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# Annual Report

# Sage-Grouse Grazing Project

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



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2018 Annual Progress Report

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

**2018 ANNUAL PROGRESS REPORT**

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

## EXECUTIVE SUMMARY

In September 2015, the U.S. 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) because of the collaborative conservation efforts among agencies and private landowners. The Sage-Grouse Initiative (SGI) implemented by the U.S. Department of Agriculture Natural Resources Conservation Service formed a large part of those conservation efforts that contributed to this decision.

The conservation efforts that resulted in a decision not to list sage-grouse for protection under the ESA must be maintained to minimize future declines in populations; the status of sage-grouse will be re-evaluated by USFWS in 2020. Information on the impacts of grazing to sage-grouse and their habitat is needed to provide support for conservation efforts. A goal of our study is to evaluate the effectiveness of the SGI in improving sage-grouse habitat and the impacts of SGI on sage-grouse vital rates and resource selection.

Since 2011, we have been collecting data to evaluate the impacts of grazing, in particular, the SGI's rest-rotation grazing system compared with the varied grazing strategies of other private landowners (hereafter Non-SGI) on sage-grouse in central Montana. This is a long-term study in its $8^{th}$ year, with 2.5 yrs of data collection left. Some deliverables and preliminary analyses are complete with long-term project deliverables in progress. Herein we present preliminary results from years 1 – 7 of the project (years 2011 – 2017) and an update of data collection during 2018.

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) sage-grouse resource selection; 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 for resource selection analyses. We measured several habitat variables to ascertain their relationship with vital rates and resource selection. 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 also measured landscape-scale habitat variables from remotely sensed data in geographical information system layers to assess the effects of habitat on nest site selection and nest success at a larger spatial scale.

Annual apparent survival estimates of sage-grouse hens from 2011 – 2017 range from 57 – 82%. The 2018 annual apparent survival estimate is at 81% as of Jul 31, 2018, 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 386 marked hens monitored from March 1, 2011 – August 14, 2017 is 1.79 yrs and the median is 1.44 yrs. Annual apparent nest success for 689 nests during 2011 – 2018 range from 30 – 64%; 2018 annual apparent nest success is 41%, but this is preliminary as we are still cleaning up data from this season.

The effects of covariates on nest success 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. 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 ($\chi^2 = 16.2$, $df = 6$, $p = 0.0128$).

Nest site selection by hens 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, analyses indicated that females selected for greater sagebrush cover. At the patch scale, analyses indicated that females selected gentler terrain and more even stands of sagebrush. 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. 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 grazing system and rest effects 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. Live and senesced grass heights were taller and litter cover was greater on SGI than Non-SGI ranches. Visual obstruction, herbaceous vegetation cover, and bare ground cover did not differ between grazing systems. 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 subject to change as data collection and analyses are works in progress. For additional information and 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 semi-arid sagebrush (*Artemisia* spp.) habitats in western North America (Schroeder et al. 1999). This species uses the sagebrush steppe year-round for most of its life history needs (Crawford et al. 2004): sagebrush is a food source available all year and is the only food source available to them during the winter, and sagebrush serves other needs such as hiding cover during nesting and brood-rearing. Sage-grouse are not the only species that rely on sagebrush. Sagebrush systems also provide important habitat for songbird species including Brewer's sparrow (*Spizella breweri*; Dreitz et al. 2015), elk (*Cervus elaphus*), mule deer (*Odocoileus hemionus*), and pronghorn (*Antilocapra americana*; Connelly et al. 2004). More than 600 species of conservation concern that depend upon sagebrush ecosystems have been identified (Rich et al. 2005). Thus, efforts to sustain sage-grouse populations are likely to benefit a variety of other wildlife species.

The loss and degradation of the sagebrush habitats upon which these several species depend has led to the extirpation of sage-grouse from over half of its original range (Schroeder et al. 2004). In September 2010, the U.S. Department of Interior Fish and Wildlife Service (USFWS) listed the sage-grouse on the candidate list for threatened and endangered species protection under the Endangered Species Act (ESA; USFWS 2010) due to several petitions for listing. In September 2015, the USFWS determined that sage-grouse did not need to be listed because current efforts by state and federal agencies as well as other partners were adequate for the conservation of this species and its habitat (USFWS 2015). However, conservation efforts must be maintained to prevent further declines in populations; USFWS will re-evaluate the status of sage-grouse in 2020. Information on the impacts of grazing to sage-grouse and their habitat will provide support for conservation efforts.

Declines in sagebrush-associated avian species are congruent with significant losses of sagebrush habitat (Braun et al. 1976, Knick 1999). Conversion of sagebrush to agriculture (Connelly et al. 2004, Smith et al. 2016); fragmentation resulting from energy (Naugle et al. 2011) or subdivision (Leu and Hanser 2011) development; conifer invasion (e.g., in Oregon and western Montana; Crawford et al. 2004, Beck et al. 2012); disease (i.e., West Nile virus; Walker and Naugle 2011); and modifications, such as prescribed fire, herbicides, and some grazing practices that lead to exotic, annual grass establishment are significant stressors on sagebrush systems (Rich et al. 2005, MTSWAP 2015). Big sagebrush steppe, the most widely distributed sagebrush system in Montana, is typically characterized by Wyoming big sage (*Artemisia tridentata* ssp. *wyomingensis*) with perennial grasses and forbs dominating at least 25% of cover (Montana Natural Heritage Program 2011).

A top priority of sage-grouse conservation is preventing further habitat loss and fragmentation (e.g., Smith et al. 2016, USFWS 2013). The USFWS, in partnership with several state agencies, has outlined range-wide conservation objectives for sage-grouse (USFWS 2013). USFWS (2013) has delineated management zones (Figure 1) with specific conservation needs for each zone. Our project falls within management zone 1, where agricultural conversion (USFWS 2013, p. 48) is identified as the biggest threat to sage-grouse habitat. USFWS (2013, p.48) has outlined four conservation actions for management zone 1 that are focused on incentivizing landowners to conserve sage-grouse 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, and the U.S. Department of Agriculture Natural Resources Conservation Service's (NRCS) Sage-Grouse Initiative (SGI) that the NRCS has implemented across the range of sage-grouse. These are intended to keep working ranches on the landscape and prevent further reduction of sage-grouse habitat due to development.

## *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. 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 (Montana Legislature 2015). Other states such as Idaho and Wyoming have taken similar actions.

The next step after preventing habitat reduction is to manage current habitat to sustain the various uses that it supports. Livestock grazing is the largest land management practice in the world (Krausman et al. 2009) and is the dominant land management practice in sagebrush habitat, impacting 70% of land in the western United States (Fleischner 1994). Thus, livestock grazing is an important consideration in managing the sagebrush habitat that is currently left. Livestock grazing impacts sagebrush habitat by altering its vegetation structure, composition, and productivity (Beck and Mitchell 2000, Hormay 1970, Krausman et al. 2009). This grazing can have negative impacts, but it also can be managed to achieve desired habitat conditions (Fuhlendorf and Engle 2001) by changing timing or intensity of grazing. Heavy livestock grazing can also decrease invertebrate biomass (Krausman et al. 2009), an important food source for sage-grouse and several other bird species. The third action outlined by USFWS (2013) in their conservation objectives report was to ("develop criteria for set-aside programs which stop negative habitat impacts and promote the quality and quantity of sage-grouse habitat" (Table 1). Our study makes progress towards this action by evaluating the effectiveness of SGI grazing systems intended to improve sage-grouse habitat in central Montana, and is designed to inform other grazing systems as well.

