Targeted Grazing Applied to Reduce Fire Behavior Metrics and Wildfire Spread

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Authorization to Submit Thesis

This thesis of Christopher Lee Schachtschneider, submitted for the degree of Master of Science with a major in Natural Resources and titled “Targeted Grazing Applied to Reduce Fire Behavior Metrics and Wildfire Spread,” has been reviewed in final form. Permission, as indicated by the signatures and dates given below, is now granted to submit final +copies to the College of Graduate Studies for approval.

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Abstract

Increasing wildfire occurrence is a growing concern in many regions throughout the world, with wildfires increasing in size and suppression cost. Targeted grazing has been suggested as a tool to create and maintain strategic fire breaks by reducing the fine herbaceous fuel load and subsequently fire behavior metrics. We evaluated the effect of domestic cattle grazing at two seasons (summer and fall) and two utilization levels (low and moderate) on fire behavior metrics, flame height and rate of spread, in big sagebrush (*Artimesia tridentata* L.) communities. Cattle grazed six blocks with 30x30 m treatment plots within each block grazed at their respective season and targeted utilization. Shrub cover and herbaceous biomass before and after grazing were estimated in 2014 and 2015. Shrub canopy cover ranged from 0% to 78% within plots and dry matter herbaceous biomass ranged from 74 to 1,190 kg/ha. Prescribed burns were applied in September of 2015 where fire behavior metrics were recorded by observers and video cameras. Statistical analysis of variance revealed that grazing was an effective tool at reducing flame height and rate of spread when shrub cover was low. However, at higher shrub canopy cover, cattle grazing for fine fuel reduction may be limited due to the wildfire's potential to carrying thought the shrub canopy.

In the second chapter, I developed a guide for managers titled 'Guide for Quantifying Shrub Cover and Herbaceous Fuel Load in the Sagebrush Steppe'. Photos were selected for shrub cover at eight levels, 5, 10, 15, 20, 25, 30, 35, and 40% and six levels of herbaceous biomass 100, 200, 300, 400, 600, and 1000 lb/ac on a dry matter basis. Measured shrub cover, total herbaceous biomass, perennial and annual grass and forb biomass were displayed with each photo. Site descriptions are listed to increase the ability to compare amongst other ecological sites. Using this guide, fuels managers and producers will be able to quickly and economically asses the effectiveness of livestock grazing for fire fuel reduction on a site.

Acknowledgements

Special acknowledgement and thanks is due to the many people who have helped me with this project. Special thanks is due for Dr. Karen Launchbaugh who saw potential in me, brought me on as an unfunded graduate student, and found a way to make it work. To Dr. Eva Strand who took over the role of my major professor as the project evolved. To Scott Jensen who bridged the gap between an idea here in Moscow to a project with his contacts and assistance in southern Idaho. The ranching community in Reynolds Creek, ID who supported us with research sites and livestock, as well as great company and assistance when needed, specifically Brad and Mary Huff, Jerry Hoagland, and Theron Hook and family. Thank you for allowing me to be a part of the community for a couple seasons. To the David Little Endowment and NRCS-CIG grant for funding the majority of this project. Zane Cam and Barry Caldwell with USDA-ARS for their support in housing, vehicles and mechanical expertise when things broke on us. To the BLM fire professionals, especially Lance Okeson, for their help in planning and implementing the prescribed burns. To Justin Trujillo and others for all the field help and lastly, to my fellow graduate students, Molly Kaweck, Janessa Joulson, and Darcy Hammond, for the endless hours of help in all aspects of this project.

Dedication

This thesis is dedicated to my loving wife, Amanda and our daughter, Cassidy for always believing in me and supporting this journey of our life. Thank you also to my father and family for the encouragement along the way.

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Abstract

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Introduction

Changing climates and management practices have created a situation where large, destructive wildland fires are of global concern (Krawchuk *et al.* 2009; Adams 2013). In the United States, the area burned has continued to grow in recent years, with wildfires consuming over 2.5 million hectares a year on average for the last decade and over 4 million hectares in 2015 (National Interagency Fire Center (NIFC) 2016). This increase in large-scale fires has, in turn, raised the cost of suppression to over US$1 billion for 12 of the last 16 years, exceeding US$2 billion in 2015 (NIFC 2016). To further exacerbate this problem, recent climate modeling suggests a lengthening in extreme fire seasons and associated incidents of large wildland fires in the future (Fule 2008). "Extreme" fire conditions occur where fuel moisture and relative humidity are low, increasing the chance of ignition and fire propagation. Current climate change predictions indicate that the area burned could double by mid-century (2046-65) (Chambers and Pellant 2008; Yue *et al.* 2013).

One landscape with a documented increase in fire activity is the sagebrush ecosystem of the Great Basin (Balch *et al.* 2013). Historically, big sagebrush steppe ecosystems (*Artemisia tridentata* Nutt.) had a fire return interval of 15 to >100 years (Miller *et al.* 2005; Mensing *et al.* 2006; Miller and Heyerdahl 2008), varying with precipitation and temperature regimes. However in the past decades, this return interval has been shortened to below the historical range in lower elevation sagebrush communities, the sagebrush communities that historically had the longest fire return intervals (Mensing *et al.* 2006). The altered fire return interval has been partially attributed to the 18th century introduction of invasive annual grasses such as cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* [L.] Nevski.) which establish within the interim space between native bunchgrasses and shrubs (DiTomaso *et al*. 2008; Strand *et al*. 2014). Plant communities with a high presence of these annual grasses are found to have a shorter fire return interval than pristine native plant communities (Knick *et al.* 2003; Brooks *et al.* 2004; Balch *et al.* 2013). Changes in climate have increased the frequency and severity of fires in sagebrush steppe ecosystems which in turn has opened up the plant communities for invasion by exotic annual plants leading to altered biodiversity, shifting water regimes, and longer fire seasons (Chambers and Pellant 2008). Today, fire is of great concern in sagebrush steppe ecosystems, with shorter fire return intervals playing a major role in the decline in shrub cover and sagebrush dependent wildlife species (Chambers and Pellant 2008; Davies *et al.* 2009).

Many factors influence fire behavior and effects, including weather, terrain features, and vegetation composition and structure. Biomass within the landscape that is available to burn contributes to fuel loads that may be consumed in wildfires or prescribed burns. Total fuel load, fuel composition (mainly driven by particle size and fuel moisture), and continuity of fuels impact fire rate of spread and flame height and must be maintained for fire to spread through the landscape (Rothermel 1972; Kerby *et al.* 2006; Nader *et al.* 2007). Fuel components in sagebrush steppe can be divided into the small diameter fuels, such as dry live or dead herbaceous matter and small twigs, and larger diameter fuels such as woody branches (Nader *et al.* 2007; Strand *et al.* 2014). Reduction and compaction of the fine fuels, which aid in ignition and propagation of wildfire, is a key factor in reducing the spread of wildfire within these ecosystems (Nader *et al.* 2007; Strand *et al.* 2014), while alterations in heavier fuels generally reduce the intensity and severity of a fire (Hulet *et al.* 2015). Many strategies for creating fuel breaks to aid in fire suppression have been proposed including mechanical alterations of fuel, green stripping, and livestock grazing (Omi 1979; Pellant 1994; Agee *et al.* 2000; Diamond *et al.* 2009). Many have proposed livestock grazing as a tool to reduce fire risk in sagebrush steppe ecosystems (Taylor 2006; Nader *et al.* 2007; Schmelzer 2009; Pellant *et al.* 2010; Strand *et al.* 2014) , and Davies *et al*. (2015) suggested that livestock grazing is the most feasible treatment both economically and logistically.

The use of livestock to alter landscape features has been extensively studied and information on livestock behavior, selectivity, and effectiveness of targeted grazing scenarios is well documented. Livestock grazing can reduce the amount of undesired vegetation (Anderson and Frank 2003; Schmelzer 2009), specifically fine herbaceous material (Davies *et al*. 2010), and specific livestock species can be utilized to target key fuel components and alter fuel load (Taylor 1994, 2006). Nader *et al.* (2000) compared grazing to mechanical, chemical, and prescribed fire treatments and found that grazing could effectively reduce wildfire risk, but states that scientific research on the topic is needed. Schmelzer (2009) demonstrated that fall grazing reduced the persistence of cheatgrass and suggested that a reduction of cheatgrass resulted in a reduction in wildfire risk the next fire season. Similarly, Diamond *et al*. (2009) showed that intensive grazing drastically reduced wildfire spread in cheatgrass dominated pastures; however, the heavy stocking rates used in this study were deemed impractical for maintaining robust native plant communities and may actually promote invasion of exotic annual grasses (Mack 1981; Knapp 1996; Strand *et al.* 2014). Davies *et al.* (2015) found that livestock grazing in the dormant season can reduce wildfire in sagebrush steppe by maintaining fuel moisture above the probability of ignition and reducing total biomass, ultimately reducing flame heights and rate of spread. As part of a restoration initiative for the Great Basin in the western US, Pellant *et al.* (2010) stated that targeted grazing is an underutilized tool for reducing fire risk and further details the decision process, considerations, and implementation for targeted grazing at a landscape scale for fire breaks. In a recent review of grazing as a fuels treatment, Strand *et al.* (2014) concluded that more focused research on the direct effects of applied grazing to reduce wildfire risk is needed.

Although livestock grazing is currently used as a tool to reduce fire risk and is periodically highlighted in popular media, few studies have validated the effectiveness of the practice (Greenleigh 2010; London 2011; Sawa 2013; Barker 2015). In particular, further research is needed to increase our understanding of how livestock grazing can be used to create fuel breaks and how these grazed fuel breaks impact fire flame height and rate of spread in big sagebrush ecosystems. These plant communities are at risk for large scale wildfires which reduce and eliminate sagebrush and promote exotic annual grasses (Davies *et al.* 2011). In response to the request for additional scientific research on the effects of livestock grazing on fuels and fire behavior metrics, we designed a replicated grazing and fire study on big sagebrush sites in Idaho, USA. The purpose of this study was to evaluate how livestock grazing implemented at two grazing intensities (low and moderate) affect fuel and fire behavior metrics. A second objective was to evaluate whether grazing can be applied at the beginning of the fire season (summer), or if grazing needs to occur shortly before the fire (fall) to sufficiently reduce fire flame height and rate of spread in big sagebrush communities, to a point where suppression efforts can be effective. We hypothesized that grazing at a moderate intensity (50% utilization) would reduce both flame height and rate of spread and that timing of grazing would not be a factor in altering these metrics. We further hypothesized that increased shrub cover would negate any effects of livestock grazing at reducing fire behavior metrics, because cattle generally only impact the herbaceous component of fuels and vegetation.

Methods[1]

Study Area

This study was conducted in two pastures (average elevation of 1221 and 1600 m, respectively) within the Reynolds Creek watershed located in Owyhee County, Idaho (43°12'N, 116°46’W and 43° 6'N, 116°46'W). Average precipitation within these two sites was 263 and 593 mm a year, for the low and high elevation sites respectively (Table 1), with the majority of precipitation occurring in the winter and spring months and little precipitation being received from July to September (USDA 2016a; b). The wildfire season generally

[1] All activities involving animals were approved by the University of Idaho Animal Care and Use Committee (Protocol 2014 12 v.4)

ranges from July to early October with dry lightning events throughout the summer. Study sites were located on Loamy 8-12 – (provisional R011XY001ID) and Mahogany savanna 16-22 – (provisional R025XY018ID) ecological sites (National Resouce Conservation Service (NRCS) 2014).

