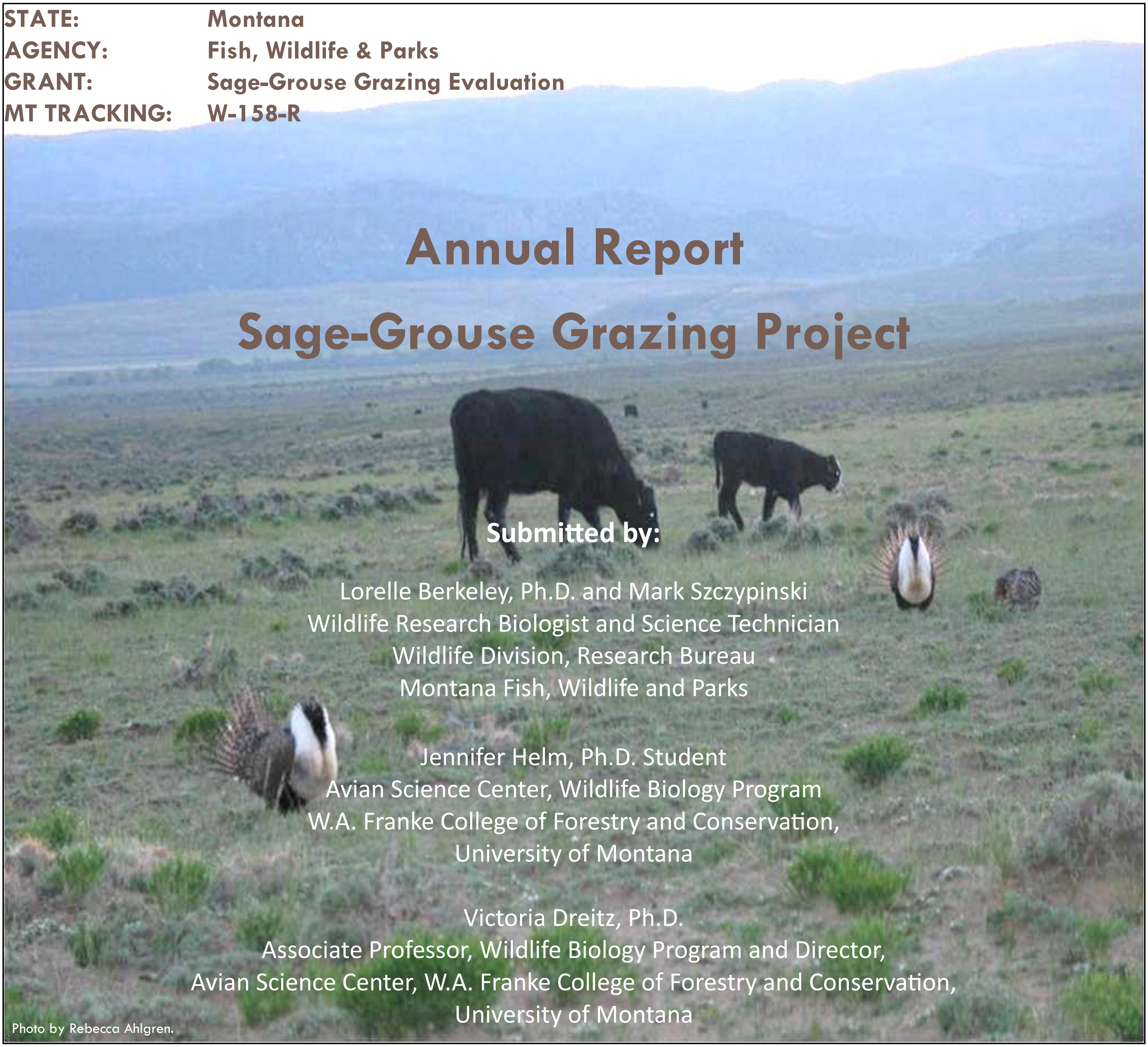

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Annual Report

Sage-Grouse Grazing Project

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Photo by Rebecca Ahlgren.

The Impacts of Grazing on Greater Sage-Grouse Habitat and Population Dynamics in central Montana

8/31/2019

FY2019 Annual Progress Report

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The Impacts of Grazing on Greater Sage-Grouse Habitat and Population Dynamics in central Montana

FY2019 ANNUAL PROGRESS REPORT

Submitted to: Montana Fish, Wildlife and Parks, and the U.S. Fish and Wildlife Service

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Period of Agreement Date: Jul 1, 2018 – Jun 30, 2019

All information in this report is preliminary and subject to further evaluation.

EXECUTIVE SUMMARY

In September 2015, the United States Department of Interior Fish and Wildlife Service (USFWS) determined that the greater sage-grouse (hereafter "sage-grouse") did not need to be listed for protection under the Endangered Species Act (ESA) due to collaborative conservation efforts among agencies and private landowners. The Sage-Grouse Initiative (SGI) implemented by the United States Department of Agriculture Natural Resources Conservation Service (NRCS) formed a large part of the conservation efforts that contributed to this decision. While the success of these efforts is laudable, the impacts of grazing on sage-grouse and their habitat are still largely unknown. The conservation efforts that resulted in a non-listing decision must be maintained to minimize future declines in populations. Information on the impacts of grazing to sage-grouse and their habitat have been needed to provide support for conservation efforts. The goals of our study were to evaluate the effectiveness of SGI rotational grazing systems in improving sage-grouse habitat, the impacts of SGI on sage-grouse vital rates and habitat use, and to help identify priority areas for conservation in central Montana. Pastures that were grazed within these systems are

hereafter referred to as "SGI-grazed". These systems often incorporated pastures that were completely rested from livestock grazing ≥15 months and are hereafter "SGI-rested".

We have collected data to evaluate the impacts of grazing on sage-grouse in central Montana since 2011. In particular, our data compare SGI's rotational grazing system with the varied grazing strategies of other private landowners (hereafter "Non-SGI"). This is a long-term study in its 9^{th} year, with 1.5 years of data collection remaining. Some deliverables and preliminary analyses are complete, and long-term project deliverables are in progress. Herein, we present preliminary results from years 1 – 8 of the project (years 2011 – 2018) and an update of data collection during 2019.

Our objectives were to evaluate the effects of SGI grazing strategies on (1) sage-grouse vital rates including hen survival, nest success, and chick survival; (2) habitat use of sage-grouse adult females and chicks; and (3) sage-grouse habitat (impacts to the sagebrush system). We collected data to estimate sage-grouse vital rates using radio telemetry. We also used radio telemetry to collect locations of hens, nests, and chicks to evaluate habitat use. We measured several habitat variables to ascertain their relationship with vital rates and habitat use. We measured herbaceous vegetation using the line-intercept technique at a set of random field plots stratified by grazing treatment (SGI-grazed, SGI-rested, and Non-SGI) to test for differences in indicators of habitat quality across the project area. We also measured vegetation data at sage-grouse nests and random points within nesting habitat using the line-intercept technique to evaluate vegetation factors that may influence nest site selection and nest success of hens. We assessed the effects of habitat on nest site selection and nest success at a larger spatial scale using remotely sensed data in geographical information system layers including bare ground, herbaceous, and shrub percent cover; distance to roads and water; and distance to and proportion of crop fields in the landscape.

Annual apparent survival estimates of sage-grouse hens from 2011 – 2018 range from 53 – 82%. The 2019 annual apparent survival estimate is 79% as of Jun 30, 2019, but fall and winter estimates still need to be observed. We used a Kaplan-Meier survival function to evaluate hen and chick survival with staggered entry designs, and we right-censored individuals with unknown fates, dropped transmitters, or that survived until their transmitters expired. The Kaplan-Meier mean survival time estimate for 426 marked hens monitored from March 1, 2011 – Sep 26, 2018 is 5.06 yrs (SE = 40.1 d) and the median is 5.49 yrs (95% confidence interval [CI] = 4.51 – 6.06 yrs). Annual apparent nest success for 767 nests during 2011 – 2019 ranges from 30 – 71%; 2019 annual apparent nest success is 71%, but this is preliminary as we are still cleaning up data from this season.

The effects of covariates on nest success from 2011 – 2015 were analyzed using Bayesian methods to fit logistic regression models relating measured covariates to daily nest survival rate. These analyses suggested that greater amounts of rainfall over a 4-day period prior to the occurrence of nest fates were associated with lower daily nest survival. Results indicated some support of greater nest success for nests farther away from county roads and highways. We will add data from 2016 – 2020 to these analyses towards the end of our study to evaluate if these relationships are sustained in the long-term.

Kaplan-Meier survival estimates for 425 chicks radio marked during 2011 – 2017 ranged from 0.19 – 0.54. The Kaplan-Meier mean survival time was 56.45 d (SE = 2.84), and the median survival time was 40 d (95% confidence interval [CI] = 32 – 58 d). The probabilities of chicks surviving until the end of the monitoring periods differed among years ($\chi^2 = 16.2$, $df = 6$, $p = 0.0128$), and we are currently conducting further analyses on chick survival.

Nest site selection by hens during 2012 – 2015 was assessed using Bayesian methods to fit logistic regression models relating measured covariates to the probability that a site was a nest versus a randomly sampled available site. At the smaller scale of the nest, analyses indicated that females selected shrubs with greater volume. At the plot scale (within 15 m of the nest; radius of line-intercept vegetation plots), analyses indicated that females selected for greater sagebrush cover. At the patch scale (within 100 m of the nest), analyses indicated that females selected gentler terrain and more even stands of sagebrush. At the landscape scale (1.61 km [1 mi] from the nest), females preferred to locate nests farther from county roads and highways but closer to two-track roads, and avoided landscapes with greater amounts of non-cropland anthropogenic disturbance (i.e., gravel or paved roads). We speculate that the preference for two-track roads may reflect the tendency for these roads to traverse the gentler terrain preferred by sage-grouse for nesting.

We used linear mixed effects models to test for impacts of grazing system and rest from grazing on vegetation metrics while accounting for variation across years and ranches. Likelihood ratio tests indicated that live grass height, senesced grass height, and litter all differed between SGI and Non-SGI ranches. Visual obstruction, percent herbaceous vegetation cover, and percent bare ground cover did not differ between grazing systems. Live and senesced grass heights were taller and litter cover was greater on SGI than Non-SGI ranches. However, after accounting for grazing system effects, the effect of pasture rest was negligible and non-significant for all variables tested. In addition, the grazing system effect sizes between SGI and Non-SGI ranches were small relative to annual variation.

This report summarizes preliminary results to date for impacts of grazing on sage-grouse and sagebrush habitat. These results should be considered preliminary and are subject to change as data collection and analyses are works in progress. For additional information, previous reports, and publications, we refer readers to our website: http://fwp.mt.gov/fishAndWildlife/diseasesAndResearch/research/sageGrouse/default.html.

BACKGROUND

The greater sage-grouse (*Centrocercus urophasianus*; hereafter "sage-grouse") is a large, ground-dwelling bird that is endemic to sagebrush-dominated (*Artemisia* spp.) habitats in western North America (Schroeder et al. 1999, Knick et al. 2013). This species uses both sagebrush steppe and sagebrush semi-desert systems (Crawford et al. 2004) year-round for most of its life history needs, where sagebrush is used as a food source (particularly during the winter when it is the only food available), and as hiding cover during nesting (Sveum et al. 1998, Guttery et al. 2013, Lockyer et al. 2015). In addition to sage-grouse, more than 600 species of conservation concern that depend upon sagebrush ecosystems have been identified (Rich et al. 2005), including Brewer's sparrow (*Spizella breweri*), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*). Thus, efforts to sustain sage-grouse populations by means of habitat conservation are likely to benefit a variety of other wildlife, especially sagebrush-obligate wildlife species (Rowland et al. 2006).