### *The Sage-Grouse Initiative (SGI) Program:*

This initiative was implemented on areas with relatively high sage-grouse densities, or "core" areas. The core areas were designated by FWP and are locations of highest conservation value for sage-grouse based on habitat and number of breeding males (Figure 2). FWP estimates the core areas include ~76% of the displaying males in Montana as of 2013. Male counts at lek sites are assumed to represent the overall sage-grouse population.

SGI grazing systems focus on improving livestock production and rangeland health while simultaneously alleviating threats to and improving habitat for sage-grouse (NRCS pers. comm., Boyd et al. 2011) and are based on rest-rotation systems, using rest or deferment from grazing to meet their objectives. These systems are implemented on ranches that contain potential sage-grouse habitat. The program is voluntary with grazing implemented for 3 years. Landowners enrolling in SGI agree to implement a grazing system in collaboration with an NRCS range conservationist who may suggest rest or deferment, installment of water sources or fences to change the distribution of livestock or the size of pastures, respectively, or to change the number of animal units in the grazing system in pastures within potential sage-grouse habitat. NRCS defines potential sage-grouse habitat based on topography and sagebrush canopy cover ≥5% (NRCS pers. comm.) with a focus on sage-grouse core areas (Figure 2). SGI grazing systems are tailored to each ranch, and may vary with the needs of the landowner or the condition of the rangelands. However, all enrolled ranches "adhere to NRCS Montana Prescribed Grazing conservation practices standards (NRCS 2012) and a set of minimum criteria: (1) utilization rates of 50% or less of current year's growth of key forage species, (2) duration of grazing ≤ 45 d, (3) timing of grazing changed by ≥ 20 days each year, and (4) a contingency plan for exceptional circumstances such as drought or fire" (Smith et al. 2017). Optionally, landowners could receive extra compensation if they agreed to rest 20% of enrolled pastures each year that are identified as sage-grouse nesting habitat (defined by NRCS as ≥ 5% sagebrush cover; Smith et al. 2017). Pastures that are "rested" are often not used for ≥15 months, providing two full nesting seasons without livestock use (Smith et al. 2017), but for our results we define rest as pastures left ungrazed for at least 12 months. Rest and deferment from grazing benefit rangeland by leaving residual grass to capture moisture, reducing temperature and evaporation from the soil through shading, providing organic matter to the soil, and improving plant productivity by allowing plants to replenish their energy reserves (Hormay 1970, Smith et al. 2017, NRCS pers. comm.). Thus, rest and deferment benefit livestock with increased forage, and benefit wildlife with increased forage and protective cover (Krausman et al. 2009). Rest-rotation grazing is currently the most common grazing strategy used to improve habitat for wildlife in sagebrush systems (Krausman et al. 2009).

## *Grazing Study:*

The goal of this study is to evaluate the effects of NRCS's SGI grazing strategies on the demography and habitat of a sage-grouse population in central Montana. Taylor et al. (2012) and Dahlgren et al. (2016) showed that adult female (hen) survival, nest success, and chick survival are the three most important drivers of population growth in sage-grouse. Therefore, the goal of our project is to investigate the impacts of grazing on these vital rates. We are also monitoring the resource selection of hens and chicks and investigating how resource selection links with vital rates: e.g., within areas used by hens, is nest success higher in some locations than others? Lastly, we are evaluating the vegetation's response to grazing in the sagebrush steppe on our study area. We are comparing vegetation variables between SGI-enrolled and non-participating ranches (Non-SGI). Non-SGI pastures were grazed using a variety management strategies, but most Non-SGI grazing in our area is characterized by grazing in pastures at the same time each year, often for longer periods than SGI pastures, and no rest. To date >400,000 acres have been enrolled in SGI across Montana, but the amount actively enrolled has changed throughout the study as some 3-year contracts began earlier and have since ended. The total effort has provided the infrastructural capacity to investigate the benefits of SGI grazing on sage-grouse populations.

This study is designed as a 10-year study because both habitat and sage-grouse may exhibit a "lag" response to management in general, and grazing in our case. Some impacts of grazing management may be observable or fully realized only after several years. In addition, the effects of grazing may be confounded with impacts from weather and other variables. Multiple years of data are needed to obtain enough sampling replicates of pastures within grazing treatments and among years to help distinguish the effects of weather or other influences from the impacts of grazing. Increased sampling also improves estimates of population vital rates and habitat measures.

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 resource selection;
3. 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 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 on sage-grouse began in 2011, we have successfully completed 8.5 yrs of data collection towards these objectives. We are halfway through our 8th (2018) season of data collection; and herein present preliminary results to date. Data from the 2018 season is still being collected and entered.

## METHODS & RESULTS

Our study is conducted in Golden Valley and Musselshell counties, Montana (Figure 2). To address our sage-grouse objectives we used radio telemetry to monitor birds in each grazing type. We also sample vegetation metrics 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 for each objective below.

## *Sage-Grouse Vital Rates*

### ACCOMPLISHMENTS:

During the reporting period of Jul 1, 2017 – Jun 30, 2018, we captured 39 individuals: 7 marked chicks from 2017 that we re-marked with adult radio transmitters during fall 2017, and 32 after hatch-year hens marked during spring 2018. During 2011 – 2017, we maintained ~100 greater sage-grouse hens marked with radio transmitters in our study population each year. In 2018, we reduced this number due to reduced funding and began the 2018 field season with 73 marked hens. Data collection and analyses to assess the effects of grazing and other variables on vital rates are ongoing. Our efforts during the fall/winter 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 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 March – April to replace hens that died since the previous spring. Hens were captured on or near leks using night-time spotlighting (Giesen et al. 1982, Wakkinen et al. 1992). Hens were fitted with 25-g necklace style very high frequency (VHF) radio transmitters (Model A4060, Advanced Telemetry Systems, Isanti, MN), morphometrics such as weight were recorded, and the hens were released. The transmitters had a mortality switch that was activated when the transmitter was 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 within the study area. We monitored marked hens from March – August from the ground with the help of seasonal field technicians each year who obtained ≥2 locations per hen each week. During September – March we monitored the hens via aerial telemetry once per month.

Nests were found by monitoring hens via radio telemetry. We monitored pre-nesting females until they begin 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 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 keep them 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. Once we approached, hens 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 keeps them warm while we are working. We affixed a 1.3 g backpack VHF radio transmitter (Model A1065, Advanced Telemetry Systems, Isanti, MN) to two 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 the suture technique described in Dreitz et al. [2011]). This method 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, 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

Our annual survival estimates of hens were measured from Apr 1st at the start of nesting season through March 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 – 2017 ranged from 42 – 65% (Table 2); the annual apparent survival during 2017 was the lowest observed during the study at 42%. The 2018 annual apparent survival estimate was at 81% as of Jul 31, 2018, 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 depend on the condition of the carcasses tested. Ours were typically in poor – fair, rather than great, condition for West Nile Virus tests because these tests require tissues to be intact and not decomposed. We usually cannot detect and collect mortalities before decomposition has begun.