Big sagebrush was the dominant shrub within the study sites (*Artemisia tridentata* ssp. *wyomingensis* Beetle & Young and *Artemisia* t*ridentata* ssp. *vaseyana* [Rydb.] Beetle, in low and high elevation pastures, respectively). Shrub species antelope bitterbrush (*Purisia tridentata* [Pursh] DC.) and rubber and yellow rabbitbrush (*Ericameria nauseosa* [Pall. ex Pursh] G.L. Nesom & Baird and *Chrysothamuns viscidiflorus* [Hook.] Nutt., respectively) were common on both sites. Bluebunch wheatgrass (*Pseudoroegneria spicata* [Prush] Á. Löve) was the dominant or co-dominant perennial grass with Sandberg bluegrass (*Poa secunda* J. Presl). Cheatgrass, a naturalized annual grass, was present at low to moderate abundance within all study sites. Other frequently observed grasses included bottlebrush squirreltail (*Elymus elymoides* [Raf.] Swezey subsp. brevifolius [J.G. Sm.] Barkworth), bulbous bluegrass (*Poa bulbosa* L.), and medusahead. Commonly observed forbs within these study sites included common yarrow (*Achillea millefoluim* L.), arrowleaf balsamroot (*Balsamorhiza sagittata* [Pursh] Nutt.), tapertip hawksbeard (*Crepis acuminata* Nutt.), western stoneseed (L*ithospermum ruderale* Douglas ex Lehm.), silky lupine (*Lupinus sericeus* Pursh), yellow salsify (*Tragopogon subius* Scop.), and bastard toadflax (*Comandra umbellata* [L.] Nutt.). A complete species list of plants observed is provided in Appendix A.

Experimental Design and Grazing Treatments

A randomized complete block design was implemented with five treatments randomly applied to 30 x 30 m plots at six different blocks on two sites. Treatments were composed of ungrazed plots (control) and combinations of timing of use (summer and fall) and grazing utilization (low and moderate). Summer grazing began when herbaceous vegetation had completed the majority of its growth and little biomass increase would be expected to occur later in the season. Fall grazing was applied in the dormant season in 2014 and three weeks prior to the prescribed burn in 2015. Low and moderate grazing target utilizations were 25-35% and 50-60%, respectively. No difference in herbaceous biomass was detected from the data collected in 2014 and 2015 between plots assigned to different treatments. Control treatments were excluded from cattle grazing in 2014 and 2015, though wild herbivores were able to access the control treatments. Cattle grazing was applied in the summer (July 1 – Aug 1) or in the fall (September 9 – 30) to the respective plots in both 2014 and 2015. Cattle were contained within each specific plot with a two strand temporary electric fence. Grazing effectiveness was visually assessed during the day and cattle numbers were adjusted as needed to meet targeted utilization in a 24-hour period. A full list of grazing dates and number of cattle used can be found in the Appendix B.

Vegetation Measurements

Two 30 m transects were set 10 m apart in each plot to determine shrub cover and herbaceous biomass. Shrub cover was estimated using the line intercept method (Canfield 1941) in the summer of 2014. Dimensions of width and height was measured for each shrub along the transect. Herbaceous biomass (g) was estimated in ten 50 x 50 cm quadrats every 3 m along each transect during the summer season for the ungrazed treatments and no more than a week before grazing for all other treatments. Observers estimated and weighed herbaceous biomass outside of the study area to assure accurate estimations within the study plots, with 85% or ±2 g accuracy achieved and maintained each day before biomass in the study areas was estimated. No biomass was removed from the plots to avoid alteration of fuel and vegetation. Quadrat data were used to calculate total herbaceous biomass per plot (kg), which was then used to calculate cattle needed to graze to the desired utilization in a 24-hour period:

Biomass per plot (kg) = Estimated biomass (g) / 5 (total area sampled m^2) x 900 (plot size m^2) /1000 (Converting g to kg) [Equation 1]

Cattle needed = Biomass per plot (kg) x target utilization (%) / estimated daily consumption (2.5% of body weight [weight (kg) x 0.025]) [Equation 2]

Percent ground cover of bare ground, woody litter, and herbaceous litter were estimated visually at each quadrat prior to grazing.

After grazing was completed in each plot, and in the fall for control plots, herbaceous biomass and ground cover estimates were again estimated in the same ten quadrats along the two transects in each plot. Final utilization was calculated by dividing the post-grazing herbaceous biomass estimate by the pre-grazing estimates.

Prescribed Burn and Fire Metrics

Prescribed burns were conducted during the wildfire season on September 28-29, 2015 under the supervision of the Bureau of Land Management (BLM) Boise, ID fire district. The Soda Fire (2 km northwest of study sites) burned over 144,500 hectares and was declared out on September 9, 2015 (Inciweb 2000) and our prescribed burns were subsequently delayed one week because of public concern with all rangeland fires in this region. Prescribed burns were ignited with drip torches by lighting a 30-m ungrazed pre-ignition zone to create a head fire simultaneously approaching all treatments (Figure 1). The first ignition on both days started in the afternoon to allow weather condition to be as close to “wildfire” conditions (increased ambient temperature and lower relative humidity) as possible. Separate ignitions were conducted at each of the six treatment blocks, implemented one after the other over two burn days (Table 2). This pre-ignition zone allowed the fire to best mimic the conditions of a wildfire moving into a firebreak (treatment plots). Air temperature ranged from 21.7 to 26.7°C, relative humidity ranged from 20-31%, and wind speeds varied from 1.6-8 km h^{-1} during the prescribed burns with gusts up to 14.5 km h^{-1} (table 2). One hour fuel moisture (moisture of herbaceous and fine fuels with particle size <6.4 mm) was 4-6% during the burns.

During the prescribed burns, observers were randomly assigned a plot to estimate flame height and rate of spread. Observers were not told what the treatment applied to their respective plots were to reduce observation bias. Steel flame height markers, alternating white and black, were placed at 10 and 20 m along each transect as reference markers. Flame height was recorded at 0, 10, 20, and 30 m from the plot boundary and averaged for each plot. Time was recorded as the fire reached 0, 10, 20, and 30 m for rate of spread, which was calculated for each segment (0-10, 10-20, and 20-30 m) and overall (0-30m) and then average to best assess rate of spread. Three video cameras were also positioned around the prescribed burns allowing observers to re-view and compare notes to video footage and confirm the best possible measurements for both flame height and rate of spread.

Statistical analysis

Analysis of variance, with the actual measured utilization added as a covariate, was used to identify effects of grazing on measured ground cover variables. Multivariate analysis of covariance was used to identify the effects of treatments on fire flame height and rate of spread. Shrub canopy cover and litter were added as covariates to further understand the interactions between livestock grazing and fire behavior metrics. Residual herbaceous biomass was not included as a covariate because it was inversely correlated with shrub cover Regression analysis was conducted on variables that were found significant in the multivariate analysis. All analyses were conducted using R Studio computer software (R Studio, 2014) and treatment effects were considered significant at $p \leq 0.05$.

Results

Fuels

Shrub cover varied from 0 to 77% canopy cover with an average of 22.7% (Table 3). No differences in shrub cover were found between treatments (p=0.78). Herbaceous biomass ranged from 150 to 1452 kg/ha in 2014 and 259 to 1780 kg/ha averaging 522 and 778 kg/ha, respectively (Table 3). No differences in pre-grazing herbaceous biomass were found between treatment plots for each year (p=0.96 and 0.15, for 2014 and 2015, respectively). Livestock grazing in 2014 was applied between July 28th and August 11th for the summer plots and September 17th to 26th in the fall grazed treatments (Appendix B). In 2015, cattle grazing was applied between June 20th and July 4th for the summer grazed plots and September 7th and 23rd in the fall grazed plots (Appendix B). Cattle number grazed in each plot varied from 1 to 11 animals to graze for one day. Actual livestock utilization for each treatment was within target ranges (Table 3).

Ground Cover

Analysis of variance revealed impacts of grazing on ground cover. Total percent bare ground was increased between summer and fall sampling in the control plots, while bare ground remained similar amongst all of the grazed treatments, pre- and post-grazing (Figure 2). Analysis of variance revealed an increase in the bare ground cover in the control plots, i.e. in the absence of grazing (p>0.01; Table 4). Utilization did not alter bare ground cover (p=0.37; Table 4). Woody litter decreased slightly within the control plots (-0.9%) while slightly increasing within all grazed treatments (Figure 2). No difference was noticed in woody litter between grazed and ungrazed plots (p=0.10) nor did utilization alter woody litter (p=0.33; Table 4). Herbaceous litter declined in the control plots by an average of 8% (Figure 2).

Grazing increased herbaceous litter compared to the control plots ($p<0.01$; Table 4). No differences were found between low and moderate treatments for actual utilization and herbaceous litter ($p=0.13$; Table 4).

Fire Behavior Metrics

A multivariate analysis of variance was used to evaluate the effects of the combination of season of use, shrub canopy cover, herbaceous litter, and calculated utilization on fire flame heights and rate of spread. Taking into account the three covariates, there was no apparent difference on fire flame height and rate of spread in the varying seasons of use ($p=0.40$; Table 5). Shrub canopy cover had a highly significant effect on flame height and rate of spread ($p<0.01$; Table 5). Further analysis shows a positive correlation between shrub canopy cover and flame height and rate of spread ($R^2=0.59$ and 0.44, respectively; Figure 3). Herbaceous litter also showed an effect on flame height and rate of spread ($p=0.02$; Table 5). Linear regression models showed that increases in herbaceous litter decreases both flame length and rate of spread ($R^2=0.51$ and 0.33, respectively) (Figure 4). Actual utilization has an effect on flame height and rate of spread according to the multivariate analysis ($p=0.02$) yet no correlations can be found with linear regression models ($R^2=0.0$ and 0.02, respectively; Figure 5).

Discussion

Herbaceous Litter and Bare Ground

Livestock grazing showed to not only remove herbaceous biomass but also change the structure of the residual fuel left behind. Herbaceous litter decreased in the control, no grazing, plots and an increase in bare ground was observed. Livestock were able to increase litter through the daily activities of grazing, traveling, and bedding. The creation of litter alters the way in which fire consumes these fuels (Nader *et al.* 2007).

Shrub Cover

The ability of targeted grazing to reduce fire behavior metrics appears to be limited to landscapes with low shrub cover. As shrub canopy cover increased, so did flame height and rate of spread. During our prescribed burns flame height appeared to reach an asymptote around 25-30% shrub canopy cover after which flamed height did not continue to increase even though shrub cover increased. Shrub canopy cover appears to be the main driving factor in flame height and rate of spread especially when it reaches above 25-30%. These results are consistent with US Forest Service prescribed burn guidelines, which states that with shrub cover greater than 30%, fire may carry though the shrub canopy even at very low herbaceous fuel loads (Brown 1982; Bunting *et al.* 1987). These results suggest that, for cattle grazing to effectively create or maintain firebreaks, shrub cover must be maintained at low levels. Brown (1982) demonstrated that increased shrub cover greatly increases fire line intensity, and rate of spread and this is supported with this data. Therefore, firebreaks implemented to reduce fire behavior metrics to a level at which firefighting can be effective should have a minimal shrub component to maintain effectiveness.

Herbaceous Litter and Bare Ground

Livestock grazing showed to not only remove herbaceous biomass but also change the structure of the residual fuel left behind. Herbaceous litter decreased in the control, no grazing, plots and an increase in bare ground was observed. Livestock were able to increase litter through the daily activities of grazing, traveling, and bedding. The creation of litter alters the way in which fire consumes these fuels (Nader *et al.* 2007).