The loss and degradation of sagebrush habitat has led to the extirpation of the sage-grouse from nearly half of its original range (Schroeder et al. 2004). The causes of loss and degradation include conversion of sagebrush to agriculture (Connelly et al. 2004, Smith et al. 2016); fragmentation resulting from energy (Naugle et al. 2011) and subdivision development (Leu and Hanser 2011); conifer invasion (e.g., in Oregon and western Montana; Connelly et al. 2004, Beck et al. 2012); and modifications such as prescribed fire, herbicides, and certain grazing practices that have led to exotic, annual grass establishment (Davies et al. 2009). Due in large part to habitat degradation concerns, several petitions to list the sage-grouse under the Endangered Species Act (ESA) led the United States Department of Interior Fish and Wildlife Service (USFWS) to place the sage-grouse on the candidate list for threatened and endangered species protection in 2010 (USFWS 2010). In 2015, USFWS determined that efforts by state and federal agencies as well as other partners had been adequate to conserve this species and its habitat without listing it under the ESA (USFWS 2015). However, conservation efforts must be maintained to prevent further population declines and a future ESA listing. Because livestock grazing is the largest land management practice in sage-grouse habitat (Dinkins et al. 2017), managers need to know how this land use impacts sage-grouse populations and habitat to help guide conservation efforts.

A top priority of sage-grouse conservation is preventing further habitat loss and fragmentation (Connelly et al. 2000, USFWS 2013, Smith et al. 2016). The USFWS, in partnership with several state agencies, has outlined range-wide conservation objectives and management zones for sage-grouse (**Error! Reference source not found.**) with specific conservation needs for each zone (USFWS 2013). Our project falls within Management Zone 1, where agricultural conversion is identified as the biggest threat to sage-grouse habitat (USFWS 2013, p. 48), and conservation actions are focused on incentivizing landowners to conserve habitat (Table 1). Current progress towards these actions includes the sodsaver provision of the 2014 Farm Bill that was signed into law in February 2014 and is intended to decrease conversion of native sagebrush and grasslands to tilled crops. Additionally, the United States Department of Agriculture Natural Resources Conservation Service (NRCS) implemented the Sage-Grouse Initiative (SGI) to help conserve sage-grouse habitat across the range of the species. In Montana, the implementation of the State's Sage-Grouse Habitat Conservation program in 2014 was a key step toward Montana's sage-grouse and sagebrush habitat conservation. Together, these efforts are intended to keep working ranches on the landscape and prevent further reduction of sage-grouse habitat. Below, we expand on how our project contributes to these existing sage-grouse conservation efforts.

Sage Grouse Habitat Conservation Program:

In September 2014, the Governor of Montana signed executive order 10-2014 establishing the Montana Sage-Grouse Oversight Team (MSGOT) and the Montana Sage-Grouse Habitat Conservation Program (State of Montana Office of the Governor 2014). The Montana Greater Sage-Grouse Stewardship Act was passed by the 2015 Montana Legislature, which provided $10 million for MSGOT to implement the Sage-Grouse Habitat Conservation Program through the Montana Department of Natural Resources and Conservation, and for competitive grant funding to establish mechanisms for voluntary, incentive-based conservation measures to benefit sage-grouse and their habitat (Legislature of the State of Montana 2015). Other states including Idaho and Wyoming have taken similar actions to prevent sage-grouse habitat reduction and degradation.

One way to avoid further sage-grouse habitat declines is to manage the various land uses supported by existing sagebrush systems, such as livestock grazing. Livestock grazing is the largest land management practice in the world (Krausman et al. 2009) and is a dominant land management practice in sagebrush habitat (e.g. Dinkins et al. 2017), impacting 70% of land in the western United States (Fleischner 1994). Livestock grazing (hereafter "grazing") impacts sagebrush habitat by altering its vegetation structure, composition, and productivity (Beck and Mitchell 2000, Krausman et al. 2009). These impacts can be either positive or negative depending on the timing and intensity of grazing; thus grazing can be manipulated to achieve desired habitat conditions (Fuhlendorf and Engle 2001, Connelly et al. 2004, Chambers et al. 2017). Grazing has varying impacts on wildlife species depending on the species in question and the outcome that is sought. For example, Golding and Dreitz (2017) show that McCown's longspurs (*Rhynchophanes mccownii*) and western meadowlarks (*Sturnella neglecta*) within the same songbird community on our study area exhibit different responses to grazing systems (Golding and Dreitz 2017): McCown's longspurs are more abundant on SGI pastures, whereas western meadowlarks are more abundant on land managed using season-long grazing. Grazing intensity has different effects depending upon the focal songbird species as well (Sutter and Ritchison 2005). Additionally, some work has shown that the biomass of invertebrates that are an important food source for sage-grouse and several other bird species may be lower in grazed than in ungrazed areas (Sutter and Ritchison 2005, Goosey et al. 2019).. However, some generalizations can be made about the effects of grazing in arid climates, including that chronically overgrazed areas in these climates can experience soil compaction, nutrient runoff, and desertification (Asner et al. 2004). Our project addresses the third conservation action outlined by USFWS (2013, Table 1) which is to "develop criteria for set-aside programs which stop negative habitat impacts and promote the quality and quantity of sage-grouse habitat." We aim to evaluate the effectiveness of SGI grazing systems intended to improve sage-grouse habitat in central Montana, which will inform other grazing systems as well.

The Sage-Grouse Initiative (SGI) Program:

SGI grazing systems in central Montana focus on improving livestock production and rangeland health while simultaneously alleviating threats to and improving habitat for sage-grouse (USDA 2015). They are implemented on ranches that contain potential sage-grouse habitat, which is defined based on topography and sagebrush canopy cover ≥5% (NRCS pers. comm.), with a focus on sage-grouse core areas (Figure 2). Core areas in Montana were designated by Montana Fish, Wildlife and Parks (FWP) as locations of highest conservation value for sage-grouse based on habitat and number of breeding males (Figure 2). FWP estimated that the core areas included ~76% of the displaying males in Montana as of 2013, which will be re-evaluated in 2023 (FWP pers. comm.).

Landowners enrolling in SGI agree to implement a 3-year grazing system in collaboration with an NRCS range management specialist. The range management specialist may suggest pasture rest, pasture deferment, changing the number of animal units, and installation of fences or water sources to adjust pasture size or livestock distribution. SGI grazing systems are tailored to each ranch, and may vary with the needs of the landowner or the condition of the rangelands, while following the NRCS Conservation Practice Standard for Prescribed Grazing (NRCS 2017, Smith et al. 2018). Additionally, plans align with four minimum criteria that are intended to support sage-grouse habitat: grazing utilization rates of ≤50% of the current year's key forage species growth, ≥20-day shift annually in the timing of grazing, a plan to address unexpected circumstances like drought or fire, and ≤45-day continuous grazing durations within any one pasture (Smith et al. 2018).

SGI grazing systems are rotational and use a combination of rest and deferment to increase vegetation cover for nesting birds (Doherty et al. 2014, Smith et al. 2018), in addition to other strategies. While there is substantial evidence that improper grazing degrades rangeland (Davies et al. 2014), there is still uncertainty about how to select the best grazing system to achieve different goals. This uncertainty results from the many confounding factors that exist when comparing grazing systems (Heady 1961), which include both ecological variables (e.g., rainfall and vegetation structure) and management attributes (e.g., goals and opportunities) (Briske et al. 2008). In cases where multiple goals exist concurrently (e.g. producing livestock, enhancing wildlife habitat, and grazing sustainably), rotational systems may be preferred over continuous (i.e., season-long) grazing with low stocking rates in order to meet all of the objectives (Krausman et al. 2009). Rest and deferment from grazing may also provide small benefits to rangeland soil crusts (Davies et al. 2014), and keep residual grass on the landscape as protective cover for wildlife (Krausman et al. 2009). However, other studies have suggested that rotation is not necessarily better than continuous grazing, and that weather variation and stocking rate account for the majority of variability in plant and animal production (Briske et al. 2008). Effects of grazing are likely locally or regionally specific and need to be determined distinctly for the region of interest. Our project will contribute to this knowledge gap by investigating the effect of SGI grazing systems on sage-grouse habitat characteristics and associated population dynamics in central Montana.

Grazing Study:

The goal of this study is to evaluate the effects of SGI grazing strategies on the demography, habitat, and habitat use of a sage-grouse population in central Montana. Adult female (hereafter "hen") survival, nest success, and chick survival are the three most important drivers of population growth in sage-grouse (Taylor et al. 2012, Dahlgren et al. 2016); the goal of our project is to investigate the effects of grazing on these vital rates. We are also monitoring the habitat use of hens and chicks and investigating how habitat use is related to vital rates. Lastly, we are evaluating the vegetation's response to grazing in the sagebrush steppe on our study area. We are comparing vegetation variables among SGI-enrolled grazed and rested pastures, and non-participating ranches (hereafter "Non-SGI"). In our study area, most Non-SGI grazing is characterized by grazing pastures at the same time each year, often for longer periods than SGI pastures, with no pasture rest. However, Non-SGI pastures may be grazed using a variety of management strategies. To date, >400,000 acres (NRCS pers. comm.) have been enrolled in SGI grazing systems across Montana.

We designed this project as a 10-year study because both sagebrush habitat and sage-grouse may exhibit a "lag" response to grazing management (e.g. Crawford et al. 2004), whereby some effects are only observable or fully realized after several years. In addition, multiple years of data are needed to obtain enough replicates of pastures within grazing treatments and among years to distinguish the effects of environmental variables from the effects of grazing.

This project has the following long-term objectives (to be completed by the final year of this project):

1. Measure the vegetation response in pastures receiving different grazing and resting treatments, relative to published sage-grouse habitat needs;
2. 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 habitat use;
3. Create habitat-based measures of fitness which can be compared among grazing treatments by measuring individual vital rates known to effect population growth in sage-grouse and relating these estimated vital rates directly to habitat variables and other important drivers;

4. Create a habitat-linked population model to:
   a. evaluate and forecast the effects 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;
5. Quantify the population-level response of sage-grouse to 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, sage-grouse response to grazing might be forecast in other areas where only lek count data are available; and
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.

Data collection began in 2011, and we have successfully completed 8.5 years of data collection towards these objectives. We are halfway through our 9th season (2019) of data collection, and herein present preliminary results through 2018. Data from the 2019 season is still being collected and entered.

METHODS & RESULTS

Our study is conducted in Golden Valley and Musselshell counties, Montana, USA (Figure 2). To address our objectives, we used radio telemetry to monitor birds in each grazing type (SGI-grazed, SGI-rested, and Non-SGI). We also sampled vegetation metrics at nests, at stratified random points in potential sage-grouse nesting habitat, and among grazing treatments in sagebrush habitat (described in more detail later). We provide a general summary of our field methods and results-to-date for each objective below.

Sage-Grouse Vital Rates

ACCOMPLISHMENTS:

During the reporting period of Jul 1, 2018 – Jun 30, 2019, we captured 42 new hens at the start of the breeding season (Mar – Apr 2019), and recaptured 7 hens throughout the 2019 spring and summer to replace their failing transmitters. During 2011 – 2017, we maintained ~100 greater sage-grouse hens marked with very high frequency (VHF) radio transmitters in our study population each year. In 2018, we reduced this number due to reduced funding and monitored 73 hens. In 2019, we continued to monitor hens that retained their VHF transmitters, and marked new hens with solar GPS (global positioning system) PTTs (platform transmitter terminal; these are described in more detail below) donated by the United States Bureau of Land Management, monitoring a total of 75 hens during 2019. Data collection and analyses to assess the effects of grazing and other variables on vital rates are ongoing. Our efforts during the fall/winter of 2019 – 2020 focused on data management and writing code in program R (versions 3.3.0 and 3.4.3, www.r-project.org, accessed Aug 21, 2018) to automate the process of formatting data for survival and habitat use analyses for hens and chicks. Below we present a summary of methods and preliminary results on sage-grouse vital rates reported to date.