For seasonal survival and resource selection, 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: spring (Apr-May) = 85 – 91%, summer (Jun-Jul) = 86 – 100%, fall (Aug-Oct) = 70 – 92%, winter (Nov-Mar) = 76 – 93%. There are few published seasonal survival estimates available for sage-grouse hens. We have slightly different definitions for seasons than Sika (2006), but our apparent hen survival estimates are comparable to what Sika (2006) observed during similar time periods. Sika (2006) measured seasonal hen survival on our study area during 2004-2005. Sika (2006) reported monthly survival from Apr – Jun was 94%. Survival during Jul 2004 and 2005 was 99% to nearly 100% each year, and Aug 2004 and 2005 survival was 94% and 84%, respectively. Our apparent seasonal survival rates were lower relative to seasonal survival estimates measured by Blomberg et al. (2013) in a Nevada population of greater sage-grouse. We caution that our annual rates were estimated using a different technique than Blomberg et al. (2013). They monitored hen survival for 328 hens from 2003-2011. Their seasonal survival estimates, represented here as mean survival ± standard error (SE) were: 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) found very little annual variation in hen survival, allowing them to pool seasonal estimates among years (above). Our seasonal rates were more variable among years.

We used package "survival" (Therneau 2016) in program R to run Kaplan-Meier survival functions that estimated the overall survival of hens during Mar 2011 – August 2017. The Kaplan-Meier estimator measured 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 2013), which was the duration that the radio transmitter was functional or the duration before the hen died or her signal was lost. The Kaplan-Meier mean survival time estimate for 386 marked hens monitored from Mar 1, 2011 – Aug 14, 2017 was 655 days (1.79 yrs; standard error [SE] = 33.6 days; 95% confidence interval [CI] = 489 – 575 days or 1.34 – 1.58 yrs) and the median was 525 days (1.44 yrs; Figure 3); we have not yet incorporated 2018 data. We used a staggered-entry design to account for marking individuals at different times throughout the study 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.

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 the reporting period (the 2018 season) was 41%. Annual apparent nest success during 2011 – 2018 ranged from 30 – 64% (Table 4). The number of marked hens that attempted at least one nest each year ranged from 64 – 85% (Table 5). Nest success has varied from 14 – 86% across the entire range of sage-grouse (including studies from Oregon, Colorado, and Idaho; Connelly et al. 2004); 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. (2017). The collection of covariates used in these models have been described below (Impacts of Grazing on Sage-Grouse Resource Selection, 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 be 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.

### CHICK SURVIVAL

We marked 52 sage-grouse chicks with radio transmitters during 2018 and seven are known to have survived until their transmitters expired (13% apparent survival). We are still organizing and analyzing the data, thus these are preliminary results that may be adjusted. These apparent survival estimates are conservative because only chicks whose fates were known were considered to survive until the end of the monitoring period; chicks whose status was 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.

We used package "survival" 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 ($\chi^2 = 16.2$, $df = 6$, $p = 0.0128$; 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 thermoregulate during their first week post-hatch and rely on the hen to keep them warm. Many chicks get chilled and die in heavy rain events during the early post-hatch period (Horak and Applegate 1998). We have not yet formally analyzed the effects of weather and other habitat variables on chick survival. Dahlgren et al. (2010), Guttery et al. (2013), and Smith et al. (2018; nest success) have found that climatic variables including precipitation (amount and timing), temperature, and drought are the primary drivers of sage-grouse reproductive success.

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); Kaplan-Meier estimates of chick survival in our study during 2011 – 2017 ranged from 19 – 54% (Table 6). 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 we can 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. 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 resource selection and survival analyses to determine how habitat variables impact survival and resource selection to help guide management for this life phase. We are also evaluating hen survival, nest success, chick survival, and the habitat needs for these life phases together to identify priority areas for conservation efforts.

## *Impacts of Grazing on Sage-Grouse Resource Selection*

### ACCOMPLISHMENTS:

Data collection and analyses to assess the effects of vegetation metrics on hen nest site selection and the seasonal resource selection 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 2,005 hen locations and 740 chick locations. We collected vegetation data at 132 nests and random points within nesting habitat to investigate the impacts of vegetation metrics on vital rates and resource selection. 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, as other studies have shown that the large majority of nests are placed within this distance (Holloran and Anderson 2005, Coates et al. 2013). 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). At points meeting these criteria, we selected the nearest sagebrush shrub ≥30 cm in height to designate the nest shrub (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 (the shrub nearest to a random point and ≥30 cm in height; Connelly et al. 2000) and extended 15 m 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. We estimated understory cover and height at this scale because previous research found relationships between herbaceous vegetation structure and nest site selection and success were strongest at a similar scale (7.5 m; Aldridge 2005). 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 (Bailey and Welling 1999, 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 yr 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 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 adult sage-grouse hens and sage-grouse chicks marked with radio transmitters to assess (1) seasonal resource selection by adult hens, (2) nest site selection by adult hens, and (3) resource selection by hens with broods or marked chicks. We are currently working on data analyses for resource selection 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 7) 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.

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 this reporting period focused on measuring vegetation metrics in the field for the 2018 season, and entering and proofreading these data. During the reporting period, we sampled 125 vegetation response plots: 43 Non-SGI, and 82 SGI (plots on current or previously enrolled since 2011). For the entire study (including data from 2012 – 2018) we have sampled 1,558 vegetation response plots: 671 plots SGI ranches, and 887 plots on Non-SGI ranches. We provide a brief summary below of how these plots were selected and measured, and results from preliminary analyses of 2012 – 2015 data (appearing in previous reports).

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. We used ArcGIS and program R to generate stratified random points using the criteria in Table 8. These criteria were used to minimize variation in the data due to spatial heterogeneity in covariates known to affect vegetation structure and composition (e.g., distance to water). We identified pastures rested each season and sampled an appropriate number of field plots in SGI and Non-SGI pastures to test for differences in vegetation structure between these treatments (based on a power analysis of 2011 data, reported in Smith 2016). Rangelands were highly dynamic and spatially heterogeneous, and assessing their condition over large areas has always been a logistical challenge (West 2003). The metrics for these vegetation plots were identical to the nest vegetation plots in "Impacts of Grazing on Sage-Grouse Resource Selection, Accomplishments, Local-Scale Vegetation Measures", except that we did not measure metrics specific to the random shrub in the center of the plot (hereafter "vegetation response plots").

### 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 were assessed with likelihood ratio tests, by comparing models with and without a fixed effect for grazing system.