Utilization

Cattle grazing at both low and moderate utilization levels can reduce fire behavior metrics to increase chances of success in wildfire suppression efforts. US federal firefighting crews have general safety guidelines which dictate the tools wildfire suppression professionals can utilize to combat a fire based on flame height and rate of spread and flame height have been established as thresholds in these guidelines (Andrews and Rothermel 1982; NIFC 1996). Wildfires with flame heights under 1.2 m can be directly attacked by hand crews and a hand dug fire line is expected to hold the fire (NIFC 1996). With flame heights above 1.2 m, hand crews become ineffective for direct attacks, however, equipment can be used until flame heights reach 2.4 m (NIFC 1996). Flame heights between 2.4 and 3.4 m are considered difficult to control at the head of the fire with any ground resource. With flame heights above 3.4 m, direct controls are considered ineffective. Reducing flame heights below any one of these thresholds increases opportunities to hold a wildfire and increases the likelihood of success with suppression efforts. Under the fire behavior conditions, we encountered, one summer moderate treatment reduced flame height below the 1.2-m threshold and subsequently stopped the fire between 10 and 20 m in one of the replicated treatments. No fuel treatment can guarantee flame height reductions below these thresholds in all wildfire conditions; however, grazing at 50% utilization in strategic locations can greatly increase the likelihood for success with suppression efforts and reduce risk for wildfire suppression personnel.

Currently, there are no rigorously defined rate of spread thresholds within firefighting guidelines similar to the flame height thresholds (NIFC 1996). Because of this, rate of spread reductions does not affect how suppression efforts are implemented as much as flame height, though it is an important component to suppression planning and management. In this study, when shrub cover was below 30%, grazing to 50% utilization reduced rate of spread by an average of 29%, which translates into more time to apply suppression tactics and increased ability to respond to a fire as weather changes interact with the wildfire to alter flame front direction and intensity. Any tool that can reduce the rate of spread will increase the effectiveness of fire suppression efforts. The results of this study supports cattle grazing of fire breaks as another tool to reduce wildfire rate of spread in strategic locations and increase the likelihood of holding and stopping a wildfire.

Season of Use

All of our grazed treatment plots were grazed in 2015, with fall treatments implemented three weeks before the prescribed burn. Our fall treatments did not asses how grazing in the dormant season affects fire behavior metrics the following year, but rather were used to assess the importance of the timing of grazing. Specifically, our objective was to identify whether livestock grazing can be implemented as soon as herbaceous biomass has peaked (summer), or if grazing needs to be done shortly before a wildfire event occurs (fall). Reduction of fire behavior metrics did not differ between the summer and fall treatments, indicating that benefits from grazing fire breaks can be achieved during the summer as soon as herbaceous plants finishes accumulating biomass (when native grasses began to flower and set seed) and that grazing benefits does carry throughout the remainder of the fire season. The timing at which peak biomass occurs in sagebrush ecosystems generally occurs at the onset of the fire season, which increases the usefulness of grazing treatments for herbaceous fuel reductions at this time.

Implications

Targeted grazing to create or maintain firebreaks will need to be managed differently than operational pasture management because grazing timing and intensity are critical to achieving the desired benefit of fuel reduction. Optimal placement of grazing treatments must be considered to maximize the benefit for fire suppression professionals during the wildfire season. Our study shows that cattle grazing in low shrub cover areas can create this benefit at the beginning of the fire season and can be utilized as another tool for fuel managers across the sagebrush steppe. Information on implementation and decision factors are widely available (Frost and Launchbaugh 2003). Studies to increase cattle distribution in pastures have focused on making unused locations more appealing through low stress livestock handling and low moisture block supplements (Bailey 2004; Bailey and Welling 2007; Bailey *et al.* 2008). This method of low stress livestock handling and low moisture block supplement has been recently applied to fuel management in a grazing and fire modeling study and was found to increase cattle density on the target area (Bruegger *et al.* 2015). Local fuel managers would need to work with producers to identify treatment locations and grazing feasibility in order to create a comprehensive fuels management plan, which includes livestock grazing.

Conclusion

Our study demonstrated that cattle grazing could significantly reduce fire behavior metrics in big sagebrush ecosystems, though high shrub cover can negate all benefits achieved from cattle grazing. Reduction of herbaceous fuel by cattle reduces flame height and rate of spread and increases the tools wildland fire fighters can use to combat a fire front. Wildfires are generally not held and put out because of a large single suppression event taken by fire managers, but rather by combinations of weather, fuels, and a little bit of luck to turn the odds in their favor. Cattle grazing to create or maintain strategically implemented fire breaks may not stop every wildfire, but it will increase the chances of reducing the scale at which a fire burns.

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Table 1 Annual precipitation, mm, by block sites in Reynolds Creek, ID. Blocks 1-3 are found in mountain big sagebrush while blocks 4-6 are in Wyoming big sagebrush. Data used came from weather stations from the USDA ARS Northwest Watershed Research Center are located within 2 miles of each block.

Blocks	10 Year Average	2014	2015
1-3	593	671	603
4-6	262.9	294	238

Table 2 Weather conditions at the time of prescribed burns for the six study blocks in 2015 in Reynolds Creek Id. Prescribed burns were conducted on September 28, 2015 for blocks 1-3 and September 29, 2015 for blocks 4-6.

Block	Air Temperature (°C)	Relative Humidity (%)	Wind Speed ($km \cdot hr^{-1}$)
1	21.7	31	3.2-8.0
2	21.7	20	3.2-8.0
3	23.3	20	3.2-8.0
4	25.6	23	0.0-1.6
5	26.7	22	3.2-6.4
6	26.7	20	3.2-8.0

Table 3 Treatment landscape average characteristics for control, and low and moderate livestock utilization treatment blocks in Reynolds Creek ID. Herbaceous biomass displayed on dry matter basis.

	Treatment	Shrub Cover (%)	2014 Pre-Grazing Herbaceous Biomass (kg ha^{-1})	2015 Pre-Grazing Herbaceous Biomass (kg ha^{-1})	2015 Utilization (%)
	No Grazing	27.6 ± 6.9	514 ± 90	887 ± 143	-
Summer	Low	22.1 ± 5.7	505 ± 103	778 ± 128	43.8 ± 1.4
	Moderate	24.4 ± 5.7	491 ± 70	818 ± 99	60.1 ± 2
Fall	Low	21.3 ± 4.6	513 ± 97	681 ± 118	31.9 ± 2.1
	Moderate	18.2 ± 3.9	585 ± 113	729 ± 118	52.9 ± 1.4

Table 4 Analysis of variance evaluating effects of grazing (yes or no) and actual utilization on ground cover measurements (bare ground, woody litter, and herbaceous litter) in study blocks in Reynolds Creek, ID.

Response bare ground cover (%)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Grazing	1	393.73	393.73	10.8309	**0.002**
Actual Utilization	1	29.05	29.05	0.7991	0.375

Response woody litter cover (%)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Grazing	1	53.49	53.487	2.7435	0.103
Actual Utilization	1	18.56	18.558	0.9519	0.333

Response herbaceous litter cover (%)

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Grazing	1	2786	2785.97	19.727	**<0.001**
Actual Utilization	1	340.7	340.74	2.4127	0.126

Table 5 Multi variate analysis evaluating the effects of season of use (Control, Summer, and Fall), shrub canopy cover (%), calculated utilization (5%), and herbaceous litter (%) on fire flame height in rate of spread from prescribed burn observations in Reynolds Creek, ID.

Factor	Df	Pillai	approx F num	Df	den Df	Pr(>F)
Season of Use	2	0.2	1.038	4	40	0.399
Shrub Cover	1	0.8	34.165	2	19	**<0.001**
Actual Utilization	1	0.3	3.635	2	19	**0.046**
Herbaceous Litter	1	0.4	5.271	2	19	**0.015**

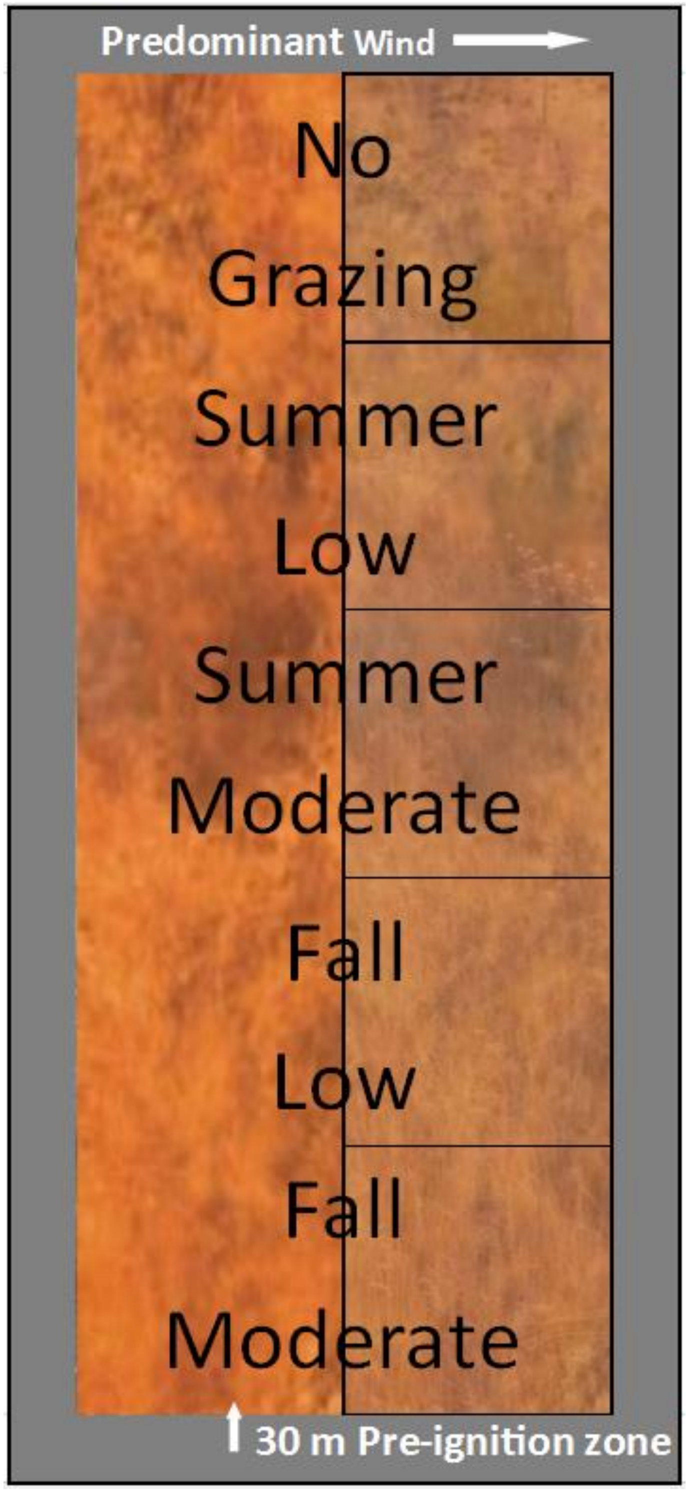

Figure 1 Study block diagram for study in Reynolds Creek, ID. Five 30 x 30 m plots were randomly given a treatment (no grazing, and combinations of summer and fall seasons and low and moderate utilizations) and a 30 m preignition zone was left ungrazed for two years to create wildfire conditions as the prescribed burn spread into the study area.

