km	1 day

Topographic Predictors			
Topographic Wetness Index	NED (USGS 2012)	10 m	NA
Slope	NED	10 m	NA

Elevation	NED	10 m	NA
Other Predictors			
Year	NA	NA	NA

Table 2: Model coefficients and their estimates for the final ordinary-least-squares model predicting invertebrate biomass.

Predictors	Estimates	Confidence Intervals	*p*-value
Intercept	0	-0.05 – 0.05	1
April Snow Water Equivalent	0.3	0.24 – 0.37	**<0.001**
Precipitation Coefficient of Variation	0.07	0.00 – 0.14	**0.036**
Max Temperature Standard Deviation	0.23	0.14 – 0.32	**<0.001**
Max Temperature Coefficient of Variation	-0.44	-0.56 – -0.32	**<0.001**
Cumulative Degree-Days	0.35	0.25 – 0.45	**<0.001**
Observations	512		
R2 / R2 adjusted	0.644 / 0.640		

Future Goals:

We have completed exploring the ability to make a predictive spatial layer for invertebrate biomass. Future work will focus on producing a peer-reviewed journal publication detailing the process used to create the spatial layer predicting invertebrate biomass.

Deliverables:

Objectives	Description	Status
Objective 1	Create a spatial layer that predicts invertebrate biomass for the sage-grouse and songbird grazing project study areas.	**Complete**

Publications	Status
Goosey, H. B., J. T. Smith, K. M. O'Neill, and D. E. Naugle. 2019. Ground-Dwelling Arthropod Community Response to Livestock Grazing: Implications for Avian Conservation. Environmental Entomology 48:856-866.	**Complete**

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