We sampled 353 and 510 vegetation response plots on Non-SGI and SGI ranches, respectively, 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 grass height was 1.50 cm (SE 0.467 cm) greater on SGI ranches, residual grass height was 1.04 cm (SE 0.432 cm) greater on SGI ranches, 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 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 for the next two and half years, Sep 2018 – Aug 2020, with final products completed in 2022. Analyses from the first five years of data suggest that sage-grouse nest survival does not seem to be impacted by SGI's rest-rotation grazing system (Smith 2016, Smith et al. 2018). We will continue to collect information on all vital rates and re-evaluate this relationship at the end of the study. 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 and the health of the sagebrush steppe.

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# TABLES

***Table 1.*** Conservation options for greater sage-grouse habitat in management zone 1 from the U.S. Fish and Wildlife Service report: U.S. Fish and Wildlife Service. 2013. Greater sage-grouse (Centrocercus urophasianus) Conservation Objectives: Final Report. U.S. Fish and Wildlife Service Denver, CO. February 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 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 – 2018 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** | 93% | | | | |

*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 – 2018 (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** | 41% | 71 | 63 / 41% | 8 / 38% | – |

*TABLE 5.* Proportion of our marked population of greater sage-grouse hens that attempted at least one nest in Golden Valley and Mussellshell Counties, Montana, USA, during 2011 – 2018.

| | **Total number of marked hens, start of nesting season** | **Hens attempting to nest / all marked hens** |
|---|---|---|
| **2011** | 101 | 78% |
| **2012** | 112 | 73% |
| **2013** | 93 | 76% |
| **2014** | 106 | 64% |
| **2015** | 100 | 66% |
| **2016** | 101 | 74% |
| **2017** | 106 | 84% |
| **2018** | 73 | 85% |

*TABLE 6.* Kaplan-Meier survival estimates of greater sage-grouse chicks in Golden Valley and Musselshell Counties, Montana, USA, during 2011 – 2018. These estimates represent the probability that a chick survives until the end of its monitoring period, which ranges from 60 – 100 days, depending on how long the transmitter remains active.

| | Total Number of Marked Chicks | Kaplan-Meier Survival Estimate | Standard Error | 95% Confidence Interval |
|---|---|---|---|---|
| **2011** | 23 | 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** | 75 | 0.21 | 0.11 | 0.08 – 0.56 |
| **2015** | 58 | 0.54 | 0.08 | 0.41 – 0.72 |
| **2016** | 45 | 0.27 | 0.08 | 0.15 – 0.49 |
| **2017** | 84 | 0.35 | 0.11 | 0.19 – 0.67 |
| **2018** | 58 | Not complete yet | | |

*TABLE 7.* 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 | | |

| Variable | Abbreviated Variable Name | Transformation |
|---|---|---|
| **Nest Shrub Covariates** | | |
| 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 8.* 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

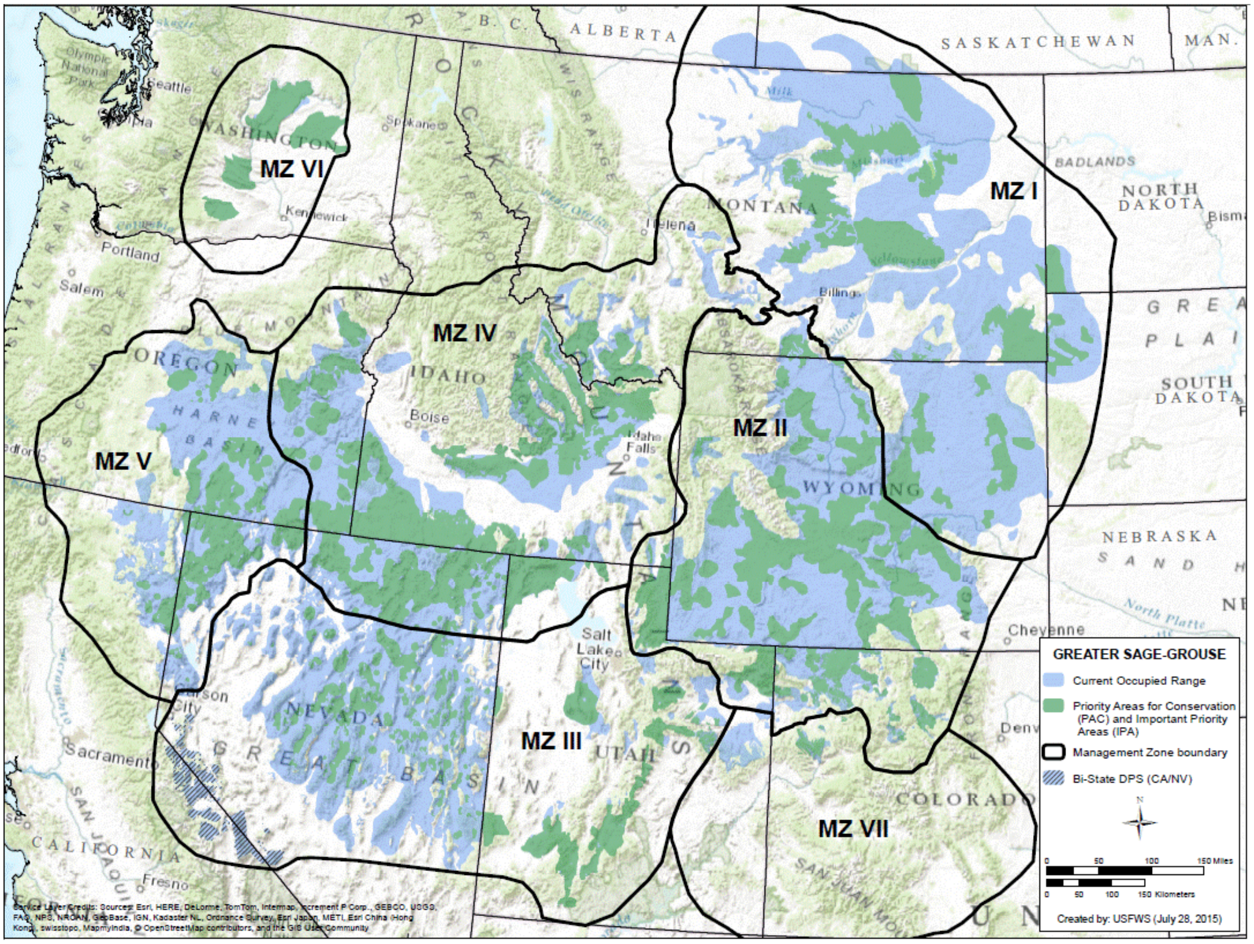


*Figure 1.* The location of Management Zones (MZ) and Priority Areas for Conservation (PAC) across the current range of the greater sage-grouse in North America. Figure taken from the U.S. Fish and Wildlife Service Website: <https://www.fws.gov/greatersagegrouse/maps.php>. Last accessed Aug 9, 2018.