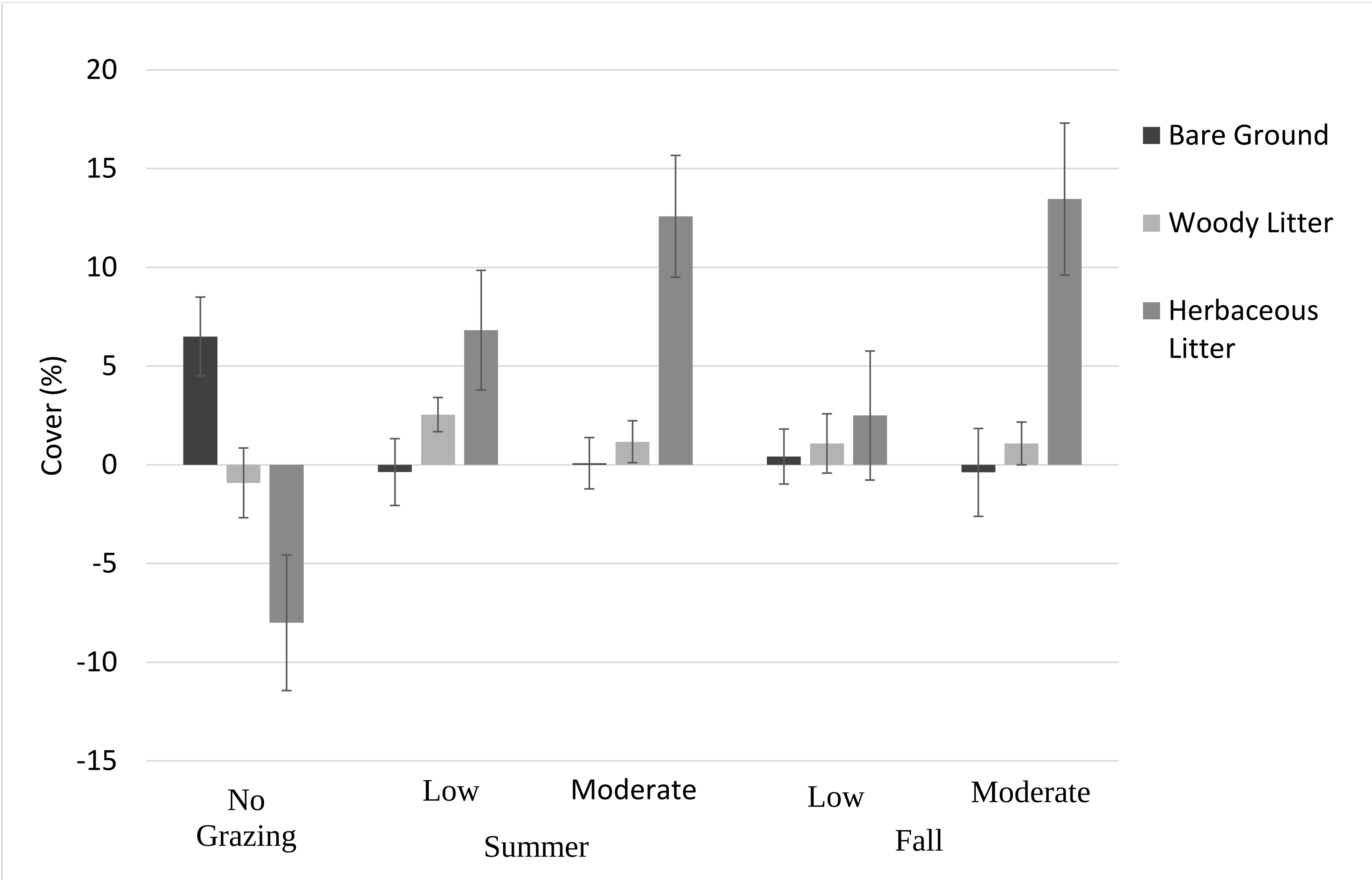

Figure 2 Percent ground cover differences, post – pre, between no grazing, and low and moderate livestock grazing treatments in Reynolds Creek, ID. No grazing sampling was done before the start of summer grazing (pre) and after grazing in the fall (post).

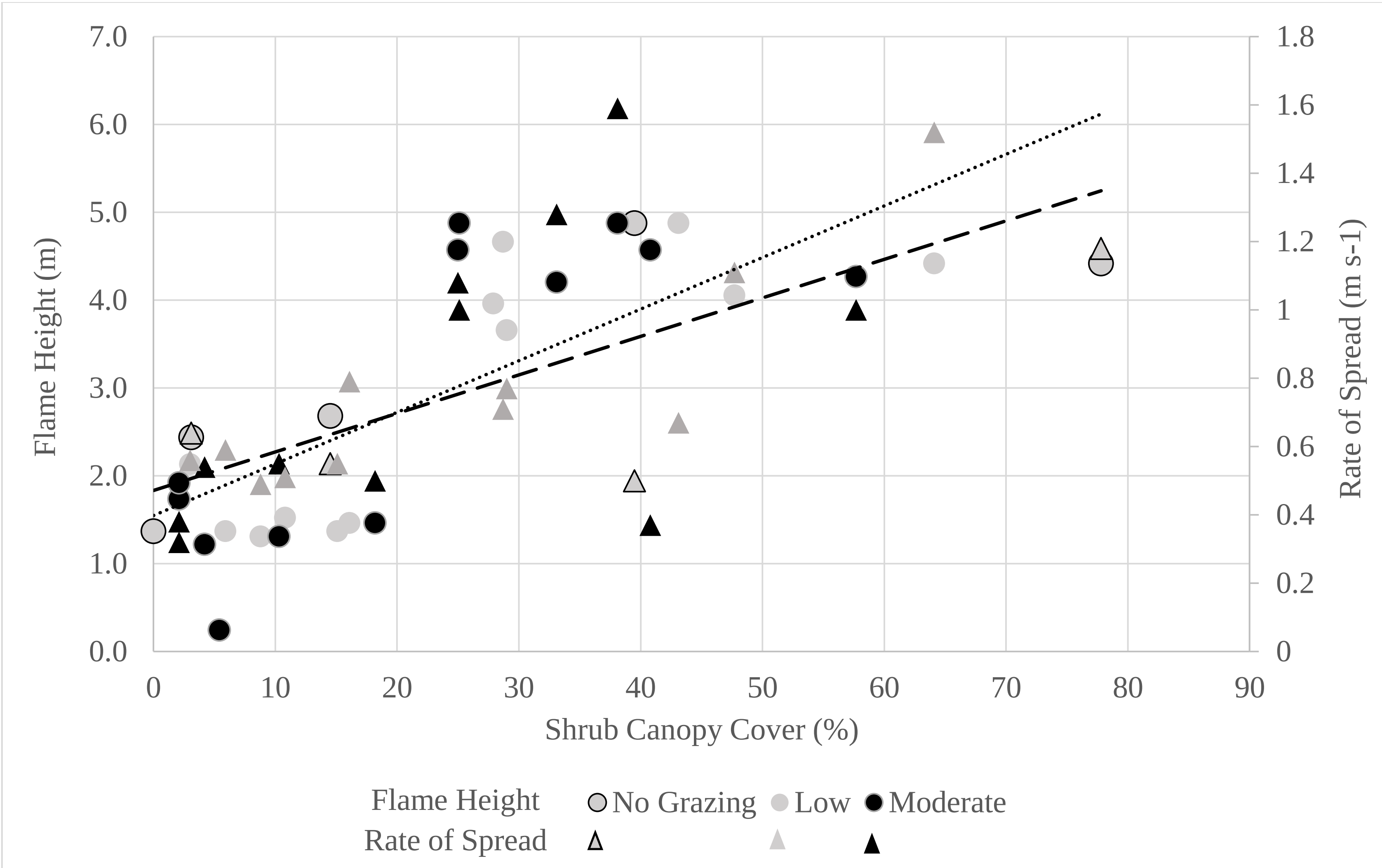

Figure 3 Effects of shrub canopy cover on flame height and rate of spread by utilization levels in Reynolds Creek, ID. Trend lines show correlation of shrub canopy cover and flame height (dotted line, R^2=0.59) and rate of spread (dashed line, R^2=0.44) for no grazing, and low and moderate livestock utilization treatments.

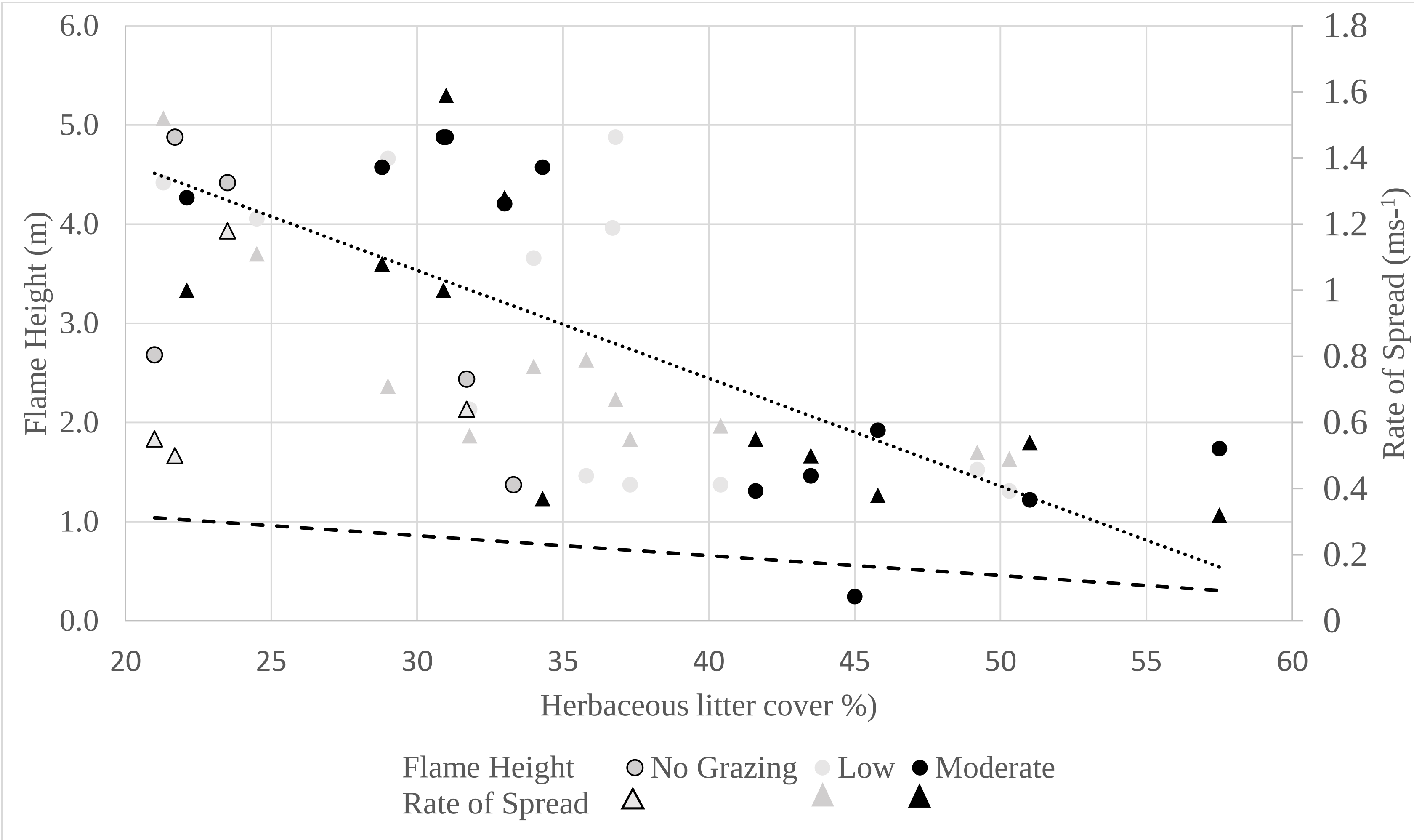

Figure 4 Effects of herbaceous litter on flame height and rate of spread by utilization levels in Reynolds Creek, ID. Trend lines show correlation of herbaceous litter cover and flame height (dotted line, R^2=0.51) and rate of spread (dashed line, R^2=0.33) for no grazing, and low and moderate treatments.