We captured and marked hens at the start of the breeding season each spring during Mar – Apr to replace hens in the marked population that had died since the previous spring. Hens were captured on or near leks using night-time spotlighting (Giesen et al. 1982, Wakkinen et al. 1992) and fit with either a 25-g necklace style VHF transmitter (Model A4060, Advanced Telemetry Systems, Isanti, MN) or a 25 g solar GPS PTT. We collected morphometrics including weight, length of both tarsi, relaxed wing chord length, and length of central tail feather for each hen and then released them. Both types of transmitters had mortality switches that activated when they were motionless for at least 4 hrs. We attempted to recapture hens at two years after initial capture to replace old transmitters with new ones before the old transmitter batteries expired. In this way, we attempted to monitor individual hens for as long as possible. This population of sage-grouse was not migratory and could be monitored continuously throughout the year. Hens marked with VHF transmitters were monitored from the ground during Mar – Aug with the help of seasonal field technicians who obtained ≥2 locations per hen each week. During Sep – Mar we monitored hen survival and movement via aerial telemetry once per month.

The VHF transmitters must be monitored from the ground. The solar GPS PTTs automatically transmit locations via satellites at pre-programmed schedules (e.g., the transmitter is programmed to collect a number of locations per day). We have a data subscription with Woods Hole Group, Inc. (Bourne, MA, USA), who processes the locations and stores them on their website. We are then able to download and view the locations on a computer at any time. We have programmed the PTTs to collect six locations per day during Sep 2 – Nov 3, four locations per day during Nov 4 – Mar 10 (when days are shorter and the PTTs do not have as much time to charge), eight locations per day during Mar 11 – May 14 (to have enough locations to find hens on the ground and monitor nests), and ten locations per day during May 15 – Sep 1 (to obtain as much information as possible during brood-rearing, as this is a time of high concern). We have deployed 40 GPS PTTs during spring 2019, and then recovered and redeployed two from hens that appeared to have died due to predation. GPS PTTs are expected to last two years before their batteries expire. They will give us more insight into how hens are moving among locations and using habitat because they can collect multiple locations daily, versus two locations per week collected using VHF transmitters. We are also able to collect more accurate nest initiation dates and mortality information because we can determine when a hen stops moving much more quickly (lack of movement denotes both a hen sitting on a nest as well as mortalities). We can obtain more detailed seasonal habitat use information and better identify corridors of movement and areas of avoidance by adult hens during all times of the year.

Nests were found by monitoring hens via radio telemetry. We monitored pre-nesting females until they began to make localized movements indicative of nesting behavior, at which point we reduced our monitoring interval to daily if possible. We attempted to locate nests from a distance of ≥10 m without flushing females. Located nests were marked with inconspicuous natural materials at a distance of ~10 m and were thereafter monitored every 2–3 days from a distance of >100 m until the nest hatched or failed. Thus, we were in close proximity to nests when they were initially found, but we did not approach nests again unless hens were off for ≥2 consecutive visits. We classified nests as successful (≥1 hatched egg with membrane detached) or failed (all eggs destroyed or missing) once females permanently moved away from their nests.

If a nest was successful, chicks were captured by hand 2 – 8 days after hatching, with most captured at ≤5 d old. We captured a hen's entire brood to ensure they were kept warm, even though we did not mark the entire brood, because at 2 – 8 days after hatching the chicks cannot yet thermoregulate and are reliant on the hen to stay warm. We homed in on the hen with telemetry just after sunset when she was typically brooding her chicks underneath her. Hens were reluctant to flush or move their brood unless a perceived danger was in very close proximity; this behavior allowed us to get close enough to capture the chicks. We could approach close enough to touch the hen and often had to gently nudge her off of her brood. The hen either flushed or walked away a short distance, typically remaining within 50 m of us throughout the entire process. The chicks were captured and placed into a cooler containing a hot water bottle that kept them warm while we were working. We affixed a 1.3 g backpack VHF radio transmitter (Model A1065, Advanced Telemetry Systems, Isanti, MN) to up to four randomly selected chicks per brood (mean number of chicks hatched per nest during this study is six to eight) via two small sutures on the lower back (similar to Dreitz et al. 2011). This has been the most successful (<1% accidental death rate) and common method used to attach radio transmitters to sage-grouse chicks (Burkepile et al. 2002, Dahlgren et al. 2010) and has been successful with other galliforms (Dreitz et al. 2011). We monitored chicks every other day for the first two weeks when mortality rates are typically highest, and ≥2 times per week thereafter until the chicks died, their tags expired, we lost their signals, or they were recaptured and fitted with an adult transmitter.

RESULTS:

HEN SURVIVAL

We used package "survival" (Therneau 2015) in program R to run Kaplan-Meier survival models that estimated the overall survival of hens during Mar 2011 – Jun 2019. The Kaplan-Meier estimator estimated the survival of individuals over a series of monitoring occasions, producing a survival function of cumulative survival through the monitoring period (Kaplan and Meier 1958, Cooch and White 2018), which was the duration that the radio transmitter was functional or before the hen died or her signal was lost. The Kaplan-Meier mean survival time estimate for 426 marked hens monitored from March 1, 2011 – Sep 26, 2018 is 5.06 yrs (SE = 40.1 d) and the median is 5.49 yrs (95% confidence interval [CI] = 4.51 – 6.06 yrs; Figure 3). We used a staggered-entry design to account for marking individuals at different times throughout the monitoring period and pooled data across years. We right censored individuals with unknown fates, dropped transmitters, and individuals that survived until their transmitters expired. Thus, our Kaplan-Meier survival estimates were conservative.

Our annual survival estimates of hens were measured from Apr 1st at the start of the nesting season through Mar 31st each year. Apparent annual survival estimates (number of hens alive at the end of the monitoring period / total number of hens alive at the start of the monitoring period) during 2011 – 2018 ranged from 42 – 82% (Table 2); the annual apparent survival during 2017 was the lowest observed during the study at 42%. The 2019 annual apparent survival estimate was 90% as of Jun 30, 2019, but fall and winter estimates still need to be observed. Excluding 2017, our annual survival estimates were comparable to those observed in other studies across the range of sage-grouse (Table 3). The lower survival we observed in 2017 may have been due to a drought over the summer that affected all of Montana. We observed that sage-grouse became concentrated in areas that still contained moisture, probably for food and water, and may have been easier for predators to find. Most of the hen mortalities appeared to be due to predation. We tested one intact carcass found in fall 2017 for diseases including West Nile Virus and Avian Flu; these tests were negative. However, whereas positive results mean disease is present with 100% certainty, negative results do not necessarily mean that disease was not present. The accuracy of these tests depends on the condition of the carcasses tested. Ours were typically in poor to fair, rather than great, condition for West Nile Virus tests because these tests require tissues to be intact with little to no decomposition. We usually cannot detect and collect mortalities before decomposition has begun.

For seasonal survival and habitat use, we defined seasons to represent biologically meaningful separations (*sensu* Blomberg et al. 2013) (Table 2). For the entire marked population, hen seasonal apparent survival estimates varied by year, and the range of estimates were as follows: Spring (Apr – May) = 84 – 95%; Summer (Jun – Jul) = 85 – 100%; Fall (Aug – Oct) = 70 – 91%; Winter (Nov – Mar) = 78 – 96%. Our apparent seasonal survival rates were lower relative to seasonal survival estimates in a Nevada population of sage-grouse, where they monitored the survival of 328 hens from 2003 – 2011 (Blomberg et al. 2013). Their seasonal survival estimates, represented here as mean survival ± standard error (SE) were as follows: Spring = 0.93 (93%) ± 0.02; Summer = 0.98 ± 0.01; Fall = 0.92 ± 0.02; and Winter = 0.99 ± 0.01 (Blomberg et al. 2013). They found very little annual variation in hen survival, allowing them to pool seasonal estimates among years, while our seasonal rates were more variable among years. In contrast, estimates of hen survival in a north-central Montana population of sage-grouse were more variable than ours (Moynahan et al. 2006), presumably due to a disease outbreak and harsh weather during their study period. Our apparent seasonal survival rates were higher relative to fall and winter estimates (defined slightly differently) in an Oregon population of sage-grouse (Anthony and Willis 2009) that may have been affected by cold winters as well.

Hen survival was previously estimated in our study area during 2004 – 2005 (Sika 2006), and while seasons were defined slightly differently, apparent hen survival estimates were comparable to our estimates. Monthly survival from Apr – Jun was 94%; while survival during Jul 2004 and Jul 2005 was 99% to nearly 100%, respectively, and survival during Aug 2004 and Aug 2005 was 94% and 84%, respectively (Sika 2006).

NEST SUCCESS

*From Smith (2016) and Smith et al. (2017).

Annual apparent nest success (number of monitored nests that successfully hatched / total number of nests monitored) during 2011 – 2019 ranged from 30 – 71% (Table 4). In comparison, nest success varied from 14 – 86% across the range of sage-grouse, including studies from Oregon, Colorado, and Idaho (Connelly et al. 2011); nest success observed during all years of our study is within the range expected for sage-grouse.

The following results were reported in Smith (2016) and Smith et al. (2018). The collection of covariates used in these models has been described below (Section: "Impacts of Grazing on Sage-Grouse Habitat Use: Accomplishments"). We used Bayesian methods to fit logistic regression models relating measured covariates to daily nest success rates during 2011 – 2015. We used indicator variables paired with each model coefficient to assess variable importance and produce model-averaged coefficient estimates, and performed an initial variable screening step, rejecting variables (i.e., Figure 4) when 85% credible intervals for coefficients overlapped zero. We included separate intercepts for each year and a random effect for individual females, as we monitored from one to seven nests for each female (all nests for an individual from 2011 – 2015) and fates of nests from the same female may not have been independent if females differed in 'quality' with respect to their ability to successfully incubate a nest.

Of the 11 variables passed to the final model, only precipitation was supported with a Bayes factor ≥ 3, with greater amounts of cumulative rainfall over a 4-day period associated with lower daily nest success (Figure 4). Distance from county roads and highways received some support from a 95% credible interval that did not overlap zero, suggesting greater success farther from these features. Grazing system (Non-SGI vs SGI), presence or absence of livestock in the pasture during nesting, current year's grazing intensity, and density of previous-years' cow pats were all unrelated to daily nest success. We will add data from 2016 – 2020 to these analyses towards the end of our study to evaluate if these relationships are sustained in the long-term.

CHICK SURVIVAL

We have marked 60 sage-grouse chicks with radio transmitters during 2019, and 31 are currently active and being monitored as of Jun 30, 2019. We are going to attempt to recapture the females of these remaining chicks during the next 4 – 6 weeks to re-mark them with adult radio transmitters and continue to monitor their vital rates and habitat use throughout the next year. We are still organizing and analyzing this season's data, and thus these results are preliminary and may be adjusted. These apparent survival estimates are conservative because we only considered chicks to be alive until the end of the monitoring period if their fates were known ; chicks whose status were unknown because they were on land we could not access or because their signals were lost, were not considered alive. Chick transmitters were guaranteed to last 60 days, and most lasted 75 – 100 days. Thus, the "Number of Surviving Chicks" is the number of chicks that survived two to three months after hatching.

We used package "survival" (Therneau 2015) in program R to run the following Kaplan-Meier survival analyses. With data pooled across years, the Kaplan-Meier mean survival time for 425 sage-grouse chicks marked with radio transmitters during 2011 – 2017 was 56.45 d (SE = 2.84), and the median survival time was 40 d (95% CI = 32 – 58 d; Figure 5). The probabilities of chicks surviving until the end of the monitoring periods differed among years ($\chi^2 = 16.2$, $df = 6$, $p = 0.0128$; Table 5, Figure 6). Individuals whose signals were lost or had unknown fates were censored from the analysis at the last time they were successfully monitored. Thus, our Kaplan-Meier survival estimates were conservative.

Weather conditions during the sensitive post-hatch time, which peaks in early June for many prairie grouse, may have a large impact on chick survival (Flanders-Wanner et al. 2004). For example, chicks cannot initially thermoregulate after they hatch (Guttery et al. 2013), and they must rely on the hen to keep them warm and survive heavy rain events during the early post-hatch period. We have not yet formally analyzed the effects of weather and other habitat variables on chick survival, but we expect that our work may support other studies showing that climatic variables including precipitation (amount and timing), temperature, and drought are the primary drivers of sage-grouse reproductive success (Dahlgren et al. 2010, Guttery et al. 2013, Smith et al. 2018).