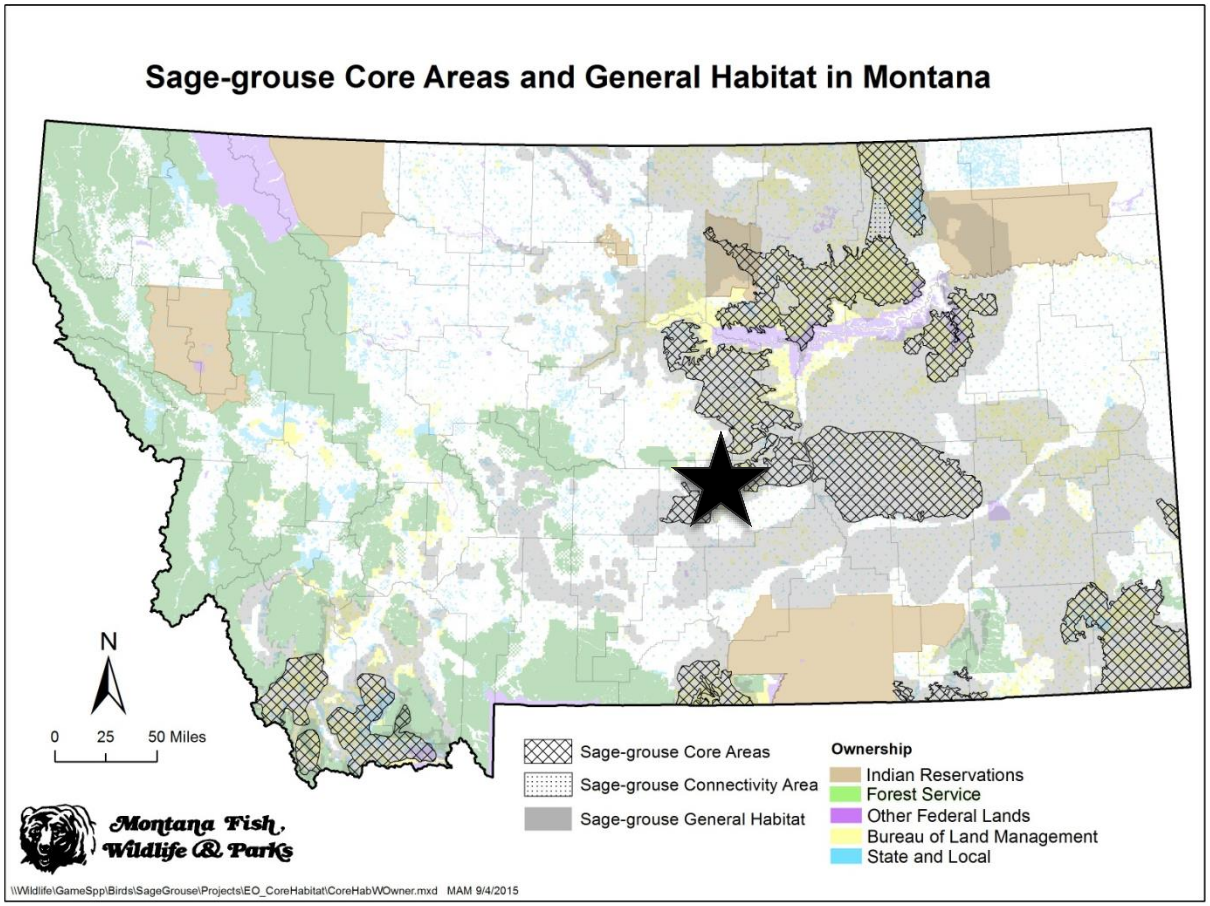


*FIGURE 2.* Greater sage-grouse core areas as defined by Montana Fish, Wildlife, and Parks. The black star represents the location of the study area for this project in Golden Valley and Musselshell Counties, Montana, USA.

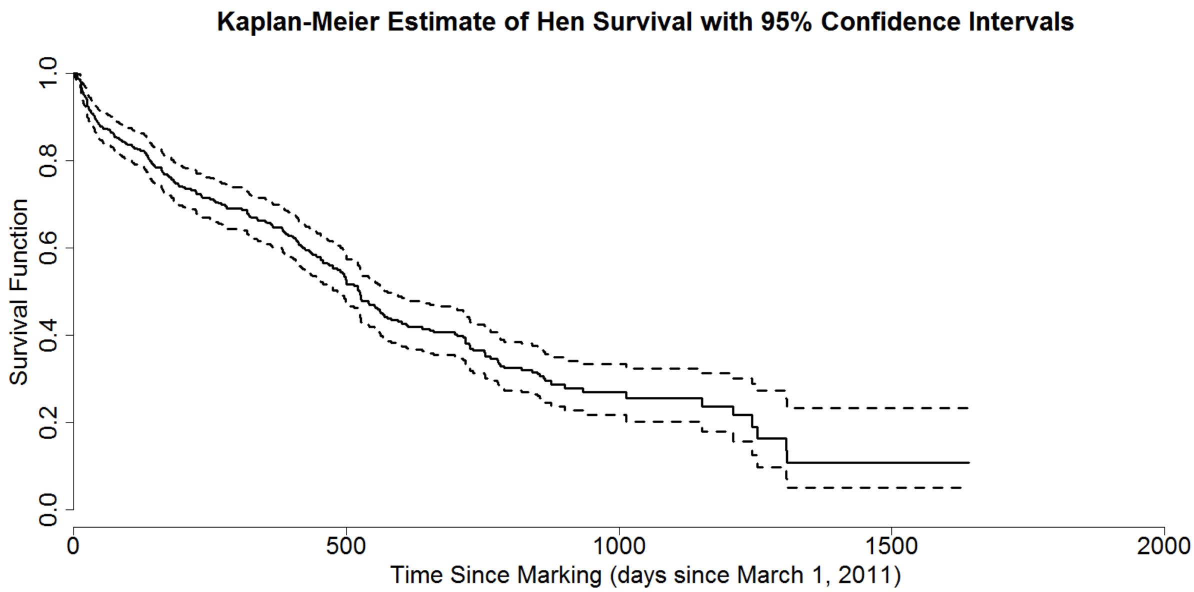


*FIGURE 3.* The Kaplan-Meier survival curve (solid line) and 95% confidence intervals (dashed lines) for greater sage-grouse hens monitored from March 1, 2011 – August 14, 2017 in Golden Valley and Musselshell Counties, Montana, USA. We used right censoring for individuals with unknown fates, dropped transmitters, and for individuals that survived until their transmitters expired. The data were pooled across years. The Kaplan-Meier mean survival time estimate was 655 days (1.79 yrs; standard error [SE] = 33.6 days; 95% confidence interval = 489 – 575 days or 1.34 – 1.58 yrs) and the median was 525 days (1.44 yrs).