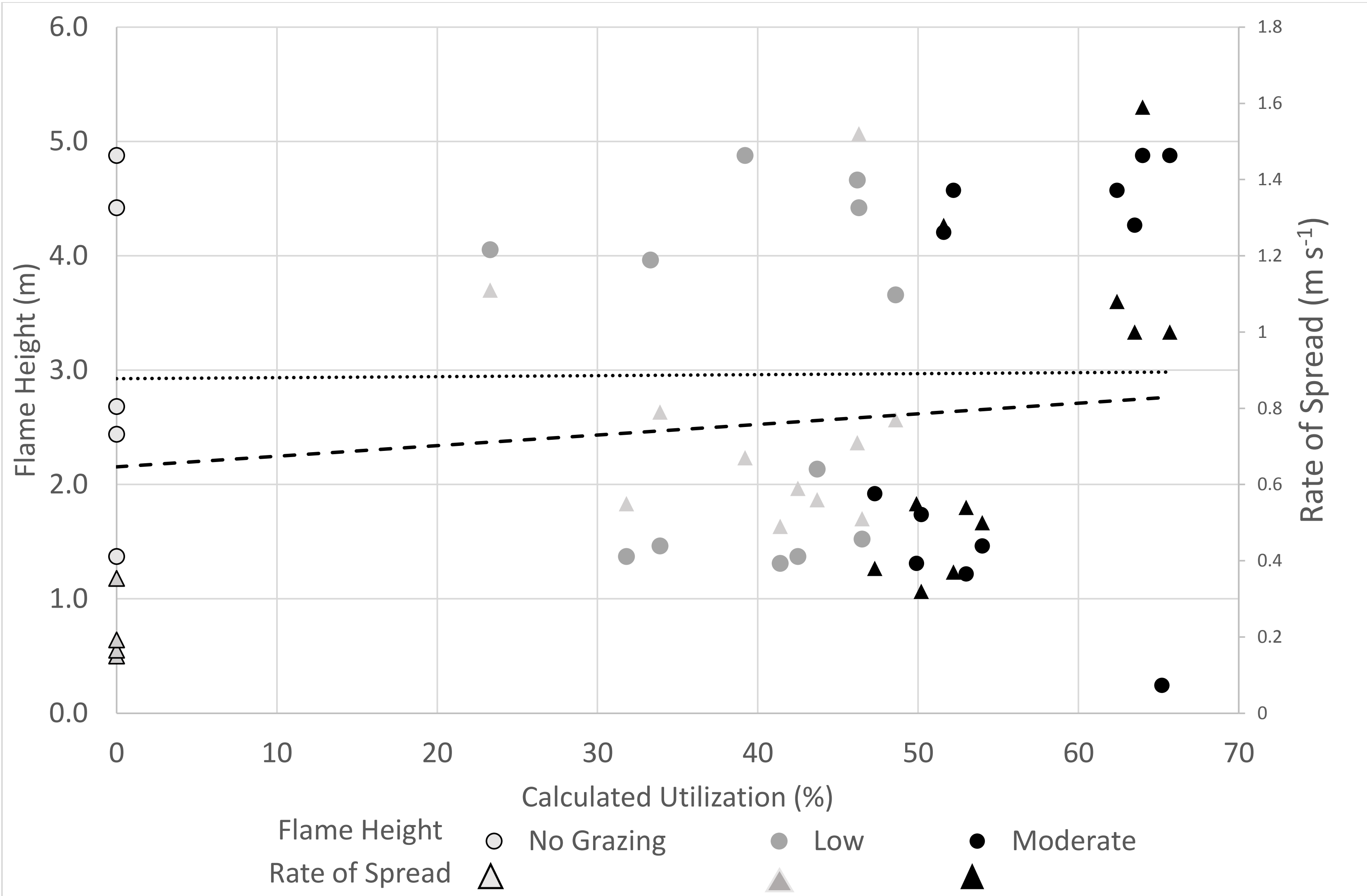

Figure 5 Effects of actual utilization on flame height and rate of spread by grazing utilization levels in Reynolds Creek, ID. Trend lines show correlation of actual utilization and flame height (dotted line, R^2=0.00) and rate of spread (dashed line, R^2=0.02) for all no grazing, and low and moderate utilization treatment.

Guide for Quantifying Shrub Cover and Herbaceous Fuel Load in the Sagebrush Steppe

Abstract

Pictures taken for the 'Targeted Grazing Applied to Reduce Fire Behavior Metrics and Wildfire Spread' were used to create a shrub cover and herbaceous fuel load visual guide. Pictures were identified for shrub cover at eight levels, 5, 10, 15, 20, 25, 30, 35, and 40% and 100, 200, 300, 400, 600, and 1000 lb/ac herbaceous vegetation on a dry matter basis. Two representative photos where selected for each category. Measured shrub cover, total herbaceous biomass, perennial and annual grass and forb biomass are displayed with each photo. Site descriptions are listed to increase the ability to compare amongst other ecological sites. We anticipate that this guide will assist fuels managers and producers to quickly and economically asses the effectiveness of livestock grazing for shrub cover, and for herbaceous fuel load and reduction on a site.

Introduction

Wildland fire has become an increasing threat in the west with over 10 million acres consumed in 2015, and over 7 million acres burned on average for the last 10 years (National Interagency Fire Center (NIFC) 2016). To improve suppression efforts, targeted livestock grazing has been suggested as a tool to reduce fine herbaceous material in strategically placed fire breaks (Nader *et al.* 2007; Schachtschneider *et al.* 2016). Livestock grazing has been shown to reduce flame height and rate of spread within sagebrush communities (Davies *et al.* 2015). In order for targeted grazing to be effective, shrub cover must be low in the targeted area (Brown 1982; Schachtschneider *et al.* 2016). To assist fuel managers and local producers in quantifying shrub cover and herbaceous fuel load we have compiled a series of photographs illustrating landscapes with varying levels of shrub cover and herbaceous fuel loads. Shrub cover data was grouped by percent shrub cover in 5 percent increments from 5-40%. Herbaceous fuel load (dry matter) was grouped in exponential increments from 80 to 1,100 pounds per acre. Each photo is displayed with shrub cover, herbaceous fuel load, ratio of perennial and annual grasses and forbs.

Methods

Field data to support this guidebook was obtained from 120, 100 ft transects implemented in the Reynolds Creek watershed in Owyhee County, Idaho. Transects were located in two pastures in the Reynolds Creek watershed located in Owyhee County, Idaho. Precipitation ranges from 9 to 19 inches a year, occurring mostly in the winter and spring months. Pastures are located on Loamy 8-12 - provisional (R011XY001ID) and Mahogany savanna 16-22 - provisional (R025XY018ID) ecological sites (National Resouce Conservation Service (NRCS) 2014).

Primary shrub species included: big sagebrush (*Artemisia tridentata* spp *wyomingensis* and *Artemisia tridentata* spp *vaseyana*, in low and high elevation pastures, respectively), antelope bitterbrush (*Purisia tridentata*) and rubber and yellow rabbitbrush (*Ericameria* nauseosa) and *Chrysothamuns* viscidiflorus, respectively). Perennial grasses included: bluebunch wheatgrass (*Pseudoroegneria spicata*), Sandberg bluegrass (*Poa secunda*), bottlebrush squirreltail (*Elymus elymoides*), and bulbous bluegrass (*Poa bulbosa*). Cheatgrass, and other annual grasses were present at low to moderate abundance within all study sites. Other annual grasses observed were medusa head (*Taeniatherum caput-medusae*) and North Africa grass (*Ventenata dubia*). Commonly found forbs included common yarrow (*Achillea millefoluim*), arrowleaf balsamroot (*Balsamorhiza sagittata*), tapertip hawksbeard (*Crepis acuminate*), western stoneseed (L*ithospermum ruderale*), silky lupine (*Lupinus sericeus*), yellow salsify (*Tragopogon subius*), and bastard toadflax (*Comandra umbellata*). A complete plant species list can be found in appendix A.

Shrub canopy cover was assessed with the line intercept method (Canfield 1941) and pictures were taken at the beginning and end of each transect. Target shrub cover percentages were set at 5, 10, 15, 20, 25, 30, 35, 40%. Transects which came within one percent of the targeted shrub cover levels were separated and evaluated for picture quality. The best two pictures were used for each targeted shrub cover group. Pictures were displayed with actual shrub cover percentage, total herbaceous dry biomass, which was also separated into percent perennial and annual grasses, and forbs.

Total herbaceous fuel load was assessed with visual estimation, with clippings done outside of the study area for calibration. Herbaceous fuel load was separated into an exponential grouping of 100, 200, 300, 400, 600, and 1,100 pounds per acre. Transects which were within 40 pounds per acre of the targeted group and assessed for picture quality. The best two pictures were used for this guide with shrub cover percentage, total herbaceous biomass, which is also separated into perennial and annual grasses, and forbs displayed on each picture.

Using this Shrub cover and Herbaceous Fuel Load Guide

The 'Guide for Quantifying Shrub Cover and Herbaceous Fuel Load in the Sagebrush Steppe' will enable fuel managers and producers to quickly and inexpensively compare onsite field conditions to the guide photos and estimate both shrub cover and herbaceous biomass. The guide is divided into two sections, shrub cover (figures 5-13) and herbaceous biomass (figures 14-19), to allow greater accuracy in estimations of each. We recommend that users isolate each category for estimation focusing on either shrub cover first, then herbaceous biomass second, to increase accuracy of each estimation.

Conclusion

It has been demonstrated that livestock grazing reduce fire behavior metrics when shrub cover is low (Schachtschneider *et al.* 2016). In order for livestock grazing to be effective, fuel managers and producers must understand what is on the ground to prescribe an effective grazing treatment.

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Figure 6 5% Shrub Cover

Shrub Cover: 5%, Total Herbaceous Biomass: 205 lbs per acre, Perennial Grasses: 40%, Annual Grasses: 50%, Forbs: 10%

Figure 7 10% Shrub Cover

Shrub Cover: 11%, Total Herbaceous Biomass: 229 lbs per acre, Perennial Grasses: 47%, Annual Grasses: 28%, Forbs: 25%

Figure 8 15% Shrub Cover

Shrub Cover: 15%, Total Herbaceous Biomass: 254 lbs per acre, Perennial Grasses: 58%, Annual Grasses: 19%, Forbs: 23%

Figure 9 20% Shrub Cover

Shrub Cover: 20%, Total Herbaceous Biomass: 113 lbs per acre, Perennial Grasses: 32%, Annual Grasses: 66%, Forbs: 2%

Figure 10 25% Shrub Cover

Shrub Cover: 25%, Total Herbaceous Biomass: 127 lbs per acre, Perennial Grasses: 35%, Annual Grasses: 61%, Forbs: 3%