Previous studies have shown chick survival to be variable and range from 12 – 50% during the first few weeks after hatching (Aldridge and Boyce 2007, Gregg and Crawford 2009, Dahlgren et al. 2010, Guttery et al. 2013). Similarly, chick survival in our study during 2011 – 2018 ranged from 19 – 54% (Table 10). However, caution should be used when comparing estimates among studies because the durations of monitoring periods often differ. For example, Gregg and Crawford (2009) and Dahlgren et al (2010) monitored sage-grouse chicks for 28 and 42 days, respectively, whereas in our study, we monitor chicks up to 100 days due to the recent availability of smaller, lighter radio transmitters with longer battery life. In addition, some studies measure "brood" survival (at least one chick from a brood lives) or unmarked chicks rather than monitoring individually marked chicks. Unmarked chicks are difficult to observe and monitor, and brood mixing may occur that results in broods containing chicks not parented by a particular hen (Dahlgren et al. 2010, Guttery et al. 2013). Thus, there are limitations when comparing unmarked chick or brood survival estimates with telemetry survival estimates. The relatively low chick survival observed during our study compared to hen survival and nest success suggests a focus for future research and conservation efforts. We are working on chick habitat use and survival analyses to determine how habitat variables impact these factors to help guide management for this life phase. We are also evaluating these factors together with the other vital rates and habitat needs for hens to help prioritize key areas for conservation efforts.

Impacts of Grazing on Sage-Grouse Habitat Use

ACCOMPLISHMENTS:

Data collection and analyses to assess the effects of vegetation metrics on hen nest site selection and the seasonal habitat use of sage-grouse hens and chicks/broods have been ongoing. During the reporting period, our efforts focused on monitoring hen and chick movements using radio telemetry: we recorded over 31,000 hen and 771 chick locations at ≤30 m accuracy. For Mar 1, 2011 – Jun 30, 2019 we have collected 13,982 hen and 5,178 chick locations at ≤30 m accuracy. We were able to collect many more hen locations during 2019 due to the GPS PTTs. During the reporting period, we collected vegetation data at 67 nests and 93 random points within nesting habitat to investigate the impacts of vegetation metrics on vital rates and nest site selection, and at an additional 82 plots stratified among grazing treatments (hereafter "vegetation response plots") to measure the impacts of grazing on sage-grouse habitat, though this number will increase because we are still collecting vegetation response plot data at the time of this report. For the study duration of 2011 – Jun 30, 2019 we have collected vegetation data at 726 nests, 1,089 random points within nesting habitat, and 1,499 at vegetation response plots. Below we present a summary of methods and results on the impacts of vegetation and some grazing indices on the nest-site selection of sage-grouse hens, as reported in Smith (2016) and Smith et al. (2018).

We examined covariates falling into four categories: 1) local-scale vegetation surrounding the nest, 2) livestock grazing variables, 3) anthropogenic disturbance, and 4) weather. Candidate variables were screened for collinearity using condition indices (Belsley et al. 1980). If we observed a condition index >30, we examined the variables implicated by high (>0.5) variance decomposition proportions and removed them one at a time, retaining the variable with the simplest biological interpretation, until all condition indices were <30 (Belsley et al. 1980). As one of our primary goals was to elucidate the relative effect sizes of variables across categories, we scaled and centered all variables to zero mean and unit variance before fitting models.

LOCAL-SCALE VEGETATION MEASURES

To evaluate the effects of vegetation on nest success and nest-site selection, we sampled vegetation at nests after they reached their estimated hatch date (for failed nests) or after the nests successfully hatched. We made identical measurements at random points within potential nesting habitat to quantify resources available to nesting females. We used ArcGIS (ESRI Inc., Redlands, CA) and program R to generate random points that were constrained to be within 6.4 km of leks, not in cropland, and in a sagebrush-dominated land cover. Available points were generated within 6.4 km of leks from which females were captured because sage-grouse place the majority of their nests within 5 kilometers of a lek. Available points were further constrained to areas with ≥5% visually-estimated sagebrush canopy cover at the plot scale (15 m radius), as the importance of sagebrush as a nest substrate and sagebrush cover surrounding nests have been firmly established by numerous studies of nest site selection in sage-grouse (Hagen et al. 2007). In fact, in Montana, it has been suggested that sage-grouse preferentially select areas of ≥15% sagebrush cover for nesting (Wallestad and Pyrah 1974). At points meeting these criteria, we selected the nearest sagebrush shrub ≥30 cm in height to designate as the nest shrub, based on the finding that mean height of sage-grouse nests ranges from 29 – 80 centimeters (Connelly et al. 2000). We sampled two available points for each nest. Plots at random points were measured during the same week as nest plots that were in the same area.

Local-scale vegetation plots measured in the field were centered on the nest bowl or a random shrub (described above) and extended 15 meters in each cardinal direction ("spokes"). We established plots with two, perpendicular 30 m tapes intersecting at the nest shrub. Canopy cover of sagebrush and other shrubs was estimated with the line intercept method along both tapes (Canfield 1941, Wambolt et al. 2006). Cover of understory vegetation, height of live and senesced grasses, and height of shrubs were estimated with measurements taken at 8 points located 3 and 6 m from the plot center in each cardinal direction. Previous research found relationships between herbaceous vegetation structure and nest site selection and success were strongest at a similar scale (7.5m, Aldridge and Brigham 2002). At each of these 8 points, we used a 20 x 50-cm quadrat (Daubenmire 1959) to estimate absolute percent cover of understory herbaceous vegetation, litter, and bare ground. Absolute cover estimates were made beneath the shrub canopy and included only the uppermost canopy when overlapping canopies occurred. We recorded the maximum vertical height, excluding inflorescences, of undisturbed live and senesced material on the nearest grass plant, and the tallest live portion, excluding inflorescences, of the nearest shrub. All technicians were trained to estimate cover by a single lead observer each year and periodically checked throughout the season for consistency (i.e., individual estimates within ±5% for all cover classes). We estimated visual obstruction with a Robel pole (Robel et al. 1970) placed in the nest bowl and at points 1, 3, and 5 m from the nest shrub in each cardinal direction, taking readings from 4 m at a height of 1 m above the ground facing toward the nest bowl (modified from Martin et al. 1997). The 4 readings from each direction at the nest bowl were averaged to quantify visual obstruction at the nest, and the 12 readings 1–5 m from the nest were averaged to quantify visual obstruction at the plot. We measured the maximum height (h), maximum width (m), and greatest width perpendicular to the axis of the maximum width (p) of the nest shrub to calculate nest shrub volume using the formula for the volume of a half-ellipsoid ($\frac{2}{3}\pi\frac{m}{2}\frac{p}{2}h$). When the nest was located beneath >1 shrub with a contiguous canopy, the shrubs were treated as a single shrub for measurement purposes.

LIVESTOCK GRAZING

To quantify intensity of livestock presence and grazing during the nesting season, we counted cattle dung pats and estimated the proportion of herbaceous plants grazed within a 15-m radius of each nest shrub or available point. Density of dung pats may be indicative of patterns of forage utilization and vegetation structure in areas grazed by livestock (Roche et al. 2012), but also contains information about livestock presence independent of grazing. We recorded the total number of dung pats, categorizing them as current year or previous years, distinguished by the level of degradation and oxidation. Dung pats from the current year were used to index local use by livestock during the current nesting season, as livestock turn-out dates in our study area coincided closely with the beginning of the nesting season. Counts of dung pats from previous years were used to index intensity of previous years' livestock use, which was used as a candidate variable in nest site selection models to test whether females avoided signs of heavy livestock use when selecting a nest site. Cattle dung pats may persist in arid ecosystems for up to 6 years (Lussenhop et al. 1982), therefore previous years' dung pat density represented a relative index of use integrated over the past several grazing seasons (Milchunas et al. 1989). As dung pats reflect presence of livestock but not necessarily grazing, we also recorded the number of plants exhibiting evidence of grazing during the current year from a sample of 100 randomly selected herbaceous plants, 25 from each quadrant of the plot. Finally, grazing records were obtained from most landowners to determine whether livestock had been present in the pasture at any time during nesting, and observers recorded livestock presence or absence in the pasture at each visit to the nest. Where grazing records were lacking or disagreed with field observations, we used field observations.

ANTHROPOGENIC DISTURBANCE

At nests and available points, field technicians recorded distance to the nearest visible two-track (primitive dirt) road. We used a GIS coverage to estimate distance from each nest or available point to the nearest major (gravel or paved) road and to the nearest two-track when field estimates were unavailable. We estimated distance to the nearest crop field, excluding alfalfa, using the Cropland Data Layer (USDA-NASS 2016) and parcel boundaries from the Montana Cadastral Mapping Project (Montana State Library 2016). We first built a binary cropland raster indicating all 30-m cells classified as cropland in >1 year between 2008 and 2016. We then determined the area of each parcel classified as cropland and masked out pixels from the binary cropland raster that were located in parcels with <4 ha (10 ac) of cropland. This eliminated small fragments of cropland that likely arose from misclassification of other land cover classes in the Cropland Data Layer. We then estimated the distance from each nest or available point to the nearest cropland pixel in the cleaned cropland raster. Finally, we used a disturbance footprint raster (Carr et al. 2017) to estimate the cumulative amount of anthropogenic disturbance (e.g., landscape fragmentation due to urban development, energy, minerals, and transportation) in the landscape surrounding each nest or available point. We took the mean percent disturbed from all 90-m pixels within 1 km of the point of interest.

WEATHER

We estimated daily weather conditions experienced by nesting females using the DAYMET daily gridded meteorological dataset (Thornton et al. 2014). For each nest-day, we extracted total precipitation, minimum temperature, and maximum temperature from the DAYMET dataset, estimating values at nest locations using bilinear interpolation from the 1 km-resolution rasters. We subsequently used these daily precipitation estimates to derive the previous day's precipitation and temporal 'moving window' variables indicating the total precipitation that fell at a given location in the preceding 2, 3, 4, or 5 days, inclusive.

RESULTS:

*From Smith (2016) and Smith et al. (2018).

NEST SITE SELECTION, 2012 – 2015

We collected location data on sage-grouse hens and chicks marked with radio transmitters to assess (1) seasonal habitat use by hens, (2) nest site selection by hens, and (3) habitat use by hens with broods or marked chicks. We are currently working on data analyses for habitat use by hens and chicks, which may be completed beyond the term of this agreement. Preliminary results for nest site selection are reported below.

We used Bayesian methods to fit logistic regression models relating measured covariates (Table 6) to the probability that a site was a nest (1) versus a randomly sampled available site (0). We used indicator variables paired with each model coefficient to assess variable importance and produce model-averaged coefficient estimates (Kuo and Mallick 1997). We performed an initial screening of variables by fitting univariate nest site selection models to each candidate variable and rejecting variables when 85% credible intervals for coefficients overlapped zero. Of the 16 variables passing variable screening, seven were supported with Bayes factors ≥ 3 (Figure 7). These were nest shrub volume, plot-scale (15 m) sagebrush cover, patch-scale (100 m) roughness, patch-scale sagebrush heterogeneity, distance to county roads and highways, distance to two-track roads, and proportion of the landscape (1.61 km) disturbed. At the scale of the nest substrate, females selected shrubs with greater volume. At the plot scale, females selected for greater sagebrush cover. At the patch scale, females selected gentler terrain and more even stands of sagebrush. Finally, females preferred to locate nests farther from county roads and highways but closer to two-track roads, and avoided landscapes with greater amounts of non-cropland anthropogenic disturbance (i.e., gravel and paved roads).

We do not have a not have a clear biological interpretation of selection of nest sites closer to two-track roads. We speculate that this preference may reflect the tendency for two-track roads to traverse terrain preferred by sage-grouse for nesting, e.g., areas of gentle topography. We found no evidence of selection with respect to herbaceous vegetation metrics, current-year's livestock use intensity, or density of previous-years' cow pats. We will add data from 2016 – 2020 to these analyses towards the end of our study to evaluate if these relationships are sustained in the long-term.