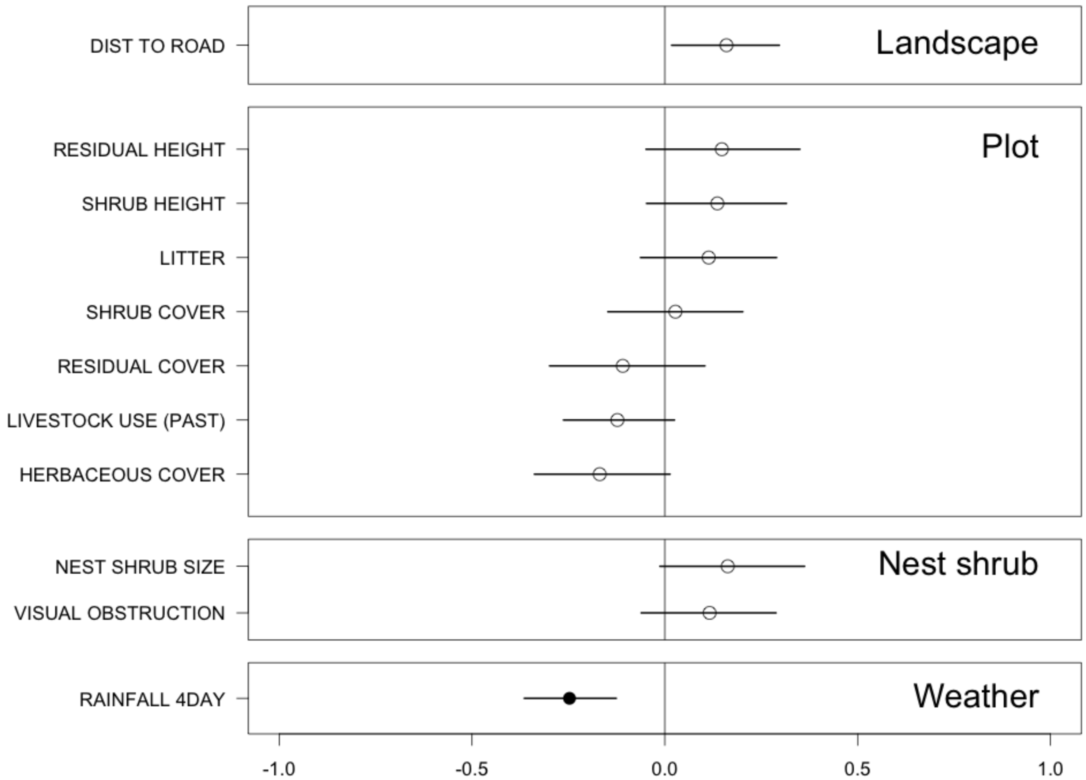


*FIGURE 4.* Coefficient estimates from logistic regression model describing variables influencing daily nest survival of sage-grouse nests (*n*=412) in Golden Valley and Musselshell Counties, Montana, USA from 2011 to 2015. Filled circles identify important variables supported by Bayes factors and error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

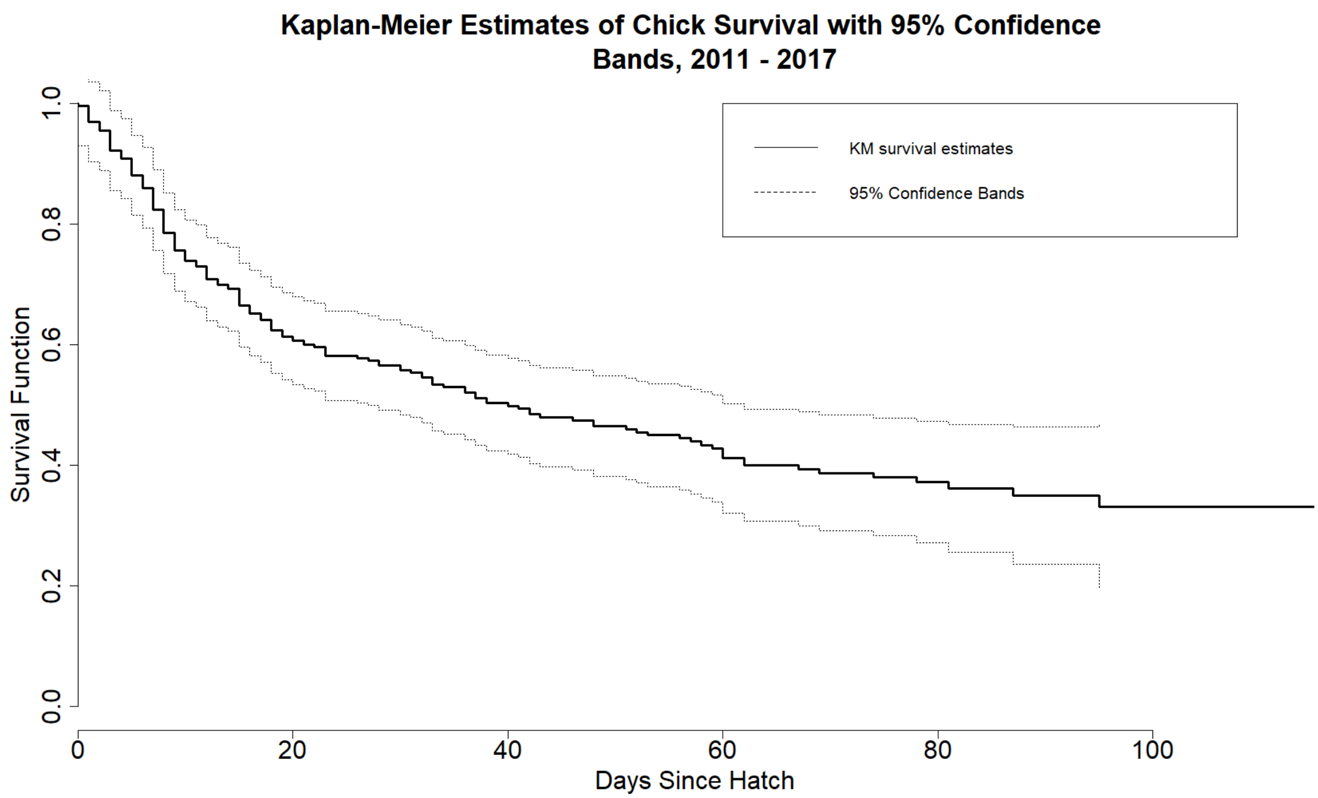


*FIGURE 5.* Kaplan-Meier survival curve and 95% confidence intervals for greater sage-grouse chicks marked with radio transmitters in Golden Valley and Musselshell Counties, Montana, USA during 2011 – 2017. Mean survival time for marked chicks was 56.45 d (SE = 2.84), and the median survival time was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