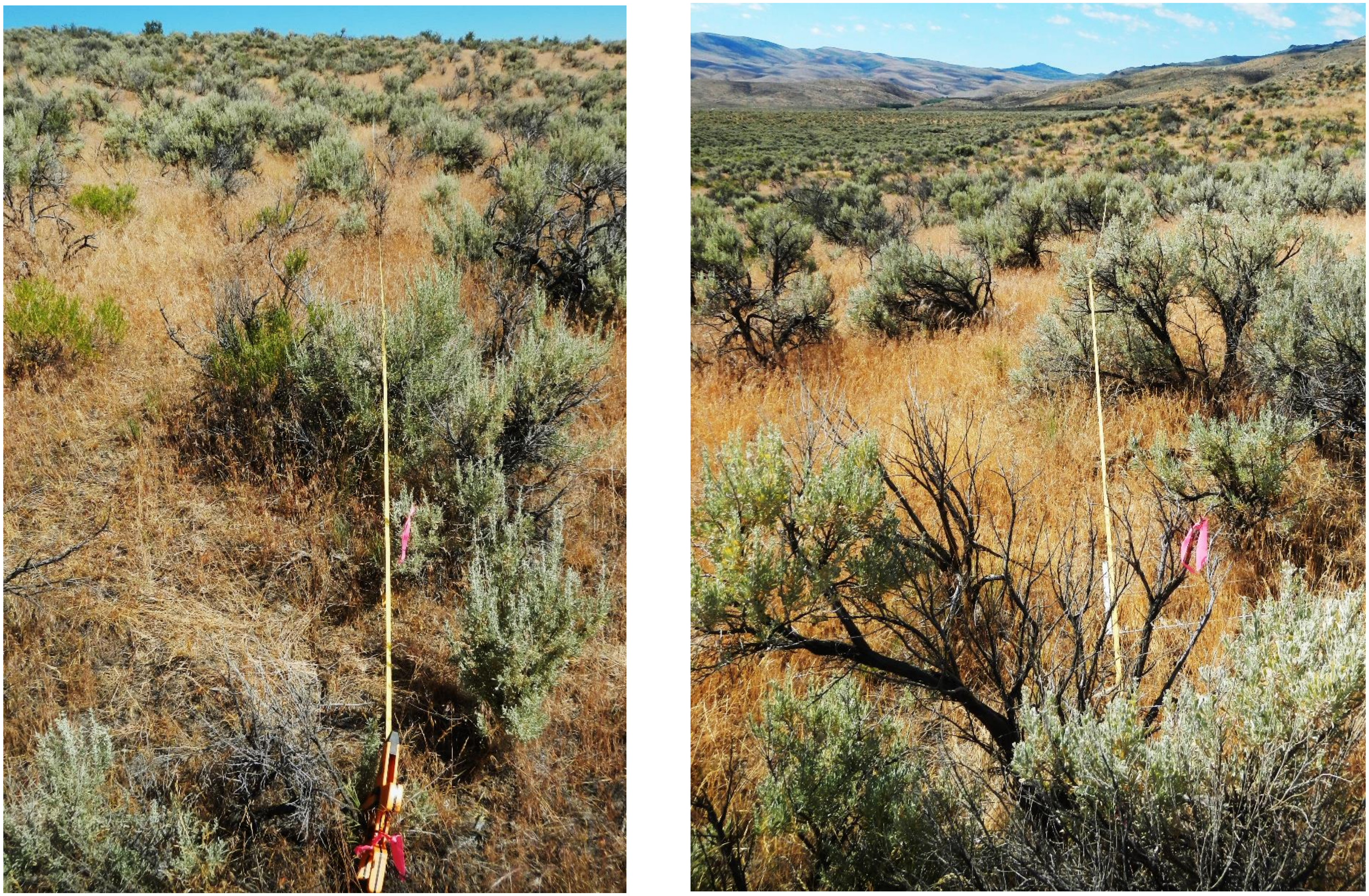

Figure 11 30% Shrub Cover

Shrub Cover: 30%, Total Herbaceous Biomass: 163 lbs per acre, Perennial Grasses: 42%, Annual Grasses: 48%, Forbs: 10%

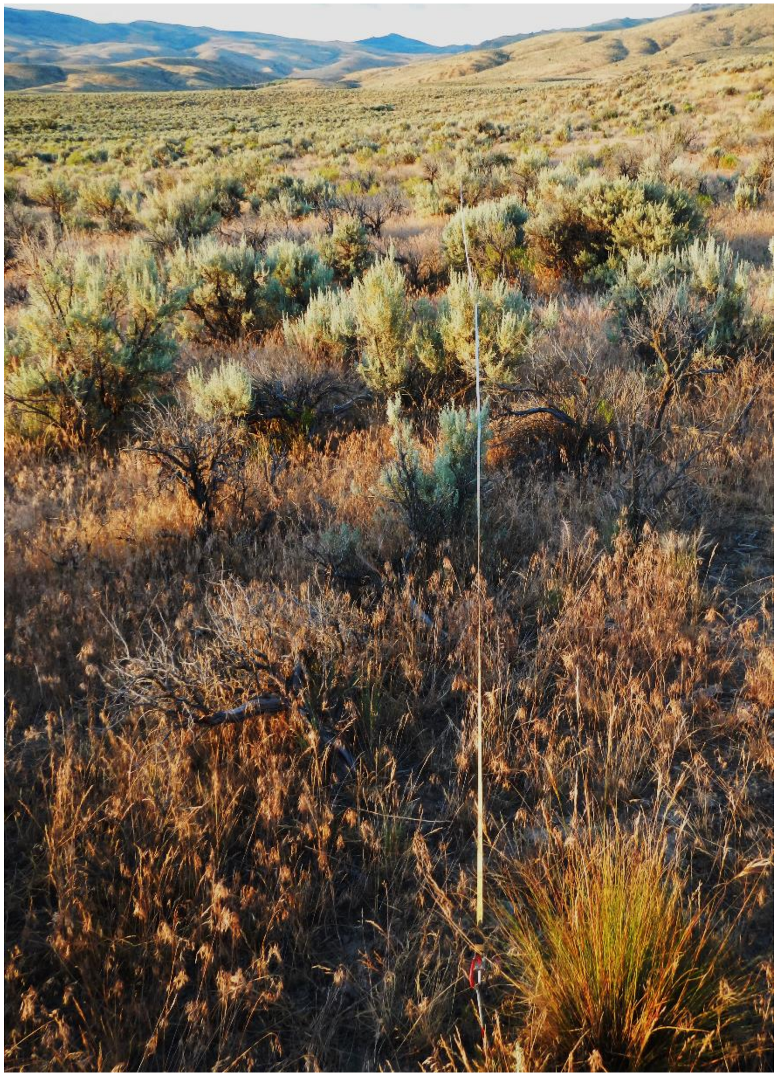

Figure 12 35% Shrub Cover

Shrub Cover: 36%, Total Herbaceous Biomass: 57 lbs per acre, Perennial Grasses: 30%, Annual Grasses: 66%, Forbs: 5%

Figure 13 40% Shrub Cover

Shrub Cover: 40%, Total Herbaceous Biomass: 141 lbs per acre, Perennial Grasses: 28%, Annual Grasses: 59%, Forbs: 13%

Figure 14 100 pounds per acre

Shrub Cover: 29%, Total Herbaceous Biomass: 100 lbs per acre, Perennial Grasses: 33%, Annual Grasses: 57%, Forbs: 10%

Figure 15 200 Pounds per Acre

Shrub Cover: 3%, Total Herbaceous Biomass: 206 lbs per acre, Perennial Grasses: 38%, Annual Grasses: 35%, Forbs: 26%

Figure 16 300 Pounds per Acre

Shrub Cover: 0%, Total Herbaceous Biomass: 300 lbs per acre, Perennial Grasses: 42%, Annual Grasses: 44%, Forbs: 14%

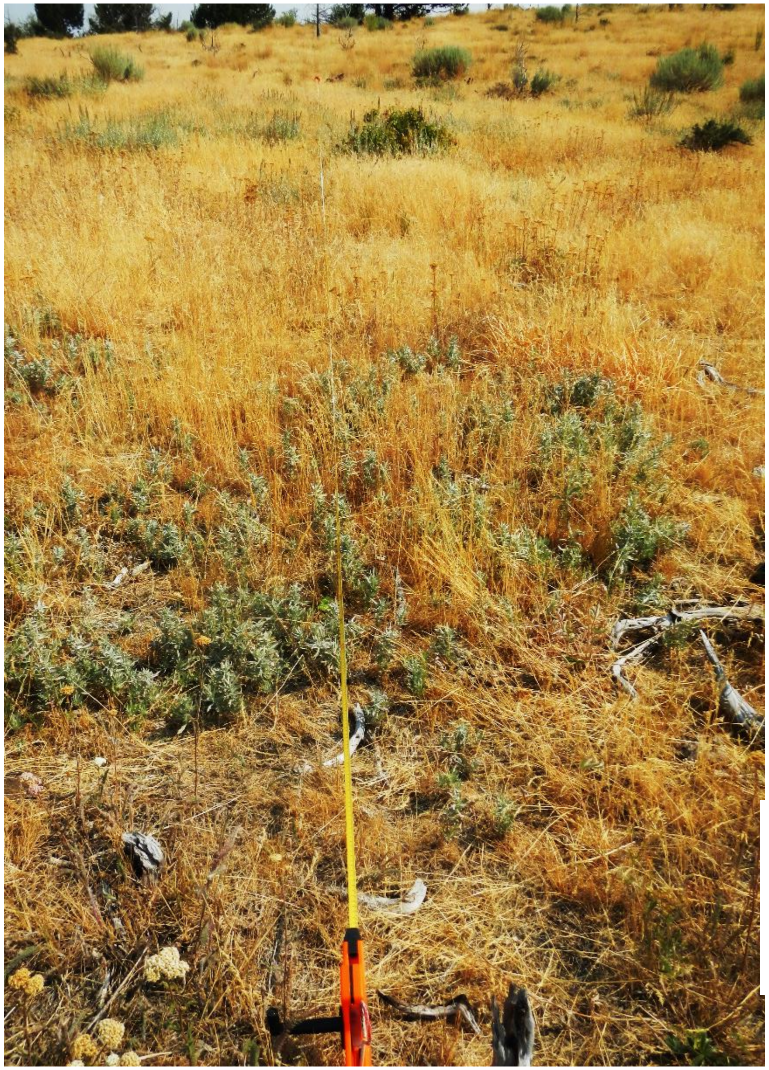

Figure 17 400 Pounds per Acre

Shrub Cover: 3%, Total Herbaceous Biomass: 400 lbs per acre, Perennial Grasses: 67%, Annual Grasses: 6%, Forbs: 27%

Figure 18 600 Pounds per Acre

Shrub Cover: 3%, Total Herbaceous Biomass: 615 lbs per acre, Perennial Grasses: 36%, Annual Grasses: 9%, Forbs: 55%

Figure 19 1,100 Pounds per Acre

Shrub Cover: 18%, Total Herbaceous Biomass: 1062 lbs per acre, Perennial Grasses: 86%, Annual Grasses: 1%, Forbs: 13%

Appendix A- Floral Checklists by pastures

Floral Checklist for Reynolds Creek - Wyoming big sagebrush site

Scientific Name	Code	Common Name	Origin
TREES			
Juniperus occidentalis Hook.	JUOC	Western juniper	N
SHRUBS			
Amelanchier utahensis Koehne	AMUT	Utah serviceberry	N
Artemisia nova A. Nelson	ARNO	Black sagebrush	N
Artemisia tridentata Nutt. spp. *wyomingensis* Beetle & Young	ARTRW	Wyoming big sagebrush	N
Chrysothamnus viscidiflorus (Hook.) Nutt.	CHVI	Yellow rabbitbrush	N
Ericameria nauseosa (Pall. ex Pursh) G.L. Nesom & Baird	ERNA	Rubber rabbitbrush	N
Purshia tridentata (Pursh) DC.	PUTR	Antelope bitterbrush	N
Rosa woodsii Lindl.	ROWO	Woods' rose	N
Tetradymia canescens DC.	TECA	Spineless horsebrush	N
Tetradymia glabrata Torr. & A. Gray	TEGL	Littleleaf horsebrush	N
FORBS			
Achillea millefolium L.	ACMI	Common yarrow	N
Allium acuminatum Hook.	ALAC	Tapertip onion	N
Arabis L.	ARABI	Rockcress	I, N
Astragalus filipes Torr. ex A. Gray	ASFI	Basalt milkvetch	N
Astragalus lentiginosus Douglas ex Hook.	ASLE	Freckled milkvetch	N
Calochortus macrocarpus Douglas	CAMA	Sagebrush mariposa lily	N
Chaenactis douglasii (Hook.) Hook. & Arn.	CHDO	Douglas' dustymaiden	N
Cirsium neomexicanum A. Gray	CINE	New Mexico thistle	N
Collinsia parviflora Lindl.	COPA	Maiden blue eyed Mary	N
Collomia grandiflora Douglas ex Lindl.	COGR	Grand collomia	N
Comandra umbellata (L.) Nutt.	COUM	Bastard toadflax	N
Crepis acuminata Nutt.	CRAC	Tapertip hawksbeard	N
Delphinium bicolor Nutt.	DEBI	Little larkspur	N
Draba verna L.	DRVE	Spring draba	I
Epilobium L.	EPILO	Willowherb	I, N
Erigeron linearis (Hook.) Piper	ERLI	Desert yellow fleabane	N
Erigeron pumilus Nutt.	ERPU	Shaggy fleabane	N