Impacts of Grazing on Sagebrush Habitat

**From Smith (2016) and Smith et al. (2018).*

ACCOMPLISHMENTS:

Efforts during the reporting period focused on entering data from vegetation plots measured during the 2019 field season. A brief summary of how these plots were selected and measured, and results from preliminary analyses (appearing in previous reports) has been described below.

We used herbaceous vegetation measurements at a set of stratified random field plots among grazing treatments to test for differences in indicators of habitat quality across the project area. The locations of plots were stratified based on several criteria (Table 7) to minimize variation in the data due to spatial heterogeneity in covariates known to affect vegetation structure and composition. We identified pastures rested each season and sampled an appropriate number of field plots in SGI-grazed , SGI-rested , and Non-SGI pastures to test for differences in vegetation structure among these treatments. Rangelands were highly dynamic and spatially heterogeneous, and assessing their condition over large areas has always been a logistical challenge (West 2003). We used ArcGIS (ESRI Inc., Redlands, CA) and program R to generate stratified random points using the criteria in Table 7. The metrics for these vegetation plots were identical to the nest vegetation plots in Objective 2, except that we did not measure variables specific to the random shrub in the center of the plot.

RESULTS:

GRAZING IMPACTS ON SAGEBRUSH HABITAT, 2012 – 2015

We used linear mixed effects models to test for grazing system and rest effects (fixed effects) on vegetation metrics while accounting for variation across years and ranches (random effects). Our years were defined as Apr 1 – Mar 31. For example, year 2012 was defined as Apr 1, 2012 – Mar 31, 2013. Linear mixed effects models were fit using the lme4 package (Bates et al. 2015) in program R. Significance of fixed effects was assessed with likelihood ratio tests, by comparing models with and without a fixed effect for grazing system.

We sampled 353 vegetation plots on Non-SGI ranches and 510 vegetation plots on SGI ranches during 2012 – 2015 (Figure 8). Likelihood ratio tests indicated that live grass height ($\chi^2 = 9.4$, $df = 1$, $p = 0.002$), residual grass height ($\chi^2 = 5.3$, $df = 1$, $p = 0.021$), bare ground ($\chi^2 = 4.9$, $df = 1$, $p = 0.027$), and litter ($\chi^2 = 6.6$, $df = 1$, $p = 0.010$) all differed between Non-SGI and SGI ranches. Grazing system effect sizes, however, were small relative to annual variation: live and residual grass heights were greater on SGI ranches: 1.50 cm (SE 0.467 cm) and 1.04 cm (SE 0.432 cm) greater, respectively. Bare ground cover was 6.05% (SE 2.695%) lower on SGI ranches, and litter cover was 4.52% (SE 1.762%) higher on SGI ranches. Visual obstruction ($\chi^2 = 0.22$, $df = 1$, $p = 0.642$) and herbaceous vegetation cover ($\chi^2 = 0.27$, $df = 1$, $p = 0.605$) did not differ between grazing systems (Figure 9). After accounting for grazing system effects, the effect of pasture rest was negligible and non-significant for all variables tested. We sampled 1,500 total vegetation plots during 2012 – 2019, with roughly half each on Non-SGI and SGI ranches, respectively. This number is not final as we are still entering data from 2019. We will add data from 2016 – 2020 to the above analyses at the end of our study to evaluate if these relationships are sustained with the long-term data set.

FUTURE GOALS

We will continue data collection over the next year and a half, 2019 – 2020, with final products completed in 2022. During Aug – Sep 2019, we will attempt to capture radio marked chicks that survive until they are adults and fit them with adult-sized radio transmitters to continue monitoring them throughout the year. During Sep 2019 – Mar 2020, we will conduct monthly flights to monitor the fall and winter survival and habitat use of hens that are marked with VHF radio transmitters. We will automatically receive 4 – 6 locations from the hens marked with GPS radio transmitters. Beginning in Mar 2020, the number of locations collected will increase to eight per day as we begin monitoring birds during nesting for our final season of data collection. We will also continue to work on data, analyses, and products through this fall and winter.

Sage-grouse nest survival does not seem to be impacted by SGI's rotational grazing systems (Smith 2016, Smith et al. 2018) in the short-term (1 – 5 years). We will continue to collect information on all vital rates to determine if SGI's rotational grazing influences these sensitive vital rates, and reassess grazing effects on nest success with five more years of data. Chick survival is low in our study relative to nest success and hen survival, suggesting that this vital rate may be the one to focus on for future conservation and management efforts in our area. The number and health of these chicks are important factors in limiting the growth of populations. Thus, chick survival information will benefit both wildlife managers and private landowners who are working together to support sage-grouse conservation.

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TABLES

Table 1. Conservation options for greater sage-grouse habitat in Management Zone 1 from the United States Fish and Wildlife Service (USFWS) report: USFWS. 2013. Greater sage-grouse (*Centrocercus urophasianus*) Conservation Objectives: Final Report. United States Fish and Wildlife Service, Denver, Colorado, USA. Feb 2013, p. 48.

Conservation Action	Description
1	Revise Farm Bill policies and commodity programs that facilitate ongoing conversion of native habitats to marginal croplands (e.g., through the addition of a 'Sodsaver' provision), to support conservation of remaining sagebrush-steppe habitats.
2	Continue and expand incentive programs that encourage the maintenance of sagebrush habitats.
3	Develop criteria for set-aside programs which stop negative habitat impacts and promote the quality and quantity of sage-grouse habitat.
4	If lands that provide seasonal habitats for sage-grouse are taken out of a voluntary program, such as CRP[a] or SAFE[b], precautions should be taken to ensure withdrawal of the lands minimizes the risk of direct take of sage-grouse (e.g., timing to avoid nesting season). Voluntary incentives should be implemented to increase the amount of sage-grouse habitats enrolled in these programs.

[a] *Conservation Reserve Program*

[b] *State Acres for Wildlife Enhancement*

Table 2. Apparent seasonal and annual survival (number of hens still alive / total number of hens monitored) of radio-marked greater sage-grouse hens in Golden Valley and Mussellshell Counties, Montana during 2011 – 2019 for both SGI and Non-SGI areas combined. We measure annual survival from Apr 1 – Mar 31.

Year / Season	Apr-May (Spring)	Jun-July (Summer)	Aug – Oct (Fall)	Nov – Mar (Winter)	Annual
2011	88%	91%	83%	90%	57%
2012	84%	93%	85%	89%	82%
2013	93%	86%	87%	90%	67%
2014	91%	100%	70%	79%	75%
2015	95%	98%	91%	96%	77%
2016	89%	94%	82%	85%	70%
2017	90%	86%	74%	78%	42%
2018	89%	85%	76%	93%	53%
2019	93%	97%	*	*	90%*

* These measurements have yet to occur; the annual estimate is the estimate from Apr 1 – Jul 31, 2019, but will change as we continue through the year.

Table 3. Summary of annual adult female greater sage-grouse survival estimates from several studies across the greater sage-grouse range.

Survival Estimate	Location	Reference
75 – 98%	Central Montana, our study area	Sika 2006
48 – 78%	Wyoming	Holloran 2005
48 – 75%	Idaho	Connelly et al. 1994
57%	Alberta	Aldridge and Brigham 2001
61%	Colorado	Connelly et al. 2011
37%	Utah	Connelly et al. 2011

Table 4. Apparent nest success (number of monitored nests that hatched at least one chick / total number of nests monitored) of our marked population of greater sage-grouse hens in Golden Valley and Mussellshell Counties, Montana, USA during 2011 – 2019 (SGI and Non-SGI areas combined). Total number of nests monitored are presented as well as number of nests per nest attempt. Nest success for 1st nests = # successful 1st nests / total 1st nests attempted; 2nd nests = # successful 2nd nests / total 2nd nests attempted; 3rd nests = # successful 3rd nests / total 3rd nests attempted.

	Overall Apparent Nest Success	Total Number of Nests	Number of 1st Nests / Nest success	Number of 2nd Nests / Nest success	Number of 3rd Nests / Nest success
2011	30%	103	79 / 28%	22 / 41%	1 / 0%
2012	54%	91	82 / 52%	9 / 67%	–
2013	39%	84	69 / 39%	15 / 40%	1 / 100%
2014	64%	74	68 / 63%	6 / 67%	–
2015	51%	76	69 / 54%	8 / 38%	–
2016	36%	85	68 / 35%	17 / 41%	–
2017	43%	106	81 / 42%	24 / 46%	1 / 100%
2018	40%	72	63 / 41%	8 / 38%	–
2019	71%	69	61 / 67%	8 / 100%	–*

* As of July 31, 2019, there is still one sage-grouse hen nesting, which is the latest we have observed a hen on a nest during the entire 9 years of this study.

Table 5. Kaplan-Meier survival estimates of greater sage-grouse chicks in Golden Valley and Musselshell Counties, Montana, USA, during 2011 – 2018. These represent the probability that a chick would survive to 75 days, when it is adult-sized and relatively independent from the hen.

	Total Number of Marked Chicks	Kaplan-Meier Survival Estimate	Standard Error	95% Confidence Interval
2011	24	0.40	0.15	0.20 – 0.82
2012	81	0.19	0.05	0.11 – 0.34
2013	57	0.39	0.10	0.24 – 0.65
2014	77	0.37	0.09	0.23 – 0.60
2015	58	0.54	0.08	0.41 – 0.72
2016	44	0.31	0.08	0.19 – 0.52
2017	82	0.47	0.07	0.35 – 0.63
2018	46	0.22	0.07	0.12 – 0.40
2019	60	Still monitoring chicks		

Table 6. Covariates considered in building nest success and nest-site selection functions (from Smith 2016).

Variable	Abbreviated Variable Name	Transformation
Landscape Covariates (0 - 1.61 km from nest)		
Distance to major road (county, highway)	DIST TO ROAD[a,b]	Logarithmic[a,b]
Distance to two-track road	DIST TO 2TRACK[a,b]	Logarithmic[a,b]
Distance to cropland	DIST TO CROPLAND[a,b]	Logarithmic[a,b]
Distance to mesic vegetation	DIST TO MESIC[a,b]	Quadratic[a]; Logarithmic[b]
Proportion of landscape disturbed (non-cropland)	PROPORTION DISTURBED[a,b]	
Proportion of landscape in cropland	PROPORTION CROPLAND[a,b]	
Proportion of landscape in sagebrush landcover (≥5%)	PROPORTION SAGE[a,b]	
Patch (0 - 100 m from nest) Covariates		
Topographic roughness	ROUGHNESS[a]	
Sagebrush cover	SAGEBRUSH COVER[a,b]	
Standard deviation of sagebrush cover	SAGE HETEROGENEITY[a,b]	
Plot (0-15 m from nest) Covariates		
Live grass height	GRASS HEIGHT[a,b]	
Residual grass height	RESIDUAL HEIGHT[a,b]	
Total herbaceous cover	HERBACEOUS COVER[a,b]	
Bare ground	BARE GROUND[a,b]	Quadratic[a]
Residual herbaceous cover	RESIDUAL COVER[a,b]	
Litter cover	LITTER COVER[a,b]	
Visual obstruction (Robel pole)	VISUAL OBSTRUCTION[a,b]	
Shrub height	SHRUB HEIGHT[a,b]	
Sagebrush cover	SAGEBRUSH COVER[a,b]	Quadratic[a]
Total shrub cover	SHRUB COVER[a,b]	Quadratic[a]
Shrub cover * residual grass height		
Shrub cover * total herbaceous cover		
Nest Shrub Covariates		

Variable	Abbreviated Variable Name	Transformation
Maximum live grass height at nest	GRASS HEIGHT[a,b]	
Maximum residual grass height at nest	RESIDUAL HEIGHT[a,b]	
Visual obstruction (Robel pole)	VISUAL OBSTRUCTION[a,b]	
Nest shrub volume	NEST SHRUB SIZE[a,b]	
Nest substrate (other = 0, sagebrush = 1)	NEST SUBSTRATE[b]	
Grazing Covariates		
Pasture grazed during nesting	GRAZED DURING[b]	
Livestock use index, current year	LIVESTOCK INDEX (CURRENT)[a,b]	
Livestock use index, historical	LIVESTOCK INDEX (PAST)[a,b]	
Grazing system (Other = 0, SGI RGS = 1)	SGI RGS[b]	
Precipitation Covariate (Daily)		
Predicted total rainfall in last 4 days	RAINFALL 4DAY[b]	
Other Covariates		
Hen age (juvenile = 0, adult = 1)	HEN AGE[b]	
Nest attempt (1st = 0, 2nd or 3rd = 1)	NEST ATTEMPT[b]	

[a] Variable or transformation was considered as a candidate in nest selection model
[b] Variable or transformation was considered as a candidate in nest survival model

Table 7. Criteria for inclusion of sampling plots used to measure vegetation response to grazing systems (from Smith 2016).