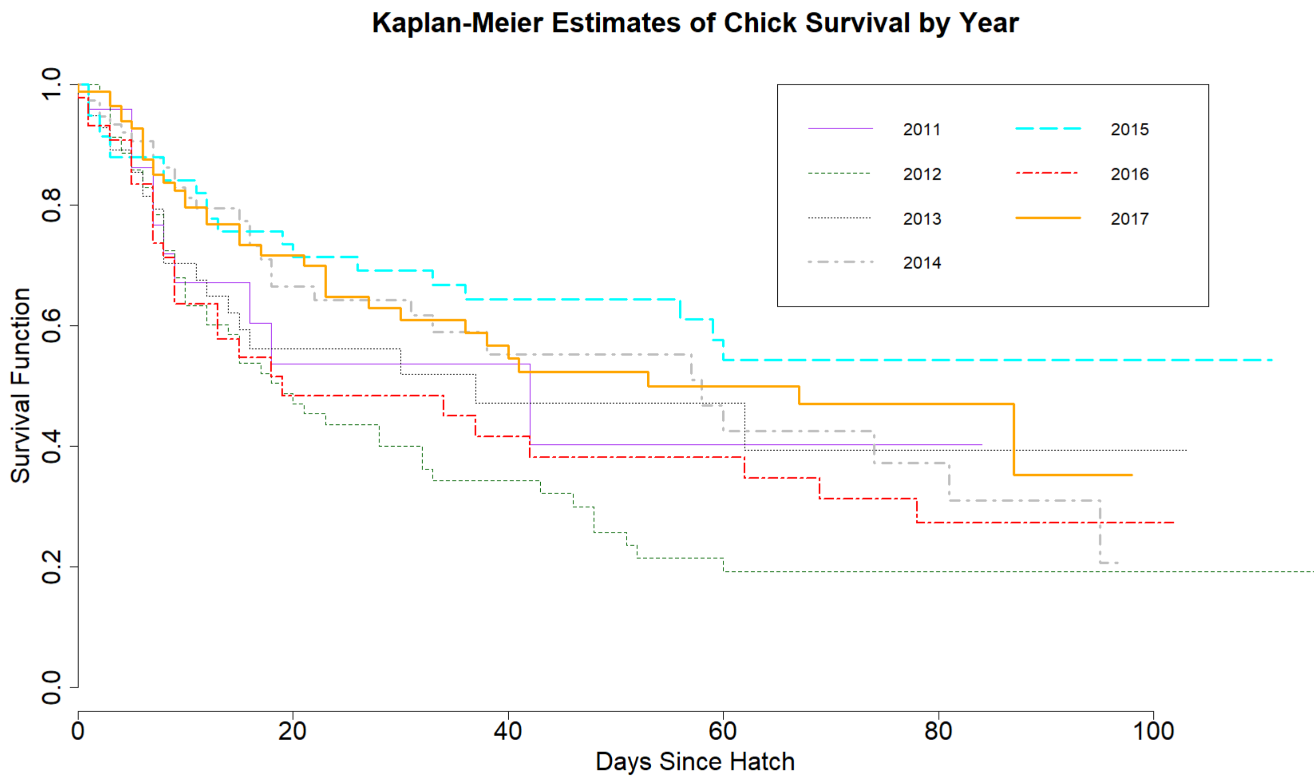


*FIGURE 6.* Kaplan-Meier survival curves by year for greater sage-grouse chicks marked with radio transmitters in Golden Valley and Musselshell Counties, Montana, USA during 2011 – 2017. Confidence intervals are not shown to make it easier to read the figure. Confidence intervals are reported in Table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

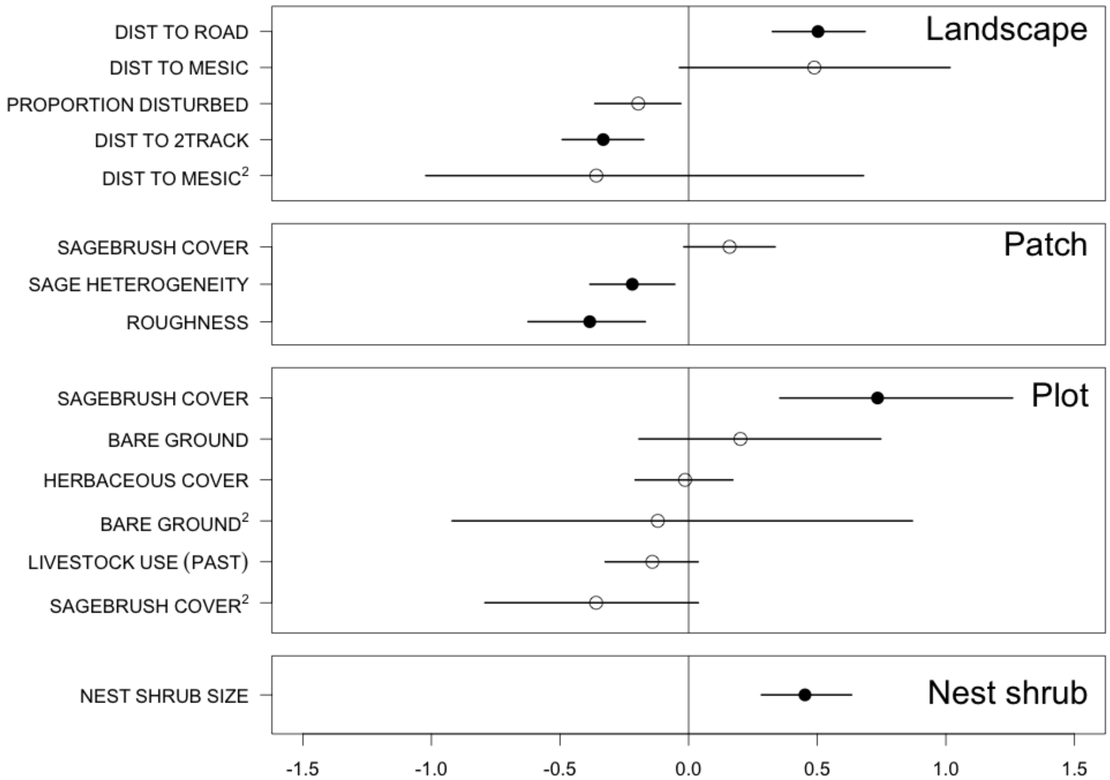


*FIGURE 7.* Coefficient estimates from a logistic regression model describing variables influencing the selection of nest sites (n = 322) by sage-grouse in Golden Valley and Musselshell Counties, Montana, USA from 2012 – 2015. Filled circles identify variables supported by Bayes factors and error bars 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).