Scientific Name	Code	Common Name	Origin
FORBS			
Eriogonum microthecum Nutt. var. *laxiflorum* Hook.	ERMIL	Slender buckwheat	N
Eriogonum strictum Benth. var. *proliferum* (Torr. & A. Gray) C.L. Hitchc.	ERSTP	Blue Mountain buckwheat	N
Eriophyllum lanatum (Pursh) Forbes	ERLA	Common woolly sunflower	N
Erodium cicutarium (L.) L'Hér. ex Aiton	ERCI	Redstem stork's bill	I
Lactuca serriola L.	LASE	Prickly lettuce	I
Lepidium perfoliatum L.	LEPE	Clasping pepperweed	I
Linum lewisii Pursh	LILE	Lewis flax	N
Lithospermum ruderale Douglas ex Lehm.	LIRU	Western stoneseed	N
Lomatium dissectum (Nutt.) Mathias & Constance	LODI	Fernleaf biscuitroot	N
Lupinus pusillus Pursh	LUPU	Rusty lupine	N
Lupinus sericeus Pursh	LUSE	Silky lupine	N
Madia Molina	MADIA	Tarweed	N
Penstemon Schmidel	PENST	Penstemon	N
Penstemon deustus Douglas ex Lindl.	PEDE	Scabland penstemon	N
Phlox hoodii Richardson	PHHO	Spiny phlox	N
Phlox longifolia Nutt.	PHLO	Longleaf phlox	N
Potentilla L.	POTEN	Cinquefoil	I, N
Sisymbrium altissimum L.	SIAL	Tall tumblemustard	I
Stellaria L.	STELL	Starwort	I, N
Tragopogon dubius Scop.	TRDU	Yellow salsify	I
Zigadenus venenosus S. Watson	ZIVE	Meadow deathcamas	N
GRASSES			
Achnatherum hymenoides (Roem. & Schult.) Barkworth	ACHY	Indian ricegrass	N
Achnatherum thurberianum (Piper) Barkworth	ACTH	Thurber's needlegrass	N
Bromus hordeaceus L.	BRHO	Soft brome	I
Bromus tectorum L.	BRTE	Cheatgrass	I
Elymus elymoides (Raf.) Swezey	ELEL	Squirreltail	N
Festuca idahoensis Elmer	FEID	Idaho fescue	N
Leymus cinereus (Scribn. & Merr.) Á. Löve	LECI	Great Basin wildrye	N
Poa bulbosa L.	POBU	Bulbous bluegrass	I
Poa secunda J. Presl	POSE	Sandberg bluegrass	N
Pseudoroegneria spicata (Pursh) Á. Löve	PSSP	Bluebunch wheatgrass	N
Taeniatherum caput-medusae (L.) Nevski	TACA	Medusahead	I

Scientific Name	Code	Common Name	Origin
GRASSES			
Vulpia bromoides (L.) Gray	VUBR	Brome fescue	I

List compiled by Justin J. Trujillo and Eva Strand

Floral Checklist for Reynolds Creek - Mountain big sagebrush site

Scientific Name	Code	Common Name	Origin
TREES			
Juniperus occidentalis Hook.	JUOC	Western juniper	N
SHRUBS			
Amelanchier utahensis Koehne	AMUT	Utah serviceberry	N
Artemisia tridentata Nutt. ssp. *vaseyana* (Rydb.) Beetle	ARTRV	Mountain big sagebrush	N
Chrysothamnus viscidiflorus (Hook.) Nutt.	CHVI	Yellow rabbitbrush	N
Ericameria nauseosa (Pall. ex Pursh) G.L. Nesom & Baird	ERNA	Rubber rabbitbrush	N
Prunus virginiana L.	PRVI	Chokecherry	N
Purshia tridentata (Pursh) DC.	PUTR	Antelope bitterbrush	N
Ribes cereum Douglas	RICE	Wax currant	N
Rosa woodsii Lindl.	ROWO	Wood's rose	N
Symphoricarpos oreophilus A. Gray	SYOR	Mountain snowberry	N
Tetradymia canescens DC.	TECA	Spineless horsebrush	N
FORBS			
Achillea millefolium L.	ACMI	Common yarrow	N
Agastache urticifolia (Benth.) Kuntze	AGUR	Nettleleaf giant hyssop	N
Agoseris Raf.	AGOSE	Mountain-dandelion	N
Allium acuminatum Hook.	ALAC	Tapertip onion	N
Amsinckia Lehm.	AMSIN	Fiddleneck	N
Apocynum androsaemifolium L.	APAN	Spreading dogbane	N
Arabis L.	ARABI	Rockcress	I, N
Artemisia ludoviciana Nutt.	ARLU	White sagebrush, Cudweed sagewort	N
Aster L.	ASTER	Aster	I, N
Astragalus filipes Torr. ex A. Gray	ASFI	Basalt milkvetch	N
Astragalus lentiginosus Douglas ex Hook.	ASLE	Freckled milkvetch	N
Balsamorhiza sagittata (Pursh) Nutt.	BASA	Arrowleaf balsamroot	N
Castilleja Mutis ex L. f.	CASTI	Indian paintbrush	N
Chenopodium L.	CHENO	Goosefoot	I, N
Cirsium neomexicanum A. Gray	CINE	New Mexico thistle	N
Collomia grandiflora Douglas ex Lindl.	COGR	Grand collomia	N
Crepis acuminata Nutt.	CRAC	Tapertip hawksbeard	N
Descurainia pinnata (Walter) Britton	DEPI	Western tansymustard	N
Equisetum L.	EQUIS	Horsetail	N
Erigeron pumilus Nutt.	ERPU	Shaggy fleabane	N

Scientific Name	Code	Common Name	Origin
FORBS			
Erigeron speciosus (Lindl.) DC.	ERSP	Aspen fleabane, Splendid fleabane	N
Eriogonum heracleoides Nutt.	ERHE	Parsnipflower buckwheat	N
Hieracium scouleri Hook. var. *albertinum* (Farr) G.W. Douglas & G.A. Allen	HISCA	Western hawkweed	N
Iva axillaris Pursh	IVAX	Povertyweed	N
Lactuca serriola L.	LASE	Prickly lettuce	I
Lepidium campestre (L.) W.T. Aiton	LECA	Field pepperweed	I
Lithospermum ruderale Douglas ex Lehm.	LIRU	Western stoneseed	N
Lomatium dissectum (Nutt.) Mathias & Constance	LODI	Fernleaf biscuitroot	N
Lupinus sericeus Pursh	LUSE	Silky lupine	N
Madia glomerata Hook.	MAGL	Mountain tarweed	N
Orthocarpus luteus Nutt.	ORLU	Yellow owl's-clover	N
Phacelia Juss.	PHACE	Phacelia	N
Potentilla glandulosa Lindl.	POGL	Sticky cinquefoil	N
Potentilla gracilis Douglas ex Hook.	POGR	Slender cinquefoil	N
Senecio serra Hook.	SESE	Tall ragwort	N
Sisymbrium altissimum L.	SIAL	Tall tumblemustard	I
Solidago missouriensis Nutt.	SOMI	Missouri goldenrod	N
Tragopogon dubius Scop.	TRDU	Yellow salsify	I
Triteleia grandiflora Lindl.	TRGR	Largeflower triteleia, Wild hyacinth	N
GRASSES			
Bromus hordeaceus L.	BRHO	Soft brome	I
Bromus tectorum L.	BRTE	Cheatgrass	I
Elymus albicans (Scribn. & J.G. Sm.) Á. Löve			
Elymus elymoides (Raf.) Swezey	ELEL	Squirreltail	N
Festuca idahoensis Elmer	FEID	Idaho fescue	N
Koeleria macrantha (Ledeb.) Schult.	KOMA	Prairie Junegrass	N
Leymus cinereus (Scribn. & Merr.) Á. Löve	LECI	Great Basin wildrye	N
Melica bulbosa Geyer ex Porter & J.M. Coult.	MEBU	Oniongrass	N
Poa bulbosa L.	POBU	Bulbous bluegrass	I
Poa pratensis L.	POPR	Kentucky bluegrass	I
Poa secunda J. Presl	POSE	Sandberg bluegrass	N
Pseudoroegneria spicata (Pursh) Á. Löve	PSSP	Bluebunch wheatgrass	N
Taeniatherum caput-medusae (L.) Nevski	TACA	Medusahead	I

Scientific Name	Code	Common Name	Origin
GRASSES			
Ventenata dubia (Leers) Coss.	VEDU	North Africa grass	I
GRASS-LIKE PLANTS			
Carex L.	CAREX	Sedge	I, N
Carex geyeri Boott	CAGE	Geyer's sedge	N
Juncus balticus Willd.	JUBA	Baltic rush	N

List compiled by Justin J. Trujillo and Eva Strand

Appendix B- Cattle Grazing Dates and Numbers

			2014			2015		
Plot ID	**Block**	**Treatment**	**Production (kg ha^{-1})**	**Cattle Used**	**Date Grazed**	**Production (kg ha^{-1})**	**Cattle Used**	**Date Grazed**
J-M-01	6	Summer Moderate	218	1.4	1-Aug-14	515	3.3	22-Jun-15
J-M-02	6	Fall Moderate	228	1.4	25-Sep-14	309	2.0	9-Sep-15
J-M-03	6	No Grazing	240	-	-	398	-	-
J-M-04	6	Fall Low	182	1.2	25-Sep-14	293	1.9	9-Sep-15
J-M-05	6	Summer Low	230	1.5	1-Aug-14	416	2.6	22-Jun-16
J-M-06	6	No Grazing	238	-	-	372	-	-
J-M-07	6	Summer Moderate	252	1.6	31-Jul-14	516	3.3	23-Jun-15
J-M-08	6	Summer Low	336	2.1	31-Jul-14	496	3.2	23-Jun-16
J-M-09	6	Fall Moderate	202	1.3	25-Sep-14	259	1.6	10-Sep-15
J-M-10	6	Fall Low	214	1.4	25-Sep-14	287	1.8	10-Sep-15
J-N-01	5	Fall Moderate	236	1.5	26-Sep-14	298	1.9	11-Sep-15
J-N-02	5	Fall Low	242	1.5	26-Sep-14	362	2.3	11-Sep-15
J-N-03	5	Summer Moderate	218	1.4	28-Jul-14	347	2.2	24-Jun-15
J-N-04	5	Summer Low	204	1.3	28-Jul-14	347	2.2	24-Jun-16
J-N-05	5	No Grazing	150	-	-	361	-	-
J-N-06	5	Fall Moderate	178	1.1	26-Sep-14	306	1.9	12-Sep-15
J-N-07	5	Summer Low	276	1.8	28-Jul-14	439	2.8	25-Jun-15
J-N-08	5	Fall Low	204	1.3	26-Sep-14	268	1.7	12-Sep-15
J-N-09	5	No Grazing	190	-	-	300	-	-
J-N-10	5	Summer Moderate	224	1.4	31-Jul-14	505	3.2	25-Jun-16
J-S-01	4	Summer Moderate	262	1.7	3-Aug-14	586	3.7	20-Jun-15
J-S-02	4	No Grazing	362	-	-	960	-	-
J-S-03	4	Summer Low	272	1.7	3-Aug-14	530	3.4	20-Jun-16
J-S-04	4	Fall Low	734	4.7	24-Sep-14	330	2.1	7-Sep-15