Variable	Acceptable Range	Data Source
Slope	0 – 5 degrees	10 m DEM (National Elevation Dataset)
Soil Type[1]	60C, 60D, 64A, 64B, 68C	NRCS SSURGO Database[3]
Distance to Water[2]	200 – 1500 m	Local NRCS records, National Hydrography Dataset[4]

[1]Soil map units chosen for inclusion are salty clay loams that typically support sagebrush in the study area.
[2]Field checked.
[3]http://soildatamart.nrcs.usda.gov
[4]http://nhd.usgs.gov

FIGURES

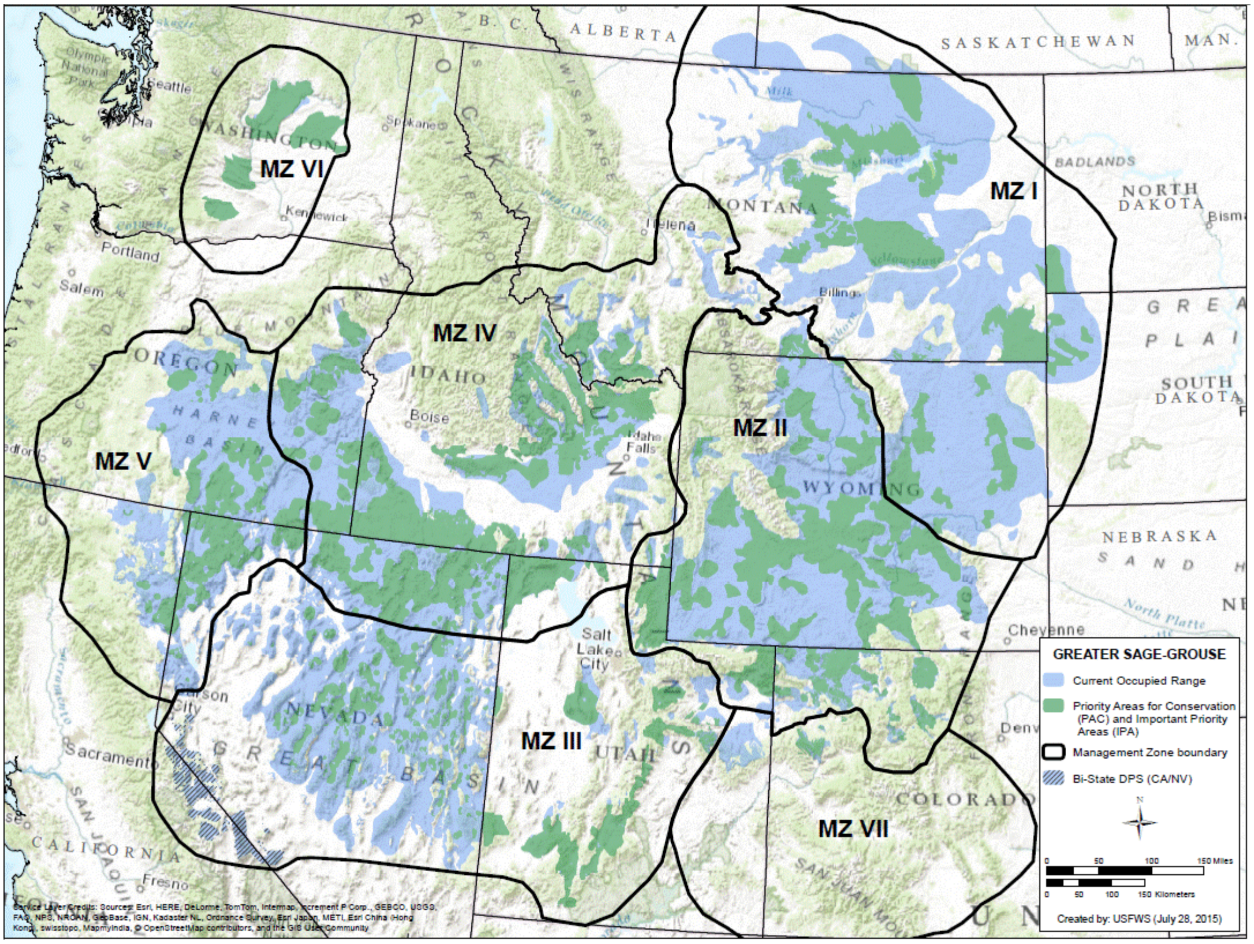

Figure 1. The location of Management Zones (MZ) and Priority Areas for Conservation (PAC) across the current range of the greater sage-grouse. Figure taken from the United States Fish and Wildlife Service Website: <https://www.fws.gov/greatersagegrouse/maps.php>. Last accessed Aug 1, 2019.

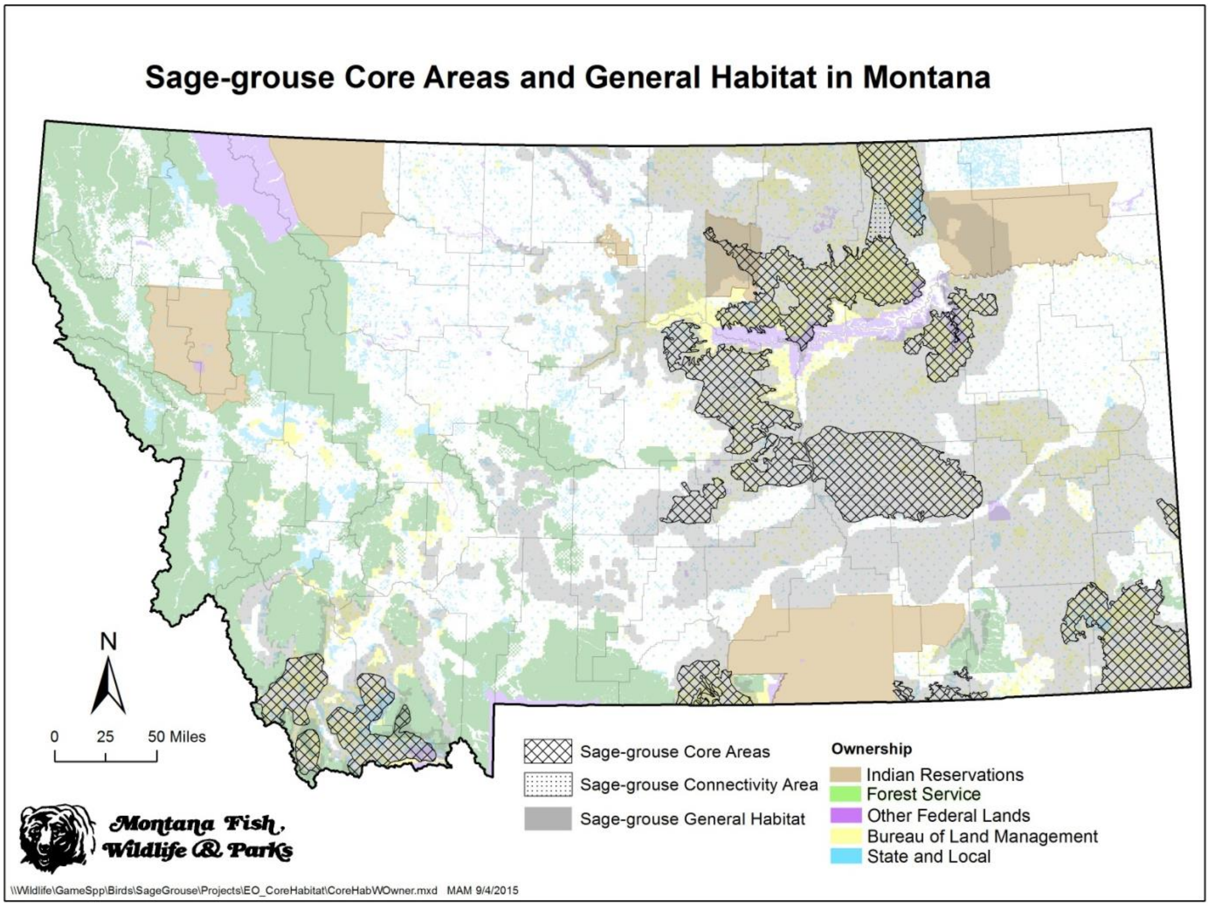

Figure 2. Greater sage-grouse core areas as defined by Montana Fish, Wildlife, and Parks. The black star represents the location of the study area for this project in Golden Valley and Musselshell Counties, Montana, USA.

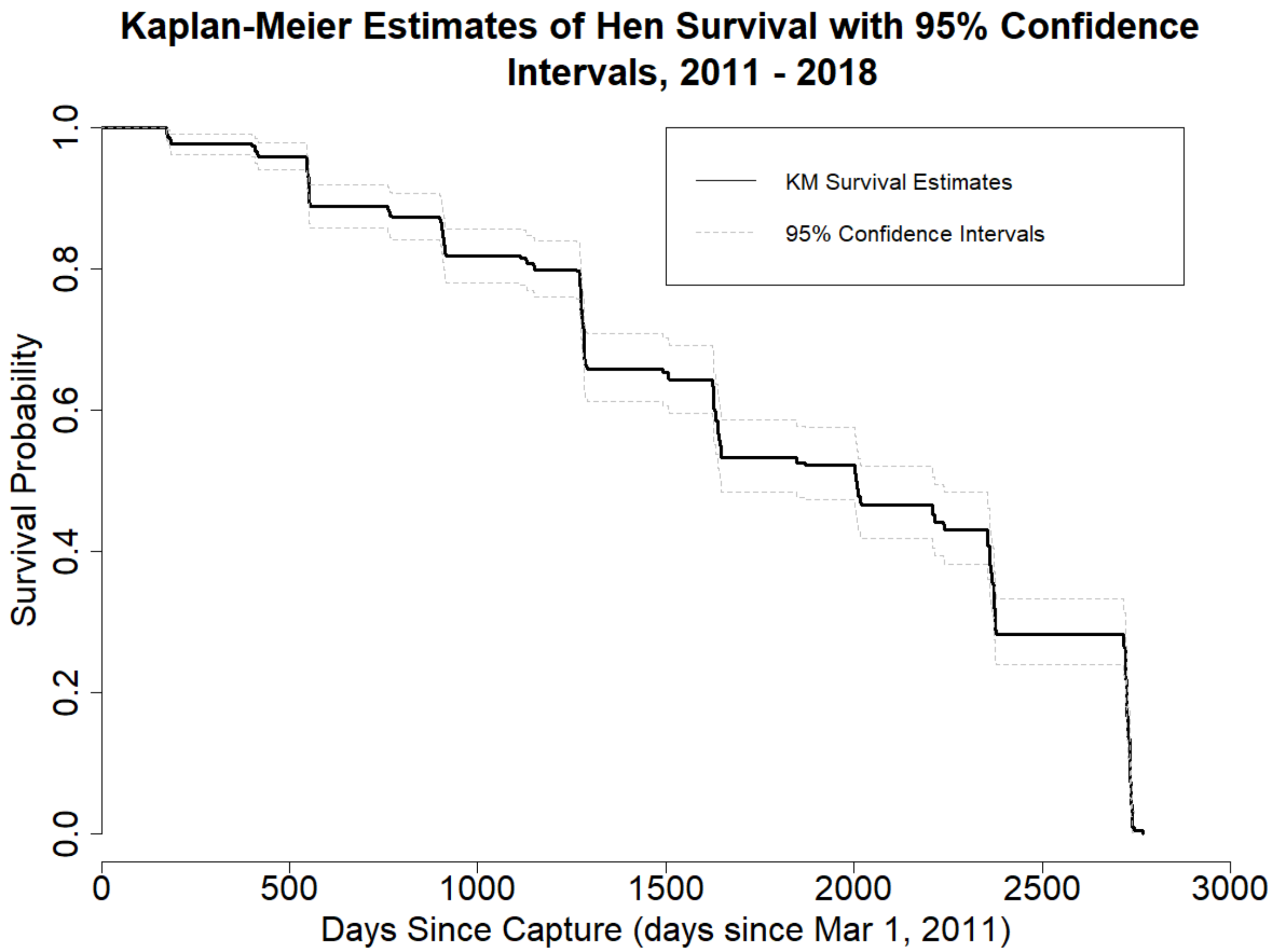

Figure 3. The Kaplan-Meier survival curve (solid line) and 95% confidence intervals (dashed lines) for greater sage-grouse hens monitored from March 1, 2011 – September 26, 2018 in Golden Valley and Musselshell Counties, Montana, USA. We used right censoring for individuals with unknown fates, dropped transmitters, and for individuals that survived until their transmitters expired. The data were pooled across years. The Kaplan-Meier mean survival time estimate was 1,848.5 days (5.06 yrs; standard error [SE] = 40.1 days; 95% confidence interval = 1,646 – 2,213 days or 4.51 – 6.06 yrs) and the median was 2,005 days (5.49 yrs).