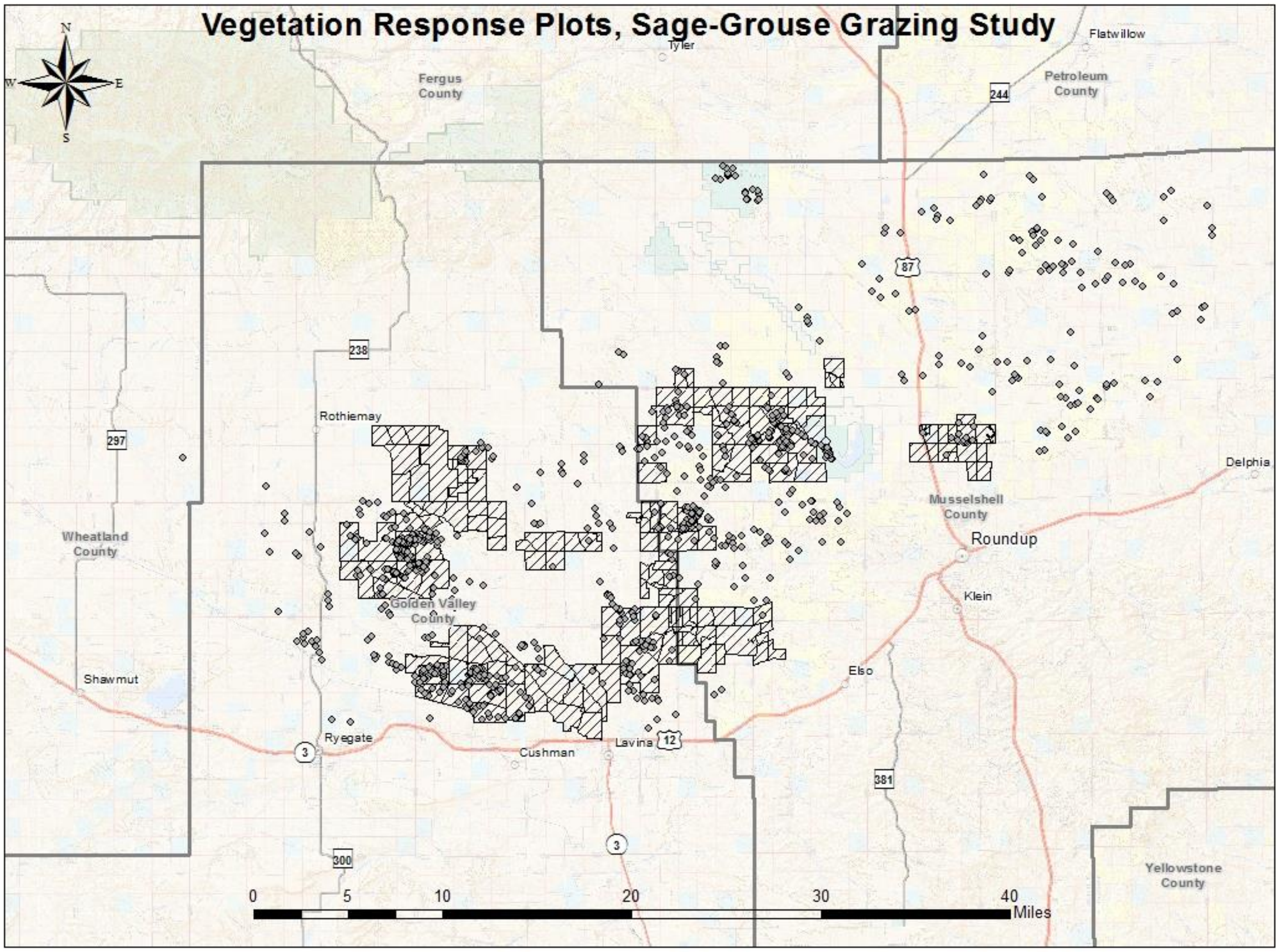


*FIGURE 8.* Locations of vegetation response plots measured during 2012 – 2015 to evaluate the effects of Sage Grouse Initiative (SGI) rotational grazing systems and grazing systems of non-enrolled ranches (Non-SGI) on greater sage-grouse habitat in Musselshell and Golden Valley Counties, Montana, USA. 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.

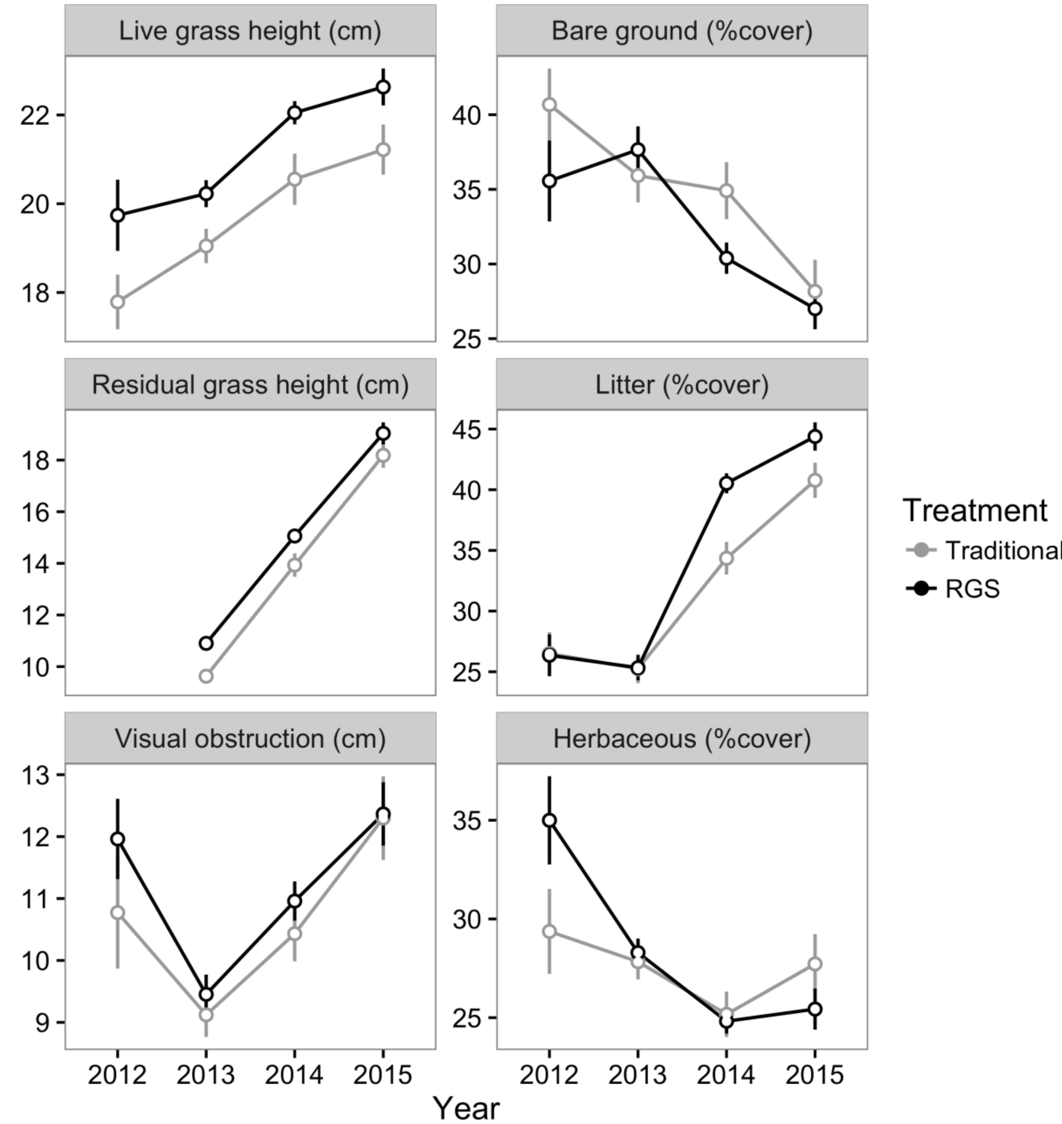


*FIGURE 9.* Means and standard errors of vegetation metrics measured at vegetation response plots on ranches enrolled in Sage Grouse Initiative (SGI) rotational grazing systems (labeled “RGS” in this figure) and on non-enrolled (Non-SGI) ranches (labeled “Traditional” in this figure) in Golden Valley 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).