			2014			2015		
Plot ID	Block	Treatment	Production (kg ha^{-1})	Cattle Used	Date Grazed	Production (kg ha^{-1})	Cattle Used	Date Grazed
J-S-05	4	Fall Moderate	298	1.9	24-Sep-14	318	2.0	7-Sep-15
J-S-06	4	Fall Low	282	1.8	24-Sep-14	360	2.3	8-Sep-15
J-S-07	4	Fall Moderate	346	2.2	24-Sep-14	415	2.6	8-Sep-15
J-S-08	4	No Grazing	310	-	-	347	-	-
J-S-09	4	Summer Low	368	2.3	2-Aug-14	434	2.8	21-Jun-15
J-S-10	4	Summer Moderate	464	2.9	2-Aug-14	521	3.3	21-Jun-16
T-M-01	2	Fall Moderate	1170	7.4	19-Sep-14	1304	8.3	17-Sep-15
T-M-02	2	Fall Low	1102	7.0	20-Sep-14	1405	8.9	17-Sep-15
T-M-03	2	No Grazing	978	-	-	1436	-	-
T-M-04	2	Summer Moderate	738	4.7	8-Aug-14	1059	6.7	30-Jun-15
T-M-05	2	Summer Low	652	4.1	8-Aug-14	893	5.7	30-Jun-15
T-M-06	2	Summer Low	1324	8.4	9-Aug-14	1153	7.3	2-Jul-15
T-M-07	2	Fall Moderate	1020	6.5	19-Sep-14	1069	6.8	19-Sep-15
T-M-08	2	No Grazing	598	-	-	1256	-	-
T-M-09	2	Fall Low	1036	6.6	21-Sep-14	983	6.2	19-Sep-15
T-M-10	2	Summer Moderate	780	5.0	9-Aug-14	1141	7.2	2-Jul-15
T-N-01	3	Summer Moderate	808	5.1	10-Aug-14	1144	7.3	4-Jul-15
T-N-02	3	Summer Low	552	3.5	10-Aug-14	1071	6.8	4-Jul-15
T-N-03	3	Fall Moderate	540	3.4	9/22/2014	942	6.0	21-Sep-15
T-N-04	3	Fall Low	344	2.2	9/22/2014	950	6.0	21-Sep-15
T-N-05	3	No Grazing	874	-	-	1492	-	-
T-N-06	3	Summer Low	604	3.8	11-Aug-14	1104	7.0	6-Jul-15
T-N-07	3	Fall Moderate	590	3.7	22-Sep-14	890	5.7	23-Sep-15
T-N-08	3	No Grazing	544	-	-	1211	-	-
T-N-09	3	Fall Low	452	2.9	22-Sep-14	804	5.1	23-Sep-15
T-N-10	3	Summer Moderate	588	3.7	11-Aug-14	1277	8.1	6-Jul-15

			2014			2015		
Plot ID	**Block**	**Treatment**	**Production (kg ha^{-1})**	**Cattle Used**	**Date Grazed**	**Production (kg ha^{-1})**	**Cattle Used**	**Date Grazed**
T-S-01	1	No Grazing	1014	-	-	1471	-	-
T-S-02	1	Summer Low	1452	9.2	5-Aug-14	1780	11.3	26-Jun-15
T-S-03	1	Fall Moderate	764	4.9	17-Sep-14	1069	6.8	13-Sep-15
T-S-04	1	Fall Low	872	5.5	17-Sep-14	1217	7.7	13-Sep-15
T-S-05	1	Summer Moderate	732	4.7	6-Aug-14	1159	7.4	26-Jun-15
T-S-06	1	No Grazing	668	-	-	1044	-	-
T-S-07	1	Summer Low	608	3.9	5-Aug-14	1046	6.6	28-Jun-15
T-S-08	1	Fall Moderate	714	4.5	18-Sep-14	1147	7.3	15-Sep-15
T-S-09	1	Summer Moderate	602	3.8	6-Aug-14	1052	6.7	28-Jun-15
T-S-10	1	Fall Low	488	3.1	18-Sep-14	913	5.8	15-Sep-15

Appendix C: Statistical Analysis

```
> Data <- read.csv("E:/Thesis.chris/Data/Data_Set.csv",header=T)
> library(ggplot2)
> site=as.factor(Data[,2])
> TRT=as.factor(Data[,"Treatment"])
> GZ=as.factor(Data$Grazed)
> Cal.UT=Data[,"Cal.UT"]
> #Production
> ##shrub
> summary(aov(Data$Shrub~TRT))
            Df Sum Sq Mean Sq F value Pr(>F)
TRT          4    620   155.0   0.438  0.781
Residuals   55  19482   354.2
> ##2014 pre bio
> summary(aov(Data$x14.Pre.Bio~TRT))
            Df  Sum Sq Mean Sq F value Pr(>F)
TRT          4   17244    4311   0.156   0.96
Residuals   55 1521710   27667
> ##2015 Pre bio
> summary(aov(Data$x15.Pre.Bio~TRT))
            Df  Sum Sq Mean Sq F value Pr(>F)
TRT          4  588847  147212   1.765  0.149
Residuals   55 4586379   83389
> #Ocular cover comparision
> bg=Data[,"x15.Post.BG"]-Data[,"x15.Pre.BG"]
> wdy=Data[,"x15.Post.Wdy"]-Data[,"x15.Pre.Wdy"]
> lit=Data[,"x15.Post.Litr"]-Data[,"x15.Pre.Litr"]
> OC=as.matrix(cbind(bg,wdy,lit))
> summary.aov(manova(OC~GZ*Cal.UT))
 Response bg :
            Df  Sum Sq Mean Sq F value   Pr(>F)
GZ           1  393.73  393.73 10.8309 0.001716 **
Cal.UT       1   29.05   29.05  0.7991 0.375130
Residuals   57 2072.08   36.35
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

 Response wdy :
            Df  Sum Sq Mean Sq F value Pr(>F)
GZ           1   53.49  53.487  2.7435 0.1031
Cal.UT       1   18.56  18.558  0.9519 0.3334
Residuals   57 1111.28  19.496

 Response lit :
            Df Sum Sq Mean Sq F value    Pr(>F)
GZ           1 2786.0 2785.97 19.7270 4.161e-05 ***
Cal.UT       1  340.7  340.74  2.4127    0.1259
Residuals   57 8049.9  141.23
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

> ##Mancova
> #factors
> Fire=subset(Data, Burn=="Y")
> fire=as.matrix(Fire[,25:26])
> sea=as.factor(Fire[,"Season"])
```

```
> ut=as.factor(Fire[,"Utilization"])
> sh=Fire[,"Shrub"]
> trt=as.factor(Fire[,"Treatment"])
> cal.ut=Fire[,"Cal.UT"]
> bio=Fire[,"x15.Post.Bio"]
> bio=bio*2
> lit=Fire$x15.Post.Litr
> site=as.factor(Fire$Site)
> fit=manova(fire~sea + sh + cal.ut + lit)
> summary(fit)
          Df  Pillai approx F num Df den Df    Pr(>F)
sea        2 0.18804    1.038      4     40   0.39978
sh         1 0.78243   34.165      2     19 5.095e-07 ***
cal.ut     1 0.27676    3.635      2     19   0.04605 *
lit        1 0.35683    5.271      2     19   0.01510 *
Residuals 20
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
> summary(lm(fire~sh))
Response FH :

Call:
lm(formula = FH ~ sh)

Residuals:
    Min      1Q  Median      3Q     Max
-1.5985 -0.8228  0.0052  0.6768  1.8280

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 1.678180   0.306605   5.473 1.26e-05 ***
sh          0.055531   0.009389   5.914 4.21e-06 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Residual standard error: 0.9745 on 24 degrees of freedom
  (4 observations deleted due to missingness)
Multiple R-squared:  0.5931,   Adjusted R-squared:  0.5761
F-statistic: 34.98 on 1 and 24 DF,  p-value: 4.208e-06


Response ROS :

Call:
lm(formula = ROS ~ sh)

Residuals:
     Min       1Q   Median       3Q      Max
-0.56182 -0.12067 -0.05929  0.12519  0.68863

Coefficients:
            Estimate Std. Error t value Pr(>|t|)
(Intercept) 0.471560   0.084200   5.601 9.17e-06 ***
sh          0.011281   0.002578   4.375 0.000204 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

```
Residual standard error: 0.2676 on 24 degrees of freedom
  (4 observations deleted due to missingness)
Multiple R-squared:  0.4437,	Adjusted R-squared:  0.4205 
F-statistic: 19.14 on 1 and 24 DF,  p-value: 0.0002035 


> summary(lm(fire~lit))
Response FH :

Call:
lm(formula = FH ~ lit)

Residuals:
     Min       1Q   Median       3Q      Max 
-1.86044 -0.94908 -0.09258  0.89181  2.00216 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept)  6.77022    0.76671   8.830 5.26e-09 ***
lit         -0.10523    0.02112  -4.983 4.34e-05 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 

Residual standard error: 1.071 on 24 degrees of freedom
  (4 observations deleted due to missingness)
Multiple R-squared:  0.5085,	Adjusted R-squared:  0.488 
F-statistic: 24.83 on 1 and 24 DF,  p-value: 4.344e-05 


Response ROS :

Call:
lm(formula = ROS ~ lit)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.52519 -0.16149 -0.01258  0.13171  0.75170 

Coefficients:
             Estimate Std. Error t value Pr(>|t|)    
(Intercept)  1.461265   0.209272   6.983 3.21e-07 ***
lit         -0.020096   0.005764  -3.486  0.00191 ** 
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 

Residual standard error: 0.2923 on 24 degrees of freedom
  (4 observations deleted due to missingness)
Multiple R-squared:  0.3362,	Adjusted R-squared:  0.3085 
F-statistic: 12.15 on 1 and 24 DF,  p-value: 0.001906 


> summary(lm(fire~cal.ut))
Response FH :

Call:
lm(formula = FH ~ cal.ut)
```

```
Residuals:
    Min      1Q  Median      3Q     Max 
-1.9233 -1.6021  0.1398  1.4404  1.8932 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 3.006765   0.684296   4.394 0.000194 ***
cal.ut      0.002198   0.015132   0.145 0.885703    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 

Residual standard error: 1.527 on 24 degrees of freedom
  (4 observations deleted due to missingness)
Multiple R-squared:  0.0008787,	Adjusted R-squared:  -0.04075 
F-statistic: 0.02111 on 1 and 24 DF,  p-value: 0.8857 


Response ROS :

Call:
lm(formula = ROS ~ cal.ut)

Residuals:
     Min       1Q   Median       3Q      Max 
-0.46612 -0.24925 -0.09109  0.17539  0.76553 

Coefficients:
            Estimate Std. Error t value Pr(>|t|)    
(Intercept) 0.646622   0.158731   4.074 0.000437 ***
cal.ut      0.002779   0.003510   0.792 0.436296    
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1 

Residual standard error: 0.3542 on 24 degrees of freedom
  (4 observations deleted due to missingness)
Multiple R-squared:  0.02545,	Adjusted R-squared:  -0.01516 
F-statistic: 0.6268 on 1 and 24 DF,  p-value: 0.4363 
```