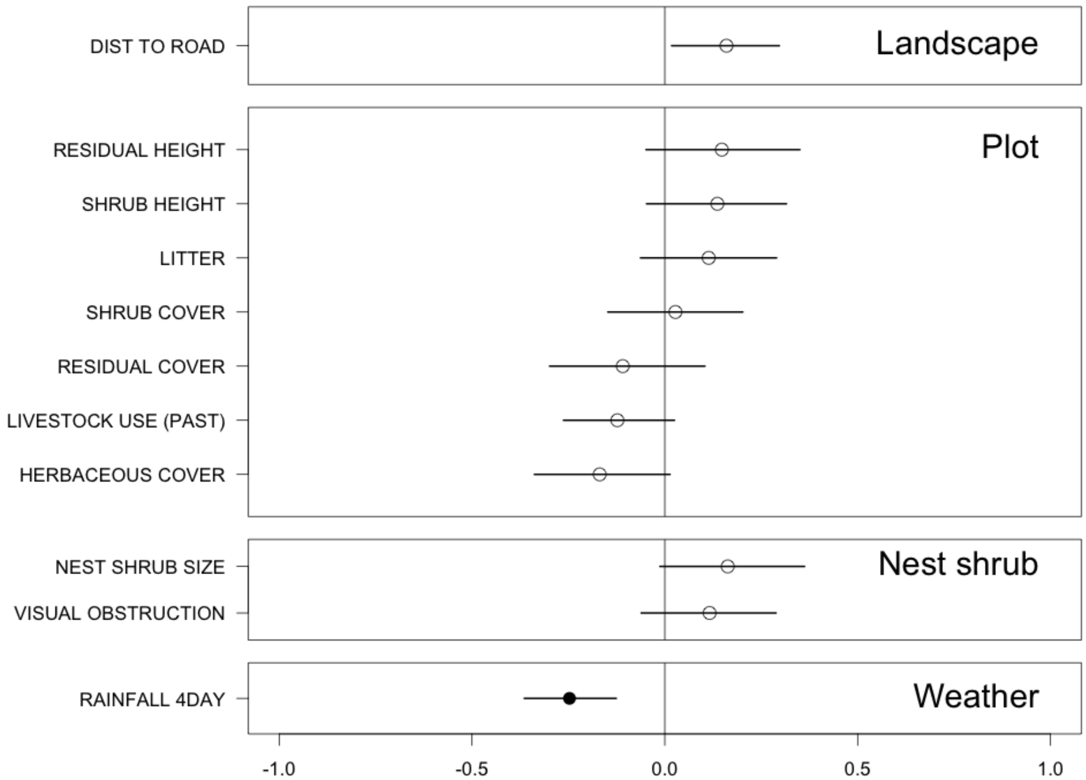

Figure 4. Coefficient estimates from logistic regression model describing variables influencing daily nest survival of sage-grouse nests (n=412) in Golden Valley and Musselshell Counties, Montana, USA from 2011 to 2015. Filled circles identify important variables supported by Bayes factors and error bars represent 95% credible intervals.

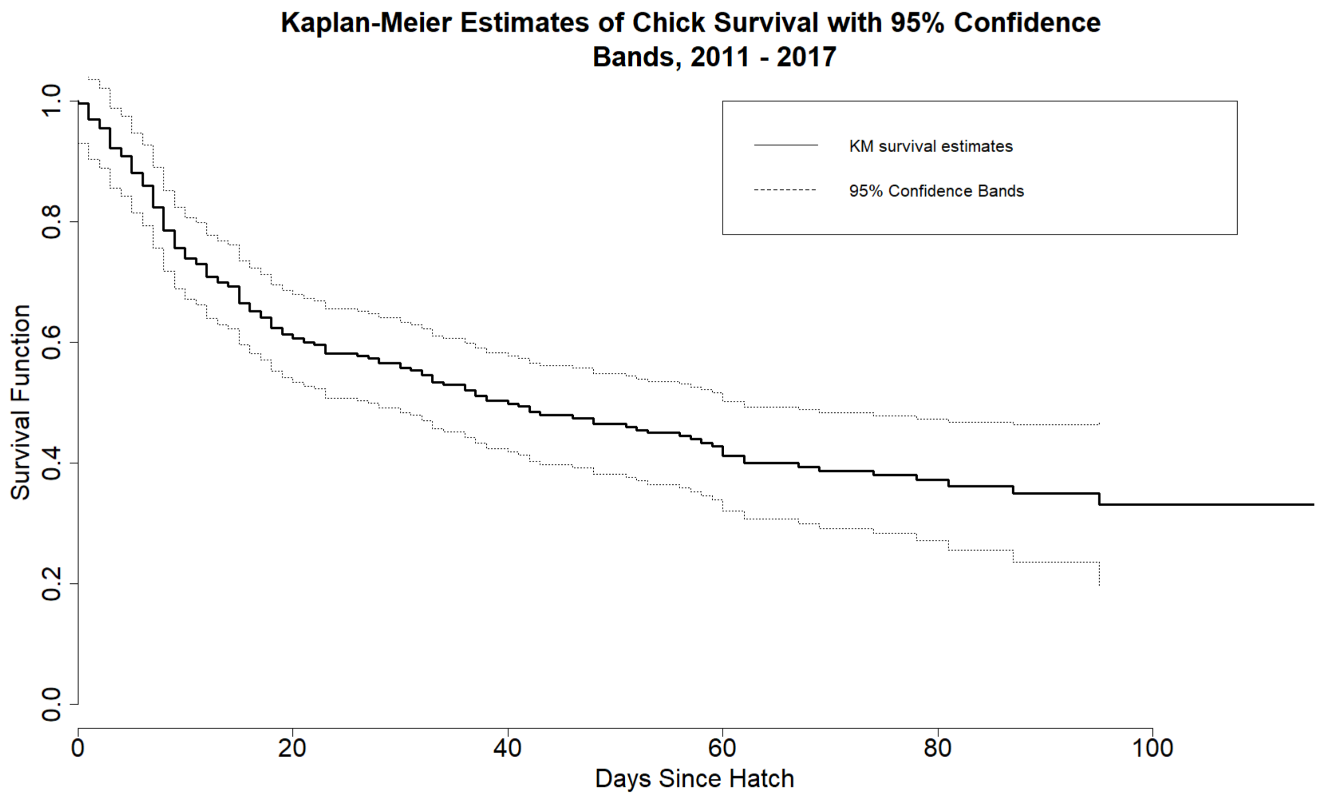

Figure 5. Kaplan-Meier survival curve and 95% confidence intervals for greater sage-grouse chicks marked with radio transmitters in Golden Valley and Musselshell Counties, Montana, USA during 2011 – 2017. Mean survival time for marked chicks was 56.45 d (SE = 2.84), and the median survival time was 40 d (95% CI = 32 – 58). The data were pooled across years.

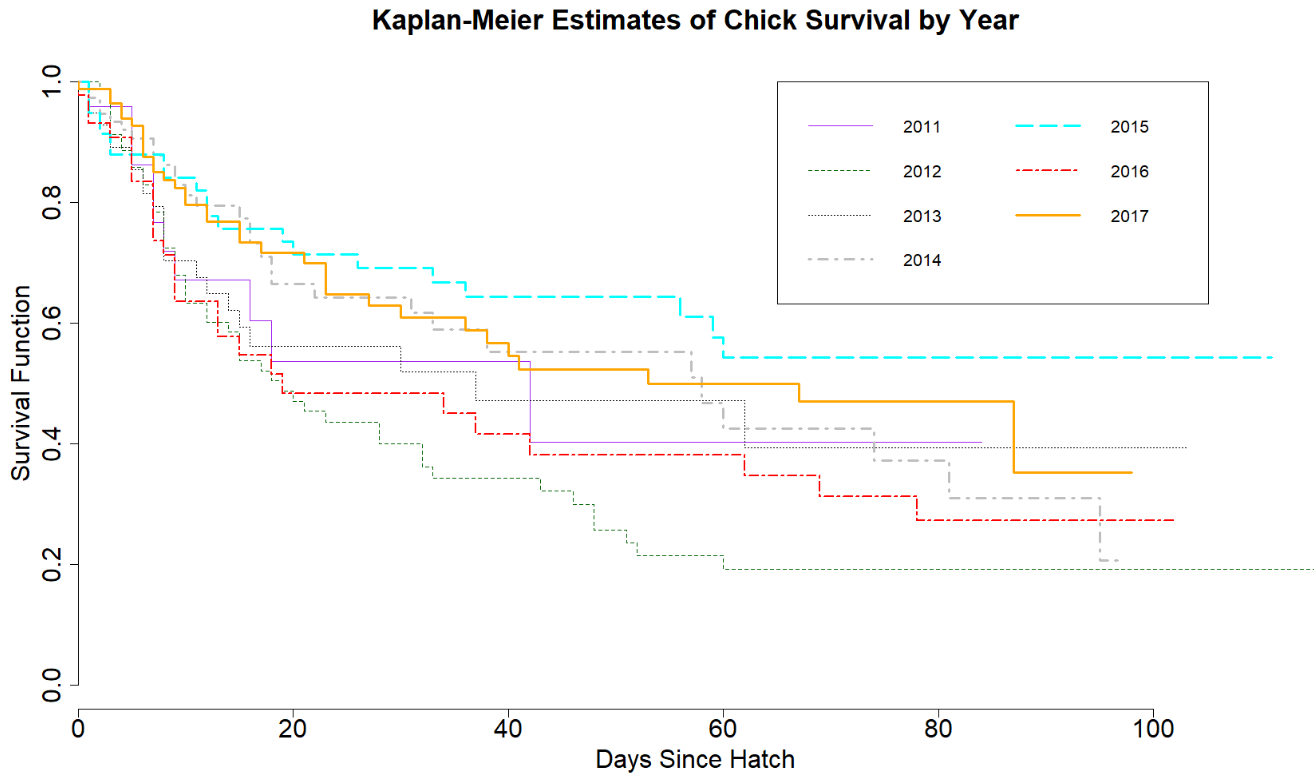

Figure 6. Kaplan-Meier survival curves by year for greater sage-grouse chicks marked with radio transmitters in Golden Valley and Musselshell Counties, Montana, USA during 2011 – 2017. Confidence intervals are not shown to make it easier to read the figure. Confidence intervals are reported in Table 10.

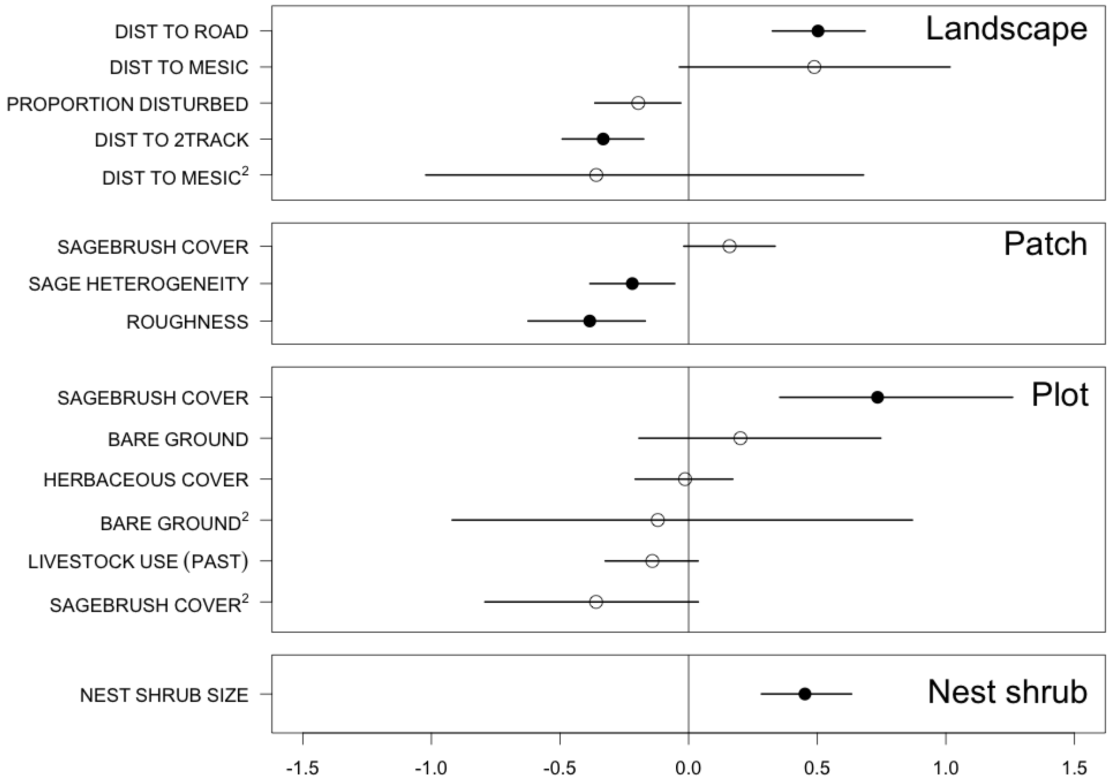

Figure 7. Coefficient estimates from a logistic regression model describing variables influencing the selection of nest sites (n = 322) by sage-grouse in Golden Valley and Musselshell Counties, Montana, USA from 2012 – 2015. Filled circles identify variables supported by Bayes factors and error bars represent 95% credible intervals. Selection of nest sites was driven not by herbaceous vegetation characteristics but by preference for greater shrub cover (SAGECOV) and size (N_SHRUBVOL), gentle topography (P_ROUGH), avoidance of county roads and highways (D_MROAD), and avoidance of non-cropland anthropogenic disturbance at the landscape scale (L_DISTURB). Figure from Smith (2016).

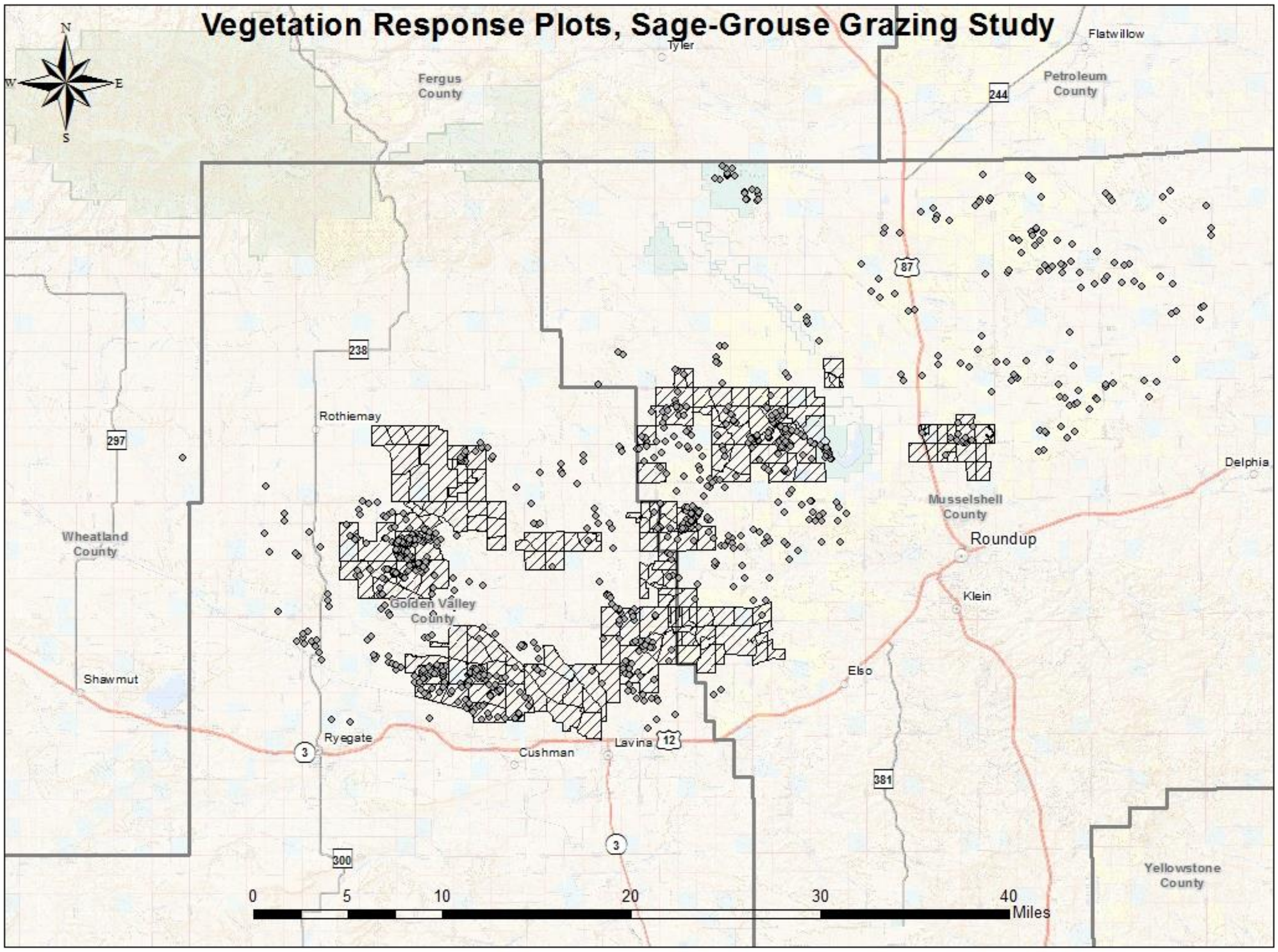

Figure 8. Locations of vegetation response plots measured during 2012 – 2015 to evaluate the effects of Sage Grouse Initiative (SGI) rotational grazing systems and grazing systems of non-enrolled ranches (Non-SGI) on greater sage-grouse habitat in Musselshell and Golden Valley Counties, Montana, USA. The Lake Mason units are satellite units of the Charles M Russell National Wildlife Refuge. The SGI-enrolled land shown in hatched polygons includes the original participating ranches in 2011 - 2013. Enrolled land is dynamic, with different contracts ending and starting each year.

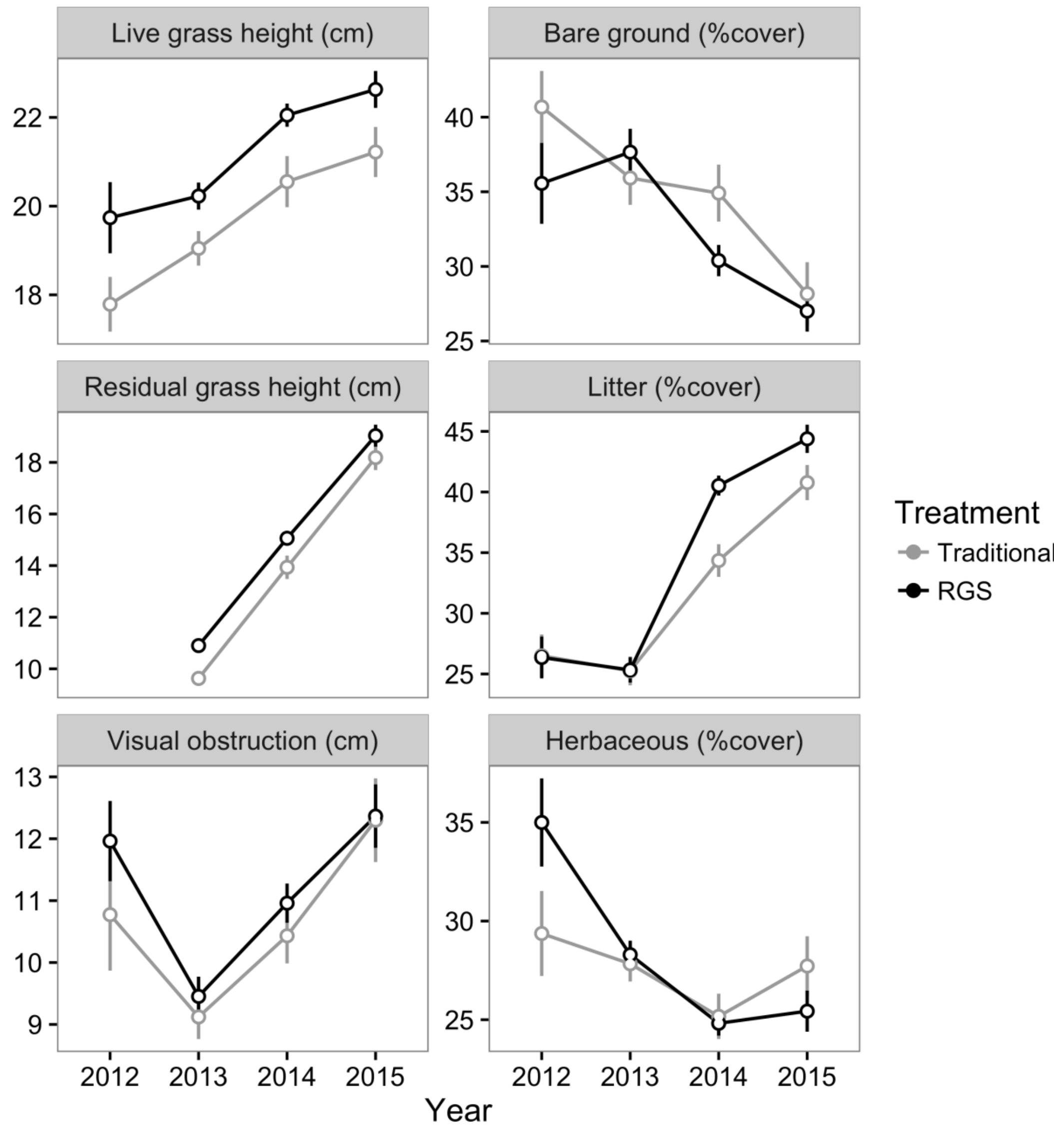

Figure 9. Means and standard errors of vegetation metrics measured at vegetation response plots on ranches enrolled in Sage Grouse Initiative (SGI) rotational grazing systems (labeled "RGS" in this figure) and on non-enrolled (Non-SGI) ranches (labeled "Traditional" in this figure) in Golden Valley and Musselshell Counties, Montana, USA during 2012 – 2015. Likelihood ratio tests revealed that live grass height, residual grass height, bare ground cover, and litter cover all differed significantly between SGI and Non-SGI ranches. Estimated effect sizes were small, however, relative to annual variation. From Smith (2016) and Smith et al. (2018).